Affectionately dedicated

to all my

CHILDREN

and

GRANDCHILDREN

FOREWORD

It gives me pleasure to introduce this text-book on Engineering Drawing by Prof. N. D. Bhatt of the Birla Vishvakarma Mahavidyalaya to students of Engineering. Prof. Bhatt has been teaching this subject for over twenty years and has deservedly earned the reputation of being one of the best teachers in the subject.

This book covers the syllabus usually prescribed for the Pre-engineering and First Year of the Degree and Diploma courses in Engineering and deals with the fundamental principles of this basic subject which have been treated by Prof. Bhatt with his characteristic lucidity.

ELEMENTARY ENGINEERING DRAWING

PREFACE

From the very early days, man realized that if he had to construct any structure or machine correctly and methodically, he must first record his ideas before starting construction work. These recorded ideas become more vivid and forceful if they are shown on paper in form of a drawing of the structure or machine. Such a drawing will be of very great help to the man who looks after the construction of this structure or machine.

Indeed, "technical drawing is the language of engineering". Without the good knowledge of drawing, an engineer is nowhere and he could not have constructed the various magnificent structures or intricate machines. Evidently, any one connected in any way, with engineering construction must understand this language of engineers. Technical drawing is, therefore, indispensable today and shall continue to be so as long as engineering and technology continue to be of use in the activities of man.

By means of drawing, the shape, size, finish, colour and construction of any object (no matter how complex) can be described accurately and clearly. The engineer should develop his skill, in two phases of technical drawing; first, he must be able to draw clearly and rapidly, the freehand technical sketches; secondly, he must be proficient in drawing to scale the instrumental drawing. The purpose of the present volume is to give the basic principles of the instrumental drawing only.

The book covers the syllabi in Engineering Drawing of many University Colleges and Polytechnics in India and has been written keeping in view the difficulties of a beginner in the subject of Engineering Drawing. I am quite hopeful that this book will serve its purpose very well for young and budding engineers.

I am highly indebted to Principal S. B. Junnarkar for his valuable guidance and for his kindness to write a suitable foreword for the book. I am also thankful to Prof. V. B. Priyani of Birla Vishvakarma Mahavidyalaya for going through the initial manuscript and for offering constructive suggestions. Finally, I feel grateful to the following:

(i) The authorities of the Universities of Bombay, Poona and Gujarat, and the Department of Technical Education, Bombay, for their kind permission to include a few questions set at their examinations. (ii) Mr. N. M. Panchal and Mr. M. D. Bhatt for their help in preparing pencil sketches. (iii) Mr. L. D. Bhatt for preparing the excellent typed manuscript. (iv) Mr. Ramanbhai C. Patel of Charotar Book Stall for careful proof-reading and for his efforts to see the book out in proper time. (v) The Anand Press authorities for the care and interest shown in the printing and get-up of this book. (vi) The Prabhat Process Studio for the promptness and good work of block-making.

Any suggestion to improve the value of this book will be gratefully received and will be incorporated in subsequent editions after due scrutiny.

June 30, 1958 **N. D. BHATT**

EIGHTH EDITION

Upto six editions, the book hardly underwent any fundamental change. Under the

ENGINEERING DRAWING

[PLANE AND SOLID GEOMETRY]

[IN FIRST ANGLE PROJECTION METHOD]

by

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ANAND

[FIFTIETH REVISED AND ENLARGED EDITION: 2011]

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FORTY-SECOND EDITION

The first edition was originally published in 1958 and now has entered in its 42nd Edition during 42 years, proves its popularity and utility among the teachers as well as the students of Engineering Institutions of our country.

This edition has been entirely revised and enlarged by adding the following *four* chapters: (1) Screw Threads (2) Screwed Fastenings (3) Riveted Joints and Welded Joints (4) Computer Aided Drafting.

It was thought desirable to include this fourth chapter on 'Computer Aided Drafting' which has now acquired an important place in this subject. We are thankful to Dr. S. S. Khandare of Y. C. College of Engineering, Nagpur for contributing this chapter. We are also highly obliged to Shri R. C. Patel of Charotar Publishing House, Anand for correcting the Proofs.

This book provides a wealth of information and describes an exciting new paradigm and is also a valuable tool for all the Engineering students, who wish to deepen and acquire a sound knowledge of this important subject (Language of Engineers) without which a really satisfactory progress cannot be achieved in any branch of Engineering.

We shall feel obliged to receive comments, suggestions and opinions from the readers to enhance the utility of the book.

August 15, 2000

N. D. BHATT
V. M. PANCHAL

FIFTIETH EDITION

We are inundated with joy to present before you the FIFTIETH EDITION of this most standard text-book. At the outset, we would like to mention that splendid response to earlier editions is prodigious. Despite such favourable responses, it was felt that the utility of the book could be further enhanced. This is one of the most comprehensive revisions since the book was first published. As a result, all the drawings have been redrawn with utmost intelligibility. Many new examples, drawings are incorporated along with some new text matter. This text-book is thoroughly revised, extensively enlarged, completely updated. Chapter on Computer Aided Drafting (CADr) is entirely rewritten with inclusion of 50 *self-interactive and self-learning practice modules*. This book accompanied by a computer CD as a novel pedagogical concept, containing *51 selected audiovisual animation modules* presented for better visualization and understanding of the subject of Engineering Drawing.

We take this opportunity to thank Prof. V. M. Panchal, Former Professor in Mechanical Engineering, Faculty of Technology and Engineering, M. S. University of Baroda for revising the entire book and adding many new typical examples. We express our hearty gratitude to Prof. Pramod R. Ingle, Lecturer in Mechanical Engineering, B and B Institute of Technology, Vallabh Vidyanagar for redraw all the drawings with precision, rewriting the chapter on Computer Aided Drafting (CADr) and revising the entire book.

We are also indebted to Prof. R. S. Bhatt, Associate Professor In Mechanical Engineering, Birla Vishvakarma Mahavidyalaya (Engineering College), Vallabh Vidyanagar, Anand; Prof. Mukesh A. Bulsara, Assistant Professor in Mechanical Engineering, G. H. Patel College of Engineering and Technology (GCET), Vallabh Vidyanagar, Prof. N. V. Patel, Ex-Professor

ELEMENTARY ENGINEERING DRAWING

TABLE OF CONTENTS

Chapter 1

DRAWING INSTRUMENTS AND THEIR USES

1-1. INTRODUCTION

Drawing instruments are used to prepare drawings easily and accurately. The accuracy of the drawings depends largely on the quality of instruments. With instruments of good quality, desirable accuracy can be attained with ease. It is, therefore, essential to procure instruments of as superior quality as possible.

Below is the list of minimum drawing instruments and other drawing materials which every student must possess:

1. Drawing board
2. T-square
3. Set-squares — 45° and 30°-60°
4. Drawing instrument box, containing:
   (i) Large-size compass with inter-changeable pencil and pen legs
   (ii) Lengthening bar
   (iii) Small bow compass
   (iv) Large-size divider
   (v) Small bow divider
   (vi) Small bow ink-pen
   (vii) Inking pen
5. Scales
6. Protractor
7. French curves

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 1 for Introduction of the subject and various drawing instruments.

1-2. DRAWING BOARD (Fig. 1-1)

Drawing board is rectangular in shape and is made of strips of well-seasoned soft wood about 25 mm thick. It is cleated at the back by two battens to prevent warping. One of the edges of the board is used as the *working edge*, on which the T-square is made to slide. It should, therefore, be perfectly straight. In some boards, this edge is grooved throughout its length and a perfectly straight ebony edge is fitted inside this groove. This provides a true and more durable guide for the T-square to slide on.

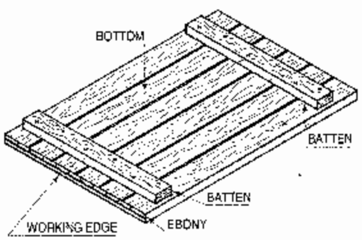


Fig. 1-1

TABLE 1-1
SIZES OF DRAWING BOARDS

B0	1000 × 1500
B1	700 × 1000
B2	500 × 700
B3	350 × 500

Drawing board is made in various sizes. Its selection depends upon the size of the drawing paper to be used. The sizes of drawing boards recommended by the Bureau of Indian Standards (IS:1444-1989) are tabulated in table 1-1.

For use in schools and colleges, the last two sizes of the drawing boards are more convenient. Large-size boards are used in drawing offices of engineers and engineering firms. The drawing board is placed on the table in front of the student, with its working edge on his left side. It is more convenient if the table-top is sloping downwards towards the student. If such a table is not available, the necessary

CONTENTS OF CD-ROM

NOTE ABOUT THE CD ACCOMPANYING THE BOOK

This book is accompanied by a CD, which contains audiovisual modules for better visualization and understanding of the subject.

It has been found in our research done over hundreds of students and dozens of colleges and universities that visualization IQ is lacking in different quantities among male and female students. It is therefore necessary to aid learning process by use of high quality computer animations as a novel pedagogical concept.

This CD contains 51 modules and CD is provided FREE with 50th Edition of the book.

Chapter No.	Chapter Name	Module No.	Particulars
1	Drawing Instruments and their uses	Module 01	Introduction of the subject and Various Drawing Instruments.
2	Sheet layout and freehand sketching	Module 02	Introduction of sheets and sheet layout
3	Lines, Lettering and Dimensioning	Module 03	Type of lines, Lettering and Dimensioning
5	Geometrical Construction	Module 04	To draw parallel line : To draw perpendicular to a given line: Problem 5-5
		Module 05	To divide a line in equal parts: Problem 5-8
		Module 06	To divide a circle in equal parts: Problem 5-10
		Module 07	To trisect a right angle: Problem 5-13
		Module 08	To construct an ogee or reverse curve: Problem 5-22
		Module 09	To construct regular polygons problem 5-26
		Module 10	Special methods of drawing regular polygons: Problem 5-27
		Module 11	Special methods of drawing regular polygons: Problem 5-29
6	Curves Used in Engineering Practice	Module 12	General method of constructin of an ellipse: Problem 6-1
		Module 13	Concentric circles method to draw an ellipse : Method ii of problem 6-2
		Module 14	General method of construction of a parabola: Problem 6-8
7	Loci of Points	Module 15	The simple slider crank mechanism: Problem 7-6
		Module 16	The offset slider crank mechanism:

Chapter No.	Chapter Name	Module No.	Particulars
11	Projections on Auxiliary Planes	Module 25	Projection of a point on an auxiliary plane
		Module 26	To determine true shape of a plane figure: Problem 11-8
12	Projections of Planes	Module 27	Projection of oblique planes: Problem 12-7
13	Projections of Solids	Module 28	Types of Solids
		Module 29	Pentagonal Prism:Axis inclinded to the V.P. and Parallel to the H.P.: Problem 13-10
		Module 30	Hexagonal Pyramid: Axis inclined to both the H.P. And the V.P.: Problem 13-22
14	Sections of Solids	Module 31	Sections of Cylinders: Section plane inclinded to the base: Problem 14-17
		Module 32	Sections of Cones: Problem 14-26
15	Development of Surfaces	Module 33	Method of Development of Surfaces
		Module 34	Development of the Lateral Surface of a Pentagonal Prism: Problem 15-3
		Module 35	Development of the Lateral Surface of a truncated cone: Problem 15-22
16	Intersection of Surfaces	Module 36	Line of Intersection
		Module 37	Intersection of Cylinder and Cylinder: Problem 16-8
		Module 38	Intersection of Cone and Cylinder: Problem 16-22 (Cutting-plane Method)
17	Isometric Projection	Module 39	Introduction to Isometric Projection
		Module 40	Isometric Drawing of Planes or Plane Figures: Problem 17-1, Problem 17-2
		Module 41	Isometric Drawing of Planes or Plane Figures. Problem 17-7 (Method of Points)
		Module 42	Isometric Drawing of Frustum of the Hexagonal Pyramid: Problem 17-16 (Methods of Drawing Non-Isometric Lines)
		Module 43	Isometric Drawing of Pentagonal Pyramid: Problem 17-17 (Co-ordinate or Offset Method)

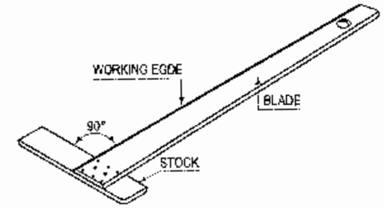


FIG. 1-2

Uses:

(i) The T-square is used for drawing horizontal lines. The stock of the T-square is held firmly with the left hand against the working edge of the board, and the line is drawn from left to right as shown in fig. 1-3. The pencil should be held slightly inclined in the direction of the line (i.e. to the right) while the pencil point should be as close as possible to the working edge of the blade. Horizontal parallel lines are drawn by sliding the stock to the desired positions.

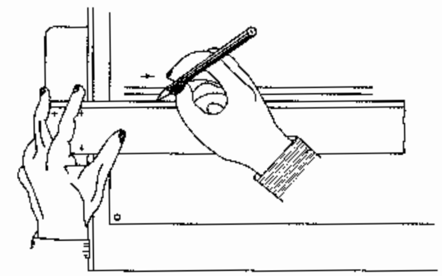


FIG. 1-3

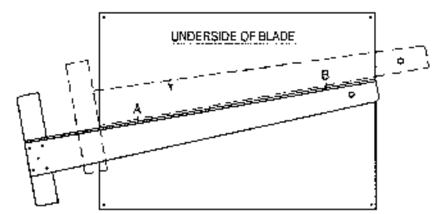


FIG. 1-4

1-4. SET-SQUARES (Fig. 1-5)

The set-squares are made of wood, tin, celluloid or plastic. Those made of transparent celluloid or plastic are commonly used as they retain their shape and accuracy for a longer time. Two forms of set-squares are in general use. A set-square is triangular in shape with one of the angle as right angle. The 30°-60° set-square of 250 mm length and 45° set-square of 200 mm length are convenient sizes for use in schools and colleges.

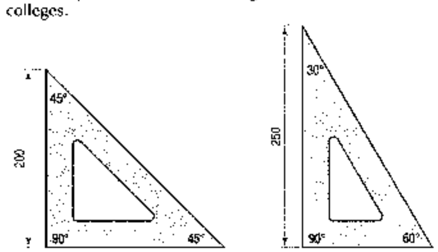


FIG. 1-5

Uses:

Problem 1-1. *To draw a line perpendicular to a given horizontal line from a given point within it.*

(i) Place the T-square a little below the given line (fig. 1-6).

(ii) Arrange any one set-square with one of the edges containing the right angle touching the working edge of the T-square, and the other edge passing through the given point.

(iii) Hold the T-square and the set-square in this position firmly with the left hand.

(iv) With the right hand, draw the required line through the given point in the upward direction as shown by the arrow. The pencil point should always be in contact with the edge of the set-square. A perpendicular from any given point outside the line can also be drawn in the same manner. Vertical parallel lines may be drawn by sliding the set-square along the edge of the T-square to the required positions.

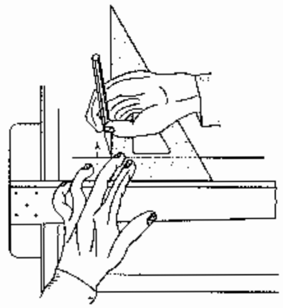


FIG. 1-6

Problem 1-2. *To draw a line inclined at 45°, 30° or 60° to a given horizontal line from a given point.*

(i) Place the edge containing the right angle of the 45° set-square on the edge of the T-square (fig. 1-7).

(ii) Slide it so that its longest edge (hypotenuse) passes through the given point and then draw the required line. The same line will make 45° angle with the vertical line passing through that point.

(iii) By turning the set-square

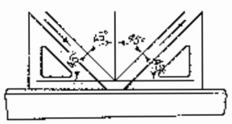


FIG. 1-7

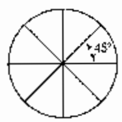
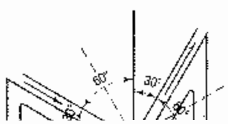
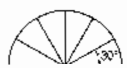


FIG. 1-8





Problem 1-3. *To draw a line inclined at 15° to a given horizontal line from a given point.*

(i) Place the 30°-60° set-square with its longer edge containing the right angle, coinciding with the edge of the T-square (fig. 1-11).

(ii) Arrange the 45° set-square with its longest edge on the longest edge of the 30°-60° set-square.

(iii) Slide the 45° set-square so that one of its edges containing the right angle passes through the given point, and draw the required line. The line drawn with the other edge will make 15° angle with the vertical line and 105° or 75° angles with the horizontal line. *A circle may thus be divided into 24 equal parts with the aid of the set-squares* (fig. 1-12).

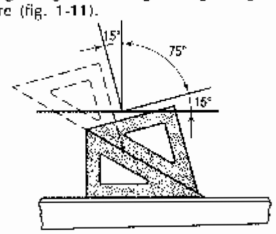


FIG. 1-11

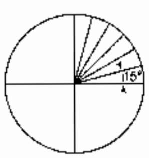


FIG. 1-12

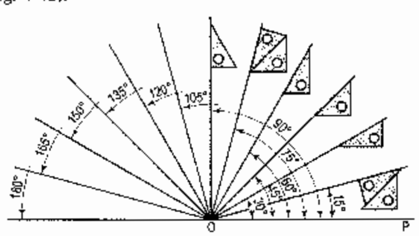


FIG. 1-13

Fig. 1-13 shows methods of drawing lines (with the aid of the T-square and set-squares) making angles with the horizontal line in multiples of 15° upto 180°.

Problem 1-4. *To draw a line parallel to a given straight line through a given point.*

The line AB and the point P are given (fig. 1-14).

Problem 1-5. *To draw a line perpendicular to a given line through a point within or outside it.*

The line PQ and the point O are given (fig. 1-15).

Method I:

(i) Arrange the longest edge of one set-square along PQ.

(ii) Place the second set-square or T-square as base along one of the edges containing the right angle.

(iii) Holding the base set-square firmly, rotate the first set-square so that its other edge containing the right angle coincides with the edge of the base set-square.

(iv) Slide the first set-square till its longest edge is on the point O and draw the required line AB.

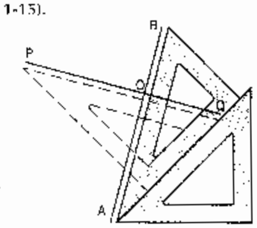


Fig. 1-15

Method II:

(i) Arrange one set-square with an edge containing the right angle along the line PQ (fig. 1-16).

(ii) Place the second set-square or T-square as a base under the longest edge.

(iii) Slide the first set-square on the second till the other edge containing the right angle is on the point O and draw the required line AB.

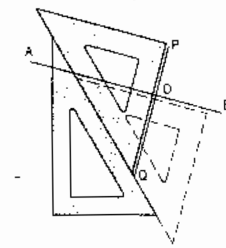


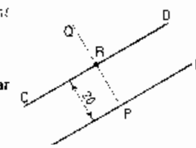
Fig. 1-16

Problem 1-6. *To draw a line parallel to a given straight line at a given distance, say 20 mm from it (fig. 1-17).*

Let AB be the given line.

(i) From any point P in AB, draw a line PQ perpendicular to AB (Problem 1-5).

(ii) Mark a point R such that PR = 20 mm.



(1) Large-size compass with interchangeable pencil and pen legs (fig. 1-18): The compass is used for drawing circles and arcs of circles. It consists of two legs hinged together at its upper end. A pointed needle is fitted at the lower end of one leg, while a pencil lead is inserted at the end of the other leg. The lower part of the pencil leg is detachable and it can be interchanged with a similar piece containing an inking pen. Both the legs are provided with knee joints. Circles upto about 120 mm diameter can be drawn with the legs of the compass kept straight. For drawing larger circles, both the legs should be bent at the knee joints so that they are perpendicular to the surface of the paper (fig. 1-19).

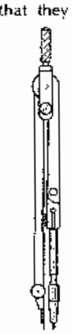


Fig. 1-18

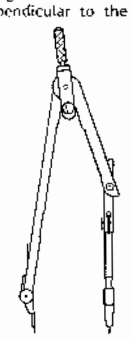


Fig. 1-19

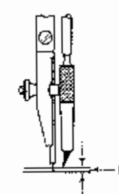


Fig. 1-20

As the needle is required to be inserted slightly inside the paper, it is kept longer than the lead point. *The setting of the pencil-lead relative to the needle, and the shape to which the lead should be ground are shown in fig. 1-20.*

To draw a circle, adjust the opening of the legs of the compass to the required radius. Hold the compass with the thumb and the first two fingers of the right hand and place the needle point lightly on the centre, with the help of the left hand. Bring the pencil point down on the paper and swing the compass about the needle-leg with a twist of the thumb and the two

Curves drawn with the compass should be of the same darkness as that of the straight lines. It is difficult to exert the same amount of pressure on the lead in the compass as on a pencil.

It is, therefore, desirable to use slightly softer variety of lead (about one grade lower, HB or H) in the compass than the pencil used for drawing straight lines, to maintain uniform darkness in all the lines.

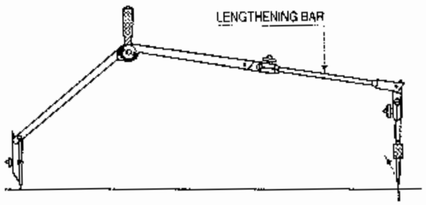


Fig. 1-21

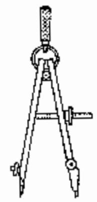


Fig. 1-22

Fig. 1-23

(4) Large-size divider: The divider has two legs hinged at the upper end and is provided with steel pins at both the lower ends, but it does not have the knee joints (fig. 1-23).

In most of the instrument boxes, a needle attachment is also provided which can be interchanged with the pencil part of the compass, thus converting it into a divider.

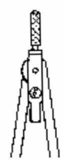
The dividers are used:

(i) to divide curved or straight lines into desired number of equal parts,

(ii) to transfer dimensions from one part of the drawing to another part, and

(iii) to set-off given distances from the scale to the drawing.

They are very convenient for setting-off points at equal distances around a given point or along a given line.



(ii) Step this distance lightly from one end of the line, say B, turning the divider first in one direction and then in the other. If the last division falls short, increase the set distance by approximately $\frac{1}{3}$ of the difference by means of the nut, keeping the other point of the divider on the paper. If the last division goes beyond the end of the line, decrease the set distance by $\frac{1}{3}$ of the difference.

(iii) Re-space the line, beginning from the starting point, and adjusting the divider until the required setting is obtained.

With some practice, it will be possible to obtain the desired result with less trials and in short time. The trial divisions should be set-off as lightly as possible so that the paper is not pricked with large and unnecessary holes.

Any arc or a circle can similarly be divided into any number of equal divisions.

(6) Small bow ink-pen: It is used for drawing small circles and arcs in ink.

(7) Inking pen (fig. 1-25): This is used for drawing straight lines and non-circular arcs in ink. It consists of a pair of steel nibs fitted to a holder made of metal or ivory. Ink is filled between the two nibs to about 6 mm length by means of a quill which is usually fitted to the cork of the ink bottle. The gap between the nibs through which the ink flows and upon which the thickness of the line depends is adjusted by means of the screw S.

The pen should be kept sloping at about 60° with the paper in the direction of drawing the line and the ends of the nibs should be slightly away from the edge of the T-square or set-square. The screw should be on the side, farther from the T-square.

As the ink dries rapidly, the pen should be used immediately after it is filled. The inside faces of the nibs should be frequently cleaned for the ink to flow freely and to maintain uniformity in thickness of lines. Ink should never be allowed to dry within the pen. There should be no ink on the outside of the nibs and hence,

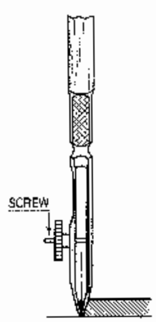


Fig. 1-25

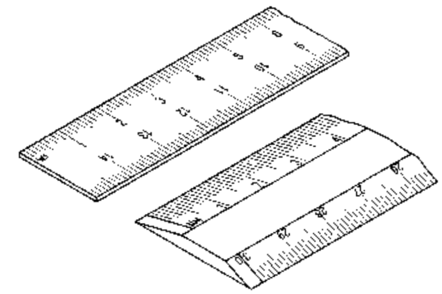


FIG. 1-26

Various other types of scales are described in chapter 4.

The scale is used to transfer the true or relative dimensions of an object to the drawing. It is placed with its edge on the line on which measurements are to be marked and, looking from exactly above the required division, the marking is done with a fine pencil point. *The scale should never be used as a straight-edge for drawing lines. The card-board scales are available in a set of eight scales. They are designated from M1 to M8 as shown in table 1-2.*

TABLE 1-2
STANDARD SCALES

Designation	Description		Scale
M1	Full size		1:1
	50	cm to a metre	1:2
M2	40	cm to a metre	1:2.5
	20	cm to a metre	1:5
M3	10	cm to a metre	1:10
	5	cm to a metre	1:20
M4	2	cm to a metre	1:50

1-7. PROTRACTOR (FIG. 1-27)

Protractor is made of wood, tin or celluloid. Protractors of transparent celluloid are in common use. They are flat and circular or semi-circular in shape. The commonest type of protractor is semi-circular and of about 100 mm diameter. Its circumferential edge is graduated to 1° divisions, is numbered at every 10° interval and is readable from both the ends. The diameter of the semi-circle (viz. straight line 0-180°) is called the base of the protractor and its centre O is marked by a line perpendicular to it.

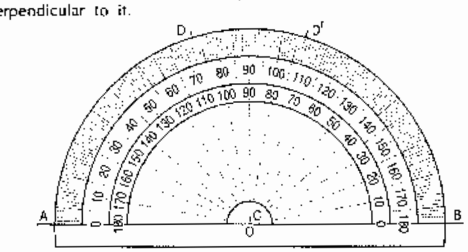


FIG. 1-27

The protractor is used to draw or measure such angles as cannot be drawn with the set-squares. A circle can be divided into any number of equal parts by means of the protractor.

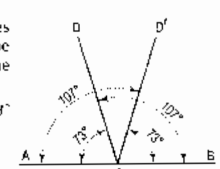


FIG. 1-28

Problem 1-8. *To draw a line making an angle of 73° with a given line through a given point in it.*

Let AB be the line and C the point in it.

(i) Set the protractor with its base coinciding with AB (fig. 1-28) and its centre exactly on the point C.

(ii) Mark a point D opposite to the 73° division and join C with D. Then $\angle ACD = 73°$ (fig. 1-28). Another point D' can be marked against the reading from the

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known points. Longest possible curves exactly coinciding with the freehand curve are then found out from the french curve. Finally, neat continuous curve is drawn with the aid of the french curve. Care should be taken to see that no corner is formed anywhere within the drawn curve.

1-9. DRAWING PAPERS

Drawing papers are available in many varieties. For ordinary pencil-drawings, the paper selected should be tough and strong. It should be uniform in thickness and as white as possible. When the rubber eraser is used on it, its fibres should not disintegrate. Good quality of paper with smooth surface should be selected for drawings which are to be inked and preserved for a long time. It should be such that the ink does not spread. Thin and cheap quality paper may be used for drawings from which tracings are to be prepared. The standard sizes of drawing papers recommended by the Bureau of Indian Standards (B.I.S.), are given in table 2-1.

Surface area of A0 size is one square metre. Successive format sizes (from A0 to A5) are obtained by halving along the length or doubling along the width. The areas of the two subsequent sizes are in the ratio 1:2. See fig. 1-30.

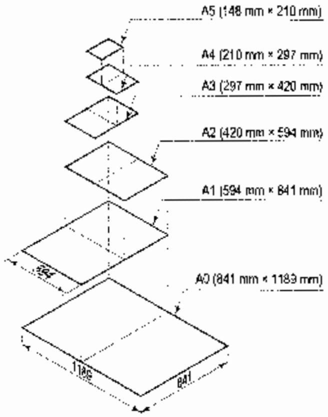


FIG. 1-30

1-10. DRAWING PENCILS

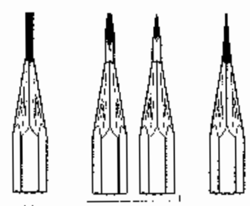
The accuracy and appearance of a drawing depend very largely on the quality of the pencils used. With cheap and low-quality pencils, it is very difficult to draw *lines of uniform shade and thickness*. The grade of a pencil lead is usually shown by figures and letters marked at one of its ends. Letters HB denote the medium grade. The increase in hardness is shown by the value of the figure put in front

Great care should be taken in mending the pencil and sharpening the lead, as the uniformity in thickness of lines depends largely on this. The lead may be sharpened to two different forms:

(i) Conical point and
(ii) Chisel edge.

The conical point is used in sketch work and for lettering etc. With the chisel edge, long thin lines of uniform thickness can be easily drawn and hence, it is suitable for drawing work.

To prepare the pencil lead for drawing work, the wood around the lead from the end, other than that on which the grade is marked, is removed with a pen-knife, leaving about 10 mm of lead projecting out, as shown in fig. 1-31(a).



(a) (b) (c)

FIG. 1-31

The chisel edge [fig. 1-31(b)] is prepared by rubbing the lead on a sand-paper block, making it flat, first on one side and then on the other by turning the pencil through a half circle. For making the conical end [fig. 1-31(c)] the pencil should be rotated between the thumb and fingers, while rubbing the lead.

The pencil lead should occasionally be rubbed on the sand-paper block (while doing the drawing work) to maintain the sharpness of the chisel edge or the pointed end.

Instead of wooden pencils, Mechanical clutch pencils with a different lead size and grade like 5 mm, 4 mm and H, 2H, HB etc., are also available. Sharpening is not required in such pencils.

1-11. ERASER (RUBBER)

Soft India-rubber is the most suitable kind of eraser for pencil drawings. It should be such as not to spoil the surface of the paper. Frequent use of rubber should be avoided by careful planning.

1-12. DRAWING PINS, CLIPS OR ADHESIVE TAPES

These are used to fix the drawing paper on the drawing board. The needle part

1-13. SAND-PAPER BLOCK

It consists of a wooden block about 150 mm × 50 mm × 12 mm thick with a piece of sand-paper pasted or nailed on about half of its length, as shown in fig. 1-33.

The sand-paper, should be replaced by another, when it becomes dirty or worn out. This block should always be kept within easy reach for sharpening the pencil lead every few minutes.

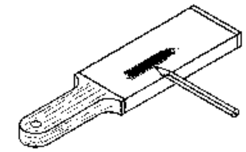


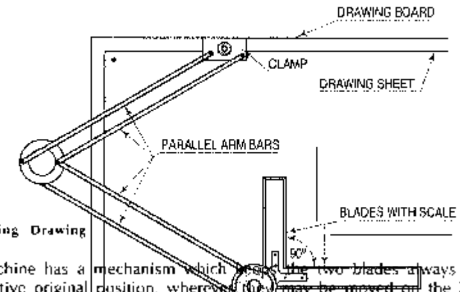
FIG. 1-33

1-14. DUSTER

Duster should preferably be of towel cloth of convenient size. Before starting work, all the instruments and materials should be thoroughly cleaned with the duster. The rubber crumbs formed after the use of the rubber should be swept away by the duster and not by hand. The underside of the T-square and the set-squares or the drafting machine which continuously rub against the paper should be frequently cleaned.

1-15. DRAFTING MACHINE (FIG. 1-34)

The uses and advantages of the T-square, set-squares, scales and the protractor are combined in the drafting machine. Its one end is clamped by means of a screw, to the distant longer edge of the drawing board. At its other end, an adjustable head having protractor markings is fitted. Two blades of transparent celluloid accurately set at right angles to each other are attached to the head.



The machine has a mechanism which keeps the two blades always parallel to their respective original position, wherever they may be moved on the board. The blades have scales marked on them and are used as straight edges. In some machines, the blades are removable and hence a variety of scales can be used. The blades may be set at any desired angle with the help of the protractor markings.

Thus, by means of this machine, horizontal, vertical or inclined parallel lines of desired lengths can be drawn anywhere on the sheet with considerable ease and saving of time. Drafting machines are common among the college students and draughtsmen.

1-16. ROLL-N-DRAW (FIG. 1-35)

It consists of graduated roller, scale of 16 centimeter and protactor. It is ideal for drawing vertical lines, horizontal lines, parallel lines, angles and circles.

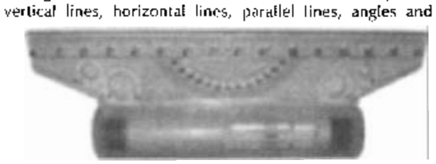
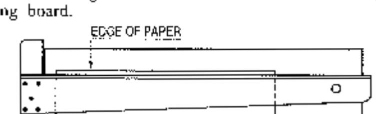


FIG. 1-35

1-17. GENERAL SUGGESTIONS FOR DRAWING A SHEET

(1) **Cleaning the instruments:** Clean the drawing board and the T-square and place them on the table, with the working edge of the board on your left-hand side and the stock of the T-square attached to that working edge. Clean all other instruments and materials and place them on a neat piece of paper by the side of the board. When a drafting machine is used, clean the drafting machine before fixing on drawing board.



of a much smaller size than that of the board, it may be placed with its lower edge at about 50 mm from the bottom edge of the board. Insert a pin in the left-hand top corner of the paper and at about 10 mm from its edges. Adjust the paper with the right hand, bringing its upper edge in line with the working edge of the T-square (fig. 1-36).

Stretch the paper gently to make it perfectly flat and insert the second pin at the right-hand bottom corner. In the same manner, fix two more pins at the remaining corners. Push the pins down firmly till their heads touch the surface of the paper.

(3) **Border lines:** Perfectly rectangular working space is determined by drawing the border lines. These may be drawn *at equal distances of about 20 mm to 25 mm from the top, bottom and right-hand edges of the paper and at about 25 mm to 40 mm from the left-hand edge.* More space on the left-hand side is provided to facilitate binding of the drawing sheets in a book-form, if so desired.

To draw the border lines (fig. 1-37): [Dimensions shown are in mm.]

(i) Mark points along the left-hand edge of the paper at required distances from the top and bottom edges and through them, draw horizontal lines with the T-square or by mini-drafter.

(ii) Along the upper horizontal line, mark two points at required distances from the left-hand and right-hand edges, and draw vertical lines through them by mini-drafter.

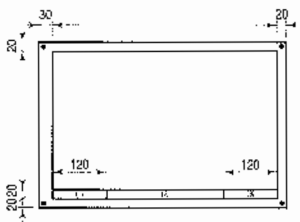


FIG. 1-37

(iii) Erase the extra lengths of lines beyond the points of intersection.

(iv) One more horizontal line at about 10 mm to 20 mm from the bottom border line may also be drawn and the space divided into three blocks. A title block as shown in fig. 2-2 must be drawn in left-hand bottom corner above block-3; in which

(a) name of the institution,

(b) title of the drawing, and

(c) name, class etc. of the student may be written.

EXERCISES 1

1. In an A2 size sheet, copy fig. 1-38(a) to fig. 1-38(g) as per layout shown in fig. 1-39. [All dimensions are in mm.]

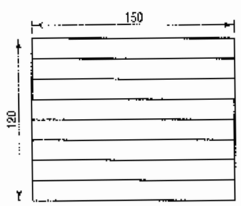


FIG. 1-38(a)

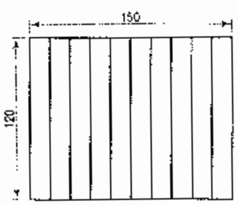


FIG. 1-38(b)

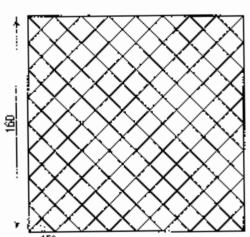


FIG. 1-38(c)

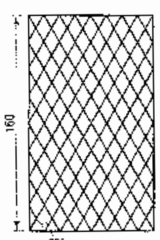


FIG. 1-38(d)

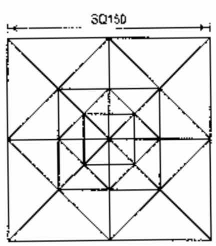
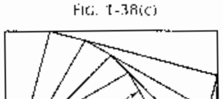


FIG. 1-38(e)



3. Without using a protractor, draw triangles having following base angles on a 75 mm long line as base:
(i) 75° and 15°, (ii) 60° and 75°, (iii) 135° and 15°, (iv) 105° and 45°.
4. Draw a line 125 mm long and divide it into seven equal parts by means of a divider.
5. Copy fig. 1-40(a) to fig. 1-40(d) as per layout shown in fig. 1-41.
[All dimensions are in mm.]

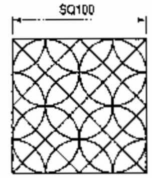


FIG. 1-40(a)

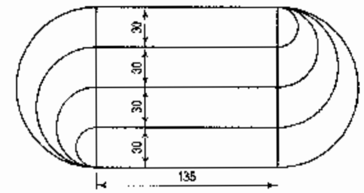


FIG. 1-40(b)

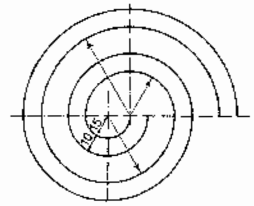


FIG. 1-40(c)

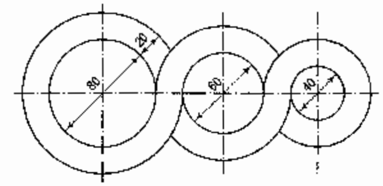
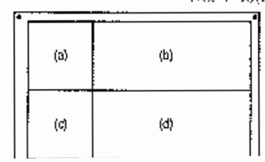


FIG. 1-40(d)



(b) To prevent warping of the board .... are cleated at its back.
(1) packings (2) wooden blocks (3) battens.
(c) The two parts of the T-square are ____ and ____ .
(1) vertical and horizontal edge (2) straight edge (3) stock (4) blade.
(d) The T-square is used for drawing ______ lines.
(1) vertical (2) curve (3) horizontal.
(e) Angles in multiples of 15° are constructed by the combined use of ______ and ______.
(1) T-square (2) set-squares (3) protractor.
(f) To draw or measure angles, ____ .... is used.
(1) set-squares (2) T-square (3) protractor.
(g) For drawing large-size circles, ________ is attached to the compass.
(1) straight bar (2) bow compass (3) lengthening bar.
(h) Circles of small radii are drawn by means of a ______.
(1) lengthening bar (2) bow divider (3) bow compass.
(i) Measurements from the scale to the drawing are transferred with the aid of a ______.
(1) scale (2) compass (3) divider.
(j) The scale should never be used as a ______ for drawing straight lines.
(1) set-squares (2) working edge (3) straight edge.
(k) ______ is used for setting-off short equal distances.
(1) compass (2) bow divider (3) scale.
(l) For drawing thin lines of uniform thickness the pencil should be sharpened in the form of ______ .
(1) chisel edge (2) conical (3) pointed.
(m) Pencil of ____ grade sharpened in the form of ______ is used for sketching and lettering.
(1) soft (2) low (3) conical point (4) chisel.
(n) ______ are used for drawing curves which cannot be drawn by a compass.
(1) bow compass (2) protractor (3) French curves.
(o) To remove unnecessary lines ______ is used.
(1) duster (2) chalk (3) sand box (4) eraser.

Chapter 2
SHEET LAYOUT AND FREE-HAND SKETCHING

2-1. SHEET LAYOUT

(1) **Sheet sizes:** The preferred sizes of the drawing sheets recommended by the Bureau of Indian Standards (B.I.S.) are given below as per SP : 46 (2003). Refer fig. 1-30:

TABLE 2-1

A0	841 × 1189	880 × 1230
A1	594 × 841	625 × 880
A2	420 × 594	450 × 625
A3	297 × 420	330 × 450
A4	210 × 297	240 × 330
A5	148 × 210	165 × 240

The layout of the drawing on a drawing sheet should be done in such a manner as to make its reading easy and speedy. Fig. 2-1(a) and fig. 2-1(b) shows an A1 size sheet layout. All dimensions are in millimetres.

(2) **Margin:** Margin is provided in the drawing sheet by drawing margin lines [fig. 2-1(a)]. Prints are trimmed along these lines. After trimming, the prints would be of the recommended trimmed sizes of the trimmed sheets.

(3) **Border lines:** Clear working space is obtained by drawing border lines as

(6) **Grid reference system** (zones system): The *grid reference system* is drawn on the sheet to permit easy location on the drawing such as details, alterations or additions. The rectangle of grid along the length should be referred by numerals 1, 2, 3... etc. and along the width by the capital letters A, B, C, D etc. as shown in fig. 2-1(b).

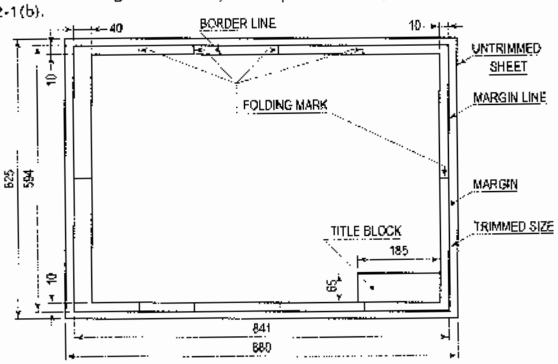
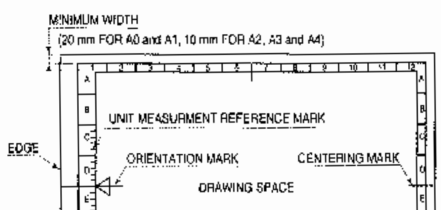


FIG. 2-1(a)



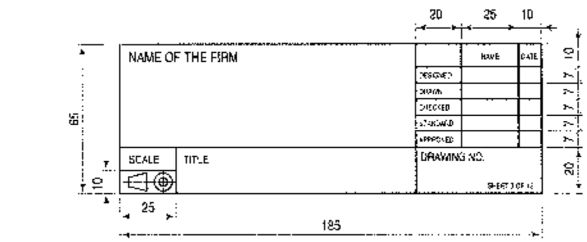


FIG. 2-2

TABLE 2-2
PARTICULARS OF TITLE BLOCK

	Name of the firm.
	Title of the drawing.
	Scale.
	Symbol for the method of projection.
	Drawing number.
	Initials with dates of persons who have designed, drawn, checked, standards and approved.
	No. of sheet and total number of sheets of the drawing of the object.

(8) List of parts or the bill of materials: When drawings of a number of constituent parts of an object are drawn in a single drawing sheet, a list of these parts should be placed above or beside the title block in a tabular form. It should provide the following minimum particulars for each part:

Part no., name or description, no. off i.e. quantity required, material and sometime stock size of raw material, remarks.

Additional information such as job and order number, instructions regarding finish, heat-treatment, tolerances (general) and references pertaining to jigs, fixtures, tools, gauges etc. may be, if necessary included in the title block or given separately in tabular form.

(9) Revisions of drawing: For locating a portion of the drawing for the purpose of

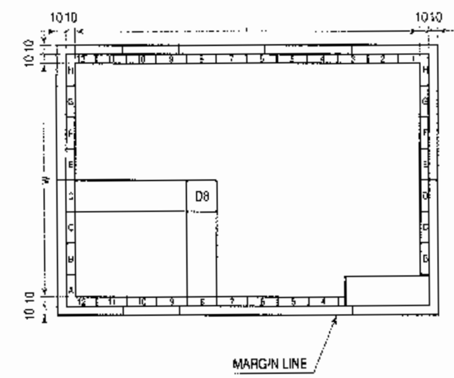


FIG. 2-3

(10) Folding marks: Folding marks are made in the drawing sheet as shown in fig. 2-1(a). They are helpful in folding of prints in proper and easy manner. Two methods of folding of prints are in general use. Method I is suitable for prints which are to be filed or bound. It allows prints to be unfolded or refolded without removing them from the files.

Fig. 2-4(i) shows the folding diagram for folding an A1 size sheet by method I. It is folded in *two* stages, viz. lengthwise [fig. 2-4(ii)] and crosswise [fig. 2-4(iii)].

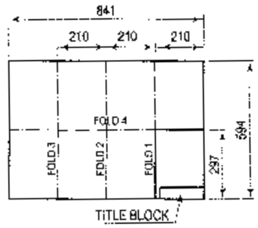


FIG. 2-5

Dimensions for folding of various sizes of drawing sheets by the *two* methods are given below:

Method I				Method II			
Sheet size	Horizontal dimensions from left (mm)	Vertical dimensions from bottom (mm)	No. of folds	Sheet size	Horizontal dimensions from left (mm)	Vertical dimensions from bottom (mm)	No. of folds
A0	130 + 109 + 190 × 5	297 × 2 + 247	9	A0	139 + 210 × 5	297 + 297 + 247	7
A1	146 + 125 + 190 × 3	297 + 297	6	A1	211 + 210 × 3	297 + 297	4
A2	116 + 96 × 3 + 190	297	1	A2	174 + 210 × 2	297 + 123	3
A3	125 + 105 + 190	297	1	A3	210 + 210	297	1

The final size of the folded print in method I will be 297 mm × 190 mm, while that in method II will be 297 mm × 210 mm. In either case the title block is visible in the top part of the folded print.

(11) Scales and scale drawing: Sometime machine part is required to draw larger or smaller than their actual size. For example a crankshaft of an engine would be drawn to a reduced scale, while connecting rod's bolt is to be drawn to enlarged scale. The scale of drawing must be indicated in the title block as shown in fig. 2-2. When details are drawn to the different scale in the same drawing sheet corresponding scale should be mentioned under each such detail.

2-2. TYPES OF MACHINE DRAWINGS

Machine drawings are prepared for various purposes and they are further classified as under:

(1) Production drawing: A production drawing is legal document of company. It is used by the technicians on the shop-floor for manufacturing the parts. It must provide informations about part number, dimensions, tolerance, surface finish, material and stock size, manufacturing process, special finishing process if required, and no. off required for each assembly. It is further sub-classified as:

(i) Part drawing or detailed drawing

(ii) Assembly drawing.

(2) Exploded assembly drawing: It represents the details of machine in a pictorial form as it is assembled. It helps the mechanics for dismantling machine for repairing purpose.

(3) Schematic assembly drawing: This type of assembly drawing is used for explaining working principle of any machine.

(4) Drawing for instruction manual: This is assembly drawing without dimensions. Each part of machine is numbered so that it can be easily dismantled or assembled if required. This is also used for explaining working principle of each part.

(5) Drawing for installation: This is assembly drawing with overall dimensions. It is used for the preparation of foundation for installing machine.

(6) Drawing for catalogue: Special assembly drawings are prepared for catalogues, with overall and principal dimensions.

(7) Tabular drawing: This is part drawing. It is used when components of same shape but different dimensions are to be manufactured.

(8) Patent drawing: It is generally assembly drawing either in pictorial form or principal view of orthographic projection of machine. It is used for obtaining *patent* of the machine.

2-3. FREE-HAND SKETCHING

(1) Sketching or freehand: Sketching or freehand is a first step to the preparation

(2) **Sketching materials:**

(i) A soft-grade pencil, preferably HB or H sharpened to a conical point.

(ii) A soft rubber-eraser.

(iii) A paper in form of a sketch-book or a pad.

Above the *three* things are absolutely essential for sketching.

Sometimes, cross-sectioned graph paper ruled with light lines is also used instead of a plain paper. These lines and squares help in drawing straight lines and also maintaining proportions.

As such papers may not always be readily available, it is advisable to learn sketching without their aid.

(3) **To sketch straight lines:** Horizontal lines are sketched with the motion of the wrist and the fore-arm. They are sketched from left to right [fig. 2-6(i)]. To sketch a horizontal line, mark the end points. Hold the pencil at about 30 mm distance from the lead point. Swing it from left to right and backwards, between the two points and without touching the surface of the paper, till the correct direction is achieved. Then begin to draw the line (with the wrist-motion) with short and light strokes. Shift the hand after each stroke. Keep your eyes on the point at which the line is to end. Finish finally with a dark and firm line. Take proper care to maintain straightness and correct direction of the line.

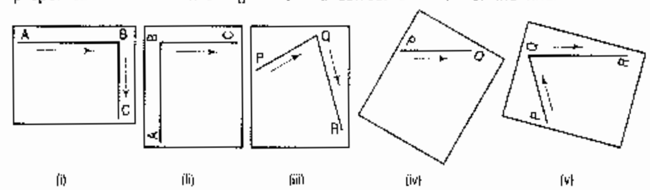


FIG. 2-6

Vertical lines are sketched downwards [fig. 2-6(i)] with the movement of fingers. They may also be sketched by converting them into horizontal lines by revolving the paper as shown in fig. 2-6(ii). Vertical or horizontal lines near the edges of a sketch-book may be drawn by sliding fingers along those edges, thus using them as guides. Inclined lines, when they are nearly horizontal, are sketched from

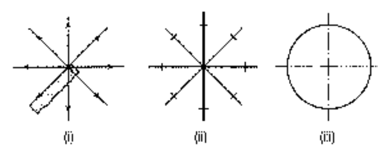


FIG. 2-7

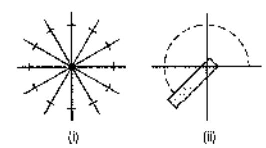


FIG. 2-8

Large circles may be sketched as described above by adding a few extra radial lines [fig. 2-8(i)]. An easier method is to mark a number of points by means of a trammel (at radius-distance from the centre) and to sketch the circle through these points [fig. 2-8(ii)].

Large circles can also be drawn by making a compass of fingers and a pencil. Keep the little finger as a pivot at the centre. Hold the pencil stationary so that its point is at radius-distance from the centre and touches the paper. Rotate the paper with the other hand. The pencil-point will mark the circle on the paper. Two pencils may also be used as a compass. One pencil is held as a pivot, while the other describes the circle as the paper is rotated.

A circle of small radius can be sketched within a square. Sketch the circumscribing square (length of the side equal to the diameter of the circle) and mark the diagonals [fig. 2-9(i)]. Mark the mid-points of the sides of the square and four points on the diagonals at radius-distance from the centre [fig. 2-9(ii)]. Sketch a neat circle through the eight points [fig. 2-9(iii)].

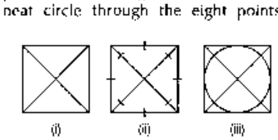


FIG. 2-9

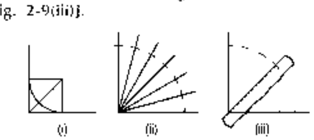


FIG. 2-10

Arcs of small radii are conveniently drawn by constructing squares [fig. 2-10(i)]. Large-radii arcs may be drawn by one of the methods described above for large circles. Radial-line and trammel methods are shown in fig. 2-10(ii) and fig. 2-10(iii)

(ii) Insert centre lines for arcs and circles, and block-in the main shapes [fig. 2-12(ii)].

(iii) Sketch arcs and circles, and build-up the details [fig. 2-12(iii)].

(iv) Erase all construction lines. Dim all the lines and then make them bold and firm [fig. 2-12(iv)] starting with the curves. Keep the centre lines fainter. Insert all dimensions. Print the title.

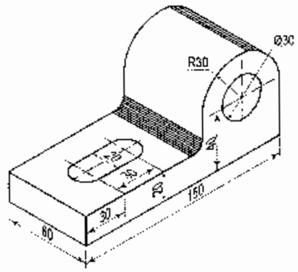
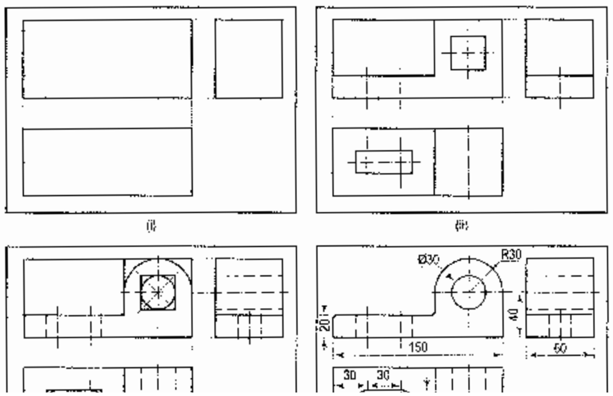


FIG. 2-11



EXERCISES 2

1. Prepare, giving all details, a neat sketch of a simple title block provided in a drawing sheet. What is its size, as recommended by the B.I.S.?
2. Make a sketch of an A1 size drawing sheet, showing in it, the border lines, margin lines, folding marks, zones and the title block. Give the untrimmed and trimmed sizes of this sheet.
3. Fill-up the blanks in the following by appropriate words or numerals selected from those given in the list as shown below.

   (i) The size of the title block for all sizes of drawing sheets is .... mm × .... mm.

   (ii) The zones along the length of the sheet are designated by ________, while those along its width by ________.

   (iii) For locating a portion of a drawing, the sheet is divided into a number of ________.

   (iv) For A1 size sheet the number of zones suggested by B.I.S. along the length are ...., while those along the width are ____________.

   (v) The drawing sheet is so folded that the ...._____ is always on the top.

   (vi) Horizontal lines are sketched from ________ to ________ while vertical lines are sketched from . ... to ____________.

   (vii) Three things absolutely essential for sketch-work are ....______, ________ and ________.

   (viii) A sketch is considered to be good when its features are shown in correct ________.

List of words and numerals for Ex. 3:

1. Title block	7. Proportions	13. Eraser	19. Top
2. Pencil	8. Right	14. Left	20. Compass
3. 210	9. 85	15. 16	21. 65
4. Numerals	10. Letters	16. Position	22. Blocks
5. Paper	11. Bottom	17. Zones	23. 8

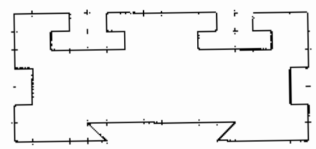


FIG. 2-13

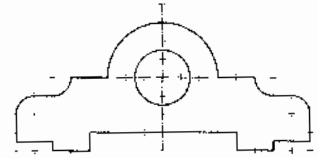


FIG. 2-14

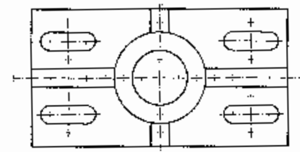


FIG. 2-15

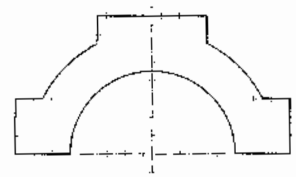


FIG. 2-16

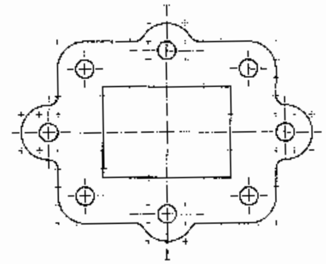


FIG. 2-17

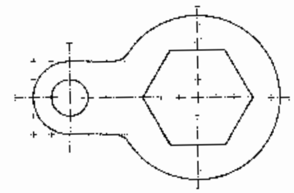


FIG. 2-18

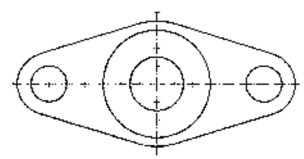


FIG. 2-20

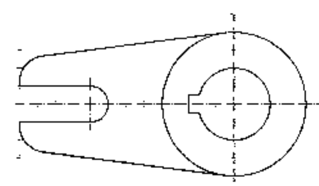


FIG. 2-21

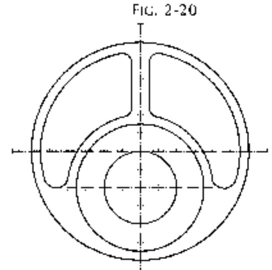


FIG. 2-22

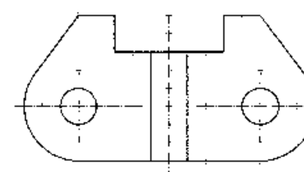
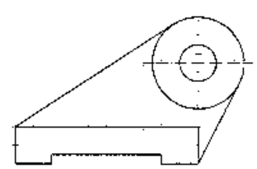
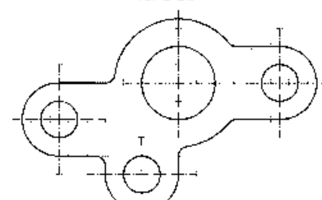


FIG. 2-23





Chapter 3 LINES, LETTERING AND DIMENSIONING

3-0. INTRODUCTION

This chapter deals with various types of lines, lettering and dimensioning which are used in engineering drawing.

3-1. LINES

Various types of lines used in general engineering drawing are shown in fig. 3-1 as described by SP 46:2003.

(1) **Line thickness:** The thicknesses of lines are varied according to the drawing and are finalized either *by ink* or *by pencil.*

(2) **Inked drawings:** The thicknesses of lines in various groups are shown in table 3-1. The line-group is designated according to the *thickness of the thickest line*. For any particular drawing a line-group is selected according to its size and type. All lines should be sharp and dense so that good prints can be reproduced.

TABLE 3-1

Line-group mm	Type of line						
	A	B	C	D	E	F	G
1.2	1.2	0.6	0.4	0.4	1.2	0.4	0.4
0.8	0.8	0.4	0.3	0.3	0.8	0.3	0.3
0.5	0.5	0.3	0.2	0.2	0.5	0.2	0.2
0.3	0.3	0.2	0.1	0.1	0.3	0.1	0.1

(3) **Pencil drawings:** For drawings finalized with pencil, the lines can be divided

TABLE 3-3

[illegible]	[illegible]
Initial work and construction lines	H
Outlines, dotted lines, section-plane lines, dimension lines, arrowheads	2H
Centre lines, section lines	3H or 4H

[illegible]	[illegible]	[illegible]
A	Contiouous thick or Contiouous wide	Visible outlines, visible edges; crests of screw threads; limits of length of full deph thread,lines of cuts and section arrows; parting lines of moulds in views; main representations in diagrams, maps, flow charts; system lines(structural metal engg.)
B	Continuous thin (narrow) (straight or curved)	Imaginary lines of intersection; grid, dimension, extension, projection, short centre, leader, reference lines; hatching; outlines of revolved sections; root of screw threads; interpretation lines of tapered features; framing of details; indication of repetitiv details;
C	Continuous thin (narrow) freehand	Limits of partial or interrupted views and sections, if the limit is not a chain thin line
D	Continuous thin (narrow) with zigzags (straight)	Long-break line
E	Dashed thick (wide)	Line showing permissible of surface treatment
F	Dashed thin (narrow)	Hidden outlines; hidden edges
G	Chain thin Long-dashed dotted (narrow)	Centre line; lines of symmetry; trajectories; pitch circle of gears, pitch circle of holes,

Drawing pencils are graded according to increase in relative hardness. They are marketed with the labelled as H, 2H, 3H, 4H, 5H, 6H etc. Students are advised to use pencils as recommended in table 3-3, for getting accurate, clean and neat drawings.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 3 for Type of lines, lettering and dimensioning.

3-1-1. TYPES OF LINES (Fig. 3-2 and Fig. 3-3)

(1) **Outlines** (A): Lines drawn to represent visible edges and surface boundaries of objects are called outlines or principal lines. They are continuous thick or wide lines (fig. 3-2).

(2) **Margin lines** (A): They are continuous thick or wide lines along which the prints are trimmed [fig. 2-1(a)].

(3) **Dimension lines** (B): These lines are continuous thin lines. They are terminated at the outer ends by pointed arrowheads touching the outlines, extension lines or centre lines (fig. 3-2).

(4) **Extension or projection lines** (B): These lines also are continuous thin lines. They extend by about 3 mm beyond the dimension lines (fig. 3-2).

(5) **Construction lines** (B): These lines are drawn for constructing figures. They are shown in geometrical drawings only. They are continuous thin light lines.

(6) **Hatching or section lines** (B): These lines are drawn to make the section evident. They are continuous thin lines and are drawn generally at an angle of 45° to the main outline of the section. They are uniformly spaced about 1 mm to 2 mm apart (fig. 3-2).

(7) **Leader or pointer lines** (B): Leader line is drawn to connect a note with the feature to which it applies. It is a continuous thin line (fig. 3-2).

(8) **Border lines** (B): Perfectly rectangular working space is determined by drawing the border lines [fig. 2-1(a)]. They are continuous thin lines.

(9) **Short-break lines** (C): These lines are continuous, thin and wavy. They are drawn freehand and are used to show a short break, or irregular boundaries (fig. 3-3).

(10) **Long-break lines** (D): These lines are thin ruled lines with short zigzags within them. They are drawn to show long breaks (fig. 3-3).

(11) **Hidden or dotted lines** (E or F): Interior or hidden edges and surfaces are shown by hidden lines. They are also called dotted lines. They are of medium thickness and made up of short dashes of approximately equal lengths of about 2 mm spaced

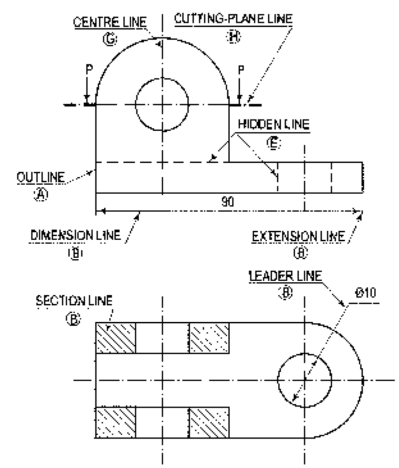
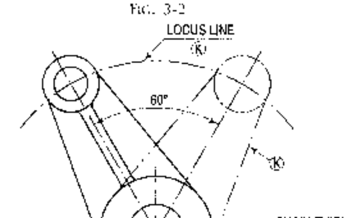


FIG. 3-2



3-2. LETTERING (IS : 9609-2001)

Writing of titles, dimensions, notes and other important particulars on a drawing is called *lettering*. It is an important part of a drawing. However accurate and neat a drawing may be drawn. Its appearance is spoiled and sometimes, its usefulness is impaired by poor lettering. Lettering should, therefore, be done properly in clear, legible and uniform style. It should be in plain and simple style so that it could be done *freehand* and *speedily*.

Note: Use of drawing instruments in lettering takes considerable time and hence, it should be avoided. Efficiency in the art of lettering can be achieved by careful and continuous practice.

(1) **Single-stroke letters:** The Bureau of Indian Standards (IS : 9609-2001) recommends single-stroke lettering for use in engineering drawing. These are the simplest forms of letters and are usually employed in most of the engineering drawings.

The word single-stroke should not be taken to mean that the letter should be made in one stroke without lifting the pencil.

It actually means that the thickness of the line of the letter should be such as is obtained in one stroke of the pencil. The horizontal lines of letters should be drawn from left to right and vertical or inclined lines, from top to bottom.

Single-stroke letters are of *two* types:

(i) vertical and
(ii) inclined.

Inclined letters lean to the right, the slope being 75° with the horizontal. The size of a letter is described by its height. According to the height of letters, they are classified as:

(i) Lettering 'A' (refer to table 3-4 and fig. 3-8)
(ii) Lettering 'B' (refer to table 3-5 and fig. 3-8).

TABLE 3-4

LETTERING A $\left(d = \frac{h}{14}\right)$

Lettering height Height of capitals	h	$\left(\frac{14}{14}\right)$ h	2.5	3.5	5	7	10	14	20

TABLE 3-5

LETTERING B $\left(d = \frac{h}{10}\right)$

Lettering height Height of capitals	h	$\left(\frac{10}{10}\right)$ h	2.5	3.5	5	7	10	14	20
Height of lower-case letters	c	$\left(\frac{7}{10}\right)$ h	–	2.5	3.5	5	7	10	14
Spacing between characters	a	$\left(\frac{2}{10}\right)$ h	0.5	0.7	1	1.4	2	2.8	4
Minimum spacing of base lines	b	$\left(\frac{14}{10}\right)$ h	3.5	5	7	10	14	20	28
Minimum spacing between words	e	$\left(\frac{6}{10}\right)$ h	1.5	2.1	3	4.2	6	8.4	12
Thickness of lines	d	$\left(\frac{1}{10}\right)$ h	0.25	0.35	0.5	0.7	1	1.4	2

In lettering 'A' type, the height of the capital letter is divided into 14 parts, while in lettering 'B' type it is divided into 10 parts. The height of the letters and numerals for engineering drawing can be selected from 2.5, 3.5, 5, 7, 10, 14 and 20 mm according to the size of drawing. The ratio of height to width varies but in case of most of the letters it is 6 : 5.

Lettering is generally done in capital letters. Different sizes of letters are used for different purposes.

The main titles are generally written in 6 mm to 8 mm size, sub-titles in 3 mm to 6 mm size, while notes, dimension figures etc. in 3 mm to 5 mm size. The drawing number in the title block is written in numerals of 10 mm to 12 mm size.

Fig. 3-4 shows single-stroke vertical capital letters and figures with approximate proportions.

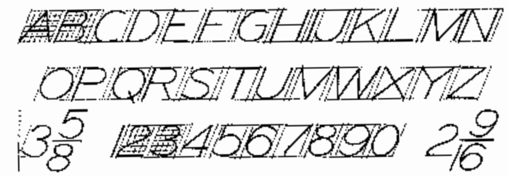
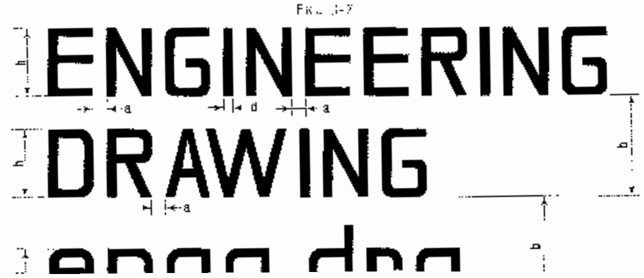


Fig. 3-5

Fig. 3-6

Fig. 3-7



Therefore, H or HB grade of pencil is recommended for this purpose. The spacing between two letters should not necessarily be equal. The letters should be so spaced that they do not appear too close together or too much apart.

Judging by the eye, the back ground areas between the letters should be kept approximately equal. The distance between the words must be uniform and at least equal to the height of the letters. Refer to fig. 3-8.

Lettering should be so done as can be read from the front with the main title horizontal, i.e. when the drawing is viewed from the bottom edge.

All sub-titles should be placed below but not too close to the respective views. Lettering, except the dimension figures, should be underlined to make them more prominent.

(2) Gothic letters: Stems of single-stroke letters, if given more thickness, form what are known as *gothic* letters. These are mostly used for main titles of ink-drawings. The outlines of the letters are first drawn with the aid of instruments and then filled-in with ink.

The thickness of the stem may vary from $\frac{1}{5}$ to $\frac{1}{10}$ of the height of the letters. Fig. 3-9 shows the alphabet and figures in gothic with thickness equal to $\frac{1}{7}$ of the height.

Fig. 3-9

The former indicate sizes, viz. length, breadth, height, depth, diameter etc. The latter show locations or exact positions of various constructional details within the object. The letter F represents functional dimensions, while NF represents non-functional dimensions.

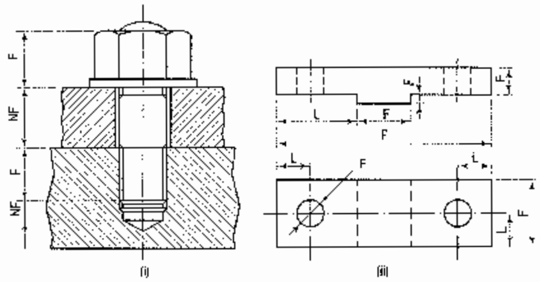


Fig. 3-10

3-4. DIMENSIONING TERMS AND NOTATIONS

(1) Dimension line (fig. 3-11): Dimension line is a thin continuous line. It is terminated by arrowheads touching the outlines, extension lines or centre lines.

(2) Extension line (fig. 3-11): An extension line is also a thin continuous line drawn in extension of an outline. (Formerly, the B.I.S. had recommended that a gap of about 1 mm should be kept between the extension line and an outline or object boundry.) It extends by about 3 mm beyond the dimension line.

(3) Arrowhead (fig. 3-11): An arrowhead is placed at each end of a dimension line. Its pointed end touches an outline, an extension line or a centre line. The size of an arrowhead should be proportional to the thickness of the outlines. *The length of the arrowhead should be about three times its maximum width.* It is drawn freehand with two strokes made in the direction of its pointed end. The space between them is neatly filled up. Different types of arrow heads are shown in fig. 3-11(a). Generally closed and filled arrowhead is widely used in engineering drawing.

Note (fig. 3-11): A note gives information regarding specific operation relating to

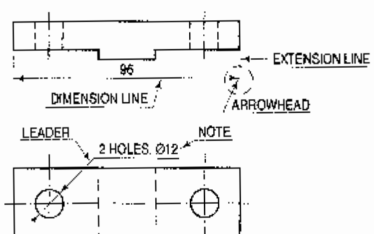


Fig. 3-11

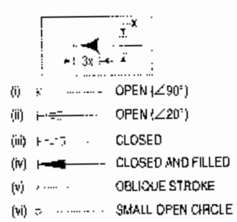


Fig. 3-11(a)

Fig. 3-11(b)

3-5. PLACING OF DIMENSIONS

The *two* systems of placing dimensions are:

(1) Aligned system and

(2) Unidirectional system.

(1) Aligned system (fig. 3-12): In the aligned system *the dimension is placed perpendicular to the dimension line in such a way that it may be read from the bottom edge or the right-hand edge of the drawing sheet.* The dimensions should be placed *near the middle* and *above*, but clear of the dimension lines.

3-6. UNIT OF DIMENSIONING

As far as possible all dimensions should be given in *millimetres*, omitting the abbreviation mm. Even when it is not convenient to give dimensions in millimetres and another unit is used, only the dimension figures are written. But a foot note such as '*all dimensions are in centimetres*' is inserted in a prominent place near the title block. The *height* of the *dimension figures* (as stated earlier) should be from *3 mm to 5 mm*. The decimal point in a dimension should be quite distinct and written in line with the bottom line of the figure (fig. 3-27). A zero must always precede the decimal point when the dimension is less than unity.

3-7. GENERAL RULES FOR DIMENSIONING

(1) Dimensioning should be done so completely that further calculation or assumption of any dimension, or direct measurement from the drawing is not necessary.

(2) Every dimension must be given, but none should be given more than once.

(3) A dimension should be placed on the view where its use is shown more clearly.

(4) Dimensions should be placed outside the views, unless they are clearer and more easily read inside.

(5) Mutual crossing of dimension lines and dimensioning between hidden lines should be avoided. Dimension lines should not cross any other line of the drawing.

(6) An outline or a centre line should never be used as a dimension line. A centre line may be extended to serve as an extension line (fig. 3-13).

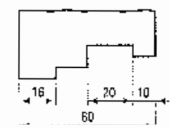
(7) Aligned system of dimensioning is recommended.

3-8. PRACTICAL HINTS ON DIMENSIONING

(1) Dimension lines should be drawn at least 8 mm away from the outlines and from each other.

(2) Dimensions in a series may be placed in any one of the following *two* ways:

(i) *Continuous or chain dimensioning* (fig. 3-14): Dimensions are arranged in a straight line. An overall dimension is placed outside the smaller



(4) When a number of parallel dimension lines are to be shown near each other, the dimensions should be staggered (fig. 3-16).

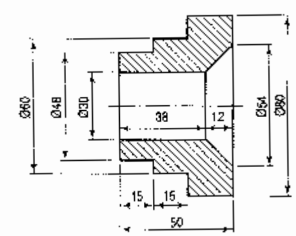


FIG. 3-16

(5) Dimensions should be shown where the shape is easily identified.

(6) Arrowheads should ordinarily be drawn within the limits of the dimensioned feature. But when the space is too narrow, they may be placed outside (fig. 3-17). A dot may also be used to replace an arrowhead. Due to lack of space, the dimension figure may be written above the extended portion of the dimension line, but *preferably on the right-hand side* (fig. 3-17).

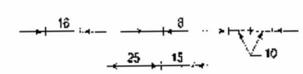


FIG. 3-17

(7) Dimensions of cylindrical parts should as far as possible be placed in the views in which they are seen as *rectangles* (fig. 3-18). The dimension indicating a diameter should always be preceded by the symbol ø. *Dimension of a cylinder should not be given as a radius.*

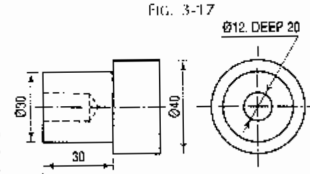


FIG. 3-18

Fig. 3-19 shows various methods of dimensioning different sizes of circles. Dimensions should be shown in one view only, the same dimension must not be repeated in other view.

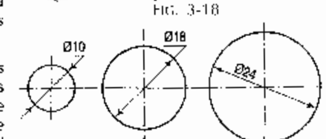


FIG. 3-19

In case of a large-size bore or a pitch circle, the dimension may be shown by a diagonal diameter (fig. 3-21).

But (in aligned system) a dimension should not be placed within 30° zone of the vertical centre line as shown by the shaded space in fig. 3-21.

Holes on pitch circles when equally spaced should be dimensioned as shown in fig. 3-21. When holes are not equally or uniformly spaced on the pitch circle, they should be located by angles with one of the two main centre lines (fig. 3-22).

Arcs of circles should be dimensioned by their respective radii. Dimension line for the radius should pass through the centre of the arc. The dimension figure must be preceded by the letter *R*. Fig. 3-23 shows different methods of showing the radii of arcs.

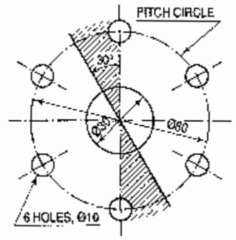


FIG. 3-21

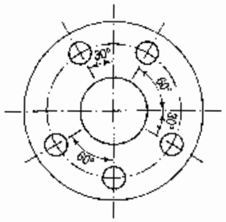


FIG. 3-22

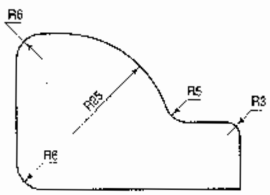


FIG. 3-23

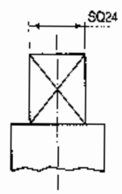


FIG. 3-24

(8) Letters SQ should precede the dimension for a rod of square cross-section (fig. 3-24). The word SPHERE should be placed before the dimension (radius *R* or diameter ø) of a spherical part (fig. 3-25).

(9) Angular dimensions may be given by any one of the methods shown in fig. 3-26.

(10) Fig. 3-27 shows a method of dimensioning a countersunk hole. The maximum diameter is also sometimes given.

(11) Methods of dimensioning a chamfer is shown in fig. 3-28.

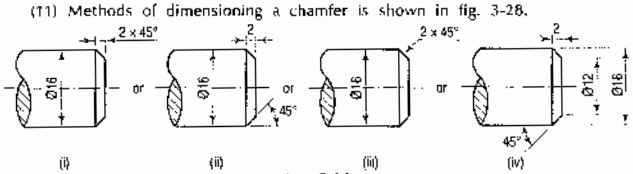


FIG. 3-28

(12) Designation and size, along with the useful length must be given while dimensioning an external screw thread (fig. 3-29). In case of internal screw thread, in addition to the size and type, the depth of the drilled hole before tapping must also be given (fig. 3-30).

(13) Left-hand thread and multiple-start thread should be dimensioned as shown in fig. 3-31 and fig. 3-32 respectively.

(14) A slope or taper is defined as unit alteration in a specified length. The specified length is measured along the base line in case of flat pieces and along the axis in case of shafts.

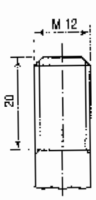


FIG. 3-29

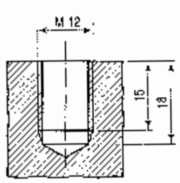


FIG. 3-30

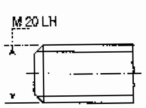


FIG. 3-31

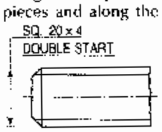


FIG. 3-32

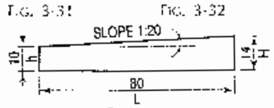
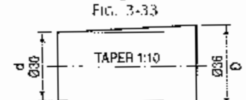


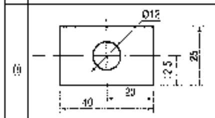
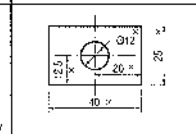
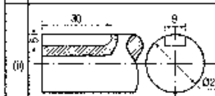
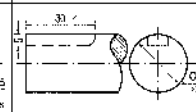
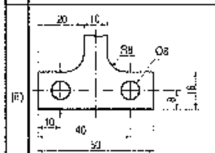
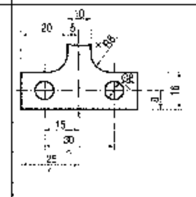
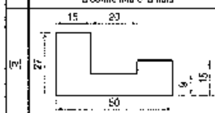
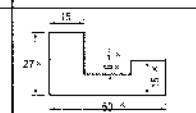
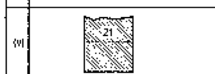
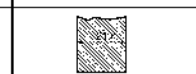
FIG. 3-33

(15) Fig. 3-33 shows the method of indicating slope on a flat piece. It is written parallel to the sloping line.



H − h   1

(19) Study carefully fig. 3-37 for correct dimensioning.
Incorrect dimensioning is shown by cross (X) in the figure.

	CORRECT	INCORRECT	REASONS FOR INCORRECT
(i)	 Dimensions should be placed outside view		1. Arrow head not proportionate. 2. Hole dimension shown in figure. Leader line not ends horizontally. 3. Dimension '40' is too close. 4. Placing dimensions methods mix. Dimension '40' is according to aligned method.
(ii)	 Dim. should be marked from visible outlines		1. A key-way is shown with dotted line where the dimensions are placed. 2. Leader line for the shaft diameter is drawn horizontal touching the boundary line.
(iii)	 Dimensions should be given from the outlines (finished surface) or a centre line of a hole		1. Dimensions are given form the mid-line of the object. 2. Dimensions of holes are shown inside the figure. 3. Dimensions are shown in vertical line. 4. Smaller dimensions (25 mm) precedes the larger dimensions (30 mm). 5. Fillet radius is not shown.
(iv)			1. Dimension lines are used as extension. 2. Dimensions are placed inside the view. 3. Dimension 27 and 50 not written according to aligned system.
(v)			Section overlap the dimension 21

EXERCISES 3

1. Write freehand, in single-stroke (i) vertical capital letters and (ii) inclined capital letters of 3 mm height, the following paragraph from page 39.
'All letters should ___ ___ i.e. intensely black'.
2. Write freehand, in single-stroke vertical lower-case letters of 3 mm height, the following two paragraphs from page 37.
'Writing of titles, ___ freehand and speedily'.
3. Write freehand, the paragraphs stated in Ex. 2 above, in single-stroke inclined lower-case letters of 3 mm height.
4. Print in gothic letters of 12 mm height, the titles of Chapters 1, 2 and 3.
5. Fill-in the blanks with appropriate words selected from the list given below:
   (a) Writing of titles, notes etc. on a drawing is called ______.
   (b) Efficiency in the art of lettering is achieved by continuous ______.
   (c) Lettering should be in plain and simple style so that it could be done ______ and ______.
   (d) For maintaining uniformity in size, thin and light ______ may first be drawn.
   (e) All letters should be uniform in ______, ______, ______, ______ and ______.
   (f) The inclined letters slope to the ______ at an angle of ______ degrees.
   (g) The size of the letter is described by its ______.
   (h) Main title of inked drawing is generally written in ______ letters.
   (i) The two types of single-stroke letters are ______ and ______.
   (j) Lettering is usually done in ______ letters.
   (k) Lower-case letters are usually used in ______ drawings.
   (l) Lettering should be so done as can be read from the ______ with the main title ______.

List of words for Ex. 5:

1. Inclined	6. Vertical	11. Right	16. Practice
2. Shade	7. Freehand	12. Front	17. Lettering
3. Horizontal	8. Shape	13. Guide lines	18. Spacing

B (1) long and thin chain lines
(2) thick and long chain line, thick at ends only
(3) thick continuous lines
(4) short dashes of approximately equal lengths
(5) thin continuous lines
(6) continuous, thin and wavy lines, drawn freehand
(7) thin ruled lines with short zigzags within them
(8) alternately long and short dashes
(9) dashed lines of medium thickness.

7. Fill-up the blanks in the following sentences by appropriate words selected from the list of words given below:
   (a) Two types of dimensions needed on a drawing are ______ and ______ dimensions.
   (b) The two systems of placing dimensions are ______ and ______.
   (c) In ______ system, the dimension is placed ______ to and near the ______ but clear of dimension line.
   (d) In ______ system, all dimensions are so placed that they are readable from the ______ edge of the drawing sheet. Dimension lines are ______ near the middle for inserting dimensions.
   (e) As far as possible dimensions should be given in one unit, preferably in ______.
   (f) Dimension lines should be drawn at least 8 mm away from the ______ and from ______.
   (g) An ______ or ______ should never be used as a dimension line.
   (h) Mutual ______ of dimension lines and dimensioning between ______ should be avoided.
   (i) All dimensions are shown from a common base line in ______ dimensioning.
   (j) In ______ dimensioning, dimensions are arranged in a straight line, and an ______ dimension is placed outside the small dimensions.
   (k) When a number of parallel dimensions are to be shown near each other, the dimensions should be ______.
   (l) The extension line should extend about 3 mm beyond the ______.
   (m) The line connecting a view to a note is called a ______.
   (n) The dimension indicating a diameter should be ______ by the symbol

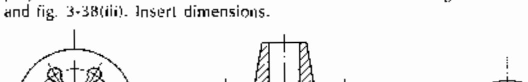
List of words for Ex. 7:

1. Thin	9. Crossing	17. Millimetres	25. Leader
2. Axis	10. Dimension line	18. Overall	26. Radius
3. Aligned	11. Dashed line	19. Outlines	27. Angle
4. Broken	12. Each other	20. Outline	28. R
5. Base line	13. Followed	21. Perpendicular	29. 45°
6. Bottom	14. Location	22. Progressive	30. Size
7. Centre line	15. Middle	23. Rectangles	31. Staggered
8. Continuous	16. Ø	24. Preceded	32. Unidirectional

Answers to Ex. 5, 6 and 7:

Ex. 5.	(a) 17	(d) 13	(g) 5	(j) 15
	(b) 16	(e) 20, 8, 14, 2 and 18	(h) 9	(k) 19
	(c) 7 and 4	(f) 11 and 10	(i) 6 and 1	(l) 12 and 3.
Ex. 6.	(a) 3	(d) 1	(g) 2	
	(b) 9	(e) 4	(h) 6	
	(c) 8	(f) 5	(i) 7.	
Ex. 7.	(a) 30 and 14	(f) 19 and 12	(k) 31	(p) 23
	(b) 3 and 32	(g) 20 and 7	(l) 10	(q) 26
	(c) 3, 21 and 15	(h) 9 and 11	(m) 25	(r) 7
	(d) 32, 6 and 4	(i) 22	(n) 24 and 16	(s) 5 and 2
	(e) 17	(j) 8 and 18	(o) 28 and 13	(t) 1, 27 and 29.

8. What are the two systems of placing dimensions on a drawing? Illustrate your answer with sketches.
9. Show by sketches the difference between (i) continuous or chain dimensioning and (ii) progressive or parallel dimensioning. What are the advantages of one above the other?
10. The orthographic views of the objects are drawn according to the First-angle projection method to 1 : 2 scale size and shown below in fig. 3-38(i), fig. 3-38(ii) and fig. 3-38(iii). Insert dimensions.



4-1. INTRODUCTION

Drawings of small objects can be prepared of the same size as the objects they represent. A 150 mm long pencil may be shown by a drawing of 150 mm length. Drawings drawn of the same size as the objects, are called full-size drawings. The ordinary full-size scales are used for such drawings.

A scale is defined as the ratio of the linear dimensions of element of the object as represented in a drawing to the actual dimensions of the same element of the object itself.

4-2. SCALES

The scales generally used for general engineering drawings are shown in table 4-1 [SP : 46].

TABLE 4-1

Reducing scales	1 : 2	1 : 5	1 : 10
	1 : 20	1 : 50	1 : 100
	1 : 200	1 : 500	1 : 1000
	1 : 2000	1 : 5000	1 : 10000
Enlarging scales	50 : 1	20 : 1	10 : 1
	5 : 1	2 : 1	
Full size scales			1 : 1

All these scales are usually 300 mm long and sub-divided throughout their lengths. The scale is indicated on the drawing at a suitable place near the title. The complete designation of a scale consists of word scale followed by the ratio, i.e. scale 1 : 1 or scale, full size.

(2) **Graphical scale:** The scale is drawn on the drawing itself. As the drawing becomes old, the engineer's scale may shrink and may not give accurate results.

However, such is not the case with graphical scale because if the drawing shrinks, the scale will also shrink. Hence, the graphical scale is commonly used in survey maps.

(3) **Representative fraction:** The ratio of the length of the object represented on drawing to the actual length of the object represented is called the Representative Fraction (i.e. R.F.).

$$\text{R.F.} = \frac{\text{Length of the drawing}}{\text{Actual length of object}}$$

When a 1 cm long line in a drawing represents 1 metre length of the object, the R.F. is equal to $\frac{1 \text{ cm}}{1 \text{ m}} = \frac{1 \text{ cm}}{1 \times 100 \text{ cm}} = \frac{1}{100}$ and the scale of the drawing will be 1 : 100 or $\frac{1}{100}$ full size. *The R.F. of a drawing is greater than unity when it is drawn on an enlarging scale.* For example, when a 2 mm long edge of an object is shown in a drawing by a line 1 cm long, the R.F. is $\frac{1 \text{ cm}}{2 \text{ mm}} = \frac{10 \text{ mm}}{2 \text{ mm}} = 5$. Such a drawing is said to be drawn on scale 5 : 1 or *five times full-size.*

4-3. SCALES ON DRAWINGS

When an unusual scale is used, it is constructed on the drawing sheet. To construct a scale the following information is essential:

(1) The R.F. of the scale.

(2) The units which it must represent, for example, millimetres and centimetres, or feet and inches etc.

(3) The maximum length which it must show.

The length of the scale is determined by the formula:

Length of the scale = R.F. × maximum length required to be measured.

It may not be always possible to draw as long a scale as to measure the longest length in the drawing. The scale is therefore drawn 15 cm to 30 cm long, longer lengths being measured by marking them off in parts.

(ii) From the zero mark, the units should be numbered to the right and its sub-divisions to the left.

(iii) The names of the units and the sub-divisions should be stated clearly below or at the respective ends.

(iv) The name of the scale (e.g. scale, 1 : 10) or its R.F. should be mentioned below the scale.

Problem 4-1. (fig. 4-1): *Construct a scale of 1 : 4 to show centimetres and long enough to measure upto 5 decimetres.*

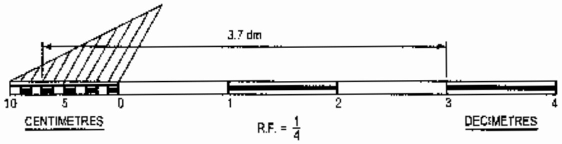


FIG. 4-1

(i) Determine R.F. of the scale. Here it is $\frac{1}{4}$.

(ii) Determine length of the scale.

Length of the scale = R.F. × maximum length = $\frac{1}{4} \times 5$ dm = 12.5 cm.

(iii) Draw a line 12.5 cm long and divide it into 5 equal divisions, each representing 1 dm.

(iv) Mark 0 at the end of the first division and 1, 2, 3 and 4 at the end of each subsequent division to its right.

(v) Divide the first division into 10 equal sub-divisions, each representing 1 cm.

(vi) Mark cms to the left of 0 as shown in the figure.

To distinguish the divisions clearly, *show the scale as a rectangle of small width (about 3 mm) instead of only a line.* Draw the division-lines showing decimetres throughout the width of the scale. Draw the lines for the sub-divisions slightly shorter as shown. Draw thick and dark horizontal lines in the middle of all alternate divisions and sub-divisions. This helps in taking measurements. Below the scale, print DECIMETRES on the right-hand side, CENTIMETRES on the left-hand side, and the R.F. in the middle.

To set-off any distance, say 3.7 dm, place one leg of the divider on 3 dm mark and

(i) Determine R.F. of the scale, here R.F. = $\frac{1}{60}$.

(ii) Determine length of the scale.

Length of the scale = $\frac{1}{60} \times 6$ m = $\frac{1}{10}$ metre = 10 cm.

(iii) Draw a line 10 cm long and divide it into 6 equal parts.

(iv) Divide the first part into 10 equal divisions and complete the scale as shown. The length 3.7 metres is shown on the scale.

Problem 4-3. (fig. 4-3): *Construct a scale of 1.5 inches = 1 foot to show inches and long enough to measure upto 4 feet.*

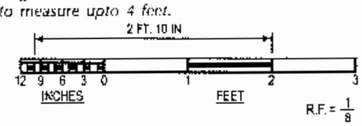


FIG. 4-3

(i) Determine R.F. of the scale. R.F. = $\frac{1.5 \text{ inches}}{1 \times 12 \text{ inches}} = \frac{1}{8}$.

(ii) Draw a line, 1.5 × 4 = 6 inches long.

(iii) Divide it into four equal parts, each part representing one foot.

(iv) Divide the first division into 12 equal parts, each representing 1". Complete the scale as explained in problem 4-1. The distance 2'-10" is shown measured in the figure.

Problem 4-4. (fig. 4-4): *Construct a scale of R.F. = $\frac{1}{60}$ to read yards and feet, and long enough to measure upto 5 yards.*

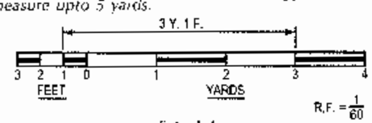


FIG. 4-4

(i) Length of the scale = R.F. × max. length = $\frac{1}{60} \times 5$ yd

$= \frac{1}{12}$ yd = 3 inches

(i) Length of the scale $= \frac{1}{84480} \times 6 = \frac{1}{14080}$ miles $= 4\frac{1}{2}''$.

(ii) Draw a line $4\frac{1}{2}''$ long and divide it into 6 equal parts. Divide the first part into 8 equal divisions and complete the scale as shown.

The distance 4 miles and 3 furlongs is shown measured in the figure.

(2) **Diagonal scales:** A diagonal scale is used when very minute distances such as 0.1 mm etc. are to be accurately measured or when measurements are required in three units; for example, dm, cm and mm, or yard, foot and inch.

Small divisions of short lines are obtained by the principle of diagonal division, as explained below.

Principle of diagonal scale: To obtain divisions of a given short line *AB* in multiples of $\frac{1}{10}$ its length, e.g. 0.1 *AB*, 0.2 *AB*, 0.3 *AB* etc. (fig. 4-6).

(i) At one end, say *B*, draw a line perpendicular to *AB* and along it, step-off ten equal divisions of any length, starting from *B* and ending at *C*.

(ii) Number the division-points, 9, 8, 7,.....1 as shown.

(iii) Join *A* with *C*.

(iv) Through the points 1, 2 etc. draw lines parallel to *AB* and cutting *AC* at 1', 2' etc. It is evident that triangles 1'1*C*, 2'2*C* ... *ABC* are similar.

Since *C*5 = 0.5*BC*, the line 5'5 = 0.5*AB*.

Similarly, 1'1 = 0.1*AB*, 2'2 = 0.2*AB* etc.

Thus, each horizontal line below *AB* becomes progressively shorter in length by $\frac{1}{10}$ *AB* giving lengths in multiples of 0.1*AB*.

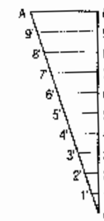


FIG. 4-6

Problem 4-6. (fig. 4-7): *Construct a diagonal scale of 3 : 200 i.e. 1 : 66 $\frac{2}{3}$ showing metres, decimetres and centimetres and to measure upto 6 metres.*

Length of the scale $= \frac{3}{200} \times 6$ m = 9 cm.

(i) Draw a line *AB* 9 cm long and divide it into 6 equal parts. Each part will show a metre.

(ii) Divide the first part *A*0 into 10 equal divisions, each showing a decimetre or 0.1 m.

(iii) At *A* erect a perpendicular and step-off along it, 10 equal divisions of any length, ending at *D*. Complete the rectangle *ABCD*.

(iv) Erect perpendiculars at metre-divisions 0, 1, 2, 3 and 4.

(v) Draw horizontal lines through the division-points on *AD*.

(vi) Join *D* with the end of the first division along *A*0, viz. the point 9.

(vii) Through the remaining points i.e. 8, 7, 6 etc. draw lines parallel to *D*9.

In △ *OFE*, *FE* represents 1 dm or 0.1 m. Each horizontal line below *FE* progressively diminishes in length by 0.1*FE*. Thus, the next line below *FE* is equal to 0.9*FE* and represents 0.9 × 1 dm = 0.9 dm or 0.09 m or 9 cm.

Any length between 1 cm or 0.01 m and 6 m can be measured from this scale. To show a distance of 4.56 metres, i.e. 4 m, 5 dm and 6 cm, place one leg of the divider at *Q* where the vertical through 4 m meets the horizontal through 6 cm and the other leg at *P* where the diagonal through 5 dm meets the same horizontal.

Problem 4-7. (fig. 4-8): *Construct a diagonal scale of R.F. = $\frac{1}{4000}$ to show metres and long enough to measure upto 500 metres.*

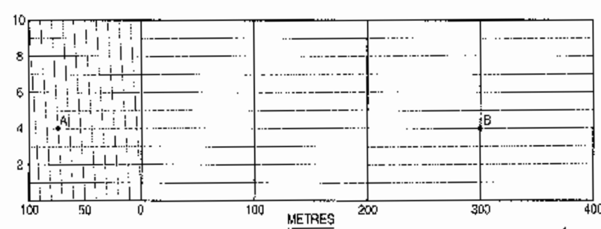


FIG. 4-8

Length of the scale $= \frac{1}{2.5} \times 20$ cm = 8 cm.

(i) Draw a line 8 cm long and divide it into 4 equal parts. Each part will represent a length of 5 cm.

(ii) Divide the first part into 5 equal divisions. Each division will show 1 cm.

(iii) At the left-hand end of the line, draw a vertical line and on it step-off 10 equal divisions of any length.

Complete the scale as explained in problem 4-6. The distance between points *C* and *D* shows 13.4 cm.

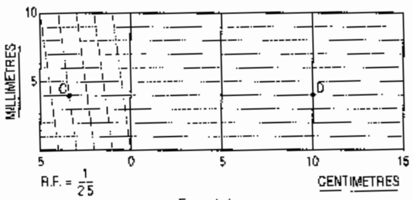
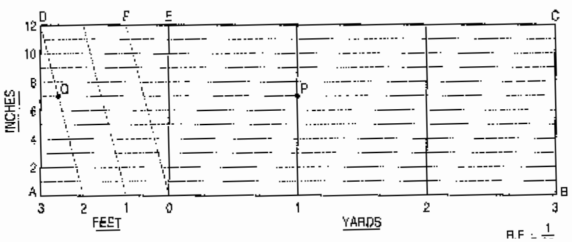


FIG. 4-9

Problem 4-9. (fig. 4-10): *Construct a diagonal scale of R.F. = $\frac{1}{32}$ showing yards, feet and inches and to measure upto 4 yards.*

Length of the scale $= \frac{1}{32} \times 4$ yd = 18 yd = $4\frac{1}{2}''$.



Problem 4-10. (fig. 4-11): *Draw a scale of full-size, showing $\frac{1}{100}$ inch and to measure upto 5 inches.*

(i) Draw a line *AB* 5" long and divide it into five equal parts. Each part will show one inch.

(ii) Sub-divide the first part into 10 equal divisions. Each division will measure $\frac{1}{10}$ inch.

(iii) At *A*, draw a perpendicular to *AB* and on it, step-off ten equal divisions of any length, ending at *D*.

(iv) Draw the rectangle *ABCD* and complete the scale as explained in problem 4-6. The line *QP* shows 2.68 inches.

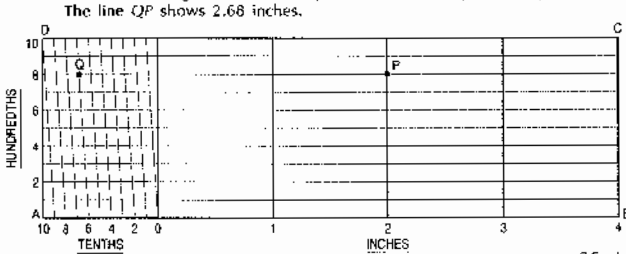
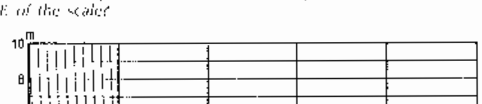


FIG. 4-11

Problem 4-11. (fig. 4-12): *The area of a field is 50,000 sq m. The length and the breadth of the field, on the map is 10 cm and 8 cm respectively. Construct a diagonal scale which can read upto one metre. Mark the length of 235 metre on the scale. What is the R.F. of the scale?*



$\therefore$ 1 sq cm $= \frac{50000}{80} = 625$ sq m.

$\therefore$ 1 cm $=$ 25 m.

Now representative fraction $= \frac{1 \text{ cm}}{25 \text{ m}} = \frac{1}{2500}$.

Length of the scale $= \frac{1}{2500} \times \frac{500 \times 100}{1} = \frac{50000}{2500} = 20$ cm.

Take 20 cm length and divide it into 5 equal parts. Complete the scale as shown in fig. 4-12.

(3) **Comparative scales:** Scales having same representative fraction but graduated to read different units are called *comparative scales*. A drawing drawn with a scale reading inch units can be read in metric units by means of a metric comparative scale, constructed with the same representative fraction. Comparative scales may be plain scales or diagonal scales and may be constructed separately or one above the other.

Problem 4-12. [fig. 4-13(i) and fig. 4-13(ii)]: *A drawing is drawn in inch units to a scale $\frac{3}{8}$ full size. Draw the scale showing $\frac{1}{8}$ inch divisions and to measure upto 15 inches. Construct a comparative scale showing centimetres and millimetres, and to read upto 40 centimetres.*

(i) *Inch scale:*

Length of the scale

$= \frac{3}{8} \times 15 = \frac{45}{8}$

$= 5\frac{5}{8}$ inches.

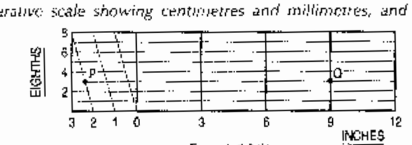


FIG. 4-13(i)

Construct the diagonal scale as shown in fig. 4-13(i).

(ii) *Comparative scale:*

Length of the scale

$= \frac{3}{8} \times 40$

$= 15$ cm.

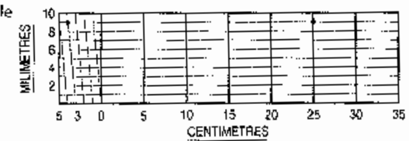


FIG. 4-13(ii)

Construct the diagonal scale as shown in fig. 4-13(ii).

The line *PQ* on the inch scale shows a length equal to $11\frac{3}{4}''$. Its equivalent, when

Length of kilometre scale $= \frac{1}{485000} \times 80 \times 1000 \times 100 = 16.5$ cm.

Length of verst scale $= \frac{1}{485000} \times 80 \times 1.067 \times 1000 \times 100 = 17.6$ cm.

Draw the two scales one above the other as shown in the figure.

Problem 4-14. (fig. 4-15): *On a road map, a scale of miles is shown. On measuring from this scale, a distance of 25 miles is shown by a line 10 cm long. Construct this scale to read miles and to measure upto 40 miles. Construct a comparative scale, attached to this scale, to read kilometres upto 60 kilometres. 1 mile = 1.609 km.*

(i) *Scale of miles:*

Length of the scale $= \frac{10 \times 40}{25} = 16$ cm.

Draw a line 16 cm long and construct a plain scale to show miles.

(ii) *Scale of kilometres:*

$$\text{R.F.} = \frac{10}{25 \times 1.609 \times 1000 \times 100} = \frac{1}{402250}$$

Length of the scale $= \frac{1}{402250} \times 60 \times 1000 \times 100 = 14.9$ cm.

Construct the plain scale 14.9 cm long, above the scale of miles and attached to it, to read kilometres.

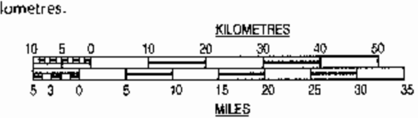


FIG. 4-15

Problem 4-15. (fig. 4-16): *The distance between Bombay and Poona is 180 km. A passenger train covers this distance in 6 hours. Construct a plain scale to measure time upto a single minute. The R.F. of the scale is $\frac{1}{200000}$. Find the distance covered by the train in 36 minutes.*

Speed of the train $= \frac{180}{6} = 30$ km/hour.

(ii) Time scale (minute scale):

Speed of the train = 30 km/hour.

i.e. 30 km is covered in 60 minutes.

As length of the scale of 15 cm represents 30 km, 60 minutes which is the time required to cover 30 km, can be represented on the same length of the scale.

(iii) Draw a line 15 cm long and divide it into 6 equal parts. Each part represents 5 km for the distance scale and 10 minutes for the time scale.

(iv) Divide the first part of the distance scale and the time scale into 5 and 10 equal parts respectively. Complete the scales as shown. The distance covered in 36 minutes is shown on the scale.

Problem 4-16. (fig. 4-17): *On a Russian map, a scale of versts is shown. On measuring it with a metric scale, 150 versts are found to measure 15 cm. Construct comparative scales for the two units to measure upto 200 versts and 200 km respectively. 1 verst = 1.067 km.*

(i) *Scale of verst:*

Length of the scale $= \frac{15 \times 200}{150} = 20$ cm.

Draw a line 20 cm long and construct a plain scale to show versts.

(ii) *Scale of kilometres:*

$$\text{R.F.} = \frac{15}{150 \times 1.609 \times 1000 \times 10} = \frac{1}{160900}$$

Length of the scale $= \frac{1}{160900} \times 200 \times 1000 \times 10 = 12.4$ cm.

Construct the plain scale 12.4 cm long, above the scale of versts and attached to it, to read kilometres (fig. 4-17).

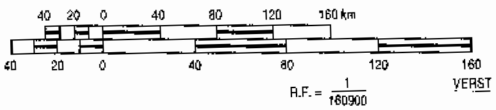


FIG. 4-17

Now, if we take a length *B0* equal to 10 + 1 = 11 such equal parts, thus representing 11 cm, and divide it into ten equal divisions, each of these divisions will represent $\frac{11}{10} = 1.1$ cm or 11 mm.

The difference between one part of *A0* and one division of *B0* will be equal 1.1 − 1.0 = 0.1 cm or 1 mm.

Similarly, the difference between two parts of each will be 0.2 cm or 2 mm.

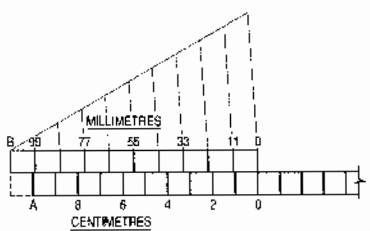


FIG. 4-18

The *upper scale B0* is the vernier. The combination of the plain scale and the vernier is the vernier scale.

In general, if a line representing *n* units is divided into *n* equal parts, each part will show $\frac{n}{n} = 1$ unit. But, if a line equal to $n + 1$ of these units is taken and then divided into *n* equal parts, each of these parts will be equal to $\frac{n+1}{n} = 1 + \frac{1}{n}$ units.

The difference between one such part and one former part will be equal to $\frac{n+1}{n} - \frac{n}{n} = \frac{1}{n}$ unit.

Similarly, the difference between two parts from each will be $\frac{2}{n}$ unit.

(b) ***Least count of a vernier:*** It is the difference of 1 primary scale division and 1 vernier scale division. It is denoted by $\angle C$.

$\angle C$ = 1 primary scale division − 1 vernier scale division.

The vernier scales are classified as under:

(i) *Forward vernier:* In this case, the length of one division of the vernier scale is smaller than the length of one division of the primary scale. The vernier divisions are marked in the same direction as that of the main scale.

(ii) *Backward vernier:* The length of each division of vernier scale is greater than the length of each division of the primary scale. The numbering is done in the opposite direction as that of the primary scale.

(i) Draw a line 16 cm long and divide it into 4 equal parts to show metres. Divide each of these parts into 10 equal parts to show decimetres.

(ii) To construct a vernier, take 11 parts of dm length and divide it into 10 equal parts. Each of these parts will show a length of 1.1 dm or 11 cm.

To measure a length representing 2.39 m, place one leg of the divider at *A* on 99 cm mark and the other leg at *B* on 1.4 m mark. The length *AB* will show 2.39 metres (0.99 + 1.4 = 2.39).

Similarly, the length, *CD* shows 0.91 metre (0.8 + 0.11 = 0.91).

The necessity of dividing the plain scale into minor divisions throughout its length is quite evident from the above measurements.

Problem 4-18. (fig. 4-20): *Construct a full-size vernier scale of inches and show on it lengths 3.67", 1.54" and 0.48".*

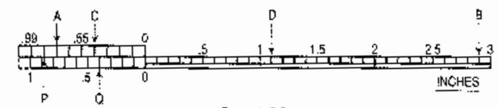


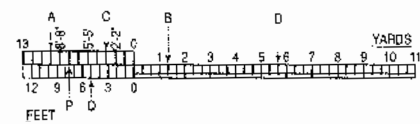
Fig. 4-20

(i) Draw a plain full-size scale 4" long and divide it fully to show 0.1" lengths.

(ii) Construct a vernier of length equal to 10 + 1 = 11 parts and divide it into 10 equal parts. Each of these parts will $\frac{11 \times 0.1}{10} = 0.11"$.

The line *AB* shows a length of 3.67" (0.77" + 2.9" = 3.67"). Similarly, lines *CD* and *PQ* show lengths of 1.54" (0.44" + 1.1" = 1.54") and 0.48" (0.88" − 0.4" = 0.48") respectively.

Problem 4-19. (fig. 4-21): *Construct a vernier scale of R.F.* $= \frac{1}{80}$ *to read inches and to measure upto 15 yards.*



(c) ***Circular vernier:*** The circular vernier are used in surveying instruments to measure angle to the required accuracy. In the case of mechanical engineering, it is used in measuring instruments such as micrometer.

Problem 4-20. *A theodolite has main scale plate of 240 mm diameter graduated to 0° to 360° with the vernier scale to read degree and minute. The main scale can read to accuracy of 0.5° and the vernier is to read one minute. Draw the scale.*

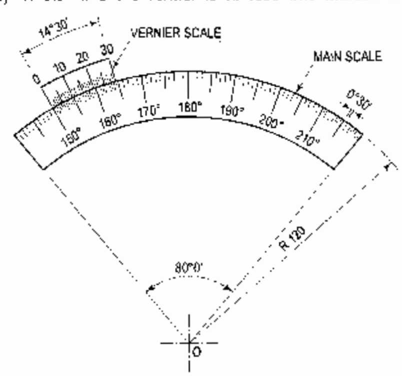


Fig. 4-22

(i) Draw an arc of radius 120 mm. (Diameter 240 mm)

(ii) Mark with the protractor graduation as shown on the main scale, each division is $\frac{1}{2}^{\circ}$.

(iii) Now one division of the main scale will read to accuracy of $\frac{1}{2}^{\circ}$.

(iv) The vernier can read upto 1 minute

i.e. 1 minute $= \frac{1}{60}^{\circ} = \left(\frac{1}{30}\right)\left(\frac{1}{2}\right)$

(5) **Scale of chords:** The scale of chords is used to set out or measure angles when a protractor is not available. It is based on the lengths of chords of different angles measured on the same arc and is constructed as shown below.

(i) Draw a line *AB* of any length (fig. 4-23).

(ii) At *B*, erect a perpendicular.

(iii) With *B* as centre, describe an arc *AC* cutting the perpendicular at a point *C*. Then, the arc *AC* (or the chord *AC*) subtends an angle of 90° at the centre *B*.

(iv) Divide *AC* into nine equal parts. This may be done

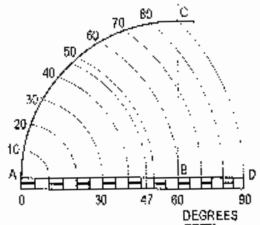
(a) by dividing the arc *AC* into three equal parts by drawing arcs with centres *A* and *C* and radius *AB*, and then

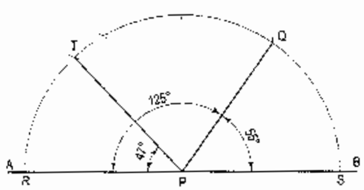
(b) by dividing each of these parts into three equal parts by trial and error method. Each of the nine equal parts subtends an angle of 10° at the centre *B*.

(v) Transfer each division-point from the arc to the straight line *AB*-produced, by taking *A* as centre and radii equal to chords *A*-10, *A*-20 etc.

(vi) Complete the scale by drawing a rectangle below *AD*. The divisions obtained are unequal, decreasing gradually from *A* to *D*. It is quite evident that the distance from *A* to a division-point on the scale is equal to the length of the chord of the angle subtended by it at the centre *B*. It may be noted that the chord *A*-60 is equal to the radius *AB*.

The scale may be fully divided, i.e. each division divided into ten equal parts to show degrees. In the figure, degrees are shown in multiples of 5.





As the scale of chords gives angles upto only 90°, angle of 125° may be set-off in two parts viz. 60° + 65° or 90° + 35° as shown in the figure.

It may also be obtained by setting-off a chord *SQ* of 55° (180° − 125°) from the right side.

Problem 4-22. (fig. 4-25): *Measure the given angle PQR by means of the scale of chords.*

(i) With *Q* as centre and radius equal to 0-60, draw an arc cutting *PQ* at *A* and *RQ* at *B*.

(ii) Take the chord length *AB* and apply it to the scale of chords which shows the angle to be of 37°.

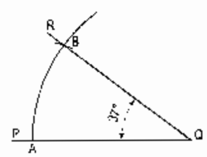


Fig. 4-25

EXERCISES 4

1. Fill-up the blanks in the following sentences, using appropriate words, selected from those given in the brackets:

(a) The ratio of the length of the drawing of the object to the actual length of the object is called .... (resulting fraction, representative figure, representative fraction).

(b) When the drawing is drawn of the same size as that of the object, the scale used is .... (diagonal scale, full-size scale, vernier scale).

(c) For drawings of small instruments, watches etc. .... scale is always used (reducing, full-size, enlarging).

(d) Drawings of buildings are drawn using .... (full-size scale, reducing scale, scale of chords).

(e) The R.F. in case of (b), (c) and (d) above would be, ... , ... and .... respectively (equal to 1, less than 1, greater than 1).

(f) When measurements are required in three units .... scale is used (diagonal, plain, comparative).

(g) The scale of chords is used to set out or measure .... (chords, lines, angles).

6. A 3.2 cm long line represents a length of 4 metres. Extend this line to measure lengths upto 25 metres and show on it units of metre and 5 metres. Show the length of 17 metres on this line.

7. Construct a diagonal scale of R.F. = $\frac{1}{6250}$ to read upto 1 kilometre and to read metres on it. Show a length of 653 metres on it.

8. On a map, the distance between two points is 14 cm. The real distance between them is 20 km. Draw a diagonal scale of this map to read kilometres and hectametres, and to measure upto 25 km. Show a distance of 17.6 km on this scale.

9. An area of 144 sq cm on a map represents an area of 36 sq km on the field. Find the R.F. of the scale for this map and draw a diagonal scale to show kilometres, hectametres and decametres and to measure upto 10 kilometres. Indicate on the scale a distance of 7 kilometres, 5 hectametres and 6 decametres.

10. Construct the following scales and show below each, its R.F. and the units which its divisions represent:

 (a) Scale of $1\frac{1}{4}''$ = 1 foot, to measure upto 5 feet and showing feet and inches.

 (b) Scale of $\frac{3}{4}''$ = 1 yard, to measure upto 10 yards and showing yards and feet.

 (c) Scale of $1\frac{3}{8}''$ = 1 mile, to measure upto 4 miles and showing miles and furlongs.

11. Construct a scale of 1" = 1 foot to read upto 6 feet and show on it, 4' – 7" length.

12. The R.F. of a scale showing miles, furlongs and chains is $\frac{1}{50688}$. Draw a scale to read upto 5 miles and show on it, the length representing 3 m 5 f 3 ch.

13. Draw a 4" long diagonal scale of 1" = 1" and show on it, the length of 2.14" and 3.79".

14. The distance between two points on a map is $5\frac{3}{4}''$. The points are actually 20 miles apart. Construct a diagonal scale of the map, showing miles and furlongs and to read upto 25 miles.

15. Construct comparative diagonal scales of metres and yards having R.F. = $\frac{1}{2700}$ to show upto 400 metres. 1 metre = 1.0936 yards.

19. Prepare a scale of knots comparative to a scale of 1 cm = 5 km. Assume suitable lengths. 1 knot = 1.85 km.

20. Draw a full-size vernier scale to read $\frac{1}{8}''$ and $\frac{1}{64}''$ lengths and mark on it lengths of $5\frac{7}{32}''$, $2\frac{51}{64}''$ and $\frac{29}{64}''$.

21. Construct a scale of R.F. = $\frac{1}{2.5}$ to show decimetres and centimetres and by a vernier to read millimetres, to measure upto 4 decimetres.

22. Construct a vernier scale to show yards, the R.F. being $\frac{1}{3300}$. Show the distance representing 2 furlongs 99 yards.

23. Construct a scale of chords showing 5° divisions and with its aid set-off angles of 25°, 40°, 55° and 130°.

24. Draw a triangle having sides 8 cm, 9 cm and 10 cm long respectively and measure its angles with the aid of a scale of chords.

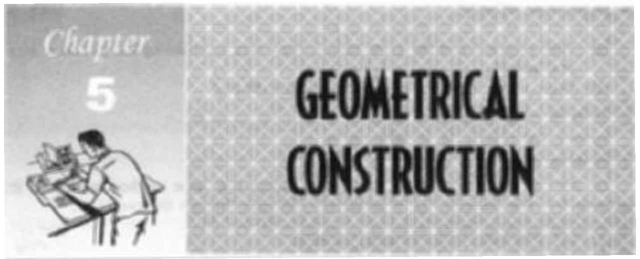
25. The distance between Vadodara and Surat is 130 km. A train covers this distance in 2.5 hours. Construct a plain scale to measure time upto a single minute. The R.F. of the scale is $\frac{1}{260000}$. Find the distance covered by the train in 45 minutes.

26. On a building plan, a line 20 cm long represents a distance of 10 m. Devise a diagonal scale for the plan to read upto 12 m, showing metres, decimetres and centimetres. Show on your scale the lengths 6.48 m and 11.14 m.

27. A room of 1728 m^3 volume is shown by a cube of 216 cm^3 volume. Find R.F. and construct a plain scale to measure upto 42 m. Mark a distance of 22 m on the scale.

28. An old plan was drawn to a scale of 1 cm = 24 m. It has shrunk so that actual length of 100 m at site now works out to 96 m as per scale on plan. Find out the shrinkage factor and the corrected R.F. of the plan. (Hint: Shrinkage factor = present length on scale/original length on scale.)

29. The actual length of 500 m is represented by a line of 15 cm on a drawing. Construct a vernier scale to read upto 600 m. Mark on the scale a length of 549 m.



5-0. INTRODUCTION

In this chapter, we shall deal with problems on geometrical construction which are mostly based on plane geometry and which are very essential in the preparation of engineering drawings. They are described as under:

(1) Bisecting a line	(11) To construct squares
(2) To draw perpendiculars	(12) To construct regular polygons
(3) To draw parallel lines	(13) Special methods of drawing regular polygons
(4) To divide a line	
(5) To divide a circle	(14) Regular polygons inscribed in circles
(6) To bisect an angle	(15) To draw regular figures using T-square and set-squares
(7) To trisect an angle	
(8) To find the centre of an arc	(16) To draw tangents
(9) To construct an ogee or reverse curve	(17) Lengths of arcs
	(18) Circles and lines in contact
(10) To construct equilateral triangles	(19) Inscribed circles.

5-1. BISECTING A LINE

Problem 5-1. *To bisect a given straight line* (fig. 5-1).

(i) Let *AB* be the given line. With centre *A* and radius greater than half *AB*, draw arcs on both sides of *AB*.

(ii) With centre *B* and the same radius, draw arcs intersecting the previous arcs at *C* and *D*.

(iii) Draw a line joining *C* and *D* and cutting *AB* at *E*.

Then $AE = EB = \frac{1}{2}AB$.

Further, *CD* bisects *AB* at right angles.

Problem 5-2. *To bisect a given arc* (fig. 5-2).

Let *AB* be the arc drawn with centre *O*. Adopt the same method as shown in problem 5-1. The bisector *CD*, if produced, will pass through the centre *O*.

5-2. TO DRAW PERPENDICULARS

Problem 5-3. *To draw a perpendicular to a given line from a point within it.*

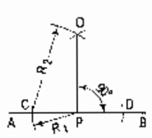


FIG. 5-3

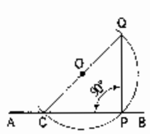


FIG. 5-4

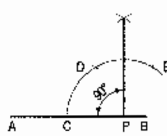


FIG. 5-5

Method I (fig. 5-3):

(a) When the point is near the middle of the line.

 Let *AB* be the given line and *P* the point in it.

 (i) With *P* as centre and any convenient radius R_1, draw an arc cutting *AB* at *C* and *D*.

 (ii) With any radius R_2 greater than R_1 and centres *C* and *D*, draw arcs intersecting each other at *O*.

 (iii) Draw a line joining *P* and *O*.

 Then *PO* is the required perpendicular.

(b) When the point is near an end of the line.

 Let *AB* be the given line and *P* the point in it.

Method II (fig. 5-4):

Problem 5-4. *To draw a perpendicular to a given line from a point outside it.*

(a) When the point is nearer the centre than the end of the line (fig. 5-6).

Let *AB* be the given line and *P* the point.

(i) With centre *P* and any convenient radius, draw an arc cutting *AB* at *C* and *D*.

(ii) With any radius greater than half *CD* and centres *C* and *D*, draw the arcs intersecting each other at *E*.

(iii) Draw a line joining *P* and *E* and cutting *AB* at *Q*.

Then *PQ* is the required perpendicular.

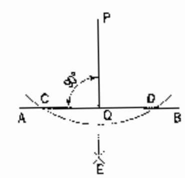


Fig. 5-6

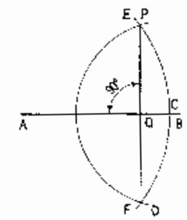


Fig. 5-7

(b) When the point is nearer the end than the centre of the line (fig. 5-7).

Let *AB* be the given line and *P* the point.

(i) With centre *A* and radius equal to *AP*, draw an arc *EF* cutting *AB* or *AB*-produced, at *C*.

(ii) With centre *C* and radius equal to *CP*, draw an arc cutting *EF* at *D*.

(iii) Draw a line joining *P* and *D* and intersecting *AB* at *Q*.

Then *PQ* is the required perpendicular.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 4 for the following problem.

Problem 5-5. *To draw perpendicular to a given line from a point outside it* (fig. 5-8).

When the point is nearer the centre than the end of the line.

Let *AB* be the given line and *P* the point.

(i) Using compass and with *P* as centre draw an arc of any radius R_1 cutting the line *AB* at points *C* and *D*.

(ii) With points *C* and *D* as centres, and with a larger radius R_2 ($> R_1$), draw arcs to cut on the side of the line *AB* in which perpendicular is to draw. The arcs intersect in point *E*.

(iii) Now join points *E* and *P*. (If required) line *EP* may be extended to meet the line *AB* at point *Q*. Line *EPQ* will be perpendicular to line *AB*.

(iv) Verify the an angle *AQP* or *BQP* using a protractor. The angle *AQP* or *BQP* is the required perpendicular.

5-3. TO DRAW PARALLEL LINES

Problem 5-6. *To draw a line through a given point, parallel to a given straight line* (fig. 5-9).

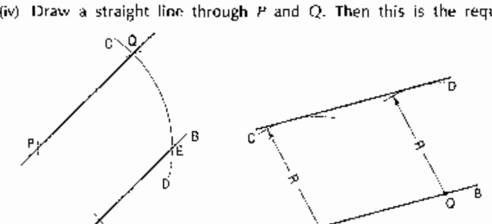
Let *AB* be the given line and *P* the point.

(i) With centre *P* and any convenient radius, draw an arc *CD* cutting *AB* at *E*.

(ii) With centre *E* and the same radius, draw an arc cutting *AB* at *F*.

(iii) With centre *E* and radius equal to *FP*, draw an arc to cut *CD* at *Q*.

(iv) Draw a straight line through *P* and *Q*. Then this is the required line.



5-4. TO DIVIDE A LINE

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 5 for the following problem.

Problem 5-8. *To divide a given straight line into any number of equal parts* (fig. 5-11).

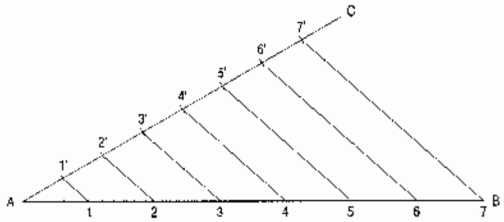


Fig. 5-11

Let *AB* be the given line to be divided into say, seven equal parts.

(i) Draw the line *AB* of given length.

(ii) Draw another line *AC* making an angle of less than 30° with *AB*.

(iii) With the help of dividers mark 7 equal parts of any suitable length on line *AC* and mark them by points 1', 2', 3', 4', 5', 6' and 7' as shown.

(iv) Join the last point 7' with point *B* of the line *AB*.

(v) Now, from each of the other marked points 6', 5' 4', 3', 2' and 1', draw lines parallel to *7'B* cutting the line *AB* at 6, 5, 4, 3, 2 and 1 respectively.

(vi) Now the line *AB* has been divided into 7 equal parts. You can verify this by measuring the lengths.

Problem 5-9. *To divide a given straight line into unequal parts* (fig. 5-12).

Let *AB* be the given line to be divided into unequal parts say $\frac{1}{6}, \frac{1}{5}, \frac{1}{4}, \frac{1}{3}$ and $\frac{1}{2}$.

(i) Draw a line *AB* of given length, say, 120 mm.

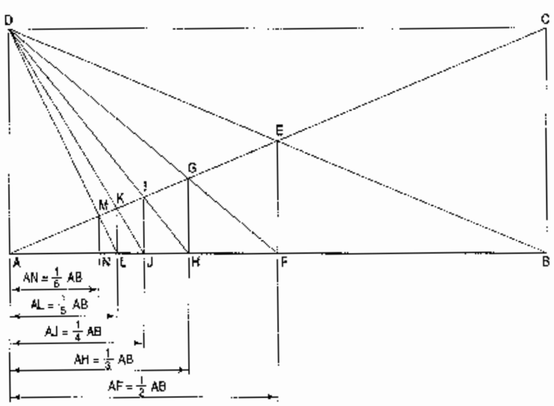
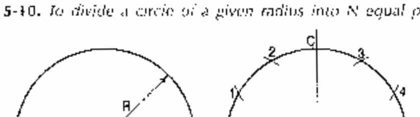


Fig. 5-12

5-5. TO DIVIDE A CIRCLE

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 6 for the following problem.

Problem 5-10. *To divide a circle of a given radius into N equal parts* (fig. 5-13).



(ii) With A as centre, and radius equal to the given radius of the circle, draw arcs cutting the circle at 2 and 7.

(iii) Similarly, with B as centre, and with the given circle radius, draw arcs to cut the circle at 3 and 6.

(iv) Similarly, from points C and D as centre, and with the given radius of circle, draw arcs to cut the circle at 1, 4 and 5, 8 respectively.

(v) Thus dividing it at the cuts are the required twelve equal parts of the circle.

5-6. TO BISECT AN ANGLE

Problem 5-11. *To bisect a given angle* (fig. 5-14).

Let ABC be the given angle.

(i) With B as centre and any radius, draw an arc cutting AB at D and BC at E.

(ii) With centres D and E and the same or any convenient radius, draw arcs intersecting each other at F.

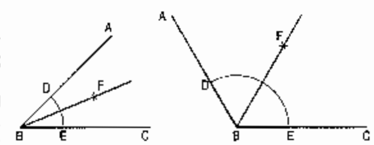


FIG. 5-14

(iii) Draw a line joining B and F. BF bisects the angle ABC, i.e. $\angle ABF = \angle FBC$.

Problem 5-12. *To draw a line inclined to a given line at an angle equal to a given angle* (fig. 5-15).

Let PQ be the given line and AOB the given angle.

(i) With O as centre and any radius, draw an arc cutting OA at C and OB at D.

(ii) With the same radius and centre P, draw an arc EF cutting PQ at F.

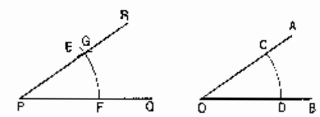


FIG. 5-15

(iii) With F as centre and radius equal to CD, draw an arc cutting the arc EF at G.

(iv) From P, draw a line passing through G. This is the required line.

5-7. TO TRISECT AN ANGLE

This book is accompanied by a computer CD, which contains an audiovisual

(iii) Draw lines joining B with P and Q. BP and BQ trisect the right angle ABC.

Thus, $\angle ABP = \angle PBQ = \angle QBC = \frac{1}{3} \angle ABC$.

5-8. TO FIND THE CENTRE OF AN ARC

Problem 5-14. *To find the centre of a given arc* (fig. 5-17).

Let AB be the given arc.

(i) In AB, draw two chords CD and EF of any lengths.

(ii) Draw perpendicular bisectors of CD and EF intersecting each other at O. Then O is the required centre.

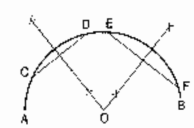


FIG. 5-17

Problem 5-15. *To draw an arc of a given radius, touching a given straight line and passing through a given point* (fig. 5-18).

Let AB be the given line, P the point and R the radius.

(i) Draw a line CD parallel to and at a distance equal to R from AB (Problem 5-7).

(ii) With P as centre and radius equal to R, draw an arc cutting CD at O.

(iii) With O as centre, draw the required arc.

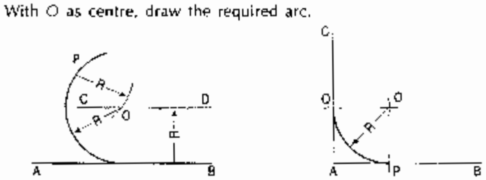


FIG. 5-18 FIG. 5-19

Problem 5-16. *To draw an arc of a given radius touching two given straight lines at right angles to each other* (fig. 5-19).

Let AB and AC be the given lines and R the given radius.

(i) With centre A and radius equal to R, draw arcs cutting AB at P and AC at Q.

(ii) With P and Q as centres and the same radius, draw arcs intersecting each other at O.

Let AB and AC be the given lines and R the given radius.

(i) Draw a line PQ parallel to and at a distance equal to R from AB.

(ii) Similarly, draw a line EF parallel to and at a distance equal to R from AC, intersecting PQ at O.

(iii) With O as centre and radius equal to R, draw the required arc.

Problem 5-18. *To draw an arc of a given radius touching a given arc and a given straight line.*

Case I: (fig. 5-22): Let AB be the given line, CD the given arc drawn with centre O and radius equal to R_1, and R_2 the given radius.

(i) With O as centre and radius equal to $(R_1 - R_2)$, draw an arc EF.

(ii) Draw a line parallel to and at a distance equal to R_2 from AB and intersecting EF at a point P.

(iii) With P as centre and radius equal to R_2, draw the required arc.

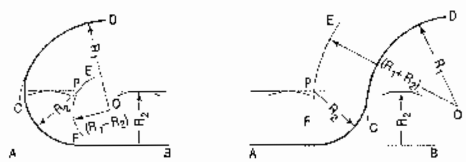


FIG. 5-22 FIG. 5-23

Case II: (fig. 5-23): Let AB be the given line, CD the given arc drawn with centre O and radius equal to R_1, and R_2 the given radius.

(i) With O as centre and radius equal to $(R_1 + R_2)$, draw an arc EF.

(ii) Draw a line parallel to and at a distance equal to R_2 from AB and intersecting EF at a point P.

(iii) With P as centre and radius equal to R_2, draw the required arc.

Problem 5-19. *To draw an arc of a given radius touching two given arcs.*

Let AB be the given arc drawn with centre O and

Case II (fig. 5-25):

(i) With O as centre and radius equal to $(R_1 - R_3)$, draw an arc EF.

(ii) With P as centre and radius equal to $(R_2 + R_3)$, draw an arc intersecting EF at a point Q.

(iii) With Q as centre and radius equal to R_3, draw the required arc.

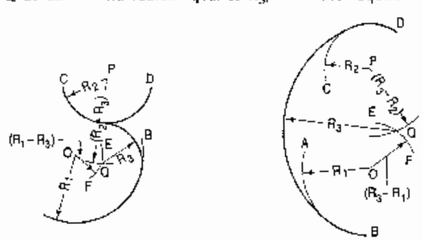


FIG. 5-25 FIG. 5-26

Case III (fig. 5-26):

(i) With O as centre and radius equal to $(R_3 - R_1)$, draw an arc EF.

(ii) With P as centre and radius equal to $(R_3 - R_2)$, draw an arc intersecting EF at a point Q.

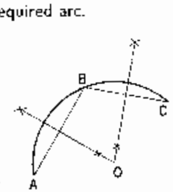
(iii) With Q as centre and radius equal to R_3, draw the required arc.

Problem 5-20. *To draw an arc passing through three given points not in a straight line* (fig. 5-27).

Let A, B and C be the given points.

(i) Draw lines joining B with A and C.

(ii) Draw perpendicular bisectors of AB and BC intersecting each other at a point O.



(iii) With O as centre and radius equal to OA or OB or

Let A, B, C, D and E be the given points.

(i) Draw lines joining A with B, B with C, C with D etc.

(ii) Draw perpendicular bisectors of AB and BC intersecting at O.

(iii) With O as centre and radius equal to OA, draw an arc ABC.

(iv) Draw a line joining O and C.

(v) Draw the perpendicular bisector of CD intersecting OC or OC produced, at P.

(vi) With P as centre and radius equal to PC, draw an arc CD.

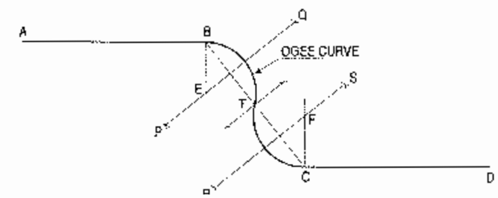
(vii) Repeat the same construction. Note that the centre of the arc is at the intersection of the perpendicular bisector and the line, or the line-produced, joining the previous centre with the last point of the previous arc.

5-9. TO CONSTRUCT AN OGEE OR REVERSE CURVE

An ogee curve or a *reverse curve* is a combination of two same curves in which the second curve has a reverse shape to that of the first curve. In other words, any curve or line or mould consist of a continuous double curve with the upper part convex and lower part concave, to some extent having shape of "S".

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 8 for the following problem.

Problem 5-22. *To draw an ogee shaped arc tangent between two parallel lines* (fig. 5-29).



(v) Similarly, from point C, draw a perpendicular line to cut the bisector line RS at F.

(vi) Points E and F are the centre points of the ogee curve. With E as centre draw an arc BT. With F as centre draw another arc CT. Arc BTC is the required ogee curve.

5-10. TO CONSTRUCT EQUILATERAL TRIANGLES

Problem 5-23. *To construct an equilateral triangle, given the length of the side* (fig. 5-30 and fig. 5-31).

(a) *With T-square and set-square only* (fig. 5-30).

(i) With the T-square, draw a line AB of given length.

(ii) With 30°–60° set-square and T-square, draw a line through A making 60° angle with AB.

(iii) Similarly, through B, draw a line making the same angle with AB and intersecting the first line at C.

Then ABC is the required triangle.

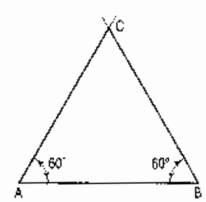


FIG. 5-30

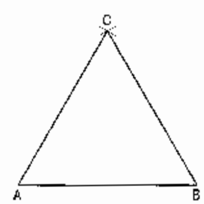


FIG. 5-31

(b) *With the aid of a compass* (fig. 5-31).

(iii) With T-square and 30°–60° set-square, draw lines through Q on both sides of and making 30° angles with PQ and cutting AB in R and T.

Then QRT is the required triangle.

(b) *With the aid of a compass* (fig. 5-33).

(i) Draw a line AB of any length.

(ii) At any point P in AB, draw the perpendicular PQ equal to the given altitude (Problem 5-3).

(iii) With centre Q and any radius, draw an arc intersecting PQ at C.

(iv) With centre C and the same radius, draw arcs cutting the first arc at E and F.

(v) Draw bisectors of CE and CF to intersect AB at R and T respectively.

Then QRT is the required triangle.

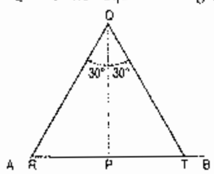


FIG. 5-32

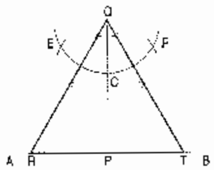


FIG. 5-33

5-11. TO CONSTRUCT SQUARES

Problem 5-25. *To construct a square, length of a side given* (fig. 5-34 and fig. 5-35).

(a) *With T-square and set-square only* (fig. 5-34).

(i) With the T-square, draw a line AB equal to the given length.

(ii) At A and B, draw verticals AE and BF.

(iii) From point A draw a line inclined at 45° to AB, cutting BF at C.

(iv) From point B draw a line inclined at 45° to AB, cutting AE at D.

(v) Draw a line joining C with D.

Then $ABCD$ is the required square.

(b) *With the aid of a compass* (fig. 5-35).

(i) Draw a line AB equal to the given length.

(ii) At A, draw a line AE perpendicular to AB. (Refer problem 5-3, Method III, fig. 5-5).

(iii) With centre A and radius AB, draw an arc cutting AE at D.

(iv) With centres B and D and the same radius, draw arcs intersecting at C.

(v) Draw lines joining C with B and D.

Then $ABCD$ is the required square.

5-12. TO CONSTRUCT REGULAR POLYGONS

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 9 for the following problem.

Problem 5-26. *To construct a regular polygon, given the length of its side.*

Let the number of sides of the polygon be seven (i.e. heptagon).

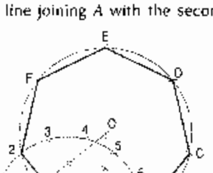
Method I: (fig. 5-36 and fig. 5-37):

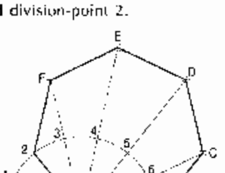
(i) Draw a line AB equal to the given length.

(ii) With centre A and radius AB, draw a semi-circle BP.

(iii) With a divider, divide the semi-circle into seven equal parts (same as the number of sides). Number the division-points as 1, 2, etc. starting from P.

(iv) Draw a line joining A with the second division-point 2.





(b) *Arc method* (fig. 5-37).

(i) With centre *B* and radius *AB*, draw an arc cutting the line *A*6-produced at *C*.

(ii) With centre *C* and the same radius, draw an arc cutting the line *A*5-produced at *D*.

(iii) Find points *E* and *F* in the same manner.

(iv) Draw lines *BC*, *CD* etc. and complete the heptagon.

Method II: General method for drawing any polygon (fig. 5-38):

(i) Draw a line *AB* equal to the given length.

(ii) At *B*, draw a line *BP* perpendicular and equal to *AB*.

(iii) Draw a line joining *A* with *P*.

(iv) With centre *B* and radius *AB*, draw the quadrant *AP*.

(v) Draw the perpendicular bisector of *AB* to intersect the straight line *AP* in 4 and the arc *AP* in 6.

(a) A *square* of a side equal to *AB* can be inscribed in the circle drawn with centre 4 and radius *A*4.

(b) A regular *hexagon* of a side equal to *AB* can be inscribed in the circle drawn with centre 6 and radius *A*6.

(c) The mid-point 5 of the line 4-6 is the centre of the circle of the radius *A*5 in which a regular pentagon of a side equal to *AB* can be inscribed.

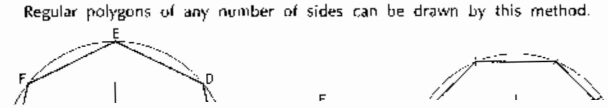
(d) To locate centre 7 for the regular *heptagon* of side *AB*, step-off a division 6-7 equal to the division 5-6.

(i) With centre 7 and radius equal to *A*7, draw a circle.

(ii) Starting from *B*, cut it in seven equal divisions with radius equal to *AB*.

(iii) Draw lines *BC*, *CD* etc. and complete the heptagon.

Regular polygons of any number of sides can be drawn by this method.



Alternative method (fig. 5-39 and fig. 5-40):

(i) On *AB* as diameter, describe a semi-circle.

(ii) With either *A* or *B* as centre and *AB* as radius, describe an arc on the same side as the semi-circle.

(iii) Draw a perpendicular bisector of *AB* cutting the semi-circle at point 4 and the arc at point 6.

(iv) Obtain points 5, 7, 8 etc. as explained in method II.

Fig. 5-40 shows *a square, a regular pentagon, a regular hexagon and a regular octagon*, all constructed on *AB* as a common side.

5-13. SPECIAL METHODS OF DRAWING REGULAR POLYGONS

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 10 for the following problem.

Problem 5-27. *To construct a pentagon, length of a side given.*

Method I: (fig. 5-41):

(i) Draw a line *AB* equal to the given length.

(ii) With centre *A* and radius *AB*, describe a circle-1.

(iii) With centre *B* and the same radius, describe a circle-2 cutting circle-1 at *C* and *D*.

(iv) With centre *C* and the same radius, draw an arc to cut circle-1 and circle-2 at *E* and *F* respectively.

(v) Draw a perpendicular bisector of the line *AB* to cut the arc *EF* at *C*.

(vi) Draw a line *FG* and produce it to cut circle-2 at *P*.

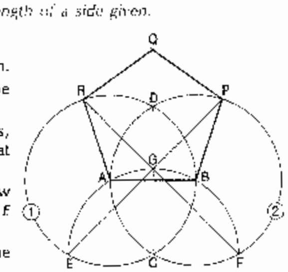


FIG. 5-41

(iv) With centre *C* and radius *CD*, draw an arc to intersect the line *AB*-produced at *E*.

(v) Then *AE* is the length of the diagonal of the pentagon.

(vi) Therefore, with centre *A* and radius *AB*, draw an arc intersecting the arc drawn with centre *B* and radius *AE* at *R*.

(vii) Again with centre *A* and radius *AE*, draw an arc intersecting the arc drawn with centre *B* and radius *AB* at *P*.

(viii) With centres *A* and *B* and radius *AE*, draw arcs intersecting each other at *Q*.

(ix) Draw lines *BP*, *PQ*, *QR* and *RA*, thus completing the pentagon.

Problem 5-28. *To construct a hexagon, length of a side given* (fig. 5-43 and fig. 5-44).

(a) *With T-square and 30°-60° set-square only* (fig. 5-43).

(i) Draw a line *AB* equal to the given length.

(ii) From *A*, draw lines *A*1 and *A*2 making 60° and 120° angles respectively with *AB*.

(iii) From *B*, draw lines *B*3 and *B*4 making 60° and 120° angles respectively with *AB*.

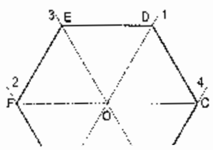
(iv) From O the point of intersection of *A*1 and *B*3, draw a line parallel to *AB* and intersecting *A*2 at *F* and *B*4 at *C*.

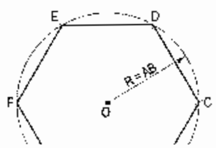
(v) From *F*, draw a line parallel to *BC* and intersecting *B*3 at *E*.

(vi) From *C*, draw a line parallel to *AF* and intersecting *A*1 at *D*.

(vii) Draw a line joining *E* and *D*.

Then *ABCDEF* is the required hexagon.





(iii) Starting with either *F* or *C* as centre and side as length, go on marking the points on the circumference, *A*, *B*, *D* and *E*.

(iv) Join points *A-B-C-D-E-F*. You will get the required Hexagon (6 sided polygon).

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 11 for the following problem.

Problem 5-29. *To inscribe a regular octagon in a given square* (fig. 5-45).

(i) Draw the given square *ABCD*.

(ii) Draw diagonals *AC* and *BD* intersecting each other at *O*.

(iii) With centre *A* and radius *AO*, draw an arc cutting *AB* at 2 and *AD* at 7.

(iv) Similarly, with centres *B*, *C* and *D* and the same radius, draw arcs and obtain points 1, 3, 4 etc. as shown.

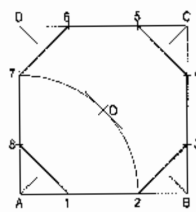


FIG. 5-45

Draw lines 2-3, 4-5, 6-7 and 8-1, thus completing the octagon.

5-14. REGULAR POLYGONS INSCRIBED IN CIRCLES

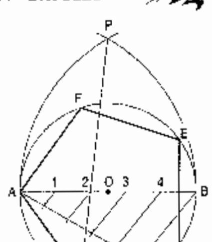
Problem 5-30. *To inscribe a regular polygon of any number of sides, say 5, in a given circle* (fig. 5-46).

(i) With centre O, draw the given circle.

(ii) Draw a diameter *AB* and divide it into five equal parts (same number of parts as the number of sides) and number them as shown.

(iii) With centres *A* and *B* and radius *AB*, draw arcs intersecting each other at *P*.

(iv) Draw a line *P*2 and produce it to meet the circle at *C*. Then *AC* is the length of the side of the pentagon.



Problem 5-32. *To inscribe a regular pentagon in a given circle* (fig. 5-48).

(i) With centre O, draw the given circle.

(ii) Draw diameters AB and CD perpendicular to each other.

(iii) Bisect AO in a point P. With centre P and radius PC, draw an arc cutting OB in Q.

(iv) With centre C and radius CQ, draw an arc cutting the circle in E and F.

(v) With centres E and F and the same radius, draw arcs cutting the circle in G and H respectively.

(vi) Draw lines CE, EG, GH, HF and FC, thus completing the required pentagon.

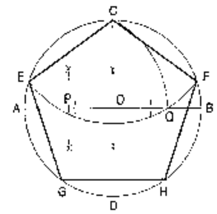


FIG. 5-48

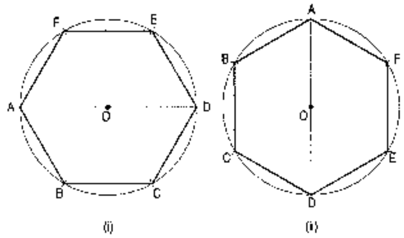


FIG. 5-49

Problem 5-33. *To inscribe a regular hexagon in a given circle* (fig. 5-49).

Apply the same method as shown in Problem 5-28(b).

Note: (a) When two sides of the hexagon are required to be horizontal the starting point for stepping-off equal divisions should be on an end of the horizontal diameter.

(b) If they are to be vertical, the starting point should be on an end of the vertical diameter.

In either case, to avoid inaccuracy, the points should be joined with the aid of T-square and 30°-60° set-square.

Problem 5-34. *To inscribe a regular heptagon in a given circle* (fig. 5-50)

Problem 5-35. *To inscribe a regular octagon in a given circle* (fig. 5-51).

(i) With centre O, draw the given circle.

(ii) Draw diameters AB and CD at right angles to each other.

(iii) Draw diameters EF and GH bisecting angles AOC and COB.

(iv) Draw lines AE, EC etc. and complete the octagon.

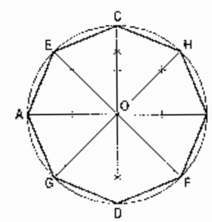


FIG. 5-51

5-15. TO DRAW REGULAR FIGURES USING T-SQUARE AND SET-SQUARES

Problem 5-36. *To describe an equilateral triangle about a given circle* (fig. 5-52).

(i) With centre O, draw the given circle.

(ii) Draw a vertical radius OA.

(iii) Draw radii OB and OC with a 30°–60° set-square, such that $\angle AOB = \angle AOC = 120°$.

(iv) At A, B and C, draw tangents to the circle, i.e. a horizontal line EF through A, and lines FG and GE through B and C respectively with a 30°–60° set-square.

Then EFG is the required triangle.

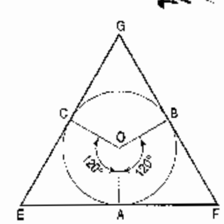
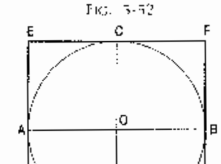


FIG. 5-52

Problem 5-37. *To draw a square about a given circle* (fig. 5-53).

(i) With centre O, describe the given circle.

(ii) Draw diameters AB and CD at right angles to each other as shown.



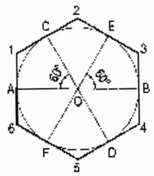


FIG. 5-54

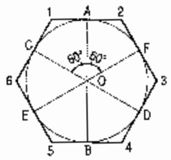


FIG. 5-55

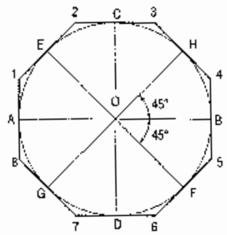


FIG. 5-56

Problem 5-39. *To describe a regular octagon about a given circle* (fig. 5-56).

(i) With centre O, describe the given circle.

(ii) Draw a horizontal diameter AB, a vertical diameter CD and diameters EF and GH at 45° to the first two.

(iii) Draw tangents at the eight points A, B.....H intersecting one another at 1, 2.....8. Then 1, 2.....8 is the required octagon.

5-16. TO DRAW TANGENTS

Problem 5-40. (fig. 5-57): *To draw a tangent to a given circle at any point on it.*

(i) With centre O, draw the given circle and mark a point P on it.

(ii) Draw a line joining O and P.

(iii) Produce OP to Q so that $PQ = OP$.

(iv) With centres O and Q and with any convenient radius, draw arcs intersecting each other at R.

(v) Draw a line through P and R. Then this line is the required tangent.

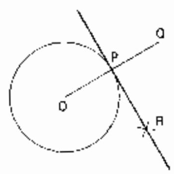


FIG. 5-57

Problem 5-41. (fig. 5-58): *To draw a tangent to a given circle from any point outside it.*

Problem 5-42. (fig. 5-59): *To draw a tangent to a given arc of inaccessible centre at any point on it.*

Let AB be the given arc and P the point on it.

(i) With centre P and any radius, draw arcs cutting the arc AB at C and D. Draw EF, the bisector of the arc CD. It will pass through P.

(ii) Through P, draw a line RS perpendicular to EF. RS is the required tangent.

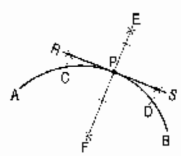


FIG. 5-59

Problem 5-43. (fig. 5-60): *To draw a tangent to a given circle and parallel to a given line.*

The circle with centre O and the line AB are given.

(i) From O, draw a line perpendicular to AB and cutting the circle at a point P or Q.

(ii) Through P or Q, draw the required tangent CD or C_1 D_1 (problem 5-40).

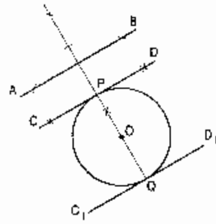


FIG. 5-60

Problem 5-44. *To draw a common tangent to two given circles of equal radii* (fig. 5-61).

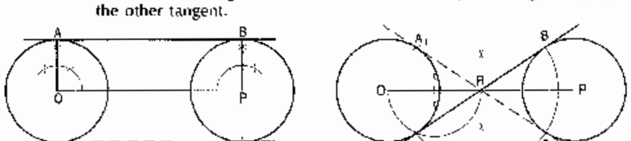
Draw the given circles with centres O and P.

(a) *External tangents* (fig. 5-61):

(i) Draw a line joining O and P.

(ii) At O and P, erect perpendiculars to OP on the same side of it and intersecting the circles at A and B.

(iii) Draw a line through A and B. This line is the required tangent. A_1 B_1 is the other tangent.



Problem 5-45. *To draw a common tangent to two given circles of unequal radii* (fig. 5-63 and fig. 5-64).

Draw the given circles with centres O and P, and radii R_1 and R_2 respectively, of which R_1 is greater than R_2.

(a) *External tangents* (fig. 5-63):

(i) Draw a line joining centres O and P.

(ii) With centre O and radius equal to $(R_1 - R_2)$, draw a circle.

(iii) From P, draw a tangent PT to this circle (Problem 5-41).

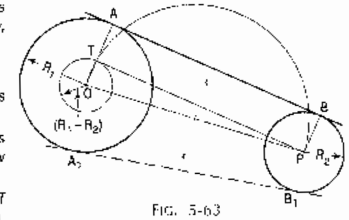


Fig. 5-63

(iv) Draw a line OT and produce it to cut the outer circle at A.

(v) Through P, draw a line PB parallel to OA, on the same side of OP and cutting the circle at B.

(vi) Draw a line through A and B. Then this line is the required tangent.

The other similar tangent will pass through A_1 and B_1.

(b) *Internal tangents* (fig. 5-64):

(i) Draw a line joining the centres O and P.

(ii) With centre O and radius equal to $(R_1 + R_2)$, draw a circle.

(iii) From P, draw a line PT tangent to this circle.

(iv) Draw a line OT cutting the circle at A.

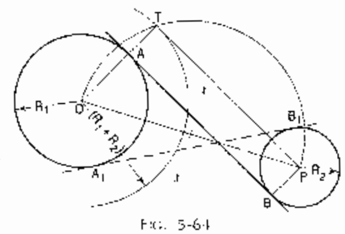


Fig. 5-64

(v) Through P, draw a line PB parallel to OA, on the other side of OP and cutting the circle at B.

(vi) Draw a line through A and B. Then this line is the required tangent. The second tangent will pass through A_1 and B_1.

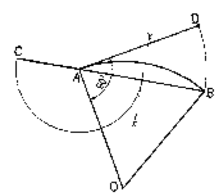


Fig. 5-65

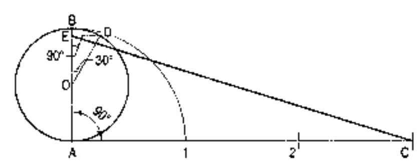


Fig. 5-66

Problem 5-47. *To determine the length of the circumference of a given circle* (fig. 5-66).

Let the circle with centre O be given.

(i) Draw a diameter AB.

(ii) At A, draw a tangent AC equal to 3 times AB.

(iii) Draw a radius OD making an angle of 30° with OB.

(iv) From D, draw a line DE perpendicular to OB.

(v) Draw a line joining E and C. Then EC is approximately equal in length to the circumference of the circle.

5-18. CIRCLES AND LINES IN CONTACT

Problem 5-48. *To draw a circle passing through a given point and tangent to a given line at a given point on it* (fig. 5-67).

A point P and a line AB with a point Q in it are given. At Q, draw a line perpendicular to AB.

(i) Draw a line joining P and Q.

(ii) Draw a perpendicular bisector of PQ to intersect the perpendicular from Q at O.

(iii) With centre O and radius OP or OQ, draw the required circle.

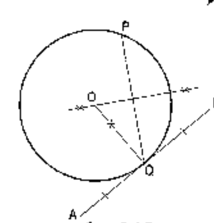


Fig. 5-67

Problem 5-49. *To draw a circle passing through a given point and touching a given*

Problem 5-50. *To draw a circle to touch a given line and a given circle at a given point on it* (fig. 5-69).

A line AB, a circle with centre C and a point P on the circle are given.

From P, draw a tangent to the circle intersecting AB in D.

(a) Draw a bisector of ∠PDB, to intersect the line through C and P at O. With centre O and radius OP, draw the required circle.

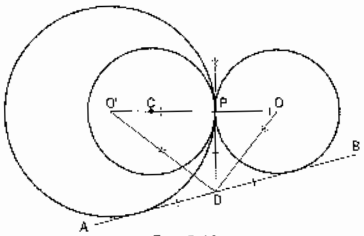


Fig. 5-69

(b) Draw a bisector of ∠PDA to meet the line through C and P at O'. Then O' is the centre of another circle which will include the given circle within it.

Problem 5-51. *To draw a circle to touch a given circle and a given line at a given point on it* (fig. 5-70).

A circle with centre C and a line AB with a point P in it are given.

Through C, draw a line perpendicular to AB and cutting the circle in E or F.

(a) Draw a line joining P and F and intersecting the circle at G.

At P, draw a perpendicular to AB intersecting the line through C and G at O. With centre O and radius OP, draw the required circle.

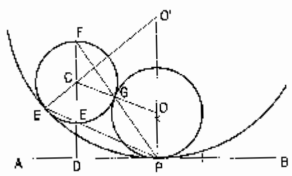
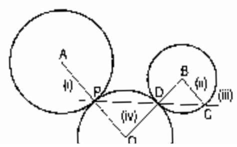


Fig. 5-70

(b) Draw a line through P and E and obtain centre O' for another circle in the same manner. It will include the given circle within it.



Problem 5-52. *To draw a circle touching two given circles, one of them at a given*

Problem 5-53. *To draw a circle touching two given circles, one of them at a given point on it* (fig. 5-72).

(i) Circles with centres A and B, and a point P on the circle A are given.

(ii) Draw a line joining centre A and the point P.

(iii) Through B, draw a line parallel to AP (if extended) and intersecting circle B in C" and D'.

(iv) Join PC" and extend to intersect circle B at D".

(v) Draw a line through D' and B to intersect the line AP at O".

(vi) Join PD' which intersect circle B at C'. Join C'B and extend to intersect AP at O'. Draw a circle with O' as centre and O'P as radius. It is the circle (1).

(vii) Draw another circle with centre as O" and the radius O"P. It is the circle (2).

Circle-(1) which includes one of the given circles, and circle-(2) which includes both of them (fig. 5-72).

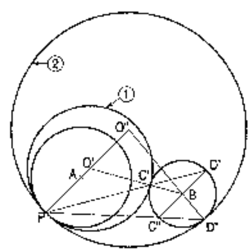


Fig. 5-72

5-19. INSCRIBED CIRCLES

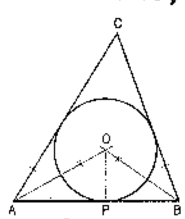
Problem 5-54. *To inscribe a circle in given triangle* (fig. 5-73).

Let ABC be the triangle.

(i) Bisect any two angles by lines intersecting each other at O.

(ii) Draw a perpendicular from O to any one side of the triangle, meeting it at P.

(iii) With centre O and radius OP, describe the required circle.



Problem 5-56. *To inscribe a circle in a regular polygon of any number of sides, say a pentagon* (fig. 5-75).

Let *ABCDE* be the pentagon.

(i) Bisect any two angles by lines intersecting each other at *O*.

(ii) From *O*, draw a perpendicular to any one side of the pentagon cutting it at *P*.

(iii) With centre *O* and radius *OP*, draw the required circle.

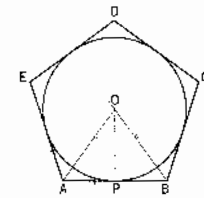


FIG. 5-75

Problem 5-57. *To draw in a regular polygon, the same number of equal circles as the sides of the polygon, each circle touching one side of the polygon and two of the other circles* (fig. 5-76).

(i) Let *ABCD* be the given square.

(ii) Draw bisectors of all the angles of the square. They will meet at *O*, thus dividing the square into four equal triangles.

In each triangle inscribe a circle (Problem 5-54). Each circle will touch a side of the square and two other circles as required.

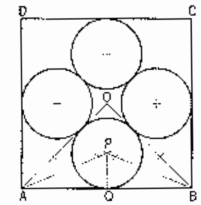


FIG. 5-76

Fig. 5-77 shows five equal circles inscribed in a regular pentagon in the same manner.

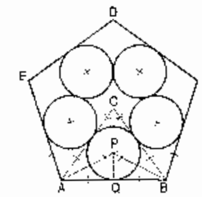
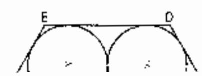


FIG. 5-77

Problem 5-58. *To draw in a regular polygon, the same number of equal circles as the sides of the polygon, each circle touching two adjacent sides of the polygon and two of the other circles* (fig. 5-78).

Let *ABCDEF* be the given hexagon.

(i) Draw the perpendicular bisectors of all sides of the hexagon. They will meet at *O* and will divide the hexagon into six equal quadrilaterals.



Problem 5-59. *To draw in a given regular hexagon, three equal circles, each touching one side and two other circles* (fig. 5-79).

(i) Draw the given hexagon.

(ii) Draw perpendicular bisectors of its two alternate sides, to intersect each other at *O* and to meet the middle side produced on both sides at 1 and 2.

(iii) Inscribe a circle in triangle *O* 1 2. Similarly, draw the other two required circles.

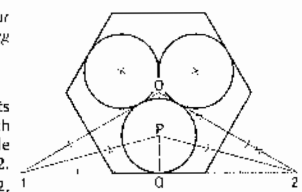


FIG. 5-79

Problem 5-60. *To draw in a given circle, any number of equal circles, say four, each touching the given circle and two of the other circles* (fig. 5-80).

(i) Divide the given circle into four equal parts by diameters *AB* and *CD*.

(ii) Draw a tangent to the circle at *D*. Draw lines bisecting ∠*AOD* and ∠*BOD* and meeting the tangent at 1 and 2.

(iii) Inscribe a circle in the triangle *O* 1 2.

Draw the other circles in the same manner. The centres for the remaining circles may also be determined by drawing a circle with centre *O* and radius *OP* to cut the diameters at the required points.

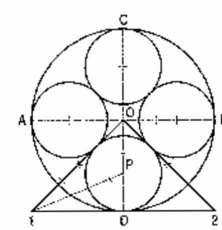
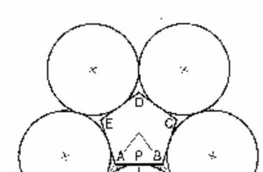


FIG. 5-80

Problem 5-61. *To draw outside a given regular polygon, the same number of equal circles as the sides of the polygon, each circle touching one side and two of the other circles* (fig. 5-81).

(i) Let *ABCDE* be the given pentagon.

(ii) Draw bisectors of two adjacent angles



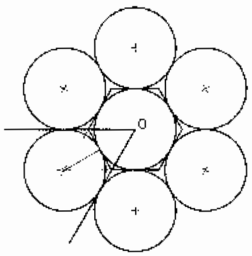


FIG. 5-82

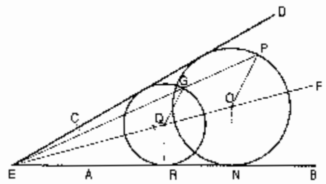


FIG. 5-83

Problem 5-63. *To draw a circle touching two converging lines and passing through a given point between them* (fig. 5-83).

(i) Lines *AB* and *CD*, and the point *P* are given.

(ii) Produce lines *AB* and *CD* to intersect at a point *E*. Draw the bisector *EF* of ∠*AEC*.

(iii) Mark any point *Q* on *EF* and from it draw a perpendicular *QR* on *AB*.

(iv) With *Q* as centre and *QR* as radius draw a circle which will touch the line *CD* also.

(v) Draw a line joining *P* with *E*, cutting the circle at a point *G*.

(vi) Draw the line *QG*.

(vii) From *P*, draw a line parallel to *QG* intersecting *EF* at a point *O*.

(viii) From *O*, draw a perpendicular *ON* to either *AB* or *CD*.

(ix) With *O* as centre and *ON* as radius, draw the required circle.

Problem 5-64. *To draw two circles touching each other and two converging lines, the smaller circle being of given radius* (fig. 5-84).

(i) Lines *AB* and *CD* and radius *R* of the smaller circle are given.

(ii) Produce lines *AB* and *CD* to intersect at a point *E*. Draw the bisector *EF* of ∠*AEC*.

(iii) Draw a line parallel to and at distance *R* from *AB* to intersect *EF* in a point *O*.

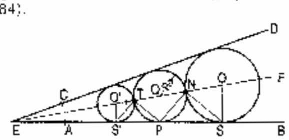


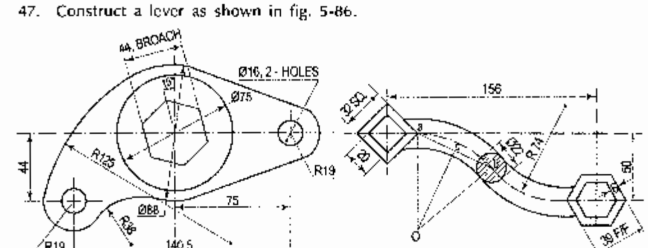
FIG. 5-84

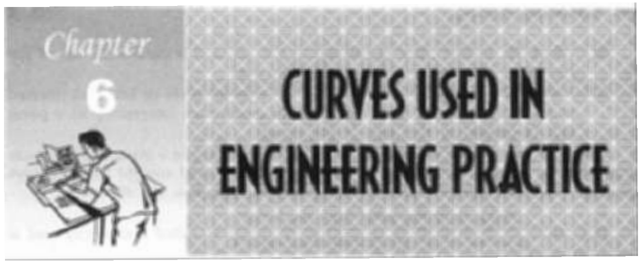
EXERCISES 5

1. Draw a line 125 mm long and quadrisect it.
2. Draw a line *AB* 80 mm long and divide it into five parts, one of them 20 mm long and the remaining each 15 mm long, by the method of bisection.
3. With centre *O* and radius equal to 50 mm, draw two arcs of any lengths on opposite sides of *O*. Bisect the two arcs and produce the bisectors till they meet.
4. Draw a line *AB* 75 mm long. At *B*, erect a perpendicular *BC* 100 mm long. Draw a line joining *A* and *C*, and measure its length. Construct a square on each line as a side.
5. Draw a line *PQ* 100 mm long. At any point *O* in it near its centre, erect a perpendicular *OA* 65 mm long. Through *A*, draw a line parallel to *PQ*.
6. Mark any point *O*. Draw a line *AB*, such that its shortest distance from *O* is 50 mm.
8. Draw a line *AB* 75 mm long. Mark a point *C*, 65 mm from *A* and 90 mm from *B*. Join *C* with *A* and *B*. Through the points *A*, *B* and *C*, draw lines (i) perpendicular and (ii) parallel to their opposite lines.
7. Construct a rectangle of sides 65 mm and 40 mm long.
9. Construct a square of 75 mm side. Draw the diagonals intersecting at *O*. From *O*, draw lines perpendicular to the sides of the square.
10. Draw a circle of 50 mm radius. Divide it (i) into 8 equal parts by continued bisection and (ii) into 12 equal parts by bisection of a line and trisection of a right angle methods.
11. Draw two lines *AB* and *AC* making an angle of 75°. Draw a circle of 25 mm radius touching them.
12. Construct a right angle *PQR*. Describe a circle of 20 mm radius touching the sides *PQ* and *QR*.
13. Draw a line *AB* of any length. Mark a point *O* at a distance of 25 mm from *AB*. With *O* as centre, draw a circle of 40 mm diameter. Describe another circle (i) of 20 mm radius, touching the circle and *AB*; (ii) of 35 mm radius, touching *AB* and the circle, and including the circle within it.
14. Draw two circles of 20 mm and 30 mm radii respectively with centres 65 mm apart. (i) Describe a third circle of 50 mm radius touching the two circles

17. The distance between the centres of two circles of 65 mm and 90 mm diameters is 120 mm. Draw an internal and an external common tangent to the two circles.
18. Draw a circle with centre O and radius equal to 30 mm. From a point P, 75 mm from O, draw a line joining P and O, and produce it to cut the circle at Q. From P and Q draw tangents to the circle.
19. Two shafts carry pulleys of 900 mm and 1350 mm diameters respectively. The distance between their centres is 2700 mm. Draw the arrangement showing the two pulleys connected by (i) direct belt (ii) crossed belt. Take 1 mm = 20 mm.
20. An arc AB drawn with 50 mm radius subtends an angle of 45° at the centre. Determine approximately the length of AB.
21. Determine the length of the circumference of a 75 mm diameter circle.
22. A point P is 25 mm from a line AB. Q is a point in AB and is 50 mm from P. Draw a circle passing through P and touching AB at Q.
23. Construct an equilateral triangle ABC of 40 mm side. Construct a square, a regular pentagon and a regular hexagon on its sides AB, BC and CA respectively.
24. The centre O of a circle of 30 mm diameter is 25 mm from a line AB. Draw a circle (i) to touch the given circle and the line AB at a point P, 50 mm from O; (ii) to touch AB and the given circle at a point Q, 20 mm from AB.
25. Two circles of 40 mm and 50 mm diameters have their centres 60 mm apart. Draw a circle to touch both circles and (i) to include the bigger circle, the point of contact on it being 75 mm from the centre of the other circle; (ii) to include both the circles, the point of contact being the same as in (i).
26. Construct a regular pentagon of 30 mm side by three different methods.
27. On a line AB 40 mm long, construct a regular heptagon by two different methods.
28. Construct a regular octagon of 40 mm side. Inscribe another octagon with its corners on the mid-points of the sides of the first octagon.
29. Construct the following regular polygons in circles of 100 mm diameter, using a different method in each case: (i) Pentagon (ii) Heptagon.
30. Draw the following regular figures, the distance between their opposite sides being 75 mm: (i) Square; (ii) Hexagon; (iii) Octagon.
31. Construct a regular octagon in a square of 75 mm side.
32. Describe a regular pentagon about a circle of 100 mm diameter.
33. Construct a triangle having sides 25 mm, 30 mm and 40 mm long. Draw three circles, each touching one of the sides and the other two sides produced.

40. Construct a square of 25 mm side. Draw outside it four equal circles, each touching a side of the square and two other circles.
41. Outside a circle of 25 mm diameter, draw five equal circles, each touching the given circle and two other circles.
42. Two lines converge to a point making an angle of 30° between them. Draw three circles to touch both these lines, the middle circle being of 25 mm radius and touching the other two circles.
43. Two lines converge to a point making an angle of 30° between them. A point P is between these lines 15 mm from one line and 25 mm from the other. Draw a circle to touch both the lines and pass through P.
44. Draw a series of four circles, each touching the preceding circle and two converging lines which make an angle of 25° between them. Take the radius of the smallest circle as 10 mm.
45. A vertical straight line AB is at a distance of 90 mm from the centre of a circle of 75 mm diameter. A straight line PQ passes through the centre of the circle and makes an angle of 60° with the vertical. Draw circles having their centres on PQ and to touch the straight line AB and the circle. Measure the radius of each circle.
46. Draw a semi-circle of 125 mm diameter and inscribe in it the largest equilateral triangle having a corner at the centre. The semi-circle is the development of a cone and the triangle that of a line on its surface. Draw the projections of the cone resting on its base on the ground showing the line in both views.
47. Construct a lever as shown in fig. 5-86.





6-0. INTRODUCTION

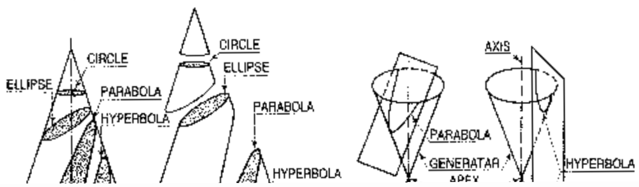
The profile of number of objects consists of various types of curves. This chapter deals with various types of curves which are commonly used in engineering practice as shown below:

1. Conic sections
2. Cycloidal curves
3. Involute
4. Evolutes
5. Spirals
6. Helix.

We shall now discuss the above in details with reference to their construction and applications.

6-1. CONIC SECTIONS

The sections obtained by the intersection of a right circular cone by a plane in different positions relative to the axis of the cone are called *conics*. Refer to fig. 6-1.



(ii) When the section plane is inclined to the axis and is parallel to one of the generators, the section is a *parabola* [fig. 6-1].

(iii) A *hyperbola* is a plane curve having two separate parts or branches, formed when two cones that point towards one another are intersected by a plane that is parallel to the axes of the cones.

The conic may be defined as the locus of a point moving in a plane in such a way that the ratio of its distances from a fixed point and a fixed straight line is always constant. The fixed point is called the *focus* and the fixed line, the *directrix*.

The ratio $\dfrac{\text{distance of the point from the focus}}{\text{distance of the point from the directrix}}$ is called *eccentricity* and is denoted by *e*. It is always less than 1 for ellipse, equal to 1 for parabola and greater than 1 for hyperbola i.e.

(i) ellipse : $e < 1$
(ii) parabola : $e = 1$
(iii) hyperbola : $e > 1$.

The line passing through the focus and perpendicular to the directrix is called the *axis*. The point at which the conic cuts its axis is called the *vertex*.

6-1-1. ELLIPSE

Use of elliptical curves is made in arches, bridges, dams, monuments, man-holes, glands and stuffing-boxes etc. Mathematically an ellipse can be described by equation $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$. Here *a* and *b* are half the length of major and minor axes of the ellipse and *x* and *y* co-ordinates.

(1) General method of construction of an ellipse:

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 12 for the following problem.

Problem 6-1. (fig. 6-2): *To construct an ellipse when the distance of the focus from the directrix is equal to 50 mm and eccentricity is* $\frac{2}{3}$.

(i) Draw any vertical line AB as directrix.

(viii) Mark any point 1 on the axis and through it, draw a perpendicular to meet *CE*-produced at 1'.

(ix) With centre *F* and radius equal to **1-1**, draw arcs to intersect the perpendicular through 1 at points P_1 and P'_1.

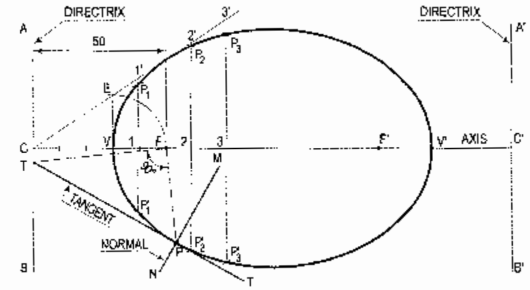
These are the points on the ellipse, because the distance of P_1 from *AB* is equal to *C*1,

$$P_1\,F = 1\text{-}1'$$

and
$$\frac{1-1'}{C1} = \frac{VF}{VC} = \frac{2}{3}.$$

Similarly, mark points 2, 3 etc. on the axis and obtain points P_2 and P'_2, P_3 and P'_3 etc.

(x) Draw the ellipse through these points. It is a closed curve having two foci and two directrices.



Directrix and focus
Fig. 6-2

(2) **Construction of ellipse by other methods:**

Ellipse is also defined as a curve traced out by a point, moving in the same plane as and in such a way that the sum of its distances from two fixed points is always the same.

The points *A*, *P*, *C* etc. are on the curve and hence, according to the definition,

$$(AF_1 + AF_2) = (PF_1 + PF_2) = (CF_1 + CF_2) \text{ etc.}$$

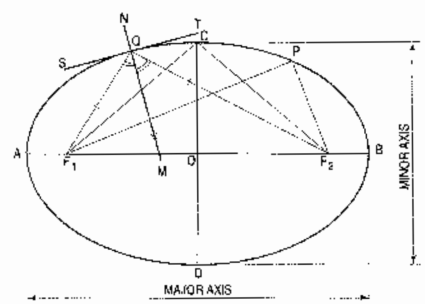
But $(AF_1 + AF_2) = AB$. $\quad\therefore (PF_1 + PF_2) = AB$, the major axis.

Therefore, *the sum of the distances of any point on the curve from the two foci is equal to the major axis.*

Again, $(CF_1 + CF_2) = AB$.

But $CF_1 = CF_2 \quad \therefore CF_1 = CF_2 = \frac{1}{2}AB.$

Hence, *the distance of the ends of the minor axis from the foci is equal to half the major axis.*



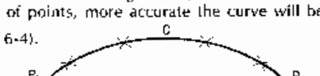
Conjugate axes
Fig. 6-3

Problem 6-2. *To construct an ellipse, given the major and minor axes.*

The ellipse is drawn by, first determining a number of points through which it is known to pass and then, drawing a smooth curve through them, either freehand or with a french curve. **Larger** the number of points, more accurate the curve will be.

Method I: *Arcs of circles method* (fig. 6-4).

(i) Draw a line *AB* equal to the



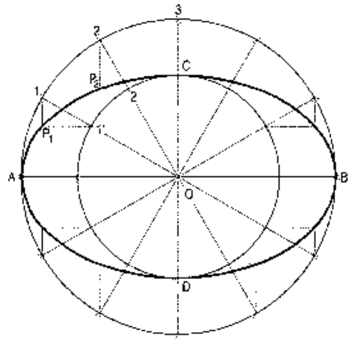
(v) With same centres and radius equal to *B*1, draw arcs intersecting the previous arcs at four points marked P_1.

(vi) Similarly, with radii *A*2 and *B*2, *A*3 and *B*3 etc. obtain more points.

(vii) Draw a smooth curve through these points. This curve is the required ellipse.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 13 for the following method II.

Method II: *Concentric circles method* (fig. 6-5).



Concentric circle method
Fig. 6-5

(i) Draw the major axis *AB* and the minor axis *CD* intersecting each other at *O*.

(ii) With centre *O* and diameters *AB* and *CD* respectively, draw two circles.

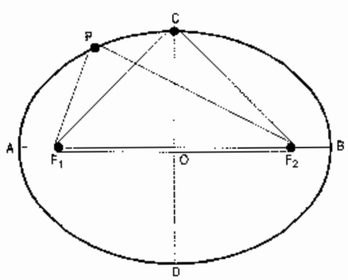
(iii) Divide the major-axis-circle into a number of equal divisions, say 12 and mark points 1, 2 etc. as shown.

(iv) Draw lines joining these points with the centre *O* and cutting the minor-axis-circle at points 1', 2' etc.

(v) Through point 1 on the major-axis-circle, draw a line parallel to *CD*, the minor axis.

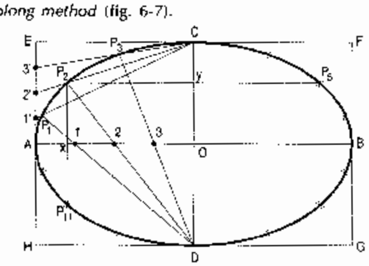
(iii) Move the pencil around the foci, maintaining an even tension in the thread throughout and obtain the ellipse.

It is evident that $PF_1 + PF_2 = CF_1 + CF_2$ etc.



Loop of the thread method
Fig. 6-6

Method IV: *Oblong method* (fig. 6-7).



Oblong method
Fig. 6-7

(i) Draw the two axes *AB* and *CD* intersecting each other at *O*.

(ii) Construct the oblong *EFGH* having its sides equal to the two axes.

An ellipse can be inscribed within a parallelogram by using the above method as shown in fig. 6-8.

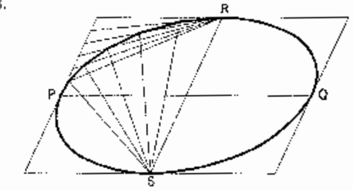
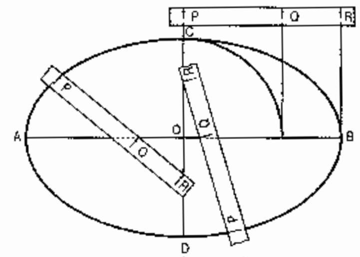


FIG. 6-8

Lines PQ and RS, joining the mid-points of the opposite sides of the parallelogram are called conjugate axes.

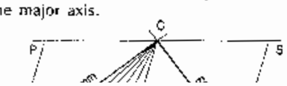
Method V: *Trammel method* (fig. 6-9).



Trammel method
FIG. 6-9

(i) Draw the two axes AB and CD intersecting each other at O. Along the edge of a strip of paper which may be used as a trammel, mark PQ equal to half the minor axis and PR equal to half the major axis.

(ii) Place the trammel so that R is on the minor axis CD and Q on the major axis AB. Then P



(i) Draw horizontal line AB = 100 mm. Take A as centre draw an arc of 80 mm. Similarly B as centre and the radius equal to 60 mm, draw the arc such that it intersects previously drawn arc at the point C. Join ABC to complete triangle.

(ii) Mark the mid point of AB such that $OA = OB$ = 50 mm. Join OC and extend CO such that $CO = OD$.

(iii) Draw parallel lines from C and D to the line AB. Similarly draw parallel lines from A and B to the line CD and complete the rhombus ($PQRS$).

(iv) Divide AO into convenient number of equal parts $A1 = 12 = 23 = 34 = 4O$ and AQ to same number of equal parts $A1' = 1'2' = 2'3' = 3'4' = 4'Q$. Join A, 1', 2', 3', 4' with D. Join $C1$ and extend it to intersect line $D1'$. Similarly join $C2$, $C3$, $C4$ and extend it to intersect $D2'$, $D3'$, $D4'$ respective. Draw smooth curve passing through all intersection.

(v) Complete the ellipse by above method for the remaining part.

(3) **Normal and tangent to an ellipse:** The normal to an ellipse at any point on it bisects the angle made by lines joining that point with the foci.

The tangent to the ellipse at any point is perpendicular to the normal at that point.

Problem 6-4. (fig. 6-3): *To draw a normal and a tangent to the ellipse at a point Q on it.*

Join Q with the foci F_1 and F_2.

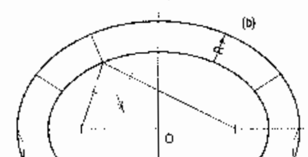
(i) Draw a line NM bisecting $\angle F_1 QF_2$. NM is the normal to the ellipse.

(ii) Draw a line ST through Q and perpendicular to NM. ST is the tangent to the ellipse at the point Q.

Problem 6-5. (fig. 6-11): *To draw a curve parallel to an ellipse and at distance R from it.*

This may be drawn by two methods:

(a) A large number of arcs of radius equal to the required distance R, with centres on the ellipse, may be described. The curve drawn touching these arcs will be parallel to the ellipse.



(iii) With O as centre and OR as radius, draw the semi-circle cutting the ellipse at a point E.

(iv) Draw the line RE.

(v) Through O draw a line parallel to RE and cutting the ellipse at points C and D. CD is the minor axis.

(vi) Through O, draw a line perpendicular to CD and cutting the ellipse at points A and B. AB is the major axis.

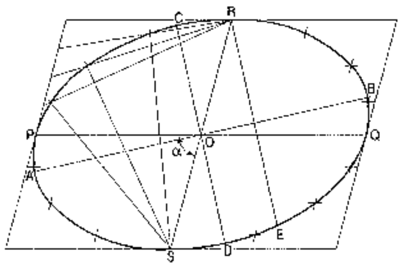


FIG. 6-12

Problem 6-7. (fig. 6-13): *To find the centre, major axis and minor axis of a given ellipse.*

(i) Draw any two chords 1-2 and 3-4 parallel to each other.

(ii) Find their mid-points P and Q, and draw a line passing through them, cutting the ellipse at points R and S. Bisect the line RS in the point O which is the centre of the ellipse.

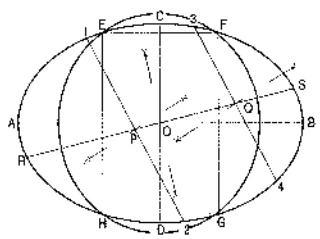


FIG. 6-13

With O as centre and any convenient radius, draw a circle cutting

Use of parabolic curves is made in arches, bridges, sound reflectors, light reflectors etc. Mathematically a parabola can be described by an equation $y^2 = 4ax$ or $x^2 = 4ay$.

(1) **General method of construction of a parabola:**

Problem 6-8. (fig. 6-14): *To construct a parabola, when the distance of the focus from the directrix is 50 mm.*

(i) Draw the directrix AB and the axis CD.

(ii) Mark focus F on CD, 50 mm from C.

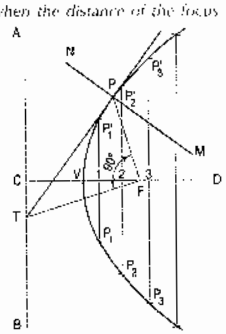
(iii) Bisect CF in V the vertex (because eccentricity = 1).

(iv) Mark a number of points 1, 2, 3 etc. on the axis and through them, draw perpendiculars to it.

(v) With centre F and radius equal to $C1$, draw arcs cutting the perpendicular through 1 at P_1 and P'_1.

(vi) Similarly, locate points P_2 and P'_2, P_3 and P'_3 etc. on both the sides of the axis.

(vii) Draw a smooth curve through these points. This curve is the required parabola. It is an open curve.



Directrix and focus
FIG. 6-14

Problem 6-9. (fig. 6-15): *To find the axis of a given parabola.*

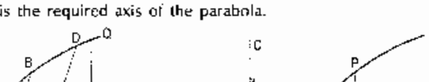
(i) Draw any two chords AB and CD across the parabola, parallel to each other and any distance apart.

(ii) Bisect AB and CD in points E and F respectively and draw a line GH passing through them. The line GH will be parallel to the axis.

(iii) Draw a chord PQ, perpendicular to GH.

(iv) Bisect PQ in the point O and through it draw a line XY parallel to GH.

Then XY is the required axis of the parabola.



Problem 6-10. (fig. 6-16): *To find the focus and the directrix of a parabola whose axis is given.*

(i) Mark any point P on the parabola and draw a perpendicular PA to the axis. Mark a point B on the axis such that $BV = VA$.

(ii) Draw a line joining B with P.

(iii) Draw a perpendicular bisector EF of BP, intersecting the axis at a point F. Then F is the focus of the parabola.

(iv) Mark a point O on the axis such that $OV = VF$. Through O, draw a line CD perpendicular to the axis. Then CD is the directrix of the parabola.

(2) Construction of parabola by other methods:

Method I: *Rectangle method* (fig. 6-17).

Problem 6-11. *To construct a parabola given the base and the axis.*

(i) Draw the base AB.

(ii) At its mid-point E, draw the axis EF at right angles to AB.

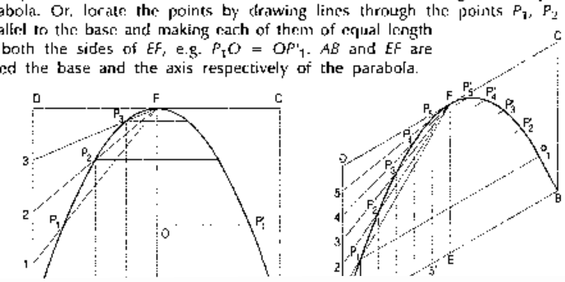
(iii) Construct a rectangle $ABCD$, making side BC equal to EF.

(iv) Divide AE and AD into the same number of equal parts and name them as shown (starting from A).

(v) Draw lines joining F with points 1, 2 and 3. Through 1', 2' and 3', draw perpendiculars to AB intersecting $F1$, $F2$ and $F3$ at points P_1, P_2 and P_3 respectively.

(vi) Draw a curve through A, P_1, P_2 etc. It will be a half parabola.

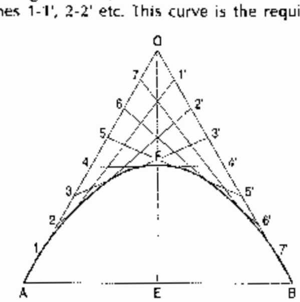
Repeat the same construction in the other half of the rectangle to complete the parabola. Or, locate the points by drawing lines through the points P_1, P_2 etc. parallel to the base and making each of them of equal length on both the sides of EF, e.g. $P_1O = OP'_1$. AB and EF are called the base and the axis respectively of the parabola.



(iii) Join O with A and B. Divide lines OA and OB into the same number of equal parts, say 8.

(iv) Mark the division-points as shown in the figure.

(v) Draw lines joining 1 with 1', 2 with 2' etc. Draw a curve starting from A and tangent to lines 1-1', 2-2' etc. This curve is the required parabola.



Tangent method
FIG. 6-19

6-1-3. HYPERBOLA

Use of hyperbolical curves is made in cooling towers, water channels etc.

Rectangular hyperbola: It is a curve traced out by a point moving in such a way that the product of its distances from two fixed lines at right angles to each other is a constant. The fixed lines are called *asymptotes.*

This curve graphically represents the Boyle's Law, viz. $P \times V = a$, P = pressure, V = volume and a is constant. It is also useful in design of water channels.

General method of construction of a hyperbola:

Mathematically, we can describe a hyperbola by

To construct the scale for the ratio $\frac{3}{2}$ draw a line VE perpendicular to CD such that $VE = VF$. Join C with E.

Thus, in triangle CVE, $\frac{VE}{VC} = \frac{VF}{VC} = \frac{3}{2}$.

(iv) Mark any point 1 on the axis and through it, draw a perpendicular to meet CE-produced at 1'.

(v) With centre F and radius equal to 1-1', draw arcs intersecting the perpendicular through 1 at P_1 and P'_1.

(vi) Similarly, mark a number of points 2, 3 etc. and obtain points P_2 and P'_2, P_3 and P'_3 etc.

(vii) Draw the hyperbola through these points.

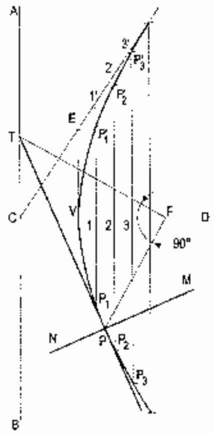


FIG. 6-20

Problem 6-13. (fig. 6-21): *To draw a hyperbola when its foci and vertices are given, and to locate its asymptotes.*

(i) Draw a horizontal line as axis and on it, mark the given foci F and F_1, and vertices V and V_1.

(ii) Mark any number of points 1, 2, 3 etc. to the right of F_1.

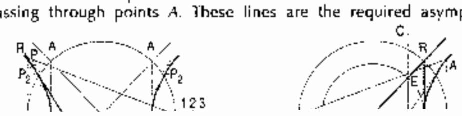
(iii) With F and F_1 as centres and radius, say $V2$, draw four arcs.

(iv) With the same centres and radius V_12, draw four more arcs intersecting the first four arcs at points P_2. Then these points lie on the hyperbola.

(v) Repeat the process with the same centres and radii V1 and V_11, $V3$ and V_13 etc. Draw the required hyperbola through the points thus obtained.

(vi) With FF_1 as diameter, draw a circle.

(vii) Through the vertices V and V_1, draw lines perpendicular to the axis, cutting the circle at four points A. From O, the centre of the circle, draw lines passing through points A. These lines are the required asymptotes.



(i) Draw a line joining A with the other focus F. Draw the bisector of $\angle FAF_1$, cutting the axis at a point B.

(ii) Through B, draw a line CD perpendicular to the axis. CD is the required directrix.

(iii) With O the mid-point of FF_1 as centre and OV_1 as radius, draw a circle cutting CD at points E and G.

(iv) Lines drawn from O and passing through E and G are the required asymptotes.

(v) The asymptotes will also pass through the points of intersection (R and S) between the circle of radius OF_1 and the vertical through V_1.

Problem 6-15. (fig. 6-23): *To draw a rectangular hyperbola, given the position of a point P on it.*

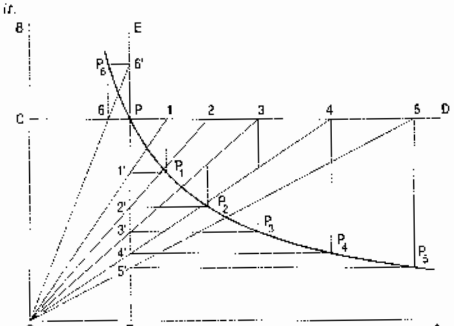


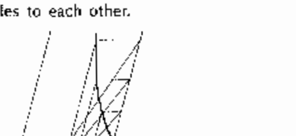
FIG. 6-23

(i) Draw lines OA and OB at right angles to each other.

(ii) Mark the position of the point P.

(iii) Through P, draw lines CD and EF parallel to OA and OB respectively.

(iv) Along PD, mark a number of points 1, 2, 3 etc. not necessarily equidistant.



6-1-4. TANGENTS AND NORMALS TO CONICS

(1) General method:

The common rule for drawing tangents and normals:

When a tangent at any point on the curve is produced to meet the directrix, the line joining the focus with this meeting point will be at right angles to the line joining the focus with the point of contact.

The normal to the curve at any point is perpendicular to the tangent at that point.

Problem 6-16. *To draw a tangent at any point P on the conics* (fig. 6-2, fig. 6-14 and fig. 6-20).

(i) Join P with F.
(ii) From F, draw a line perpendicular to PF to meet AB at T.
(iii) Draw a line through T and P. This line is the tangent to the curve.
(iv) Through P, draw a line NM perpendicular to TP. NM is the normal to the curve.

(2) Other methods of drawing tangents to conics:

Method I:

Problem 6-17. (fig. 6-25): *To draw a tangent to an ellipse at any point P on it.*

(i) With O, the centre of the ellipse as centre, and one half the major axis as radius, draw a circle.
(ii) From P, draw a line parallel to the minor axis, cutting the circle at a point Q.

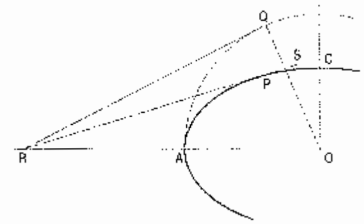


FIG. 6-25

(iii) Draw a tangent to the circle at the point Q cutting the extended major axis

(ii) Through P, draw a line PQ parallel to the axis (fig. 6-27).

Draw two lines AB and CD parallel to, equidistant from and on opposite sides of PQ, and cutting the parabola at points A and C. Draw a line joining A with C.

Through P, draw a line RS parallel to AC. RS is the required tangent.

Method III: *When the focus and the directrix are given* (fig. 6-28).

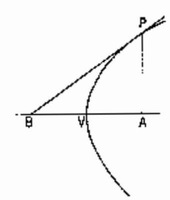


FIG. 6-26

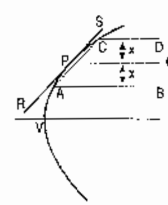


FIG. 6-27

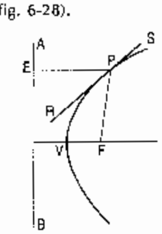


FIG. 6-28

(i) From P draw a line PE perpendicular to the directrix AB, meeting it at a point E.
(ii) Draw a line joining P with the focus F.
(iii) Draw the bisector RS of angle EPF.

Then RS is the required tangent.

Problem 6-19. (fig. 6-21): *To draw a tangent to a hyperbola at a point P on it when the axis and the foci are given.*

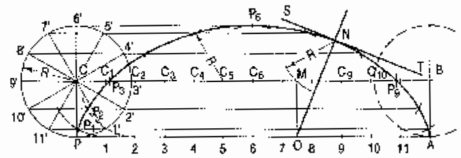
Draw lines joining P with foci F and F_1. Draw the bisector RS of $\angle FPF_1$. RS is the required tangent to the hyperbola.

Note: In fig. 6-22, the line AB is the tangent to the hyperbola at the point A.

6-2. CYCLOIDAL CURVES

These curves are generated by a fixed point on the circumference of a circle, which rolls without slipping along a fixed straight line or a circle. The rolling circle is

(ii) Draw a line PA tangential to and equal to the circumference of the circle.
(iii) Divide the circle and the line PA into the same number of equal parts, say 12, and mark the division-points as shown.
(iv) Through C, draw a line CB parallel and equal to PA.
(v) Draw perpendiculars at points 1, 2 etc. cutting CB at points C_1, C_2 etc.



Cycloid
FIG. 6-29

Assume that the circle starts rolling to the right. When point 1' coincides with 1, centre C will move to C_1. In this position of the circle, the generating point P will have moved to position P_1 on the circle, at a distance equal to P'_1 from point 1. It is evident that P_1 lies on the horizontal line through 1' and at a distance R from C_1.

Similarly, P_2 will lie on the horizontal line through 2' and at the distance R from C_2.

Construction:

(vi) Through the points 1', 2' etc. draw lines parallel to PA.
(vii) With centres C_1, C_2 etc. and radius equal to R, radius of generating circle, draw arcs cutting the lines through 1', 2' etc. at points P_1, P_2 etc. respectively.

Draw a smooth curve through points P, P_1, P_2....A. This curve is the required cycloid.

Normal and tangent to a cycloid curve: The rule for drawing a normal to all cycloidal curves:

The normal at any point on a cycloidal curve will pass through the corresponding point of contact between the generating circle and the directing line or circle.

The tangent at any point is perpendicular to the normal at that point.

Problem 6-22. (fig. 6-30): *A thin circular disc of 50 mm diameter is allowed to roll without slipping from upper edge of sloping plank which is inclined at 15° with the horizontal plane. Draw the curve traced by the point on the circumference of the disc.*

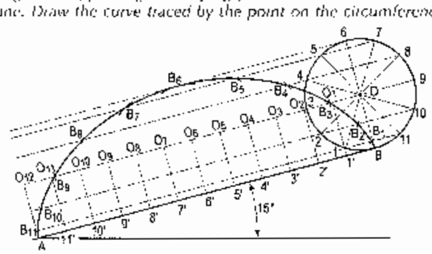


FIG. 6-30

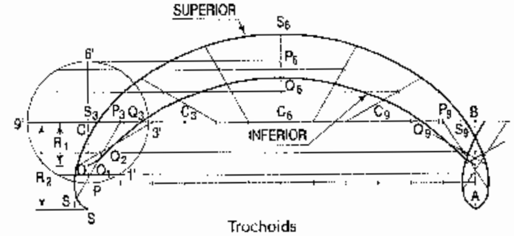
(i) Draw a line AB of length 157 mm (i.e. πD) at angle of 15° with the horizontal.
(ii) Draw a circle of 50 mm diameter at upper edge B as shown and divide the circumference of the circle in twelve equal parts. Name 1, 2, 3, 4 to 11. Draw parallel lines from 1, 2, 3, 4 to 11 to the AB. Take B as generating point on the circumference.
(iii) Draw a parallel line from the centre of circle O to line AB and equal to length of AB. Divide this line in 12 parts. Name O_1 to O_{12} as shown.
(iv) As the disc rolls from position B, the centre of disc simultaneously moves from O to O_1. Draw an arc with radius as 25 mm and centre as O_1 to intersect the line drawn from the point 1 parallel to AB. Mark intersection point as B_1. This point is on the cycloid.
(v) Similarly draw arc from the points O_2 to O_{12} such that it intersects each line drawn from 2 to 11 respectively. Join the points by smooth curve. This curve is the cycloid.

6-2-2. TROCHOID

Trochoid is a curve generated by a point fixed to a circle, within or outside its circumference, as the circle rolls along a straight line.

Method I: (fig. 6-31): Determine the positions P_1, P_2 etc. for the cycloid as shown in problem 6-20. Draw lines C_1P_1, C_2P_2 etc. With centres C_1, C_2 etc. and radius equal to R_1, draw arcs cutting C_1P_1, C_2P_2 etc. at points Q_1, Q_2 etc. respectively.

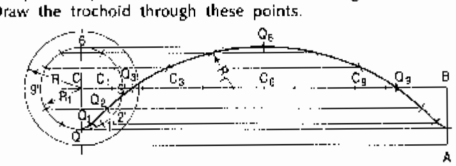
Draw a curve through these points. This curve is the inferior trochoid.



Trochoids
FIG. 6-31

Method II: (fig. 6-32): With centre C and radius equal to R_1, draw a circle and divide it into 12 equal parts.

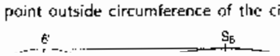
Through the division-points, draw lines parallel to *PA*. With centres C_1, C_2 etc. and radius equal to R_1, draw arcs to cut the lines through 1', 2' etc. at points Q_1, Q_2 etc. Draw the trochoid through these points.



Inferior trochoid
FIG. 6-32

(b) *Superior trochoid:*

Let *S* be the point outside circumference of the circle and at a distance R_2 from the centre.



Method I: (fig. 6-31): Adopt the same method as method I used for inferior trochoid. Point *S* will lie on the line *CP*-produced, at distance R_2 from *C*. Points S_1, S_2 etc. are obtained by cutting the lines C_1P_1-produced, C_2P_2-produced etc. with arcs drawn with centres C_1, C_2 etc. and radius equal to R_2. *S*, S_1, S_2 etc. are the points on the superior trochoid.

Method II: (fig. 6-33): Same as method II for inferior trochoid. Note that the radius of the circle is equal to R_2. A loop is formed when the circle rolls for more than one revolution.

6-2-3. EPICYCLOID AND HYPOCYCLOID

The curve generated by a point on the circumference of a circle, which rolls without slipping along another circle *outside* it, is called an *epicycloid. The epicycloid can be represented mathematically by*

$$x = (a + b)\cos\theta - a\cos\left(\frac{a+b}{a}\theta\right),$$

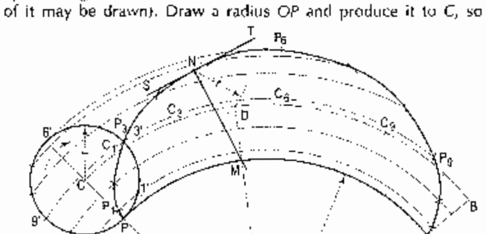
$$y = (a + b)\sin\theta - a\sin\left(\frac{a+b}{a}\theta\right)$$

where a is the radius of rolling circle.

When the circle rolls along another circle *inside* it, the curve is called a *hypocycloid*. It can be represented by mathematically $x = a\cos^3\theta$, $y = a\sin^3\theta$.

Problem 6-24. *To draw an epicycloid and a hypocycloid, given the generating and directing circles of radii r and R respectively.*

Epicycloid (fig. 6-34): With centre *O* and radius *R*, draw the directing circle (only a part of it may be drawn). Draw a radius *OP* and produce it to *C*, so that *CP* = *r*.



The position of *A* may be located by calculating the angle subtended by the arc *PA* at centre *O*, by the formula,

$$\frac{\angle POA}{360^\circ} = \frac{\text{arc } PC}{\text{circumference of directing circle}} = \frac{2\pi r}{2\pi R} = \frac{r}{R}$$

$$\therefore \quad \angle POA = 360^\circ \times \frac{r}{R}.$$

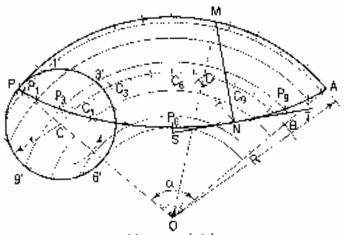
(i) Set-off this angle and obtain the position of *A*.

(ii) With centre *O* and radius equal to *OC*, draw an arc intersecting *OA*-produced at *B*. This arc *CB* is the locus of the centre *C*.

(iii) Divide *CB* and the generating circle into twelve equal parts.

(iv) With centre *O*, describe arcs through points 1', 2', 3' etc.

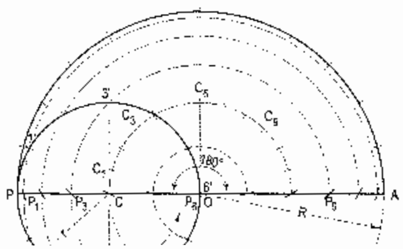
(v) With centres C_1, C_2 etc. and radius equal to *r*, draw arcs cutting the arcs through 1', 2' etc. at points P_1, P_2 etc.



Hypocycloid
FIG. 6-35

Draw the required epicycloid through the points *P*, P_1, P_2......*A*.

Hypocycloid (fig. 6-35): The method for drawing the hypocycloid is same as for epicycloid. Note that the centre *C* of the generating circle is inside the directing circle.



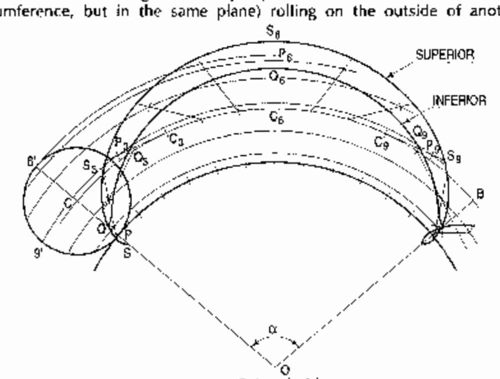
(i) With centre *N* and radius equal to *r*, draw an arc cutting the locus of the centre *C* at a point *D*.

(ii) Draw a line through *O* and *D*, cutting the directing circle at *M*.

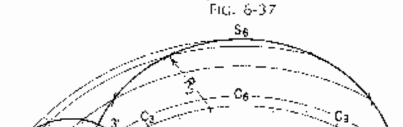
(iii) Draw a line through *N* and *M*. This line is the normal. Draw a line *ST* through *N* and at right angles to *NM*. *ST* is the tangent.

6-2-4. EPITROCHOID (FIG. 6-37 AND FIG. 6-38)

Epitrochoid is a curve generated by a point fixed to a circle (within or outside its circumference, but in the same plane) rolling on the outside of another circle.



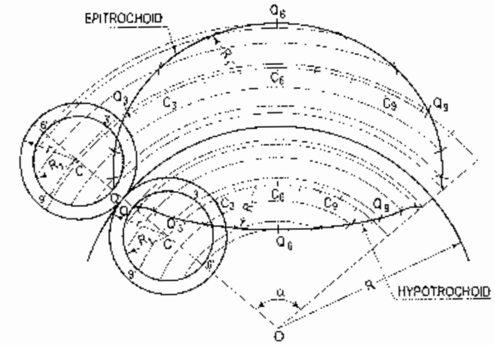
Epitrochoids
FIG. 6-37



6-2-5. HYPOTROCHOID (FIG. 6-35)

When the circle rolls inside another circle, the curve is called a hypotrochoid.

The curve is termed inferior or superior, according to the position of the point being inside or outside the rolling circle.



Inferior epitrochoid and hypotrochoid
FIG. 6-39

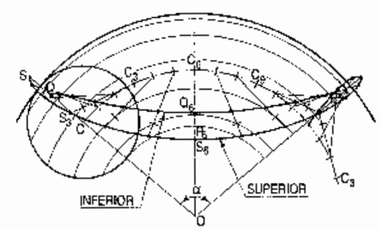
Problem 6-26. *To draw an epitrochoid and a hypotrochoid, given the rolling and directing circles and the generating points.*

These curves are drawn by applying the methods used for trochoids. Note that arcs are drawn instead of horizontal lines.

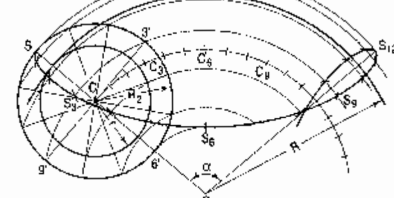
Epitrochoids:

Method I: Superior and inferior – see fig. 6-37

Method II: Superior – see fig. 6-38



Hypotrochoids
FIG. 6-40



Superior hypotrochoids
FIG. 6-41

6-3. INVOLUTE

The involute is a curve traced out by an end of a piece of thread unwound from a circle or a polygon, the thread being kept tight. It may also be defined as a curve traced out by a point in a straight line which rolls without slipping along a circle or a polygon. Involute of a circle is used as teeth profile of gear wheel. Mathematically it can be described by $x = r\cos\theta + r\theta\sin\theta$, $y = r\sin\theta - r\theta\cos\theta$.

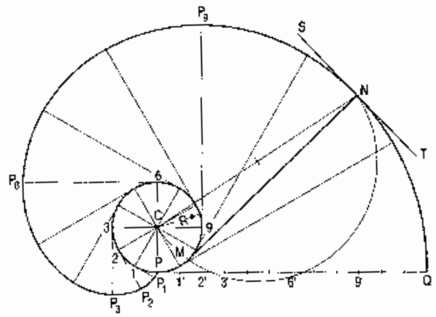
(iii) Draw tangents at points 1, 2, 3 etc. and mark on them points P_1, P_2, P_3 etc. such that $1P_1 = P1'$, $2P_2 = P2'$, $3P_3 = P3'$ etc.

Draw the involute through the points P, P_1, P_2....etc.

Normal and tangent to an involute:

The normal to an involute of a circle is tangent to that circle.

Problem 6-28. (fig. 6-42): *To draw a normal and a tangent to the involute of a circle at a point N on it.*



Involute
FIG. 6-42

(i) Draw a line joining C with N.

(ii) With CN as diameter describe a semi-circle cutting the circle at M.

(iii) Draw a line through N and M. This line is the normal. Draw a line ST, perpendicular to NM and passing through N. ST is the tangent to the involute.

Problem 6-29. (fig. 6-43): *To draw an involute of a given square.*

Let $ABCD$ be the given square.

(i) With centre A and radius AD, draw an arc to cut the line BA-produced at a point P_1.

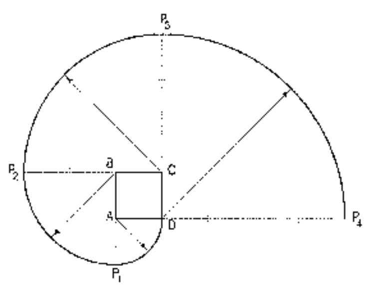


FIG. 6-43

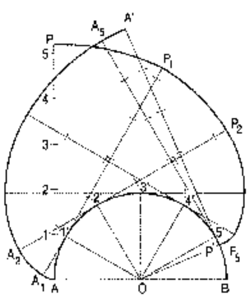
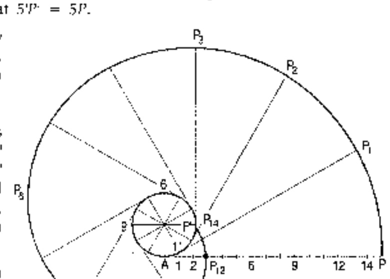


FIG. 6-44

(i) Draw the semi-circle and divide it into six equal parts.

(ii) Draw the line AP and mark points 1, 2 etc. such that $A1$ = arc $A1$, $A2$ = arc $A2$ etc. The last division $5P$ will be of a shorter length. On the semi-circle, mark a point P' such that $5'P' = 5P$.

(iii) At points 1', 2' etc. draw tangents and on them, mark points P_1, P_2 etc. such that $1'P_1 = 1P$, $2'P_2 = 2P$....and $5'P_5 = 5P_6 = 5P$. Similarly, mark points A_1, A_2 etc. such that $A_1 1' = A_1$, $A_2 2' = A2$....and $Ap' = AP$. Draw the required curves through points P, P_1....and P', and through points A, A_1.... and A'.



If AP is an inelastic string with

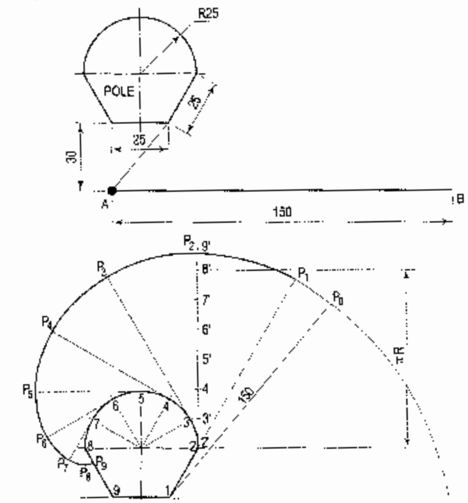
(ii) From A, draw a line passing through 1. A as centre and AP as radius, draw the arc intersecting extended line $A1'$ at P_0. Extend the side 1-2, 1 as centre and $1'P_0$ as radius, draw the arc to intersect extended line 1-2 at P_1.

(iii) Divide the circumference of the semicircle into six equal parts and label it as 2, 3, 4, 5, 6, 7 and 8.

(iv) Draw a tangent to semicircle from 2 such that $2'\text{-}P_1 = 2'\text{-}P_2$. Mark 8' on this tangent such that $2'\text{-}8' = \pi R$. Divide 2'-8' into six equal parts.

(v) Similarly draw tangents at 3, 4, 5, 6, 7 and 8 in anti-clockwise direction such that $3\text{-}P_3 = 3'\text{-}9'$, $4\text{-}P_4 = 4'\text{-}9'$, $5\text{-}P_5 = 5'\text{-}9'$, $6\text{-}P_6 = 6'\text{-}9'$, $7\text{-}P_7 = 7'\text{-}9'$, $8\text{-}P_8 = 8'\text{-}9'$ and $8\text{-}P_9 = 8'\text{-}9'$ respectively.

(vi) Join $P_1, P_2, \ldots, P_9$ with smooth curve.



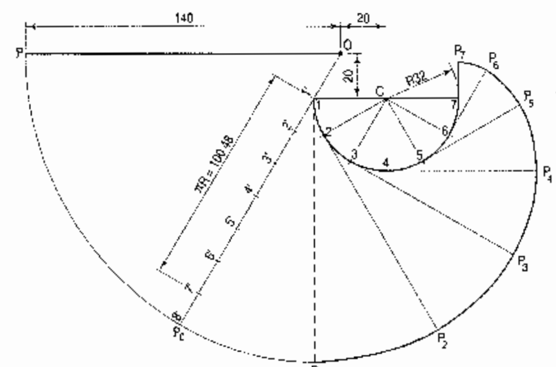


Fig. 6-47

(i) Taking C as centre, draw the semicircle of radius 32 mm as shown in fig. 6-47. Draw the horizontal line 20 mm above C. Mark O, 20 mm on left of C. Draw OP parallel to the diameter of the plate equal to 140 mm.

(ii) Divide the semi-circle into six equal parts and lable it 1, 2, 3, 4, 5, 6 and 7. Join all points with C. Now rotate the line OP about O, till it touches the semicircular plate at point 1. Mark the point 1 as point 1' on the rope.

(iii) Mark 7' on line $1'P_0$ from 1' such that $1'\text{-}7' = \pi R = 100.48$ mm. Divide 1'-7' into six equal parts and name it as 1', 2', 3', 4', 5', 6' and 7'.

(iv) Draw tangents on semicircular plate at 1, 2, 3, 4, 5, 6 and 7 in anticlockwise direction such that $1\text{-}P_1 = 1'8'$, $2\text{-}P_2 = 2'8'$, $3\text{-}P_3 = 3'8'$, $4\text{-}P_4 = 4'8'$, $5\text{-}P_5 = 5'8'$, $6\text{-}P_6 = 6'8'$, and $7\text{-}P_7 = 7'8'$ respectively.

(v) Join points $P_1, P_2, \ldots, P_7$ by smooth curve. It is involute.

Problem 6-33. (fig. 6-48): *A thin triangular equilateral plate of 20 mm side is pinned at its centroid O. An inelastic string circumscribes complete perimeter of the plate. One*

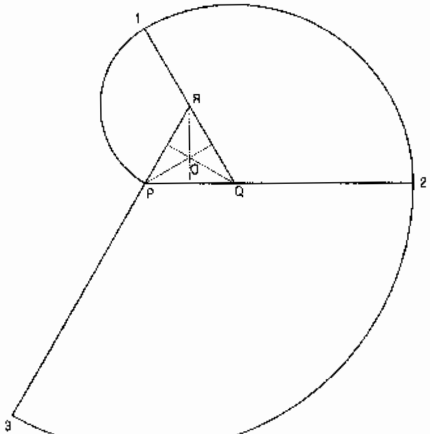
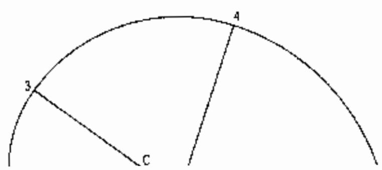


Fig. 6-48

Problem 6-34. *A regular pentagonal plate of 20 mm side is fixed at its centre. An inelastic rope is circumscribed along the perimeter of the pentagonal. Draw the path of free end of the rope when it is unwounded keeping tight for one complete turn.*



(iii) Consider starting point E. Extend line BA through A. A as centre, AE as radius draw an arc starting from E and intersecting the extended line BA at **1**.

(iv) Similarly at B, C, and D extend lines. At B as centre and $B1 = (AE + AB)$ as radius, draw the arc cutting extended line CB at 2. At C and $C3 = 3\,A1$ as radius draw arc cutting extended line CB at 3. Similarly draw arcs for extended line ED and AE cutting at 4, 5 respectively.

(v) Thus the curve obtained is involute.

6-4. EVOLUTES

APB is a given curve (fig. 6-50). O is the centre of a circle drawn through three points C, P and D on this curve. If the points C and D are moved to converge towards P, until they are indefinitely close together, then in the limit, the circle becomes the *circle of curvature* of the curve APB at P. The centre O of the circle of curvature lies on the normal to the curve at P. This centre is called the *centre of curvature* at P. The locus of the centre of curvature of a curve is called the *evolute* of the curve. A curve has only one evolute.

Problem 6-35 (fig. 6-51): *To determine the centre of curvature at a given point on a conic.*

Let P be the given point on the conic and F, the focus.

(i) Join P with F.

(ii) At P, draw a normal PN, cutting the axis at N.

(iii) Draw a line NR perpendicular to PN and cutting PF or PF-produced at R.

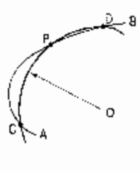


Fig. 6-50

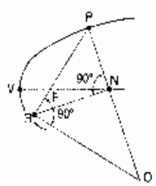


Fig. 6-51

(iv) Draw a line RO perpendicular to PR and cutting PN-produced at O. Then O is the centre of curvature of the conic at the point P.

The above construction does not hold good when the given point coincides with the vertex. As the point P approaches the vertex, the points R, N and O move nearer to one another, so that when P is at the vertex, the three points coincide on the axis.

Problem 6-36. *To determine the centre of curvature O, when the point P is at the vertex V of a conic.*

(a) ***Parabola*** (fig. 6-52): Mark the centre of curvature O on the axis such that $OF = VF$.

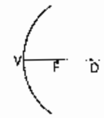


FIG. 6-52

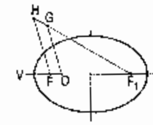


FIG. 6-53

(b) ***Ellipse*** (fig. 6-53):

Method I:

(i) Draw a line F_1G inclined to the axis and equal to VF_1.

(ii) Produce F_1G to H so that $GH = VF$. Join H with F.

(iii) Draw a line GO parallel to HF and intersecting the axis at O. Then O is the required centre of curvature.

Method II: (fig. 6-54):

(i) Draw a rectangle $AOCE$ in which

$AO = \frac{1}{2}$ major axis and

$CO = \frac{1}{2}$ minor axis.

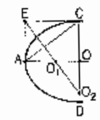


FIG. 6-54

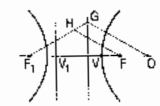


FIG. 6-55

(ii) Join A with C.

(iii) Through E, draw a line perpendicular to AC and cutting the major axis at O_1 and the minor axis O_2. Then O_1 and O_2 are the centres of curvature when the point P is at A and C respectively.

(c) ***Hyperbola*** (fig. 6-55):

(i) Draw a line F_1G inclined to the axis and equal to FV_1.

(ii) On F_1G, mark a point H such that $HG = VF$. Join H with F.

(iii) Draw a line GO parallel to HF and cutting the axis at O. Then O is the centre of curvature at the vertex V.

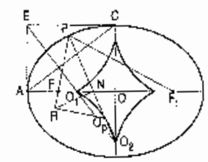


FIG. 6-56

Problem 6-37. (fig. 6-56 and fig. 6-57): *To draw the evolute of an ellipse.*

Problem 6-38. (fig. 6-58): *To draw the evolute of a parabola.*

(i) Mark a number of points on the parabola and determine the centres of curvature at these points (as shown at the point P).

(ii) Draw the evolute through these centres. Note that $PF = FR$.

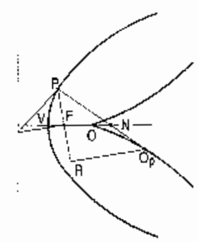


FIG. 6-58

Problem 6-39. (fig. 6-59): *To draw the evolute of a hyperbola.*

(i) Mark a number of points on the hyperbola and determine the centres of curvature at these points (as shown at the point P).

(ii) Draw the evolute through these centres. To obtain the centre of curvature at the vertex, the position of the other focus F_1 must be found.

It is determined by making use of the following rule:

The tangent at any point on the curve bisects the angle made by lines joining that point with the two foci, i.e. $\angle F_1QC = \angle FQC$.

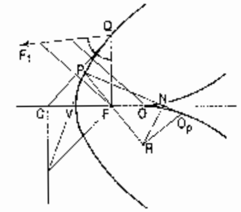


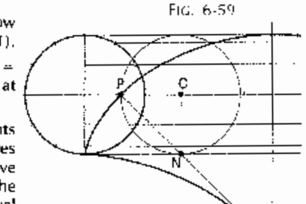
FIG. 6-59

Problem 6-40. (fig. 6-60): *To draw the evolute of a cycloid.*

(i) Mark a point P on the cycloid and draw the normal PN to it (Problem 6-21).

(ii) Produce PN to O_p so that $NO_p = PN$. O_p is the centre of curvature at the point P.

(iii) Similarly, mark a number of points on the cycloid and determine centres of curvature at these points. The curve drawn through these centres is the evolute of the cycloid. It is an equal



Through O_p, draw a line perpendicular to PO_p and intersecting the line joining C (the centre of the rolling circle) with O at a point R. The evolute is the epicycloid of the circle of diameter NR, rolling along the circle of radius OR.

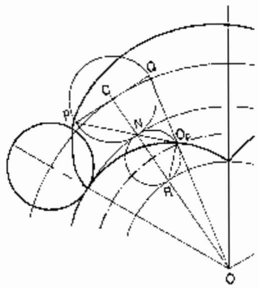


FIG. 6-61

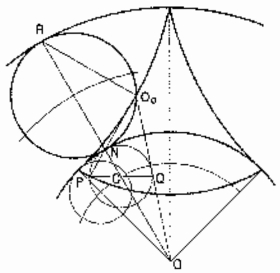


FIG. 6-62

Problem 6-42. (fig. 6-62): *To draw the evolute of a hypocycloid.*

(i) Mark a point P on the hypocycloid and draw the normal PN to it (Problem 6-24 and problem 6-25).

(ii) Draw the diameter PQ of the rolling circle. Join Q with O, the centre of the directing circle.

(iii) Produce PN to cut OQ-produced at O_p, which is the centre of curvature at the point P.

(iv) Mark a number of points on the hypocycloid and similarly, obtain centres of curvature at these points. The curve drawn through these centres is the evolute of the hypocycloid.

Through O_p, draw a line perpendicular to PO_p and intersecting OC-produced at a point R. The evolute is the hypocycloid of the circle of diameter NR rolling along the circle of radius OR.

Problem 6-43. (fig. 6-42): *To draw the evolute of an involute of a circle.*

In the involute of a circle, the normal NM at any point N is tangent to the circle at the point of contact M. M is the centre of curvature at the point N.

6-5-1. ARCHEMEDIAN SPIRAL

It is a curve traced out by a point moving in such a way that its movement towards or away from the pole is uniform with the increase of the vectorial angle from the starting line.

The use of this curve is made in teeth profiles of helical gears, profiles of cams etc.

Problem 6-44. (fig. 6-63): *To construct an Archemedian spiral of $1\frac{1}{2}$ convolutions, given the greatest and the shortest radii.*

Let O be the pole, OP the greatest radius and OQ the shortest radius.

(i) With centre O and radius equal to OP, draw a circle. OP revolves around O for $1\frac{1}{2}$ revolutions. During this period, P moves towards O, the distance equal to $(OP - OQ)$ i.e. QP.

(ii) Divide the angular movements of OP, viz $1\frac{1}{2}$ revolutions i.e. 540°, and the line QP into the same number of equal parts, say 18 (one revolution divided into 12 equal parts).

When the line OP moves through one division, i.e. 30°, the point P will move towards O by a distance equal to one division of QP to a point P_1.

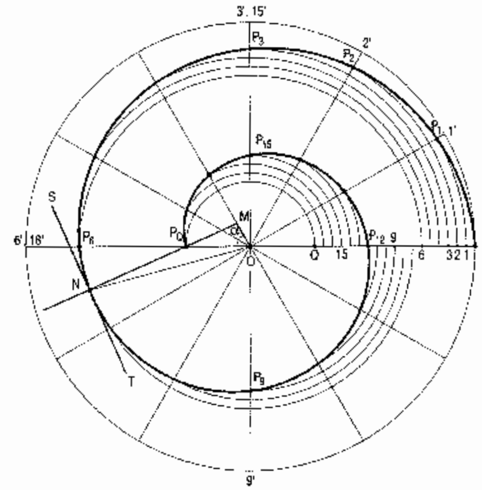
(iii) To obtain points systematically draw arcs with centre O and radii O1, O2, O3 etc. intersecting lines O1', O2', O3' etc. at points P_1, P_2, P_3 etc. respectively.

In one revolution, P will reach the 12th division along QP and in the next half revolution it will be at the point P_Q on the line 18'-O.

(iv) Draw a curve through points P, P_1, P_2, P_Q. This curve is the required Archemedian spiral.

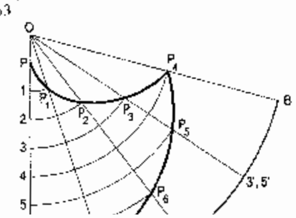
Normal and tangent to an Archemedian spiral: The normal to an Archemedian spiral at any point is the hypotenuse of the right-angled triangle having the other two sides equal in length to the *radius vector* at that point and the *constant of the curve* respectively.

The constant of the curve is equal to the difference between the lengths of any two radii divided by the circular measure of the angle between them.



Archemedian spiral
FIG. 6-63

Problem 6-46. (fig. 6-64): *A link 225 mm long, swings on a pivot O from its vertical position of rest to the right through an angle of 75° and returns to its initial position at uniform velocity. During that period, a point P moving at uniform speed along the centre line of the link from a point at a distance of 25 mm from O, reaches the end of the link. Draw the locus of the point P.*



(i) Draw a vertical line OA 225 mm ...

(vi) With centre O and radii O1, O2, O3 etc., draw arcs intersecting lines O1', O2', O3' etc. at points P_1, P_2, P_3 etc. respectively. Draw a curve through P, P_1....P_4....A. This curve is the locus of the point P.

Problem 6-47. (fig. 6-65): *A straight link PQ of 60 mm length revolves one complete revolution with uniform motion in anti-clockwise direction about hinged P. During this period an insect moves along the link from P to Q and Q to P with uniform linear motion. Draw the path of the insect and name the curve.*

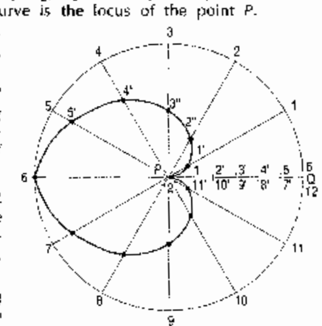


FIG. 6-65

(i) Draw circle of 60 mm radius at P as centre and divide into twelve equal parts. Name in anti-clockwise direction 1, 2, 3, 4, 5..... 12.

(ii) Divide line PQ into six equal part and mark as 1', 2', 3', 4', 5' and 6' and from Q as 7 to 12'.

(iii) Mark 1", 2", 3", 4", 5" and 6" along radius P1, P2, P3, P4, P5 and P6 respectively increasing each division of the line PQ as shown in fig 6-65.

(iv) Bottom portion is the mirror image of top portion. So drop the respective point on bottom radii.

(v) Join them with the smooth curve. The curve is archemedian spiral.

6-5-2. LOGARITHMIC OR EQUIANGULAR SPIRAL

In a *logarithmic spiral*, the ratio of the lengths of consecutive radius vectors enclosing equal angles is always constant. In other words the values of vectorial *angles* are in *arithmetical progression* and the corresponding values of *radius* vectors are in *geometrical progression.*

The logarithmic spiral is also known as *equiangular spiral* because of its property that the angle which the tangent at any point on the curve makes with the radius vector at that point is constant.

(iii) Draw a line joining D with E.

(iv) With centre A and radius AE, draw an arc cutting AB at a point 1. Through 1, draw a line 1-1' parallel to DE and cutting AC at 1'. Again, with centre A and radius A1' draw an arc cutting AB at 2. Through 2, draw a line 2-2' parallel to DE and cutting AC at 2'. Repeat the construction and obtain points 3, 4.....12. A1, A2 etc. are the lengths of consecutive radius vectors.

(v) Draw a horizontal line OQ and on it, mark OP, 1 cm long [fig. 6-66(i)]. Through O, draw radial lines making 30° angles between two consecutive lines. These are the radius vectors.

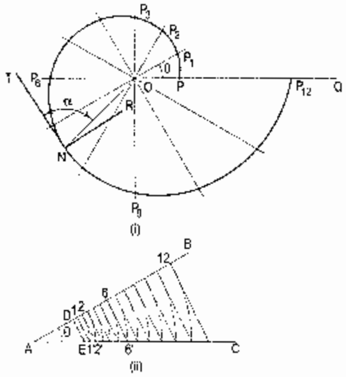


FIG. 6-66

(vi) Mark points P_1, P_2.........P_{12} on consecutive radius vectors such that OP_1 = A1, OP_2 = A2.........OP_{12} = A12.

(vii) Draw a smooth curve through P_1, P_2.....P_{12}. This curve is the required logarithmic spiral.

The equation to the logarithmic spiral is $r = a^{\theta}$ where r is the radius vector, θ is the vectorial angle and a is a constant.

Hence, $\log r = \theta \log a$.

If $\theta = 0$, $\log r = O$ $\therefore r = 1$.

When $\theta = 30° = \frac{\pi}{6}$ radians, $r = \frac{10}{9} \times 1 = \frac{10}{9}$ $\therefore \log \frac{10}{9} = \frac{\pi}{6} \log a$

i.e $\log a = \frac{6}{\pi} \log \frac{10}{9}$ $\therefore a = 1.22.$

Problem 6-49. [fig. 6-66(i)]: *To draw a normal and a tangent at a given point N on the logarithmic spiral in problem 6-46.*

6-6. HELIX

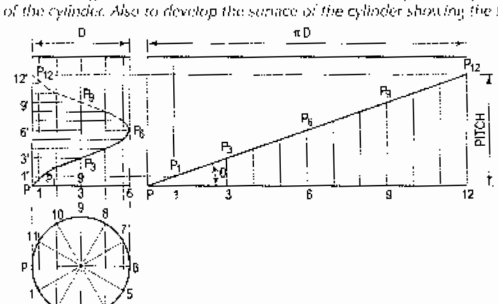
Helix is defined as a curve, generated by a point, moving around the surface of a right circular cylinder or a right circular cone in such a way that, its axial advance, i.e. its movement in the direction of the axis of the cylinder or the cone is uniform with its movement around the surface of the cylinder or the cone.

The axial advance of the point during one complete revolution is called the *pitch* of the helix. If the pitch is say 20 mm and the point starts upwards from the base of the cylinder, in one-fourth of a revolution, the point will move up a distance of 5 mm from the base. We shall now learn in the articles to follow:

1. A method of drawing a helical curve
2. Helical springs
3. Screw threads
4. Helix upon a cone.

6-6-1. A METHOD OF DRAWING A HELICAL CURVE

Problem 6-50. (fig. 6-67): *To draw a helix of one convolution, given the pitch and the diameter of the cylinder. Also to develop the surface of the cylinder showing the helix in it.*



(iv) Obtain other points in the same manner and draw the **helix** through them. The portion of the curve **from** P_6 to P_{12} will be on the back side of the cylinder and hence it will not be visible.

Fig. 6-67(ii) shows the development of the surface of the cylinder. The helix is seen as a straight line and is the hypotenuse of a right-angled triangle having base equal to the circumference of the circle and the vertical side equal to the pitch of the helix. The angle θ which it makes with the base, is called the *helix angle*. The helix angle can be expressed as $\tan\theta = \dfrac{\text{pitch}}{\text{circumference of the circle}}$.

6-6-2. HELICAL SPRINGS

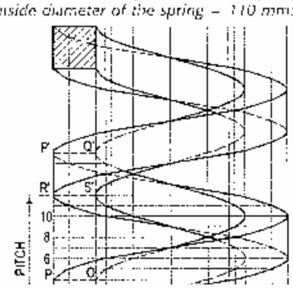
In a spring having a wire of square cross-section, the outer two corners of the section may be assumed to be moving around the axis, on the surface of a cylinder having a diameter equal to the outside diameter of the spring. The inner two corners of the section will move on the surface of a cylinder having a diameter, equal to the inside diameter of the spring. The pitch in case of each corner will be the same.

(1) Helical spring of a wire of square cross-section.

(2) Helical spring of a wire of circular cross-section.

(1) Helical spring of a wire of square cross-section.

Problem 6-51. (fig. 6-68): *Draw the projections of two complete turns of a spring of a wire of square section of 20 mm side. Outside diameter of the spring = 110 mm; pitch = 60 mm.*



Instead of full circles, semi-circles of 110 mm and 70 mm diameters for the outside and the inside diameters of the spring may be drawn in the top view.

(i) Divide each semi-circle into $\frac{12}{2}$, i.e. 6 equal parts.

(ii) Project up the division-points as lines in the front view. Let *PQSR* be the square section of the wire.

(iii) In one revolution, the point *P* will move to *P'* so that *PP'* = 60 mm

(2) Helical spring of a wire of circular cross-section.

When the wire is of circular cross-section, a helical curve for the centre of the cross-section is first traced out. A number of circles of diameter equal to that of the cross-section are then drawn with a number of points on this curve as centres. Curves, tangent to these circles, will give the front view of the spring.

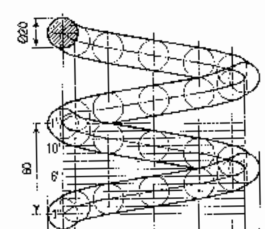
Problem 6-52. (fig. 6-69): *Draw two complete turns of a helical spring of circular cross-section of 20 mm diameter. Spring index and pitch are 6 and 60 mm respectively.*

$$\text{Spring index} = \frac{\text{Mean diameter of a coil}}{\text{Diameter of wire}}$$

(a) Mean diameter of a coil = Spring index × Diameter of wire
= 6 × 20
= 120 mm.

(b) Outside diameter of a coil = Mean diameter + Diameter of wire
= 120 mm + 20 mm
= 140 mm.

(c) Inside diameter of a coil = Mean diameter − Diameter of wire
= 120 mm − 20 mm
= 100 mm.



(i) Draw the three concentric circles of diameters 140 mm, 120 mm and 100 mm representing the outside, mean and the inside circles of coil of the spring respectively in the top view.

(ii) Divide the circles into 12 divisions. Mark the divisions on the circle of the mean diameter as 1, 2, 3 etc.

(iii) Draw the projectors passing through these divisions in the front view. Mark the pitch length along one of the projectors which is parallel to the axis

6-6-3. SCREW THREADS

These are also constructed on the principle of the helix.

In a screw thread, the *pitch* is defined as the distance from a point on a thread to a corresponding point on the adjacent thread, measured parallel to the axis. The axial advance of a point on a thread, per revolution, is called the *lead* of the screw.

In the single-threaded screws, which are most commonly used in practice, the pitch is equal to lead. Therefore, the pitch of the screw is equal to the pitch of the helix. Unless stated otherwise, *screws are always assumed to be single-threaded.*

Problem 6-53. (fig. 6-70): *Project two complete turns of a square thread having outside diameter 120 mm and pitch 45 mm.*

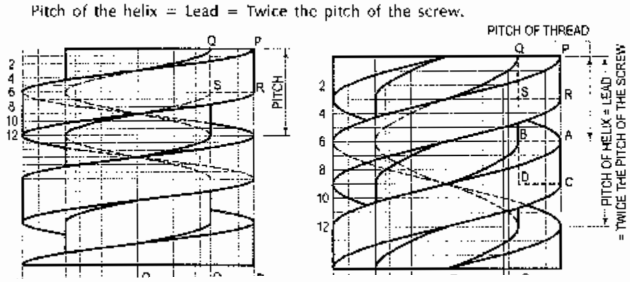
In a square thread, the thickness of the thread = the depth of the thread = 0.5 × pitch. Hence, the section of the thread will be a square of 22.5 mm side and the diameter at the bottom of the thread will be 75 mm.

Project the threads in the same manner as the spring in problem 6-51. The screw differs from the spring in having a solid cylinder inside, which completely hides the back portions of the curves.

In double-threaded screws, two threads of the same size run parallel to each other. The axial advance per revolution, viz. the lead, is made twice the lead of the single-threaded screw, the pitch of the thread being kept the same in both cases.

Hence, in double-threaded screws,

Pitch of the helix = Lead = Twice the pitch of the screw.

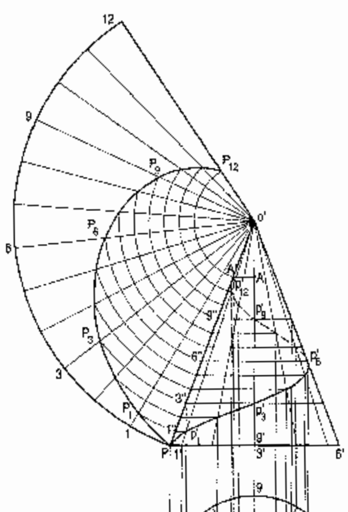


6-6-4. HELIX UPON A CONE

This curve is traced out by a point which, while moving around the axis and on the surface of the cone, approaches the apex. The movement around the axis is uniform with its movement towards the apex, measured parallel to the axis. The pitch of the helix is measured parallel to the axis of the cone.

As the whole surface of the cone is visible in its top view, the helix will be fully seen in it.

Problem 6-54. (fig. 6-72): *Draw a helix of one convolution upon a cone, diameter of base 75 mm, height 100 mm and pitch 75 mm. Also develop the surface of the cone, showing the helix on it.*



(i) Draw the projections of the cone as shown. Divide the circle into twelve equal parts and join points 1, 2 etc. with *o*. Project these points to the base-line in the front view and join them with *o'*.

(ii) Mark a point *A* on the axis at a distance of 75 mm from the base. Draw a horizontal line through *A* to cut the generators *o' P* at *A'*. Divide *PA'* into twelve equal parts.

(iii) Let *P* be the starting point. When it has moved around through 30°, it will have moved up through one division to a point p'_1 on the generator o' 1', obtained

Problem 6-55. (fig. 6-73): *A conical spring of a bicycle's seat has following specifications. Draw the front view and the top view of the spring. Only one-turn is sufficient.*

(i) Outer diameter of the coil at the bottom .... 72 mm
(ii) Outer diameter of the coil at the top .... 42 mm
(iii) Wire diameter .... 10 mm
(iv) Pitch .... 60 mm.

(a) Draw a circle of mean diameter of 72 mm in the top view.
(b) Divide the circle into 12 divisions. Mark the divisions 1, 2, 3 etc. as shown in fig. 6-73.
(c) Draw the front view of the cone with the base length 72 mm.
(d) Draw pitch length 60 mm along the line parallel to the axis of the cone. Divide this pitch length into 12 divisions and number them as 1', 2', 3' etc.
(e) Draw the vertical projectors from these points 1, 2, 3 etc. to intersect the horizontal lines from the points 1', 2', 3' etc. With the intersection point as centre and radius equal to 5 mm, draw the circles and the smooth curve touching to the top and bottom of the circles as shown in fig. 6-73.

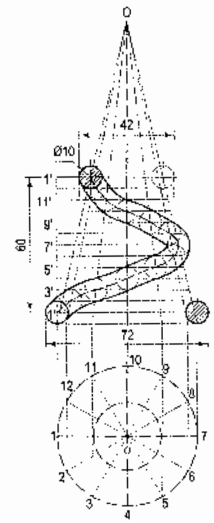


FIG. 6-73

6-7. CAM

A cam is a machine-part which, while rotating at uniform velocity, imparts reciprocating linear motion or oscillating motion to another machine-part called a follower. The motion imparted may be either uniform or variable, depending upon the shape of the cam profile.

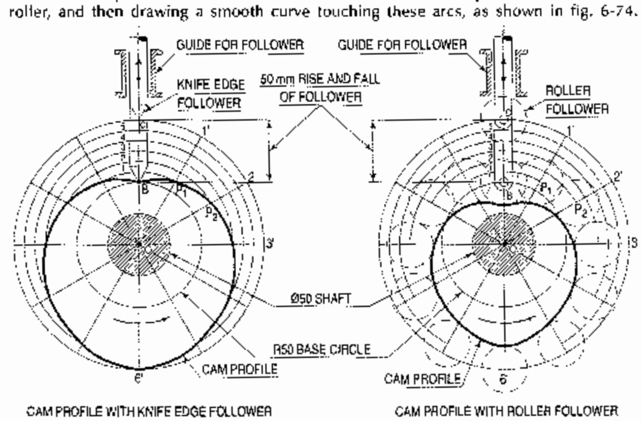
The shape of the cam to transmit uniform linear motion is determined by the application of the principle of Archemedian spiral, as shown in problem 6-44.

The cams are widely used in automates, printing machines, an I.C. engines etc.

Obtain points P_1, P_2 etc. as in the Archemedian spiral and draw the curve through them.

The point is to fall the same distance during the same period. Hence, the curve will be exactly of the same shape as for the rise.

The followers are generally provided with rollers to give smooth working. In such cases, the profile of the cam is designed initially, to transmit motion to a point (the centre of the roller) and then, a parallel curve is drawn inside it at a distance equal to the radius of the roller. This is done by first drawing a number of arcs with points on the curve as centres and radius equal to radius of the roller, and then drawing a smooth curve touching these arcs, as shown in fig. 6-74.



Cam and follower
FIG. 6-74

EXERCISES 6

4. The major axis of an ellipse is 150 mm long and the minor axis is 100 mm long. Find the foci and draw the ellipse by 'arcs of circles' method. Draw a tangent to the ellipse at a point on it 25 mm above the major axis.
5. The foci of an ellipse are 90 mm apart and the minor axis is 65 mm long. Determine the length of the major axis and draw half the ellipse by concentric-circles method and the other half by oblong method. Draw a curve parallel to the ellipse and 25 mm away from it.
6. The major axis of an ellipse is 100 mm long and the foci are at a distance of 15 mm from its ends. Find the minor axis. Prepare a trammel and draw the ellipse using the same.
7. Two fixed points A and B are 100 mm apart. Trace the complete path of a point P moving (in the same plane as that of A and B) in such a way that, the sum of its distances from A and B is always the same and equal to 125 mm. Name the curve. Draw another curve parallel to and 25 mm away from this curve.
8. Inscribe an ellipse in a parallelogram having sides 150 mm and 100 mm long and an included angle of 120°.
9. Two points A and B are 100 mm apart. A point C is 75 mm from A and 60 mm from B. Draw an ellipse passing through A, B and C.
10. Draw a rectangle having its sides 125 mm and 75 mm long. Inscribe two parabolas in it with their axis bisecting each other.
11. A ball thrown up in the air reaches a maximum height of 45 metres and travels a horizontal distance of 75 metres. Trace the path of the ball, assuming it to be parabolic.
12. A point P is 30 mm and 50 mm respectively from two straight lines which are at right angles to each other. Draw a rectangular hyperbola from P within 10 mm distance from each line.
13. Two straight lines OA and OB make an angle of 75° between them. P is a point 40 mm from OA and 50 mm from OB. Draw a hyperbola through P, with OA and OB as asymptotes, marking at least ten points.
14. Two points A and B are 50 mm apart. Draw the curve traced out by a point P moving in such a way that the difference between its distances from A and B is always constant and equal to 20 mm.
15. A circle of 50 mm diameter rolls along a straight line without slipping. Draw the curve traced out by a point P on the circumference, for one complete revolution of the circle. Name the curve. Draw a tangent to the curve at a point on it 40 mm from the line.

19. A circle of 115 mm diameter rolls on another circle of 75 mm diameter with internal contact. Draw the locus of a point on the circumference of the rolling circle for its one complete revolution.
20. A circle of 50 mm diameter rolls on another circle of 175 mm diameter. Draw and name the curves traced out by two points Q and S lying on a straight line through the centre C of the rolling circle and respectively 20 mm and 35 mm from it, when it rolls (i) outside and (ii) inside the other circle.
21. Show by means of a drawing that when the diameter of the directing circle is twice that of the generating circle, the hypocycloid is a straight line. Take the diameter of the generating circle equal to 50 mm.
22. A circle of 50 mm diameter rolls on a horizontal line for a half revolution and then on a vertical line for another half revolution. Draw the curve traced out by a point P on the circumference of the circle.
23. Draw an involute of a circle of 40 mm diameter. Also, draw a normal and a tangent to it at a point 100 mm from the centre of the circle.
24. An inelastic string 145 mm long, has its one end attached to the circumference of a circular disc of 40 mm diameter. Draw the curve traced out by the other end of the string, when it is completely wound around the disc, keeping the string always tight.
25. Draw a circle with diameter AB equal to 65 mm. Draw a line AC 150 mm long and tangent to the circle. Trace the path of A, when the line AC rolls on the circle, without slipping.
26. AB is a rope 1.6 metres long, tied to a peg at B (fig. 6-75). Keeping it always tight, the rope is wound round the pole O. Draw the curve traced out by the end A. Scale $\frac{1}{10}$ full size.

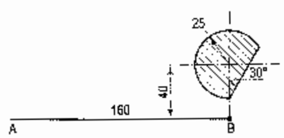


FIG. 6-75

27. Draw an Archemedian spiral of two convolutions, the greatest and the least radii being 115 mm and 15 mm respectively. Draw a tangent and a normal to the spiral at a point, 65 mm from the pole.
28. A point P moves towards another point O, 75 mm from it and reaches it while moving around it once, its movement towards O being uniform with its

Miscellaneous problems:

44. *ABC* is an equilateral triangle of side equal to 70 mm. Trace the loci of the vertices *A*, *B* and *C*, when the circle circumscribing *ABC* rolls without slipping along a fixed straight line for one half revolution.
45. The major-axis *AB* of an ellipse is 140 mm long with *P* as its mid-point. The foci F_1 and F_2 of the ellipse are 48 mm away from the mid-point *P*. Draw the ellipse and find the length of the minor axes.
46. Draw an ellipse by 'concentric circles method' and find the length of the minor axis with the help of the following data: (i) Major axes = 100 mm. (ii) Distance between foci 80 mm.
47. *PQ* is a diameter of a circle and is 75 mm long. A piece of string is tied tightly round the circumference of the semi-circle starting from *P* and finishing at *Q*. The end *Q* is then untied and the string, always kept taut, is gradually unwound from the circle, until it lies along the tangent at *P*. Draw the curve traced by the moving extremity of the string.
48. A half-cone is standing on its half base on the ground with the triangular face parallel to the V.P. An inextensible string is passed round the half-cone from a point on the periphery and brought back to the same point. Find the shortest length of the string. Take the base-circle diameter of the half-cone as 60 mm and height 75 mm.
49. One end of an inelastic thread of 120 mm length is attached to one corner of a regular hexagonal disc having a side of 25 mm. Draw the curve traced out by the other end of the thread when it is completely wound along the periphery of the disc, keeping the thread always tight.
50. A circus man rides a motor-bike inside a globe of 6 metres diameter. The motor-bike has the wheel of 1 metre diameter. Draw the locus of the point on the circumference of the motor-bike wheel for one complete revolution. Adopt suitable scale.
51. A fountain jet discharges water from ground level at an inclination of 45° to the ground. The jet travels a horizontal distance of 7.5 metre from the point of discharge and falls on the ground. Trace the path of the jet. Name the curve.
52. A coin of 35 mm diameter rolls over dinning table without slipping. A point on the circumference of the coin is in contact with the table surface in the beginning and after one complete revolution. Draw the curve traced by the

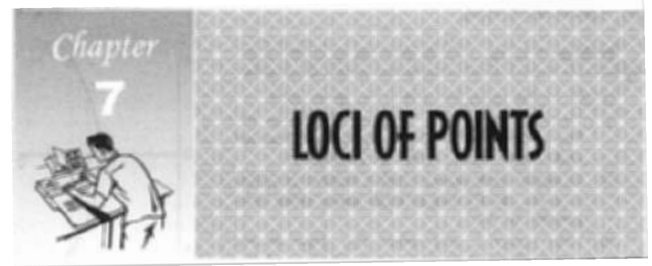
56. A circle of 60 mm diameter rolls on a horizontal line for a half revolution and then on a vertical line for another half revolution. Draw the curve traced out by a point *P* on the circumference of the circle.
57. Draw the path traced out by a point on a circumference of circle when it rolls, without slip, on vertical surface, for the distance equal to the perimeter of the circle of diameter of 40 mm.
58. Draw a helix of pitch equal to 50 mm upon a cylinder of 75 mm diameter and develop the surface of the cylinder. Assume the starting point to be on the vertical centre line in the top view.
59. Draw the projections of a helix having a helix-angle of 30°, on a cylinder of 75 mm diameter.
60. A spiral is made of a wire of rectangular cross-section 25 mm × 20 mm. Draw two complete turns of the spring. Outside diameter 100 mm, inside diameter 50 mm and pitch 50 mm.
61. Project one complete turn of a helical spring of outside diameter 75 mm and pitch 50 mm, the cross-section of wire being a circle of 20 mm diameter.
62. Draw the projections of three coils of a helical spring of steel wire 20 mm diameter. Outside diameter of the spring 100 mm and pitch 50 mm.
63. Project two complete turns of a triangular thread, outside diameter 125 mm, pitch 25 mm and angle 60°.
64. A screw having triple-start square thread has outside diameter 150 mm, lead 120 mm and pitch 40 mm. Draw its projections.
65. Draw a helix of one convolution upon a cone, diameter of the base 75 mm, axis 100 mm long and pitch 75 mm. Take apex as the starting point for the curve.
66. A point *P*, starting from the base-circle of a cone, reaches the apex, while moving around the axis through two complete turns. Assuming the movement of *P* towards the apex (measured parallel to the axis) to be uniform with its movement around the axis, draw the projections and the development of the surface of the cone showing the path of *P* in each. Diameter of the base of the cone 75 mm; axis 100 mm long.
67. A propeller screw of 20 mm diameter has a helical blade welded on its surface. The diameter of the helix is 80 mm and the pitch is 50 mm. Project

32. The distance between the foci of an ellipse is 100 mm and the minor axis is 65 mm long. Draw the evolute of the ellipse.
33. Draw the evolutes of the two curves, the data of which is given in Ex. 2.
34. Construct the evolute of the hyperbola whose data is given in Ex. 3.
35. Draw the evolute of the cycloid obtained in Ex. 15.
36. Draw the epicycloid and hypocycloid, when the generating circle and the directing circle are of 50 mm and 175 mm diameters respectively. Construct the evolutes of the two curves.
37. In a logarithmic spiral, the shortest radius is 40 mm. The length of adjacent radius vectors enclosing 30° are in the ratio 9.8. Construct one revolution of the spiral. Draw a tangent to the spiral at any point on it.
38. Draw a triangle *ABC* with *AB* = 30 mm, *AC* = 40 mm and $\angle BAC$ = 45°. *B* and *C* are the points on an Archemedian spiral of one convolution of which *A* is the pole. Find the initial line and draw the spiral.
39. *ABC* is an equilateral triangle of side equal to 70 mm. Trace the loci of the vertices *A*, *B* and *C* when the circle circumscribing *ABC* rolls without slipping along a fixed straight line for one complete revolution.
40. Draw the shape of the cam to give the same motions as in Ex. 30 to a roller of 25 mm diameter.
41. A point is raised by a cam uniformly 25 mm in $\frac{3}{8}$ of a revolution; kept at the same height for $\frac{1}{8}$ of the revolution; then allowed to drop through 10 mm height and remain there for $\frac{1}{8}$ of the revolution; lowered uniformly to its original position in $\frac{1}{4}$ of the revolution and kept there for the rest of the revolution. Draw the shape of the cam. Diameter of shaft = 40 mm. Least metal = 25 mm.
42. Two pegs *A* and *B* are fixed on the ground 6 metres apart. A string, 8 metres long has its one end tied to the peg *A*, while the other end is passed through a small ring *C* and tied to the peg *B*. A link *CD* of 1 metre length is fixed to the ring *C*. The link with the ring slides along the string. Draw the boundary of the area of the ground beyond which *D* cannot reach, as *C* slides along the string *AB*.
43. Fill in the blanks in the following with appropriate words selected from the list given below:
    (a) When a cone is cut by planes at different angles, the curves of intersection are called ________.

(g) In a conic the line passing through the fixed point and perpendicular to the fixed line is called the ________.
(h) The vertex is the point at which the ________ cuts the ________.
(i) The sum of the distances of any point on the ________ from its two foci is always the same and equal to the ________.
(j) The distance of the ends of the ________ of an ellipse from the ________ is equal to half the ________.
(k) In a ________ ________, the product of the distances of any point on it from two fixed lines at right angles to each other is always constant. The fixed lines are called ________.
(l) Curves generated by a fixed point on the circumference of a circle rolling along a fixed line or circle are called ________ ________.
(m) The curve generated by a point on the circumference of a circle, rolling along another circle inside it, is called a ________.
(n) The curve generated by a point on the circumference of a circle rolling along a straight line is called a ________.
(o) The curve generated by a point on the circumference of a circle rolling along another circle outside it, is called ________.
(p) The curve generated by a point fixed to a circle outside its circumference, as it rolls along a straight line is called ________.
(q) The curve generated by a point fixed to a circle inside its circumference, as it rolls along a circle inside it, is called ________ ________.
(r) The curve generated by a point fixed to a circle outside its circumference as it rolls along a circle outside it, is called ________ ________.
(s) The curve traced out by a point on a straight line which rolls, without slipping, along a circle or a polygon is called ________.
(t) The curve traced out by a point moving in a plane in one direction, towards a fixed point while moving around it is called a ________.
(u) The line joining any point on the spiral with the pole is called ________.
(v) In ________ ________ the ratio of the lengths of consecutive radius vectors enclosing equal angles is always constant.

List of words for Ex. 43:

1. Asymptotes	9. Equal to 1	17. Hypotrochoid	25. Rectangular
2. Axis	10. Epitrochoid	18. Involute	26. Smaller than 1



7-0. INTRODUCTION

A machine is made of the various types of mechanisms for transmitting motions. These mechanisms consist of interrelated links moving on the required path. Dimensions (generally lengths) of the links of the mechanism can be determined by plotting the path of required points. This chapter deals with problems of plotting path of points on the links of different mechanisms.

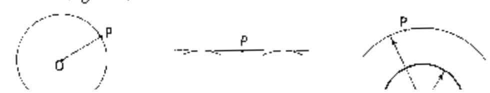
7-1. LOCI OF POINTS

A **locus** (plural loci) is the path of a point which moves in space.

(i) **The locus of a point** P **moving** in a plane about another point O in such a way that its distance from it is constant, is a circle of radius equal to OP (fig. 7-1).

(ii) The locus of a point P moving in a plane in such a way that its distance from a fixed line AB is constant, is a line through P, parallel to the fixed line (fig. 7-2).

(iii) When the fixed line is an arc of a circle, the locus will be another arc drawn through P with the same centre (fig. 7-3).



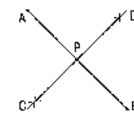


FIG. 7-4

Problem 7-1. (fig. 7-6): *To draw the locus of a point equidistant from a fixed straight line and a fixed point.*

Let AB be the given line and C the given point.

(i) From C, draw a line CD perpendicular to AB. The mid-point P of CD is equidistant from AB and C, and hence, it lies on the locus.

(ii) To obtain more points, mark a number of points 1, 2 etc. on PC and through them, draw lines parallel to AB.

(iii) With centre C and radius $D1$, draw an arc cutting the line through 1 at points P_1 and P'_1.

(iv) Similarly, obtain more points and through them, draw a smooth curve which will be the required locus.

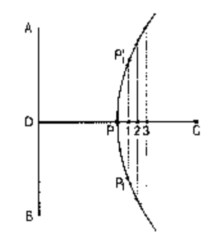


FIG. 7-6

Problem 7-2. (fig. 7-7): *To draw the locus of a point equidistant from a fixed circle and a fixed point.*

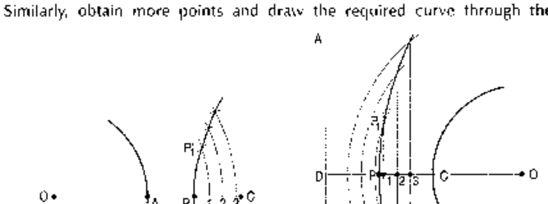
A circle with centre O and a point C are given.

(i) Draw a line joining O and C and cutting the circle at a point A. The mid-point P of the line AC will lie on the locus.

(ii) Mark a number of points 1, 2 etc. on PC and through them, draw arcs with O as centre.

(iii) With centre C and radius equal to $A1$, draw an arc cutting the arc through 1 at points P_1 and P'_1.

Similarly, obtain more points and draw the required curve through them.



(iii) Mark any point **1** on PC and through it, draw a line parallel to AB.

(iv) With centre O and radius equal to $(OC + D1)$, draw an arc cutting the line through **1** at P_1 and P'_1.

(v) Similarly, obtain more points and draw the curve through them.

Problem 7-4. (fig. 7-9): *To draw the locus of a point equidistant from two given circles.*

Circles with centres A and B are given.

(i) Draw a line joining A and B and cutting the circles at points C and D.

(ii) Find the mid-point P of the line CD.

(iii) Mark any point 1 on PD and through it, draw an arc with centre A.

(iv) With centre B and radius equal to $(BD + C1)$, draw an arc, cutting the arc through 1 at points P_1 and P'_1.

(v) Similarly, locate more points and draw the curve through them.

The curves obtained in the above four problems are also the loci of centres of circles which will touch the given line, point or circles as the case may be.

Problem 7-5. (fig. 7-9): *To draw a circle touching two given circles and a given straight line.*

The circles with centres A and B and the line EF are given.

Draw the locus of a point equidistant from one of the circles, say the smaller circle, and the line EF.

The point of intersection of this curve, with the locus of the point equidistant from the two given circles, viz. O is the centre of the required circle.

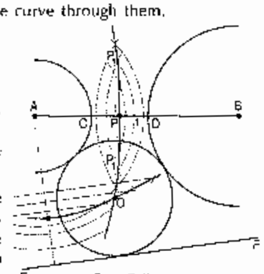


FIG. 7-9

7-2. SIMPLE MECHANISMS

In simple mechanisms, it is often necessary to know the paths of points on their moving parts. These are determined by assuming a number of different positions of the moving parts and then locating the corresponding positions of the points.

7-2-1. THE SLIDER CRANK MECHANISM

The slider crank mechanism shown diagrammatically in fig. 7-10 is one of the simplest mechanisms and it is used in internal combustion engine, sewing-machine

(1) Simple slider crank mechanism:

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 15 for the following problem of simple slider crank mechanism.

Problem 7-6. (fig. 7-10): *In a simple slider crank mechanism, the connecting rod AB is 750 mm long and the crank OA is 150 mm long. The end B moves along a straight line passing through O. Trace the locus of a point P, 300 mm from A along the rod, for one revolution of OA.*

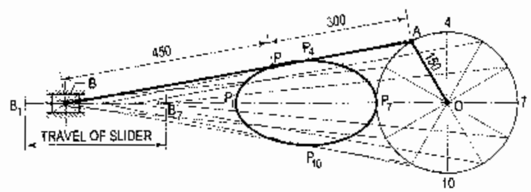


FIG. 7-10

(i) Divide the circle (path of A) into 12 equal parts.

(ii) With centre 1 and radius AB, cut the path of B at a point B_1.

(iii) Draw a line joining **1** and B_1. Again, with centre 1 and radius PA, cut the line $1B_1$ at a point P_1.

(iv) Obtain other points in similar manner and draw a smooth curve through these points. Then this curve is the locus of the point P.

Note that the distance B_1B_7 is the travel of the slider and is equal to twice the length of the crank. This distance is known as *stroke length*. But the movement of the slider is not uniform with that of the crank-end A.

(2) Offset slider crank mechanism:

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the

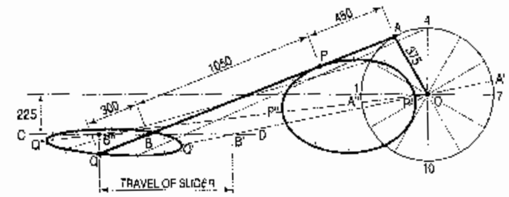


FIG. 7-11

(iii) These are found by drawing arcs with centre O and radii (i) $(AB - AO)$ and (ii) $(AB + AO)$, and cutting the path of B at points B' and B''. *The travel of the slider is shown by the distance B'' B'.* The corresponding positions of the end A for the limiting positions of B, viz. A' and A'' will be on the lines $B'O$-produced and $B''O$ respectively. The positions of P and Q, viz. P', P'' and Q', Q'' are obtained as already explained.

Problem 7-8. (fig. 7-12): *In the mechanism shown in fig. 7-12, the connecting rod is constrained to pass through the guide at D. Trace the locus of the end B and of a point P on AB for one complete revolution of the crank. AB = 1800 mm, AO = 375 mm and AP = 750 mm.*

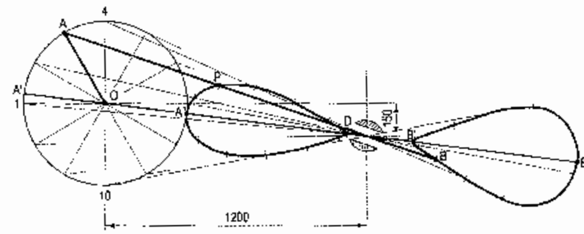


FIG. 7-12

7-2-2. A FOUR-BAR MECHANISM

This mechanism consists of four links. It is widely used in locomotive, steering mechanism of the car, pantograph and straight-line mechanisms.

Problem 7-9. (fig. 7-13): *Two equal cranks AB and CD connected by the link BD, rotate in opposite directions. Draw the locus of a point P on BD and of Q along extension of the rod beyond B for one revolution of AB.*

$AB = CD = 450$ mm; $AC = BD = 1500$ mm;

$PD = 300$ mm, $BQ = 300$ mm.

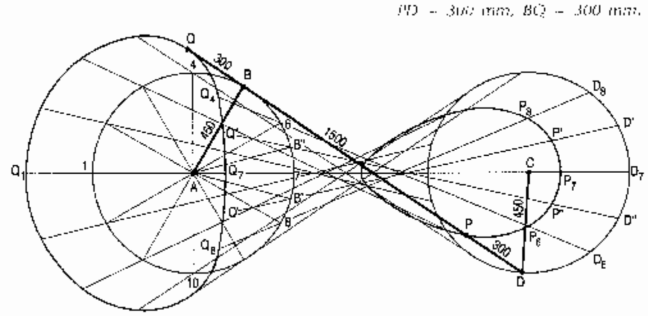


FIG. 7-13

(i) Divide one of the circles (say path of B), into 12 equal parts.

(ii) Determine the position of D on its path (the other circle), for every position of B and find the corresponding positions of P and Q for these positions as shown. It will be found that there is a wide gap between the points for positions 6, 7 and 8 of the end B. A few more positions such as AB' and AB'' etc. may be taken and points P', P'', Q', Q'' etc. may be located.

Problem 7-10. (fig. 7-14): *Two cranks AO and BQ oscillate about O and Q ... the mid-point P of the connecting link AB. AO = 450 mm;*

(i) To draw the locus of P, mark a number of points on the path of A.

(ii) With centre A_1 and radius AB, draw an arc cutting the path of B at B_1.

(iii) Mark a point P_1 on A_1B_1 such that $A_1P_1 = AP$.

(iv) Similarly, locate other points during the complete oscillation of the crank OA, from A' to A''. It is not necessary to draw the cranks in various positions.

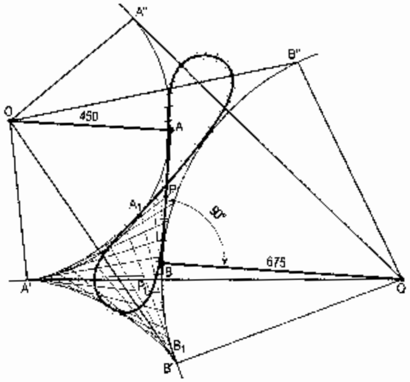
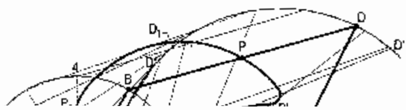


FIG. 7-14

Problem 7-11. (fig. 7-15): *Two cranks AB and CD are connected by a link BD. AB rotates about A, while CD oscillates about C. Trace the locus of the mid-point of the link BD during one complete revolution of the crank AB. AB = 450 mm, CD = 750 mm, BD = 1050 mm. Distance between A and C is equal to 900 mm.*



(i) Divide the circle into 12 equal parts. With centre 1 and radius BD, cut the path of D at D_1.

(ii) Locate P_1, the mid-point of $1D_1$. Similarly, find other points.

(iii) In addition, find points P' and P'' for limiting positions, when $AD' = (BD + AB)$ and $AD'' = (BD - AB)$.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 17 for the following problem.

Problem 7-12. (fig. 7-16): *The end A of a rod AB rotates about O, while the end B slides along a straight line. A crank CQ oscillates about Q. Draw the locus of the mid-point P of the connecting link CD for one revolution of the crank OA. AB = 1500 mm, CD = 750 mm, OA = 450 mm and CQ = 1200 mm.*

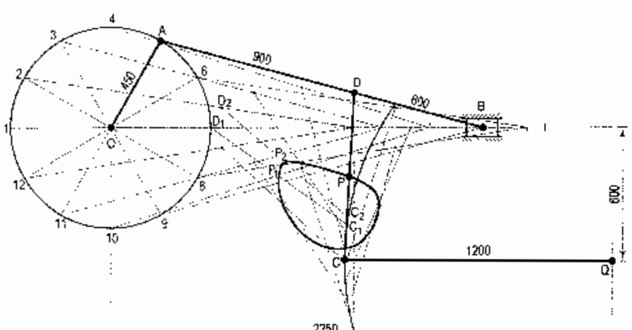
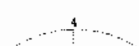


FIG. 7-16

(i) Determine points D_1, D_2 etc. for various positions of the crank OA.

(ii) With centre D_1, D_2 etc. and radius CD, draw ...



(i) Draw a circle of 100 mm diameter and divide into 5 equal parts. Mark 1, 2,......5.

(ii) Draw a chord AB 60 mm long from the point 1. (The point 1 coincides with the point A.) Divide it into 5 equal parts and number $P_1, P_2......P_6$. (The point P_6 coincides with the point B.)

(iii) When the line OA moves through one division i.e. arc AB, the point P_1 will move towards B by a distance equal to one division of the chord AB (or $P_1 P_6$).

(iv) To obtain points systematically, draw arcs with centre O and radii OP_2, OP_3, OP_4 etc. intersecting lines OP''_2, OP'_3, OP''_4 etc. at points P'''_2, P''_3, P'''_4 etc. respectively. Draw a curve through points P_1, P''_2...B.

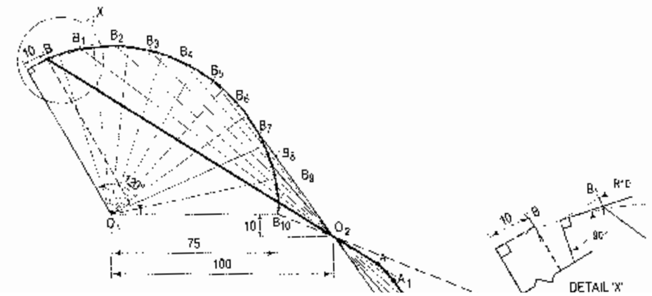
Problem 7-14. (fig. 7-18): *A mechanism as used on cup-board door is in fully open position. Draw the path of end A of the mechanism as the door moves to the fully closed position. Take AB = 175 mm.*

(i) Draw the mechanism to full size scale. Divide ∠120° into equal divisions.

(ii) Mark the successive position of the door. Mark the points B_1, B_2, etc. at 10 mm away on the perpendicular line to the door position as shown. Draw lines B_2O_2, B_3O_2,...... B_9O_2 passing through O_2.

(iii) With a centre as $B_1, B_2,... B_9$ and the radius equal to AB, draw arcs intersecting lines B_1O_2, B_2O_2,...... B_9O_2 at points A_1, A_2, A_3,.....A_9.

(iv) Join the points $A_1, A_2,... A_9$ by smooth curve.



Problem 7-15. (fig. 7-19): *A link of shaping machine mechanism is shown in fig. 7-19. A sliding block moves towards O_4 along the oscillating link with the uniform motion.*

Draw the path of the sliding block when the link O_4D rotates 40° in anti-clockwise direction. Use following data O_4D = 160 mm O_4B = 113 mm. The movement of the sliding block along the link = 67 mm.

The construction of path of the sliding block is shown in fig. 7-19.

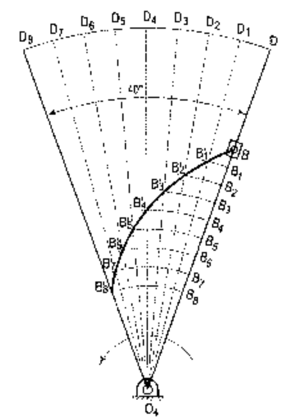
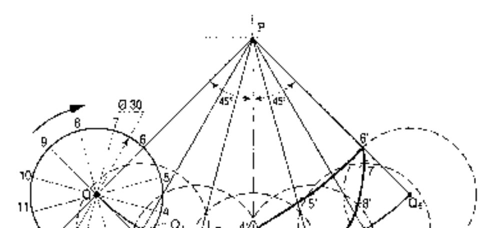


FIG. 7-19

Problem 7-16. (fig. 7-20): *A link PQ 100 mm long carries a circular disc of 30 mm diameter having centre Q. The link PQ oscillates about the hinged P from left to right and vice-versa (i.e. right to left) to maximum amplitude of 45° on either side from the vertical.*

At the same time the disc rotates uniformly through one revolution in clockwise direction. Draw the path of point on the circumference of the disc.



(iii) The disc rotates as well as oscillates with the link PQ from left to right and then right to left for completing one cycle of oscillation. The angle moved by the link PQ is (2 × 90 = 180°). Divide half cycle (i.e. 90°) into six equal parts described by the link. Each division will be of 15°.

(iv) Now draw the arc joining initial position and left extreme position. Mark the intersection of radial lines drawn from P and this arc as Q, Q_1, Q_2, Q_3, Q_4, Q_5, Q_6 and for return cycle on the same arc Q_7, Q_8, Q_9, Q_{10}, Q_{11}.

(v) When the disc rotates from 0 to 1, the rod moves PQ to PQ_1. Therefore the centre of disc moves to Q_1, Q_2, Q_3...... Q_{11} successive position, the rod (radii) will occupy the position PQ_1, PQ_2...... PQ_6 and PQ_7 to PQ_{11}.

(vi) Q_1, Q_2, Q_3, Q_4, Q_5, Q_6 as centre, draw the circle for successive position of the disc. Take point O on its circumference of the circle for the initial position as shown.

(vii) Now $1P$ as radius, draw arc intersecting the circle drawn from centre Q_1. Name this point as 1'. Similarly P as centre and radii $2P$, $3P$, $4P$, $5P$, $6P$..... $11P$ obtain other the intersection points. Join with all points by the smooth curve.

(viii) Fig. 7-20 is drawn to half scale.

Problem 7-17. (fig. 7-21): *A rod PQ 40 mm long rotates about R with a speed of 60 rpm, while Q moves along a straight line QR towards R with a speed of 108 mm per second (i.e. QR = 108 mm). Draw to full size scale the path traced out by the end P for one complete revolution of the rod. Assume that initial position of the rod PQ is along the extension of the line RQ.*

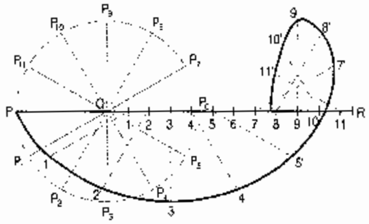


FIG. 7-21

(i) Draw a line PQR of length = 148 mm, (PQ + QR = 40 + 108 mm)

(ii) Now Q as centre PQ = 40 mm as radius, draw the circle and divide circle into twelve equal parts, label them P, P_1......P_{11}. Each part of the circle is covered by the rod in $\frac{1}{12}$ second. $\left(\frac{360}{30} = 12°\right)$ Similarly the line QR is also divide in twelve parts. Mark division as Q, 1, 2......11, R.

Problem 7-18. (fig. 7-22): *The crank O_1P_1 turns about O_1 and the connecting rod P_1Q_1 slides in the same plane on the curved surface of a shaft (with centre O_2) of 30 mm diameter. Trace the loci of the point Q_1 and R_1 which is extension of P_1Q_1 at 30 mm from the P_1 when O_1P_1 revolves one revolution. Take O_1P_1 = 30 mm. P_1Q_1 = 100 mm and O_1O_2 = 70 mm. Take scale 10 mm = 1 mm*

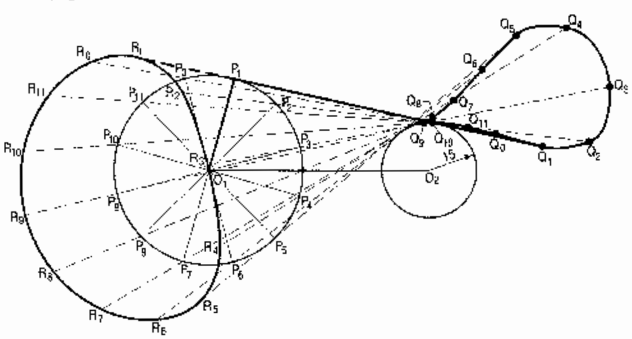


FIG. 7-22

(i) Draw a circle of 30 mm radius and centre O_1.

(ii) Mark O_1O_2 = 70 mm and draw the circle of radius 15 mm and the centre as O_2 the representing shaft.

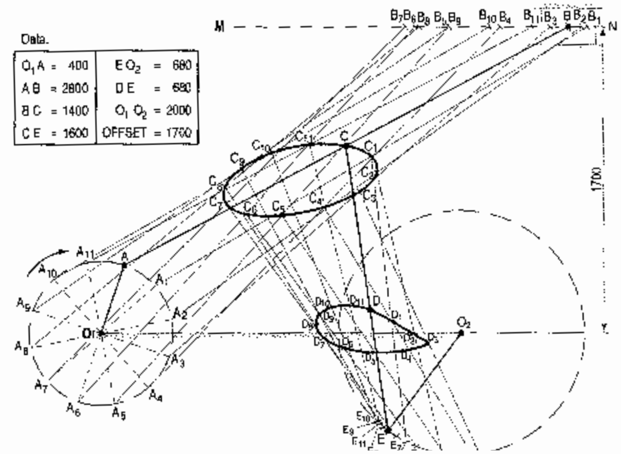
(iii) Mark any point P_1 on the circle of O_1P_1. Mark line P_1Q_1 = 100 mm making tangent to the circle of the shaft. Extend O_1P_1 to left side to R_1 such that P_1R_1 = 30 mm.

(iv) Divide the circle of radius O_1P into twelve divisions and number them P_0, P_1, P_2..... P_{11}. From P_0, P_1, P_2..... P_{11} draw tangent on the same side to the circle of the shaft. On each extended tangent QP mark the points P_0R_0, P_1R_1...... $P_{11}R_{11}$ as shown in fig. 7-22. Similarly from P_0, P_1...... P_{11} mark the length 100 mm each tangent showing end Q_1, Q_2, Q_3..... Q_{11}.

(iv) Divide the circle of $O_1 A$ into twelve parts. Number them as A_1, A_2, A_3...... A_{11}. Now A_1 as centre and AB distance as radius, draw intersection on the horizontal line MN at B_1. From B_1 mark the distance of CB on A_1B_1 from B_1 at 1400 mm. This is new position of C call as C_1. C as centre CE as radius, cut the arc at E_2 drawn from O_2. O_2E as radius, mark the point D at given distance from E (680 mm). From A_2, A_3...... A_{11} taking AB as radius draw arcs intersecting the path MN at B_2, B_3.... B_{11}. Join A_1B_1, A_2B_2 upto $A_{11}B_{11}$. On these lines mark $B_1C_1 = B_2C_2 = B_3C_3 = B_{11}C_{11}$. Join the points C, C_1, C_2....... C_{11} by smooth curve. Similarly from C_1, C_2, C_3...... C_{11}, draw arc of radius CE intersecting points E_1, E_2, E_3....... E_{11}. Join C_1E_1, C_2E_2, C_3E_3...... $C_{11}E_{11}$. Along the lines C_1E_1, C_2E_2, C_3E_3...... $C_{11}E_{11}$, mark DE respectively. Let these points be D_1, D_2, D_3...... D_{11}. Join the points by smooth curve.

Data.

O_1A = 400	EO_2 = 680
AB = 2800	DE = 680
BC = 1400	O_1O_2 = 2000
CE = 1600	OFFSET = 1700



(ii) Make slotted link of 10 mm of width and at P and R. Construct sliders of the convenient length at P and R_1.

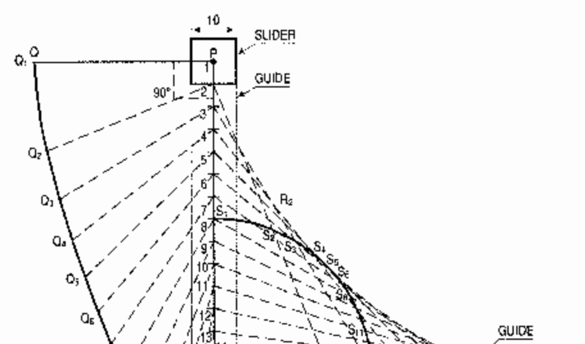
(iii) Mark the mid point of PR_1, say S_1.

(iv) Assume that the slider P moves vertically downward while R_1 will moves horizontally.

(v) Divide vertical line PR_1 into equal division and number them as 1, 2, 3, 4.....14, R_1 as shown (P, 1 are coinciding).

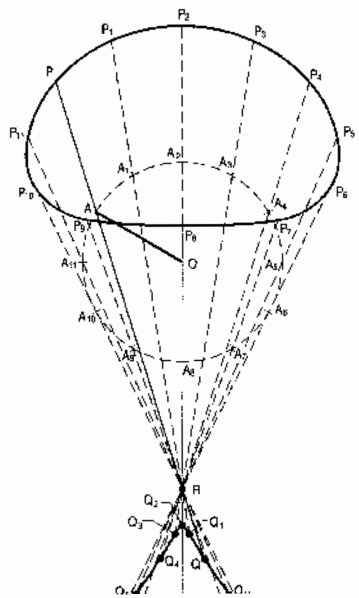
(vi) Now 1 as centre and PR_1 as radius, draw arc to cut the horizontal line passing through R_1. Let us call this point as $R1$. Join $P1R1$, $P1$ as centre mark the mid-point of $P1R1$, say this point S1, similarly from the point 2, 3....... 14, draw arc cutting the horizontal line and number them respectively $R2$, $R3$...... $R14$. Join all points Q and S respective respectively. Mark on these lines the mid-points S_2, S_3, S_4....... S_{14}. Join them with smooth curve. The curve is quater portion of ellipse. The mechanism is known as *trammel mechanism*.

(vii) The path of Q is simple to trace as shown in the fig. 7-24.



Problem 7-21. *The rod PQ as shown in fig. 7-25 is hinged (pinned) to the crank AO at A. OA rotates about O and the rod PQ is constrained to pass through the point R. Draw the loci of the ends P and Q for one complete revolution of OA. PQ = 1100 mm, OA = 220 mm, AP = 300 mm and OR = 500 mm.*

Scale: 100 mm = 10 mm.



(ii) Divide circle described by the crank OA into 12 equal divisions. Say these division A, A_1, A_2...... A_{11}.

(iii) From each points of A_1, A_2...... A_{11}, draw lines passing through R and mark length AP and RQ on respective lines. Say these points are P, P_1, P_2......P_{11} and Q, Q_1...... Q_{11}. Join respective points by smooth curves.

EXERCISES 7

1. P, Q and R are the centres of three circles of diameters 75 mm, 45 mm and 30 mm respectively. PQ = 95 mm, QR = 50 mm and PR = 75 mm. Draw a circle touching the three circles.
2. In a slider-crank mechanism, the crank OA is 450 mm long, and the connecting rod AB, 1050 mm long. Plot the locus of (i) the mid-point P of AB, and (ii) a point 600 mm from A on BA extended, for one revolution of the crank.
3. The end P of a 100 mm long line PQ (fig. 7-26) slides vertically downwards. The end Q moves along the line AB towards A and then back to B. Plot the locus of the point O on PQ and 40 mm from P.

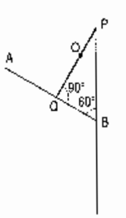


FIG. 7-26

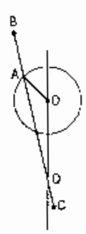


FIG. 7-27

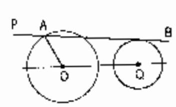


FIG. 7-28

4. The rod BC (fig. 7-27) is attached to the crank AO at A. OA rotates about O and the rod BC is constrained to pass through the point Q. Draw the loci of the ends B and C for one complete revolution of OA. BC = 1200 mm, OA = 225 mm,

ORTHOGRAPHIC PROJECTION

8-0. INTRODUCTION

Practical solid geometry or *descriptive geometry* deals with the representation of points, lines, planes and solids on a flat surface (such as a sheet of paper), in such a manner that their relative positions and true forms can be accurately determined.

8-1. PRINCIPLE OF PROJECTION

If straight lines are drawn from various points on the contour of an object to meet a plane, the object is said to be projected on that plane. The figure formed by joining, in correct sequence, the points at which these lines meet the plane, is called the *projection* of the object. The lines from the object to the plane are called *projectors*.

8-2. METHODS OF PROJECTION

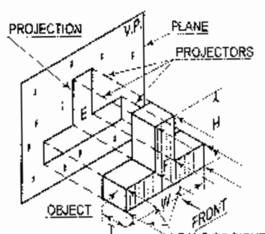
In engineering drawing following *four* methods of projection are commonly used, they are:

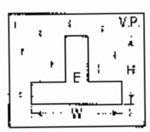
(1) Orthographic projection
(2) Isometric projection
(3) Oblique projection
(4) Perspective projection.

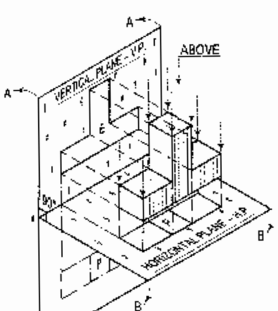
In the above methods (2), (3) and (4) represent the object by a pictorial view as eyes see it. In these methods of projection a three dimensional object is represented on a projection plane by one view only. While in the orthographic projection an object is represented by two or three views on the mutual perpendicular projection planes. Each projection view represents two dimensions of an object.

Step 2: If these rays of sight are extended further to meet perpendicularly a vertical plane (marked V.P.) set up behind the block.

Step 3: The points at which they meet the plane are joined in proper sequence, the resulting figure (marked *E*) will also be exactly similar to the front surface and this is known as an *elevation* or *front-view*. This figure is the projection of the block. *The lines from the block to the plane are the projectors.* As the projectors are perpendicular to the plane on which the projection is obtained, it is the orthographic projection. The projection is shown separately in fig. 8-1(ii). It shows only two dimensions of the block viz. the height *H* and the width *W*. It does not show the thickness. Thus, we find that only one projection is insufficient for complete description of the block.







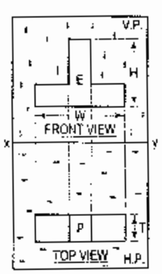


Fig. 8-2

Let us further assume that another plane marked H.P. (horizontal plane) [fig. 8-2(i)] is hinged at right angles to the first plane,

7. Two equal cranks *AB* and *CD* (fig. 7-29) rotate in opposite directions about *A* and *C* and are connected by the rod *BD*. Plot the locus of the end *P* of the link *PQ* attached at right angles to *BD* at its mid-point *Q* for one complete revolution of the cranks. AB = 300 mm; $BD = AC$ = 1050 mm; PQ = 225 mm.

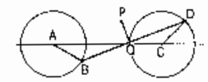


Fig. 7-29

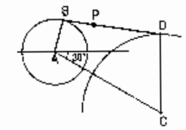


Fig. 7-30

8. Two cranks *AB* and *CD* (fig. 7-30) are connected by a link *BD*. The end *B* moves round the circumference of the circle with centre *A*, while the end *D* oscillates on an arc about *C* as centre. Plot the locus of the point *P* on *BD*, 450 mm from *B*, for one complete revolution of *AB*. AB = 450 mm, CD = 1050 mm, BD = 1350 mm and AC = 1650 mm.

9. Two equal links *AB* and *CD* (fig. 7-31) connected by a rod *BD*, oscillate about their ends *A* and *C*. Plot the locus of (i) the mid-point *P* of *BD* and (ii) the point *Q* on *BD*. $AB = CD$ = 1200 mm; BD = 900 mm; BQ = 225 mm.

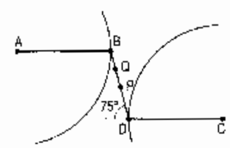


Fig. 7-31

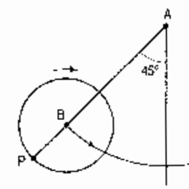


Fig. 7-32

10. The link *AB* (fig. 7-32) is 120 mm long and carries a circular disc of 40 mm radius. The end *A* is hinged while the disc can revolve about its centre *B*. The link turns uniformly to the right through 90° and at the same time the disc revolves uniformly in clockwise direction through

13. In a slider-crank mechanism, the crank O_2P is 600 mm long and the connecting rod *PQ*, 1400 mm long. Plot the path of a point 600 mm from *P* on *QP* extended for one revolution of the crank.

14. A link *AB* 120 mm long rotates about fixed pivot *A* in an anti-clockwise direction. An ant is situated at 20 mm from the pivot point moves towards the end *B* with uniform velocity, while the link has rotated through $\frac{1}{6}$ of a revolution. Trace the path of an ant.

When studied together, they supply all information regarding the shape and the size of the block. Any solid may thus be represented by means of orthographic projections or orthographic views.

8-4. PLANES OF PROJECTION

The two planes employed for the purpose of orthographic projections are called *reference planes or principal planes of projection*. They intersect each other at right angles. The *vertical plane* of projection (in front of the observer) is usually denoted by the letters V.P. It is often called the *frontal plane* and denoted by the letters F.P.

The other plane is the *horizontal plane* of projection known as the H.P. The line in which they intersect is termed the *reference line* and is denoted by the letters *xy*. The projection on the V.P. is called the *front view* or the *elevation* of the object. The projection on the H.P. is called the *top view* or the *plan*.

8-5. FOUR QUADRANTS

When the planes of projection are extended beyond the line of intersection, they form four quadrants or dihedral angles which may be numbered as in fig. 8-3. The object may be situated in any one of the quadrants, its position relative to the planes being described as *"above or below the H.P."* and *"in front of or behind the V.P."*

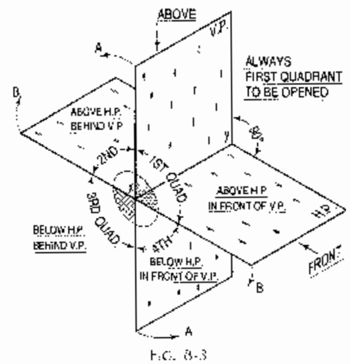


FIG. 8-3

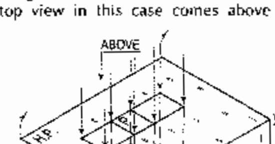
The planes are assumed to be transparent. The projections are obtained by drawing perpendiculars from the object to the planes, i.e. by looking from the front and from above. They are then shown on a flat surface by rotating one of the planes as already explained. *It should be remembered that the first and the third quadrants are always opened out while rotating the planes.* The positions of the views with respect to the reference line will change according to the quadrant in which the object may be situated. This has been explained in detail in the next chapter.

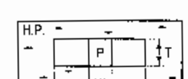
TABLE 8-1
DIFFERENCE BETWEEN FIRST-ANGLE PROJECTION METHOD AND THIRD-ANGLE PROJECTION METHOD

1.	The object is kept in the *first quadrant*.	The object is assumed to be kept in the *third quadrant*.
2.	The object lies between the observer and the plane of projection.	The plane of projection lies between the observer and the object.
3.	The plane of projection is assumed to be non-transparent.	The plane of projection is assumed to be *transparent*.
4.	In this method, when the views are drawn in their relative positions, the *plan* comes *below the elevation*, the view of the object as observed from the *left-side* is drawn to the *right of elevation*.	In this method, when the views are drawn in their relative positions, the *plan*, comes *above* the elevation, *left hand side view* is drawn to the *left hand side of the elevation*.
5.	This method of projection is now recommended by the 'Bureau of Indian Standards' from 1991.	This method of projection is used in U.S.A. and also in other countries.

8-7. THIRD-ANGLE PROJECTION

In this method of projection, the object is assumed to be situated in the third quadrant [fig. 8-4(i)]. The planes of projection are assumed to be transparent. They lie between the object and the observer. When the observer views the object from the front, the rays of sight intersect the V.P. The figure formed by joining the points of intersection in correct sequence is the front view of the object. The top view is obtained in a similar manner by looking from above. When the two planes are brought in line with each other, the views will be seen as shown in fig. 8-4(ii). The top view in this case comes above the front view.





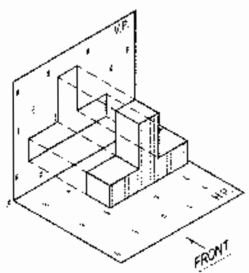
In other words, the view seen from above the object is placed on the same side of (i.e. above) the front view.

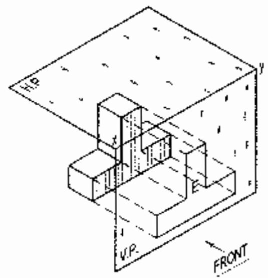
Each projection shows the view of that surface (of the object) which is nearest to the plane on which it is projected.

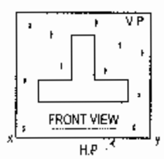
On comparison, it is quite evident that the views obtained by the two methods of projection are completely identical in shape, size and all other details. The difference lies in their relative positions only.

8-8. REFERENCE LINE

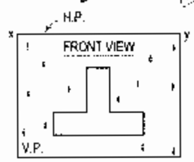
Studying the projections independently, it can be seen that while considering the front view (fig. 8-5 and fig. 8-6), which is the view as seen from the front, the H.P. coincides with the line *xy*. In other words, *xy* represents the H.P.



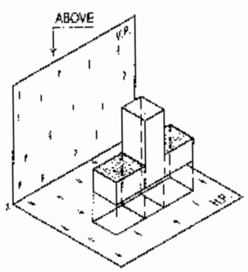


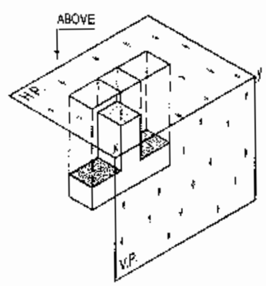


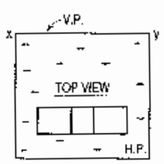
FIRST-ANGLE PROJECTION



THIRD-ANGLE PROJECTION

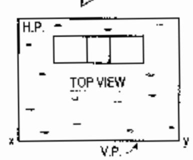






FIRST-ANGLE PROJECTION

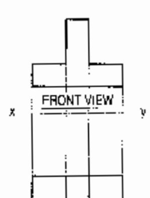
FIG. 8-7

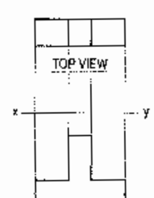


THIRD-ANGLE PROJECTION

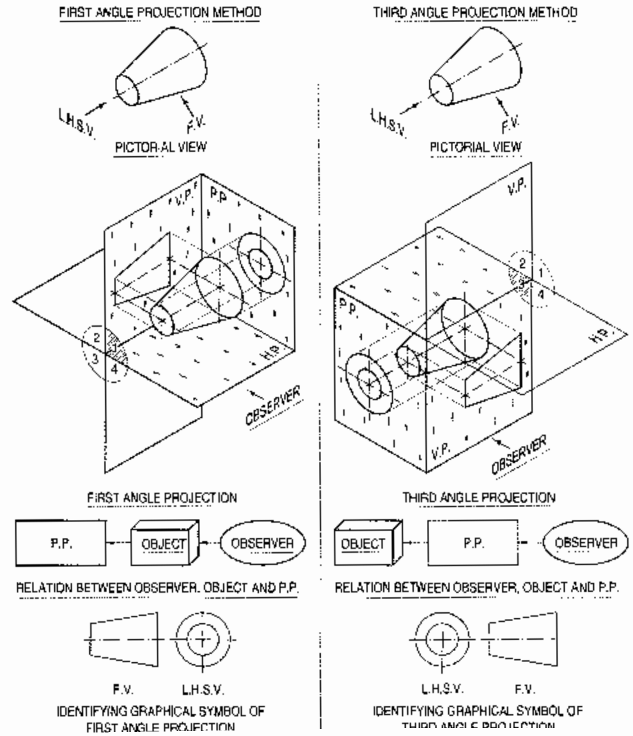
FIG. 8-8

In third-angle projection method, the H.P. is assumed to be placed above the object. The object may be situated on or above the ground. Hence, in this method, the line *xy* does not represent the ground. The line for the ground, denoted by letters GL, may be drawn parallel to *xy* and below the front view [fig. 8-9(ii)].





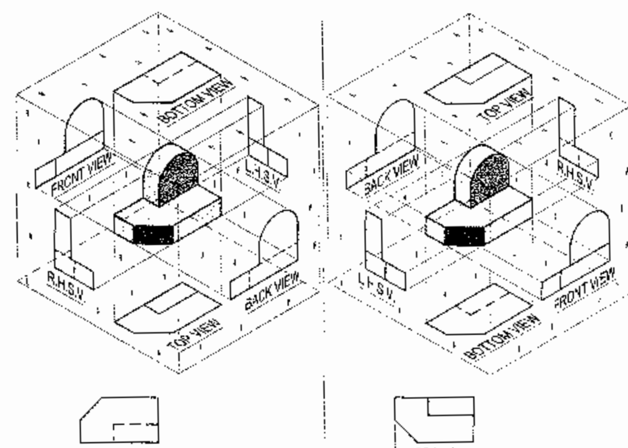
In brief, when an object is situated on the ground, in first-angle projection



(1) Front view (4) Right hand side view
(2) Top view (5) Back view
(3) Left hand side view (6) Bottom view

These projections are shown projected on the respective planes, placed by the methods of first-angle projection and third-angle projection as shown in fig. 8-12 and fig. 8-13 respectively.

Ordinarily, two views — the front view and top view are shown. Two other views i.e. L.H.S.V. or R.H.S.V. may be required to describe an object completely. Only in exceptional cases, when an object is of a very complex nature, five or six views may be found necessary.



8-9. B.I.S. CODE OF PRACTICE

The method of first-angle projection is the British standard practice. The third-angle projection is the standard practice followed in America and in the continent of Europe.

In our country, the first-angle projection method was formerly in use. The Indian Standards Institution (I.S.I.) now Bureau of Indian Standards (B.I.S.), in its earlier versions of Indian Standard (IS:696) 'Code of Practice for General Engineering Drawing' published in 1955 and revised in 1960 had recommended the use of third-angle projection method.

In the second revised version of this standard published in December 1973, the committee responsible for its preparation left the option of selecting first-angle or third-angle projection method to the users.

The committee again reviewed the position and *finally recommended revised SP:46-1988 and SP:46-2003 for implementation of first-angle method of projection in our country,* by replacing earlier IS:696 drawing standard.

Persons engaged in engineering profession may come across drawings from industries and organizations following any one method. It is therefore necessary for them to be perfectly conversant with both the methods.

In this book, the method of first-angle projection has been generally followed. Third-angle projection method is also adequately treated in the form of illustrative problems and set exercises.

Conventions employed: In this book, actual points, ends of lines, corners of solids etc., in space are denoted by capital letters *A*, *B*, *C* etc. Their *top views* are marked by corresponding small letters *a*, *b*, *c*, etc., their *front views* by small letters with dashes *a'*, *b'*, *c'*, their side views by a_1, b_1, c_1, and their auxiliary views by a'_1, b'_1, c'_1, etc. In pictorial views, the projectors from the points in space to the planes are shown by dashed lines.

The lines from the projections to the reference line *xy* (which are also called projectors, though they are the projections of the projectors) are shown as dash and dot lines. In orthographic views, the projectors and other construction lines are shown continuous, but thinner than the lines for actual projections.

8-10. TYPICAL PROBLEMS

This book is accompanied by a computer CD, which contains an audiovisual

(i) Mark the visible corners of the given block as shown
Drawing front orthogonal view:
Assume that you are viewing the object in the direction of the arrow towards the imaginary V.P. What you will see is a rectangle of height *H* and width *W* on V.P. This will be the front view. To draw this view:

(ii) Draw a reference line *xy*, which represents the intersecting line of the planes V.P. and H.P. Draw a rectangle as shown *W* and *H*, above *xy* make sure that the width is parallel to the line *xy*. The rectangle is the front orthogonal view of the object.

(iii) Draw a line parallel to and thickness of *h* to the line 1-2. The rectangle 1-2-4-3 is the front view of the horizontal *L*-shaped stem of the object.

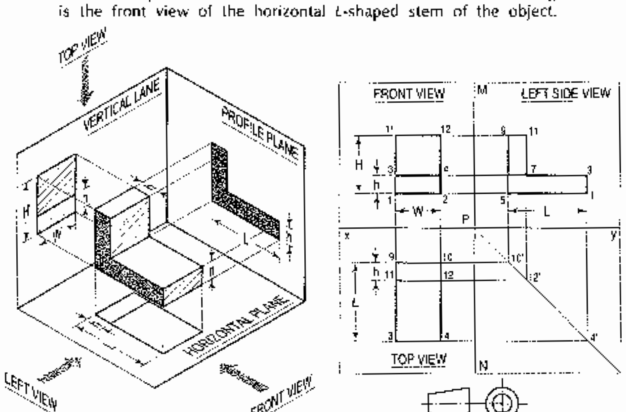


FIG. 8-14

Drawing top orthogonal view:
Now, if you look the object from the top, you will see a rectangle of

(vi) Draw a reference vertical line MN at right angles to xy cutting it at P. From P draw a construction line at 45° in the fourth quadrant.

(vii) Project lines from the points 10, 12 and 4 of the top view to meet this inclined line at 10', 12' and 4'.

(viii) Project lines from points 2, 4 and 12 from the front view parallel to line xy. From points 10', 12' and 4' project lines vertically upwards to meet these horizontal projections.

(ix) Join points 5-1-3-7-11-9. This will be the side view of the object.

(x) Finally draw the symbol of first angle projection at the right bottom corner of the drawing.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 19 for the following problem.

Problem 8-2. (fig. 8-15 and fig. 8-16): *A pictorial view of a machine bracket is shown in the figure. Draw using the first angle projection method front view, top view and right end side view.*

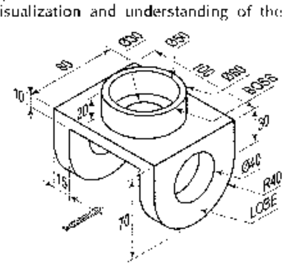
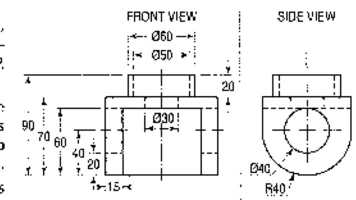


FIG. 8-15

Assume that you are viewing the object in the direction of the arrow towards the imaginary V.P. What will you see? It is a rectangle of height 70 mm and width 100 mm on V.P. This will be the front view. To draw this view:

(i) Draw a Reference line xy, which represents the intersecting line of the planes V.P. and H.P.



(ii) Draw rectangular block of size 100 × 70 and the thickness is 15 mm each on the two parallel portions of the slot.

(iii) Now on the top of this rectangular block draw a ...

(v) Draw the two holes on the parallel edges of the rectangular block. These holes are represented by dotted lines in the front view as they are hidden. This completes the front view construction.

(vi) To draw the top view, project all the details from front view.

(vii) Draw a vertical centre line form the centre of the rectangular block.

(viii) The top view of the rectangular block appears as a rectangle of size 100 × 80.

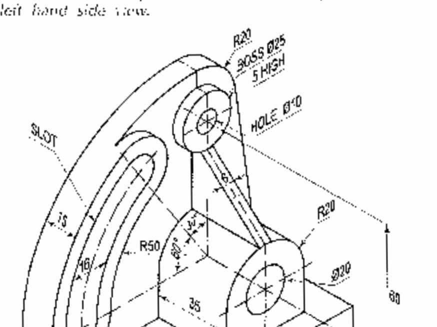
(ix) Draw the holes in the centre of the rectangle. These holes are drawn taking the common centre point on vertical centre line.

(x) The two holes of ø40 on the lobes are not visible, so they are projected as dashed lines. This completes the top view.

(xi) To draw the side view, draw projectors from all the points in front view and top view to side view. Join the intersection points. This completes the side view.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 20 for the following problem.

Problem 8-3. *Fig. 8-17 shows the pictorial view of the object. Draw the front view, top view and left hand side view.*



(i) To draw F.V. in the direction of X, L.H.S.V. and T.V.

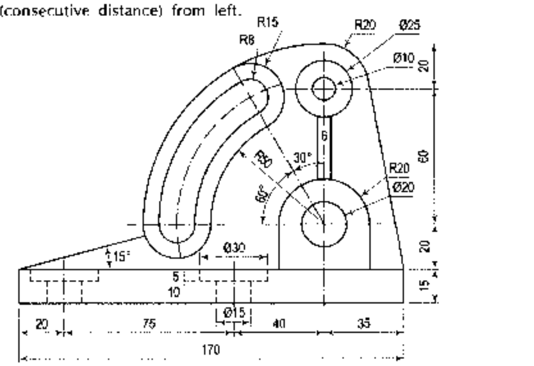
(ii) As the L.H.S.V. is to be drawn, fix the position of xy at centre of page and x_1y_1 to the left side as L.H.S.V. will come to the right of F.V.

(iii) Draw the rectangles for the F.V. (170 × 115), project it down to locate T.V. (170 × 55) and take the projections of F.V. to left to draw L.H.S.V., complete the rectangle of L.H.S.V. by taking the projections from T.V.

(iv) First we will start with F.V. (fig. 8-18).

(a) Draw the rectangle for base plate 170 × 15

(b) Draw vertical centre lines at 20 mm and 75 mm and 40 mm (consecutive distance) from left.



Front view
FIG. 8-18

(c) Draw hidden lines for 5 mm depth for two ø30 spot face holes, draw dotted lines for 2 holes of ø15 (Inside these holes).

(d) Draw horizontal centre line at 35 mm from base, in semi-circle.

(e) Referring third centre line and this horizontal line draw the circle of 10 mm radius and semicircle of 20 mm radius.

(m) Draw an arc of centre line pattern of 65 mm radius. (Draw centre line for an arc)

(n) Taking intersection of this as reference and horizontal centre line draw semi-circle of radius 15 mm and 8 mm.

(o) Also draw same arcs, where this line intersects with 30° inclined line.

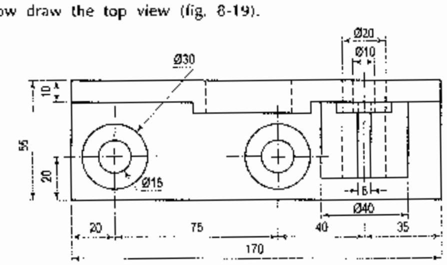
(p) Erase unwanted arcs if any.

(q) Draw inclined line at 15° from left end of block.

(r) Show the required dimensions.

(s) Now project all the required line to draw T.V.

(v) Now draw the top view (fig. 8-19).



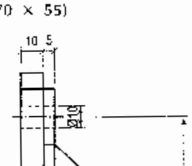
Top view
FIG. 8-19

(a) Complete the rectangle of the top view (170 × 55)

(b) Project the centre lines. (Vertical at 20, 75 and 40 consecutive distances from left and at 20 above base)

(c) Draw the two circles of ø30 and ø15 to represent spot holes.

(d) Draw projection of inclined rib 10 thick and circular slot 15 thick.



(b) Complete the rectangle at left side in L shape of 10 mm thick.
(c) Show the projections of projected semi-circle.
(d) Show hidden lines of hole in it.
(e) Show projection of projected slot and show hidden lines in it.
(f) Draw projection of boss and show hole in it by dotted line.
(g) Show inclined line for the rib.
(h) Draw front view, top view and L.H.S.V. in their relative position.

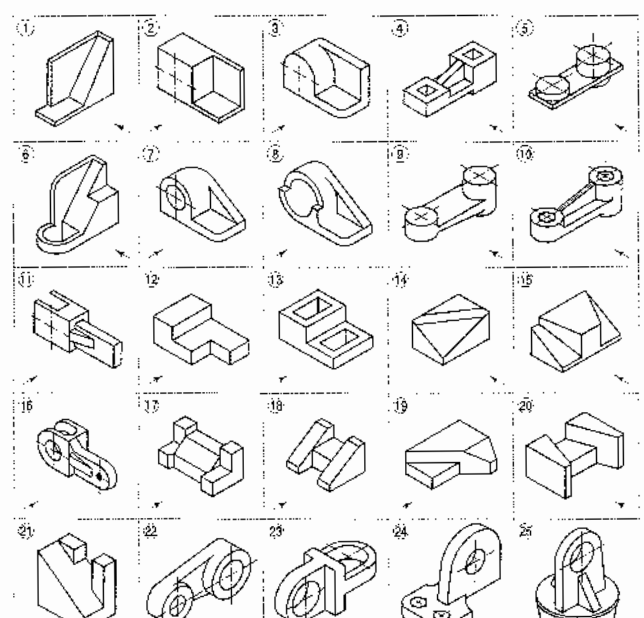
EXERCISES 8

1. Define orthographic projection. Describe briefly the method of obtaining an orthographic projection of an object.
2. Write short notes on:
   Reference planes; Reference line; Projector; Front view; Ground line.
3. Sketch neatly the symbols used for indicating the method of projection adopted in a drawing. State where this symbol is drawn on a drawing sheet.
4. Explain briefly how the reference line represents both the principal planes of projection.
5. Explain clearly the difference between the first-angle projection method and the third-angle projection method.
6. Fill-up the blanks in the following with appropriate words selected from the list of words given below:
   (a) In ______ projection, the ______ are perpendicular to the ______ of projection.
   (b) In first-angle projection method,
      (i) the ______ comes between the ______ and the ______.
      (ii) the ______ view is always ______ the ______ view.
   (c) In third-angle projection method,
      (i) the ______ comes between the ______ and the ______.
      (ii) the ______ view is always ______ the ______ view.

List of words for Exercise (6):

1. Above	5. Object	9. Projectors
2. Below	6. Orthographic	10. Plane
3. Front	7. Observer	11. Side

9. The pictorial view of different types of objects are shown in fig. 8-21. Sketch, looking from arrow, elevation, plan and end-view using first-angle projection method.



10. What dimensions of an object are given by
   (i) Front view or elevation?
   (ii) Plan or top view?
   (iii) Left-hand side view and right-hand side view?
11. Fig. 8-22 and fig. 8-23 show the orthographic projections of the objects in the first-angle projection method.
   Draw them in the third-angle projection method.

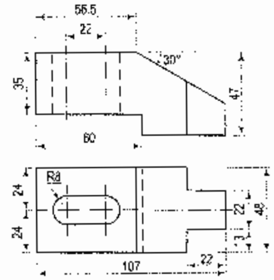


FIG. 8-22

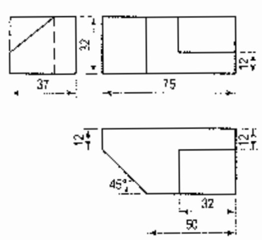
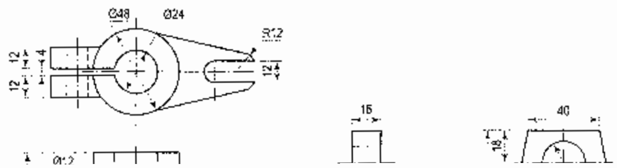
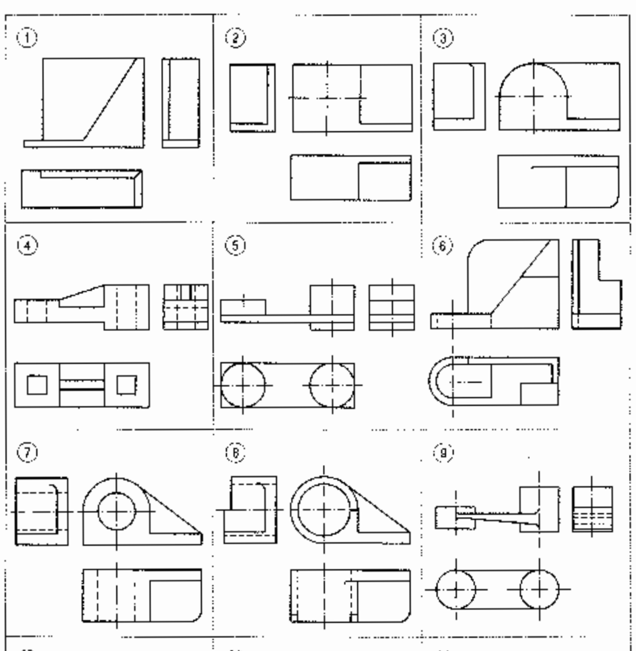


FIG. 8-23

12. Fig. 8-24 and fig. 8-25 show the orthographic projections of the objects in the third-angle projection method.
   Redraw them in the first-angle projection method.





Chapter 9

PROJECTIONS OF POINTS

9-0. INTRODUCTION

A point may be situated, in space, in any one of the four quadrants formed by the two principal planes of projection or may lie in any one or both of them. Its projections are obtained by extending projectors perpendicular to the planes.

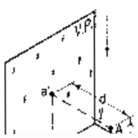
One of the planes is then rotated so that the first and third quadrants are opened out. The projections are shown on a flat surface in their respective positions either above or below or in xy.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 21 for the projections of points.

9-1. A POINT IS SITUATED IN THE FIRST QUADRANT

The pictorial view [fig. 9-1(i)] shows a point A situated above the H.P. and in front of the V.P., i.e. in the first quadrant. a' is its front view and a the top view. After rotation of the plane, these projections will be seen as shown in fig. 9-1(ii).

The front view a' is above xy



9-2. A POINT IS SITUATED IN THE SECOND QUADRANT

A point B (fig. 9-2) is above the H.P. and behind the V.P., i.e. in the second quadrant. b' is the front view and b the top view.

When the planes are rotated, both the views are seen above xy. Note that $b'o = Bb$ and $bo = Bb'$.

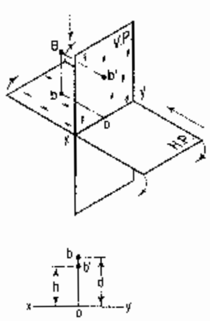
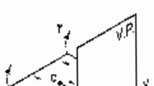
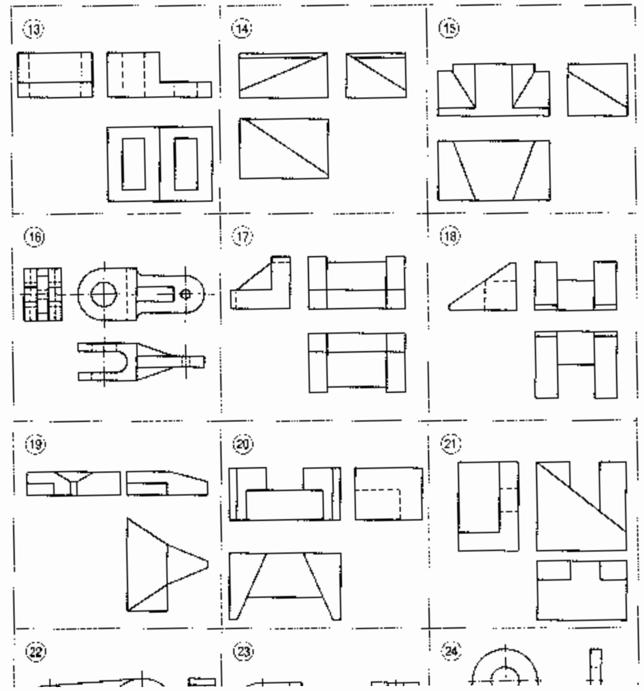


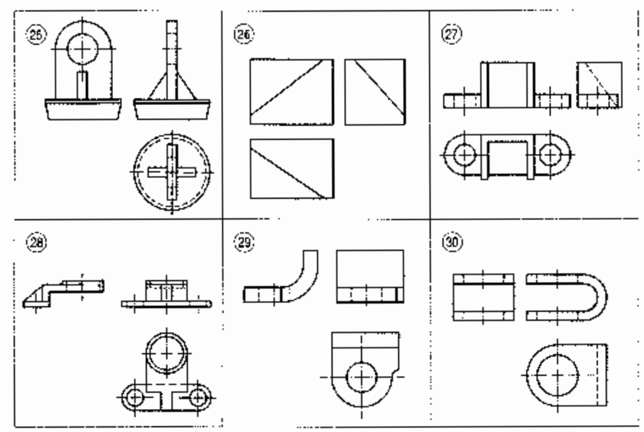
FIG. 9-2

9-3. A POINT IS SITUATED IN THE THIRD QUADRANT

A point C (fig. 9-3) is below the H.P. and behind the V.P., i.e. in the third quadrant. Its front view c' is below xy and the top view c above xy. Also $c'o = Cc$ and $co = Cc'$.







[Answer to Exercise (9), fig. 8-21]

FIG. 8-26

9-4. A POINT IS SITUATED IN THE FOURTH QUADRANT

A point E (fig. 9-4) is below the H.P. and in front of the V.P., i.e. in the fourth quadrant. Both its projections are below xy, and $e'o = Ee$ and $eo = Ee$.

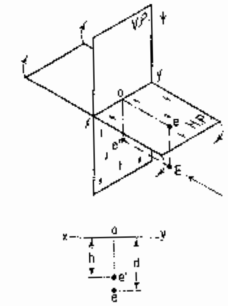


FIG. 9-4

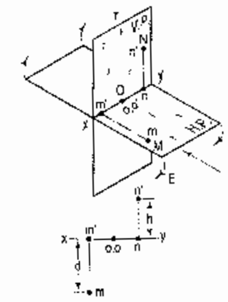


FIG. 9-5

Referring to fig. 9-5, we see that,

(i) A point M is in the H.P. and in front of the V.P. Its front view m' is in xy and the top view m below it.

(ii) A point N is in the V.P. and above the H.P. Its top view n is in xy and the front view n' above it.

(iii) A point O is in both the H.P. and the V.P. Its projection o and o' coincide with each other in xy.

9-5. GENERAL CONCLUSIONS

(i) The line joining the top view and the front view of a point is always perpendicular to xy. It is called a *projector*.

(ii) When a point is above the H.P., its front view is above xy; when it is below the H.P., the front view is below xy. The distance of a point from

(ii) Through any point o in it, draw a perpendicular.

As the point is above the H.P. and in front of the V.P. its front view will be above xy and the top view below xy.

(iii) On the perpendicular, mark a point a' above xy, such that $a'o$ = 25 mm. Similarly, mark a point a below xy, so that ao = 30 mm. a' and a are the required projections.

Problem 9-2. (fig. 9-6): *A point A is 20 mm below the H.P. and 30 mm behind the V.P. Draw its projections.*

As the point is below the H.P. and behind the V.P., its front view will be below xy and the top view above xy.

Draw the projections as explained in problem 9-1 and as shown in fig. 9-6.

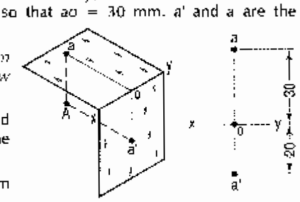
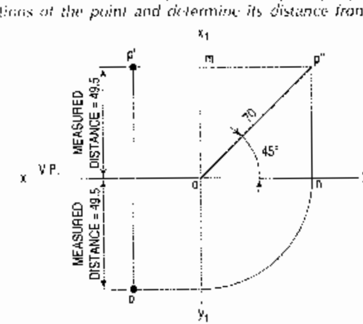


FIG. 9-6

Problem 9-3. (fig. 9-7): *A point P is in the first quadrant. Its shortest distance from the intersection point of H.P., V.P. and Auxiliary vertical plane, perpendicular to the H.P. and V.P. is 70 mm and it is equidistant from principal planes (H.P. and V.P.). Draw the projections of the point and determine its distance from the H.P. and V.P.*



Projections on auxiliary plane: Sometime projections of object on the principal (H.P. and V.P.) are insufficient. In such situation, another projection plane perpendicular to the principal planes is taken. This plane is known as auxiliary plane. The projection on the auxiliary plane is known as side view or side elevation. Refer fig. 9-8.

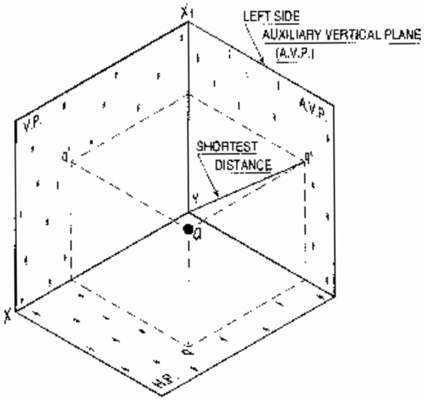


FIG. 9-8

The A.V.P. can be also taken right side also. For more details on projection on auxiliary plane, refer chapter 11.

EXERCISES 9

1. Draw the projections of the following points on the same ground line, keeping the projectors 25 mm apart.
   A, in the H.P. and 20 mm behind the V.P.
   B, 40 mm above the H.P. and 25 mm in front of the V.P.
   C, in the V.P. and 40 mm above the H.P.
   D, 25 mm below the H.P. and 25 mm behind the V.P.

4. A point P is 15 mm above the H.P. and 20 mm in front of the V.P. Another point Q is 25 mm behind the V.P. and 40 mm below the H.P. Draw projections of P and Q keeping the distance between their projectors equal to 90 mm. Draw straight lines joining (i) their top views and (ii) their front views.

5. Projections of various points are given in fig. 9-9. State the position of each point with respect to the planes of projection, giving the distances in centimetres.

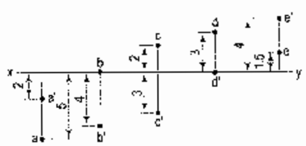


FIG. 9-9

6. Two points A and B are in the H.P. The point A is 30 mm in front of the V.P., while B is behind the V.P. The distance between their projectors is 75 mm and the line joining their top views makes an angle of 45° with xy. Find the distance of the point B from the V.P.

7. A point P is 20 mm below H.P. and lies in the third quadrant. Its shortest distance from xy is 40 mm. Draw its projections.

8. A point A is situated in the first quadrant. Its shortest distance from the intersection point of H.P., V.P. and auxiliary plane is 60 mm and it is equidistant from the principal planes. Draw the projections of the point and determine its distance from the principal planes.

9. A point 30 mm above xy line is the plan-view of two points P and Q. The elevation of P is 45 mm above the H.P. while that of the point Q is 35 mm below the H.P. Draw the projections of the points and state their position with reference to the principal planes and the quadrant in which they lie.

10. A point Q is situated in first quadrant. It is 40 mm above H.P. and 30 mm in front of V.P. Draw its projections and find its shortest distance from the intersection of H.P., V.P. and auxiliary plane.

Chapter 10

PROJECTIONS OF STRAIGHT LINES

10-0. INTRODUCTION

A straight line is the shortest distance between two points. Hence, the projections of a straight line may be drawn by joining the respective projections of its ends which are points.

The position of a straight line may also be described with respect to the two reference planes. It may be:

1. Parallel to one or both the planes.
2. Contained by one or both the planes.
3. Perpendicular to one of the planes.
4. Inclined to one plane and parallel to the other.
5. Inclined to both the planes.
6. Projections of lines inclined to both the planes.
7. Line contained by a plane perpendicular to both the reference planes.
8. True length of a straight line and its inclinations with the reference planes.
9. Traces of a line.
10. Methods of determining traces of a line.
11. Traces of a line, the projections of which are perpendicular to xy.
12. Positions of traces of a line.

10-1. LINE PARALLEL TO ONE OR BOTH THE PLANES

(FIG. 10-1)

(a) Line *AB* is parallel to the H.P.

Hence, when a line is parallel to a plane, its projection on that plane is equal to its true length; while its projection on the other plane is parallel to the reference line.

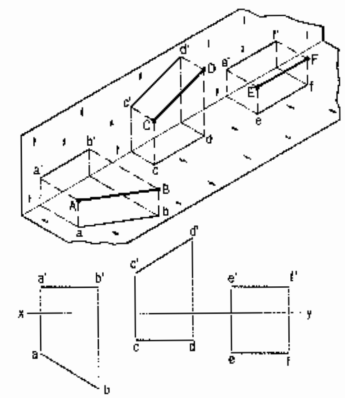
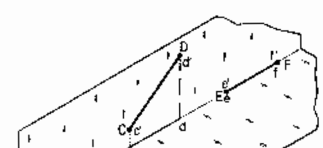


FIG. 10-1

10-2. LINE CONTAINED BY ONE OR BOTH THE PLANES

(FIG. 10-2)



Line *AB* is in the H.P. Its top view *ab* is equal to *AB*; its front view *a' b'* is in *xy*.

Line *CD* is in the V.P. Its front view *c'd'* is equal to *CD*; its top view *cd* is in *xy*.

Line *EF* is in both the planes. Its front view *e' f'* and the top view *ef* coincide with each other in *xy*.

Hence, when a line is contained by a plane, its projection on that plane is equal to its true length; while its projection on the other plane is in the reference line.

10-3. LINE PERPENDICULAR TO ONE OF THE PLANES

(FIG. 10-3)

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 22 for the line perpendicular to one of the planes.

When a line is perpendicular to one reference plane, it will be parallel to the other.

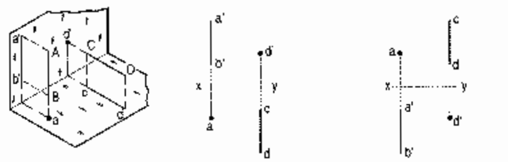


FIG. 10-3

(a) Line *AB* is perpendicular to the H.P. The top views of its ends coincide in the point *a*. Hence, the top view of the line *AB* is the point *a*. Its front view *a' b'* is equal to *AB* and perpendicular to *xy*.

(b) Line *CD* is perpendicular to the V.P. The point *d'* is its front view and the line *cd* is the top view. *cd* is equal to *CD* and perpendicular to *xy*.

Hence, when a line is perpendicular to a plane its projection on that plane is

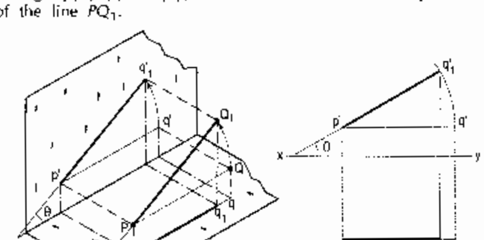
10-4. LINE INCLINED TO ONE PLANE AND PARALLEL TO THE OTHER

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 23 for the line inclined to one plane and parallel to the other.

The inclination of a line to a plane is the angle which the line makes with its projection on that plane.

(a) Line PQ_1 [fig. 10-4(i)] is inclined at an angle θ to the H.P. and is parallel to the V.P. The inclination is shown by the angle θ which PQ_1 makes with its own projection on the H.P., viz. the top view pq_1.

The projections [fig. 10-4(ii)] may be drawn by first assuming the line to be parallel to both the H.P. and the V.P. Its front view *p'q'* and the top view *pq* will both be parallel to *xy* and equal to the true length. When the line is turned about the end *P* to the position PQ_1 so that it makes the angle θ with the H.P. while remaining parallel to the V.P., in the front view the point *q'* will move along an arc drawn with *p'* as centre and *p'q'* as radius to a point q'_1 so that $p'q'_1$ makes the angle θ with *xy*. In the top view, *q* will move towards *p* along *pq* to a point q_1 on the projector through q'_1. $p'q'_1$ and pq_1 are the front view and the top view respectively of the line PQ_1.



the top view the point s will move along an arc drawn with r as centre and rs as radius to a point s_1 so that rs_1 makes the angle $\varnothing$ with xy. In the front view, the point s' will move towards r' along the line $r's'$ to a point s'_1 on the projector through s_1. rs_1 and $r's'_1$ are the projections of the line RS_1.

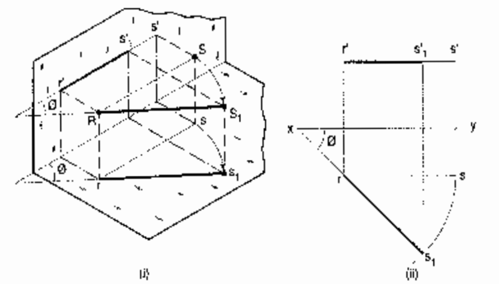
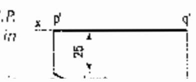


Fig. 10-5

Therefore, when the line is inclined to the H.P. and parallel to the V.P., its top view is shorter than its true length, but parallel to xy; its front view is equal to its true length and is inclined to xy at its true inclination with the H.P. And when the line is inclined to the V.P. and parallel to the H.P., its front view is shorter than its true length but parallel to xy; its top view is equal to its true length and is inclined to xy at its true inclination with the V.P.

Hence, when a line is inclined to one plane and parallel to the other, its projection on the plane to which it is inclined, is a line shorter than its true length but parallel to the reference line. Its projection on the plane to which it is parallel, is a line equal to its true length and inclined to the reference line at its true inclination.

In other words, the inclination of a line with the H.P. is seen in the front view and that with the V.P. is seen in the top view.



Problem 10-1.

Problem 10-2. (fig. 10-7): *The length of the top view of a line parallel to the V.P. and inclined at 45° to the H.P. is 50 mm. One end of the line is 12 mm above the H.P. and 25 mm in front of the V.P. Draw the projections of the line and determine its true length.*

As the line is parallel to the V.P., its top view will be parallel to xy and the front view will show its true length and the true inclination with the H.P.

(i) Mark a, the top view, 25 mm below xy and a', the front view, 12 mm above xy.

(ii) Draw the top view ab 50 mm long and parallel to xy and draw a projector through b.

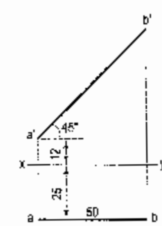


Fig. 10-7

(iii) From a' draw a line making 45° angle with xy and cutting the projector through b at b'. Then $a'b'$ is the front view and also the true length of the line.

Problem 10-3. (fig. 10-8): *The front view of a 75 mm long line measures 55 mm. The line is parallel to the H.P. and one of its ends is in the V.P. and 25 mm above the H.P. Draw the projections of the line and determine its inclination with the V.P.*

As the line is parallel to the H.P., its front view will be parallel to xy.

(i) Mark a, the top view of one end in xy, and a', its front view, 25 mm above xy.

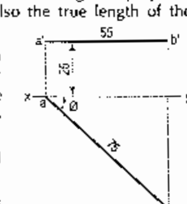


Fig. 10-8

(ii) Draw the front view $a'b'$, 55 mm long and parallel to xy. With a as centre and radius equal to 75 mm, draw an arc cutting the projector through b' at b.

Join a with b. ab is the top view of the line. Its inclination with xy, viz. $\varnothing$ is the inclination of the line with the V.P.

EXERCISES 10(a)

1. Draw the projections of a 75 mm long straight line, in the following positions:
(a) (i) Parallel to both the H.P. and the V.P. and 25 mm from each.

2. A 100 mm long line is parallel to and 40 mm above the H.P. Its two ends are 25 mm and 50 mm in front of the V.P. respectively. Draw its projections and find its inclination with the V.P.
3. A 90 mm long line is parallel to and 25 mm in front of the V.P. Its one end is in the H.P. while the other is 50 mm above the H.P. Draw its projections and find its inclination with the H.P.
4. The top view of a 75 mm long line measures 55 mm. The line is in the V.P., its one end being 25 mm above the H.P. Draw its projections.
5. The front view of a line, inclined at 30° to the V.P. is 65 mm long. Draw the projections of the line, when it is parallel to and 40 mm above the H.P., its one end being 30 mm in front of the V.P.
6. A vertical line AB, 75 mm long, has its end A in the H.P. and 25 mm in front of the V.P. A line AC, 100 mm long, is in the H.P. and parallel to the V.P. Draw the projections of the line joining B and C, and determine its inclination with the H.P.
7. Two pegs fixed on a wall are 4.5 metres apart. The distance between the pegs measured parallel to the floor is 3.6 metres. If one peg is 1.5 metres above the floor, find the height of the second peg and the inclination of the line joining the two pegs, with the floor.
8. Draw the projections of the lines in Exercises 1 to 6, assuming them to be in the third quadrant, taking the given positions to be below the H.P. instead of above the H.P., and behind the V.P., instead of in front of the V.P.

10-5. LINE INCLINED TO BOTH THE PLANES

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 24 for the line inclined to both the planes.

(a) A line AB (fig. 10-9) is inclined at θ to the H.P. and is parallel to the V.P. The end A is in the H.P. AB is shown as the hypotenuse of a right-angled triangle, making the angle θ with the base.

The top view ab is shorter than AB and parallel to xy. The front view $a'b'$ is equal to AB and makes the angle θ with xy.

Keeping the end A fixed and the angle θ with the H.P. constant, if the end B is moved to any position, say B_1, the line becomes inclined to the V.P. also.

In the top view, b will move along an arc, drawn with a as centre and ab as radius, to a position b_1. The new top view ab_1 is equal to ab but shorter than AB.

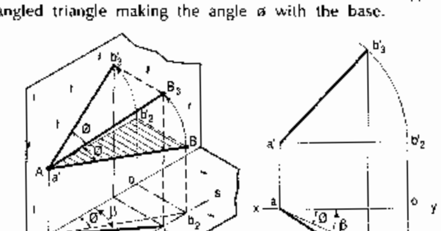
In the front view, b' will move to a point b'_1 keeping its distance from xy constant and equal to $b'o$; i.e. it will move along the line pq, drawn through b' and parallel to xy. This line pq is the locus or path of the end B in the front view. b'_1 will lie on the projector through b_1. The new front view $a'b'_1$ is shorter than $a'b'$ (i.e. AB) and makes an angle α with xy. α is greater than θ.

Thus, it can be seen that as long as the inclination θ of AB with the H.P. is constant, even when it is inclined to the V.P.

(i) its length in the top view, viz. ab remains constant; and

(ii) the distance between the paths of its ends in the front view, viz. $b'o$ remains constant.

(b) The same line AB (fig. 10-10) is inclined at $\varnothing$ to the V.P. and is parallel to the H.P. Its end A is in the V.P. AB is shown as the hypotenuse of a right-angled triangle making the angle $\varnothing$ with the base.



In the top view, b_2 will move to a point b_3 along the line rs, drawn through b_2 and parallel to xy, thus keeping its distance from the path of a, viz. b_2o constant. rs is the locus or path of the end B in the top view. The point b_3 lies on the projector through b'_3. The new top view ab_3 is shorter than ab_2 (i.e. AB) and makes an angle β with xy. β is greater than ø.

Here also we find that, as long as the inclination of AB with the V.P. does not change, even when it becomes inclined to the H.P.

(i) its length in the front view, viz. $a'b'_2$ remains constant; and

(ii) the distance between the paths of its ends in the top view, viz. b_2o remains constant.

Hence, when a line is inclined to both the planes, its projections are shorter than the true length and inclined to xy at angles greater than the true inclinations. These angles viz. α and β are called apparent angles of inclination.

10-6. PROJECTIONS OF LINES INCLINED TO BOTH THE PLANES

From Art. 10-5(a) above, we find that as long as the inclination of AB with the H.P. is constant

(i) its length in the top view, viz. ab remains constant, and

(ii) in the front view, the distance between the loci of its ends, viz. $b'o$ remains constant.

In other words if

(i) its length in the top view is equal to ab, and

(ii) the distance between the paths of its ends in the front view is equal to $b'o$, the inclination of AB with the H.P. will be equal to θ.

Similarly, from Art. 10-5(b) above, we find that as long as the inclination of AB with the V.P. is constant

(i) its length in the front view, viz. $a'b'_2$ remains constant, and

(ii) in the top view, the distance between the loci of its ends, viz. b_2o remains constant.

The reverse of this is also true, viz.

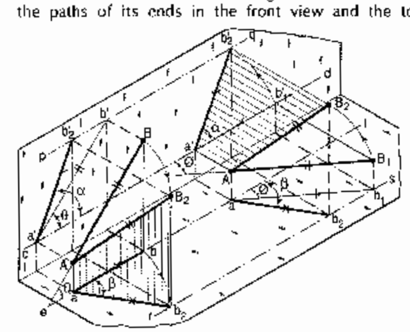
(i) if its length in the front view is equal to $a'b'_2$, and

(ii) the distance between the paths of its ends in the top view is equal to b_2o, the

Problem 10-4. *Given the line AB, its inclinations θ with the H.P. and ø with the V.P. and the position of one end A. To draw its projections.*

Mark the front view a' and the top view a according to the given position of A (fig. 10-12).

Let us first determine the lengths of AB in the top view and the front view and the paths of its ends in the front view and the top view.

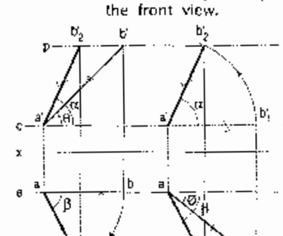


(i) (ii)

FIG. 10-11

(1) Assume AB to be parallel to the V.P. and inclined at θ to the H.P. AB is shown in the pictorial view as a side of the trapezoid $ABba$ [fig. 10-11(i)]. Draw the front view $a'b'$ equal to AB [fig. 10-12(i)] and inclined at θ to xy. Project the top view ab parallel to xy. Through a' and b', draw lines cd and pq respectively parallel to xy. ab is the length of AB in the top view and, cd and pq are the paths of A and B respectively in the front view.

(2) Again, assume AB_1 (equal to AB) to be parallel to the H.P. and inclined at ø to the V.P. In the pictorial view [fig. 10-11(ii)], AB_1 is shown as a side of the trapezoid $AB_1b'_1a'$. Draw the top view ab_1 equal to AB [fig. 10-12(ii)] and inclined at ø to xy. Project the front view $a'b'_1$ parallel to xy. Through a and b_1, draw lines ef and rs respectively parallel to xy. $a'b'_1$ is the length of AB in the front



Draw lines joining a with b_2, and a' with b'_2. ab_2 and $a'b'_2$ are the required projections. Check that $a'b'_2 = a'b'_1$.

(b) Similarly, in case (2) [fig. 10-11(ii)], if the side $B_1b'_1$ is turned about Aa' till b_1' is on the path pq, the line AB_1 will become inclined at θ to the H.P.

Hence, with a' as centre [fig. 10-12(ii)] and radius equal to $a'b'_1$, draw an arc cutting pq at a point b'_2. Project b'_2 to b_2 in the top view on the path rs.

Draw lines joining a with b_2, and a' with b'_2. ab_2 and $a'b'_2$ are the required projections. Check that $ab_2 = ab$.

Fig. 10-13 shows (in pictorial and orthographic views) the projections obtained with both the above steps combined in one figure and as described below.

First, determine

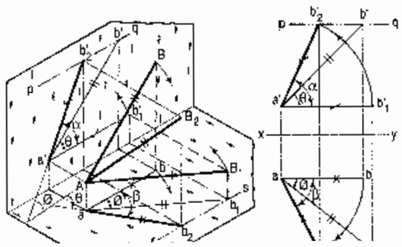
(i) the length ab in the top view and the path pq in the front view and

(ii) the length $a'b'_1$ in the front view and the path rs in the top view.

Then, with a as centre and radius equal to ab, draw an arc cutting rs at a point b_2. With a' as centre and radius equal to $a'b'_1$, draw an arc cutting pq at a point b'_2.

Draw lines joining a with b_2 and a' with b'_2. ab_2 and $a'b'_2$ are the required projections. Check that b_2 and b'_2 lie on the same projector.

It is quite evident from the figure that the apparent angles of inclination α and β are greater than the true inclinations θ and ø respectively.



A line EF (fig. 10-14), is inclined at θ to the H.P. and at ø [equal to (90° – θ)] to the V.P. The line is thus contained by the profile plane marked P.P.

The front view $e'f'$ and the top view ef are both perpendicular to xy and shorter than EF.

Therefore, when a line is inclined to both the reference planes and contained by a plane perpendicular to them, i.e. when the sum of its inclinations with the H.P. and the V.P. is 90°, its projections are perpendicular to xy and shorter than the true length.

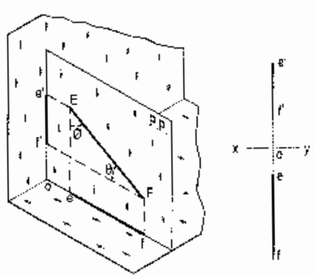


FIG. 10-14

10-8. TRUE LENGTH OF A STRAIGHT LINE AND ITS INCLINATIONS WITH THE REFERENCE PLANES

When projections of a line are given, its true length and inclinations with the planes are determined by the application of the following rule:

When a line is parallel to a plane, its projection on that plane will show its true length and the true inclination with the other plane.

The line may be made parallel to a plane, and its true length obtained by any one of the following *three* methods:

Method I:

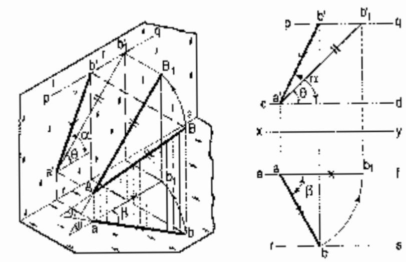
Making each view parallel to the reference line and projecting the other view from it. This is the exact reversal of the processes adopted in Art. 10-5 for obtaining the projections.

Method II:

Rotating the line about its projections till it lies in the H.P. or in the V.P.

Method III:

Projecting the views on auxiliary planes parallel to each view.



(i) (ii)

Fig. 10-15

(i) Therefore, with centre a and radius equal to ab [fig. 10-15(ii)], draw an arc to cut ef at b_1.

(ii) Draw a projector through b_1 to cut pq (the path of b') at b'_1.

(iii) Draw the line $a'b'_1$ which is the true length of AB. The angle θ, which it makes with xy is the inclination of AB with the H.P.

Again, in fig. 10-16(i) AB is shown as a side of a trapezoid ABb'a'. If the trapezoid is turned about Aa' as axis so that AB is parallel to the H.P., the new top view will show its true length and true inclination with the V.P.

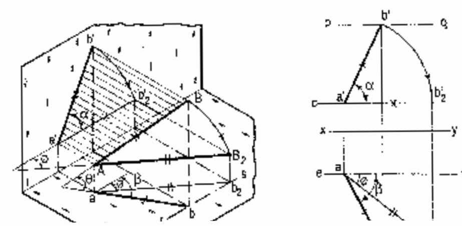
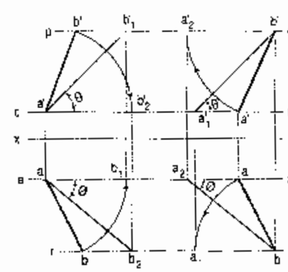


Fig. 10-17(i) shows the above two steps combined in one figure.

The same results will be obtained by keeping the end B fixed and turning the end A [fig. 10-17(ii)], as explained below.



(i) (ii)

Fig. 10-17

(i) With centre b and radius equal to ba, draw an arc cutting rs at a_1 (thus making ba parallel to xy).

(ii) Project a_1 to a'_1 on cd (the path of a') a'_1b' is the true length and θ is the true inclination of AB with the H.P.

(iii) Similarly, with centre b' and radius equal to b'a', draw an arc cutting pq at a_2'.

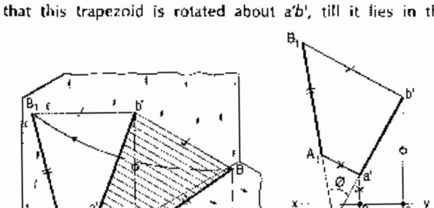
(iv) Project a_2' to a_2 on ef (the path of a). a_2b is the true length and ø is the true inclination of AB with the V.P.

Method II:

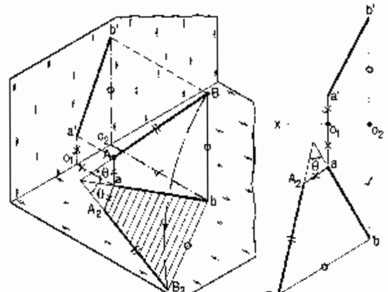
Referring to the pictorial view in fig. 10-18(i) we find that AB is the line, ab its top view and a'b' its front view.

In the trapezoid ABb'a' (i) a'A and b'B are both perpendicular to a'b' and are respectively equal to ao_1 and bo_2 (the distances of a and b from xy in the top view), and (ii) the angle between AB and a'b' is the angle of inclination ø of AB with the V.P.

Assume that this trapezoid is rotated about a'b', till it lies in the V.P.



Similarly, in trapezoid ABba in fig. 10-19(i), AB is the line and ab its top view. Aa and Bb are both perpendicular to ab and are respectively equal to $a'o_1$ and $b'o_2$ (the distances of a' and b' from xy in the front view). The angle θ between AB and ab is the inclination of AB with the H.P.



(i) (ii)

Fig. 10-19

This figure may now be assumed to be rotated about ab as axis, so that it lies in the H.P.

In the orthographic view [fig. 10-19(ii)], this trapezoid is obtained by erecting perpendiculars to ab, viz. aA_2 equal to $a'o_1$ and bB_2 equal to $b'o_2$ and joining A_2 with B_2. The line A_2B_2 is the true length of AB and its inclination θ with ab is the inclination of AB with the H.P.

Note: The perpendiculars on ab or a'b' can also be drawn on its other side assuming the trapezoid to be rotated in the opposite direction.

10-9. TRACES OF A LINE

When a line is inclined to a plane, it will meet that plane, produced if necessary. The point in which the line or line-produced meets the plane is called its *trace*.

The point of intersection of the line with the H.P. is called the *horizontal trace*, usually denoted as H.T. and that with the V.P. is called the *vertical trace* or V.T.

(ii) A line RS is perpendicular to the V.P. Its V.T. coincides with its front view which is a point. It has no H.T.

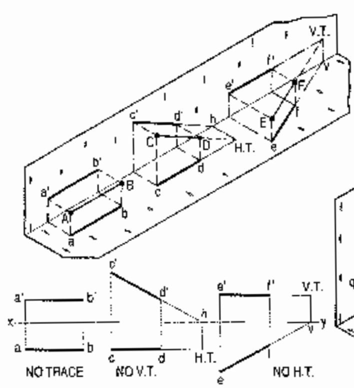


Fig. 10-20

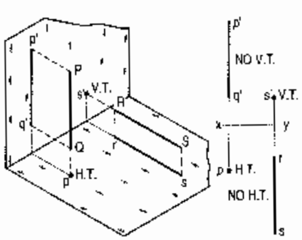
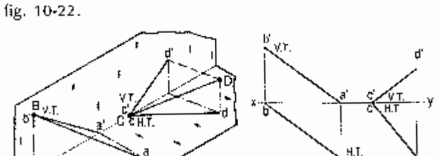


Fig. 10-21

Hence, when a line is perpendicular to a plane, its trace on that plane coincides with its projection on that plane. It has no trace on the other plane.

Refer to fig. 10-22.



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10-10. METHODS OF DETERMINING TRACES OF A LINE

Method I:

Fig. 10-23(i) shows a line *AB* inclined to both the reference planes. Its end *A* is in the H.P. and *B* is in the V.P.

a'b' and *ab* are the front view and the top view respectively [fig. 10-23(ii)].

The H.T. of the line is on the projector through *a* and coincides with *a*. The V.T. is on the projector through *b* and coincides with *b'*.

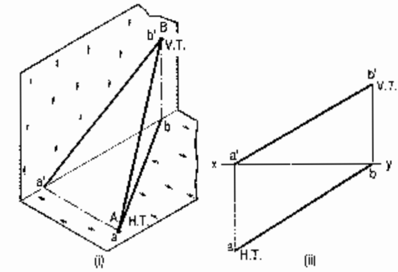


FIG. 10-23

Let us now assume that *AB* is shortened from both its ends, its inclination with the planes remaining constant. The H.T. and V.T. of the new line *CD* are still the same as can be seen clearly in fig. 10-24(i).

c'd' and *cd* are the projections of *CD* [fig. 10-24(ii)]. Its traces may be determined as described below.

(i) Produce the front view *c'd'* to meet *xy* at a point *h*.

(ii) Through *h*, draw a projector to meet the top view *cd*-produced, at the H.T. of the line.

(iii) Similarly, produce the top view *cd* to meet *xy* at a point *v*

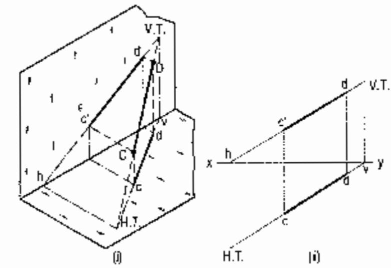


FIG. 10-24

The above is quite evident from the pictorial view shown in fig. 10-25(i).

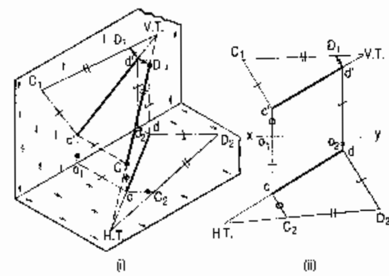
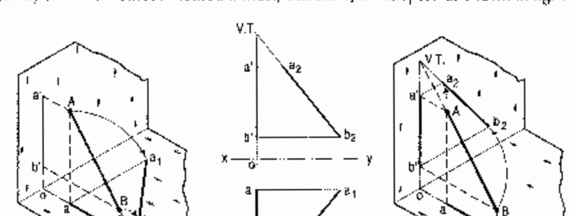


FIG. 10-25

10-11. TRACES OF A LINE, THE PROJECTIONS OF WHICH ARE PERPENDICULAR TO *xy*

When the projections of a line are perpendicular to *xy*, i.e. when the sum of its inclinations with the two principal planes of projection is 90°, it is not possible to find the traces by the first method. Method II must, therefore, be adopted as shown in fig. 10-26.



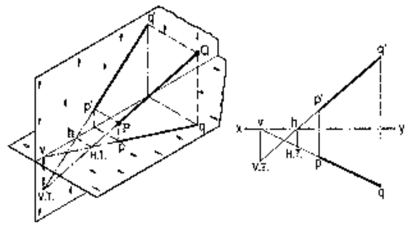


FIG. 10-27

Problem 10-6. *Projections of a line PQ are given. Determine the positions of its traces.*

Let *pq* and *p'q'* be the projections of *PQ* (fig. 10-27 and fig. 10-28).

(i) Produce the top view *pq* to meet *xy* at *v*. Draw a projector through *v* to meet the front view *p'q'*-produced at the V.T.

(ii) Through *h*, the point of intersection between *p'q'*-produced and *xy*, draw a projector to meet the top view *pq*-produced at the H.T.

Note that in fig. 10-27, the traces are below *xy* while in fig. 10-28 they are above it.

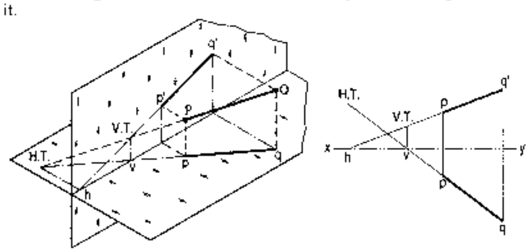


FIG. 10-28

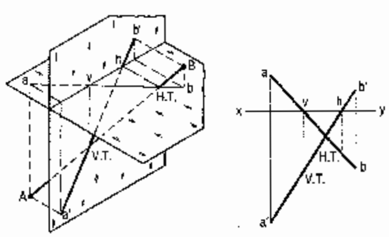


FIG. 10-29

Method II: (fig. 10-30):

At the ends *a'* and *b'*, draw perpendiculars to *a'b'*, viz. $a'A_1$ equal to ao_1 and $b'B_1$ equal to bo_2 on its opposite sides (as *a* and *b* are on opposite sides of *xy*).

Draw the line A_1B_1 intersecting *a'b'* at the V.T. of the line.

Similarly, at the ends *a* and *b*, draw perpendiculars to *ab*, viz. aA_2 equal to $a'o_1$ and bB_2 equal to $b'o_2$, on its opposite sides (as *a'* and *b'* are on opposite sides of *xy*). Join A_2 with B_2 cutting *ab* at the H.T. of the line.

Note that $A_1B_1 = A_2B_2 = AB$ and that θ and ø are the inclinations of *AB* with the H.P. and the V.P. respectively.

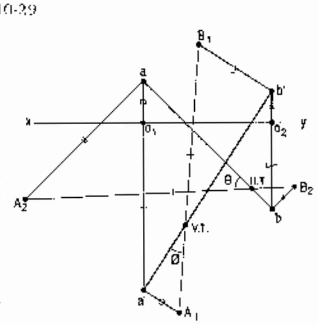


FIG. 10-30

10-13. ADDITIONAL ILLUSTRATIVE PROBLEMS

In the following problems, the ends of the lines should be assumed to be in the first quadrant, unless otherwise stated.

(ii) Again assuming AB to be parallel to the H.P. and inclined at $ø$ (equal to 45°) to the V.P., draw its top view ab_1 (equal to AB). Project the front view ab_1.

ab and ab'_1 are the lengths of AB in the top view and the front view respectively, and pq and rs are the loci of the end B in the front view and the top view respectively.

(iii) With a as centre and radius equal to ab'_1, draw an arc cutting pq in b'_2. With the same centre and radius equal to ab, draw an arc cutting rs in b_2.

Draw lines joining a with b_2 and b_2. ab'_2 and ab_2 are the required projections.

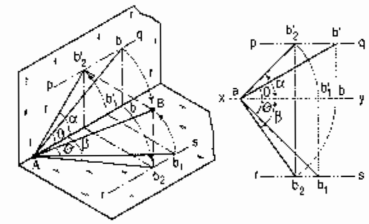
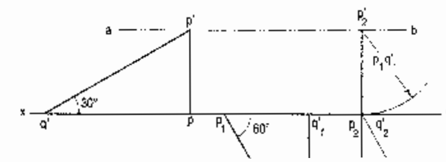


FIG. 10-32

Fig. 10-32 shows in pictorial and orthographic views, the solution obtained with all the above steps combined in one figure only.

Problem 10-9. (fig. 10-33): *A line PQ 75 mm long, has its end P in the V.P. and the end Q in the H.P. The line is inclined at 30° to the H.P. and at 60° to the V.P. Draw its projections.*



(i) the length of PQ in the top view, viz. $q'p$ and the path ab of the end P in the front view;

(ii) the length $p_1q'_1$ in the front view and the path cd of the end Q in the top view.

(iii) Mark any point p_2 (the top view of P) in xy and project its front view p'_2 in ab.

(iv) With p_2 as centre and radius equal to $p_1q'_1$, draw an arc cutting xy in q'_2. It coincides with p_2.

(v) With p_2 as centre and radius equal to $q'p$, draw an arc cutting cd in q_2. p_2q_2 and $p'_2q'_2$ are the required projections. They lie in a line perpendicular to xy because the sum of the two inclinations is equal to 90°.

Problem 10-10. (fig. 10-34): *A line PQ 100 mm long, is inclined at 30° to the H.P. and at 45° to the V.P. Its mid-point is in the V.P. and 20 mm above the H.P. Draw its projections, if its end P is in the third quadrant and Q in the first quadrant.*

The front view and the top view of P will be below and above xy respectively, while those of Q will be above and below xy respectively.

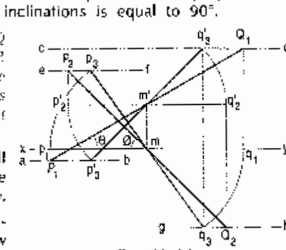


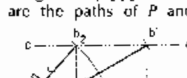
FIG. 10-34

(i) Mark m, the top view of the mid-point in xy and project its front view m', 20 mm above xy.

(ii) Through m', draw a line making an angle θ (equal to 30°) with xy and with the same point as centre and radius equal to $\frac{1}{2}$ PQ, cut it at P_1 below xy and at Q_1 above xy. Project P_1Q_1 to $p_1\ q_1$ on xy. p_1q_1 is the length of PQ in the top view. ab and cd are the paths of P and Q respectively in the front view.

(iii) Similarly, through m, draw a line making angle σ (equal to 45°) with xy and cut it with the same radius at P_2 above xy and at Q_2 below it.

(iv) Project P_2Q_2 to $p'_2q'_2$ on the horizontal line through m'. $p'_2q'_2$ is the length of PQ in the front view and ef and gh are the paths of P and Q respectively in the top view.



(v) With m as centre and radius equal to mp_1 or mq_1, draw arcs cutting ef at p_3 and gh

(ii) Assuming AB to be parallel to the V.P., draw a line ab equal to 65 mm and parallel to xy. With a' as centre and radius equal to 75 mm, draw an arc cutting the projector through b at b'. The line cd through b' and parallel to xy, is the locus of B in the front view and θ is the inclination of AB with the H.P.

(iii) Similarly, draw a line $a'b'_1$ in xy and equal to 50 mm. With a as centre and radius equal to AB, draw an arc cutting the projector through b'_1 at b_1. ef is the locus of B in the top view and $ø$ is the inclination of AB with the V.P.

(iv) With a' as centre and radius equal to $a'b'_1$, draw an arc cutting cd in b_2. With a as centre and radius equal to ab, draw an arc cutting ef in b_2. $a'b'_2$ and ab_2 are the required projections.

Problem 10-12. (fig. 10-36): *A line AB, 65 mm long, has its end A 20 mm above the H.P. and 25 mm in front of the V.P. The end B is 40 mm above the H.P. and 65 mm in front of the V.P. Draw the projections of AB and show its inclinations with the H.P. and the V.P.*

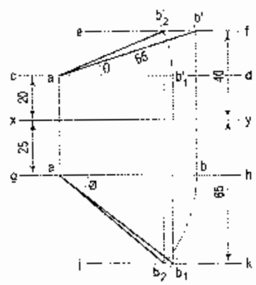


FIG. 10-36

(i) As per given positions, draw the loci cd and gh of the end A, and ef and jk of the end B in the front view and the top view respectively.

(ii) Mark any point a (the top view of A) in gh and project it to a' on cd. With a' as centre and radius equal to 65 mm, draw an arc cutting ef in b'. Join a' with b. θ, the inclination of $a'b'$ with xy, is the inclination of AB with the H.P. Project b' to b on gh. ab is the length of AB in the top view.

(iii) With a as centre and radius equal to 65 mm, draw an arc cutting jk in b_1. Join a with b_1. $ø$, the inclination of ab_1 with xy, is the inclination of AB with the V.P. Project b_1 to b'_1 on cd. $a'b'_1$ is the length of AB in the front view.

Arrange ab and $a'b'_1$ between their respective paths as shown. $a'b'_2$ and ab_2 are

Method I:

By making the line parallel to a plane (fig. 10-37):

(i) Keeping a fixed, turn ab to a position ab_1, thus making it parallel to xy. Project b_1 to b'_1 on the locus of b'. $a'b'_1$ is the true length of AB and θ is its true inclination with the H.P.

(ii) Similarly, turn $a'b'$ to the position a'_1b' and project a'_1 to a_1 on the path of a (because the end a has been moved). a_1b is the true length of AB and $ø$ is its inclination with the V.P.

Traces:

(i) Through v the point of intersection of the top view ab with xy, draw a projector to cut $a'b'$ at the V.T.

(ii) Through h the point of intersection of the front view $a'b'$ with xy, draw a projector to cut ab at the H.T. of the line.

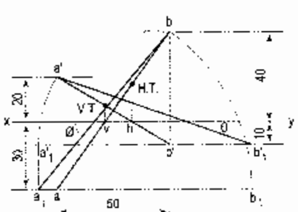


FIG. 10-37

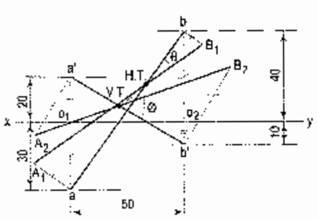


FIG. 10-38

Method II:

By rotating the line about its projections till it lies in H.P. or V.P. (fig. 10-38):

(i) At the ends a and b of the top view ab, draw perpendiculars to ab, viz. aA_1 equal to $a'o_1$ and bB_1 equal to $b'o_2$, on opposite sides of it (because a' and b' are on opposite sides of xy). A_1B_1 is the true length of AB. θ

(ii) Assuming AB to be parallel to the V.P. and inclined at 45° to the H.P., draw its front view $a'b'$ equal to AB and making an angle of 45° with xy. Project b' to b so that ab the top view is parallel to xy. Keeping the end a fixed, turn the top view ab to a position ab_1 so that it makes an angle of 60° with xy. Project b_1 to b'_1 on the locus of b'. Join a' with b'_1. $a'b'_1$ is the front view of AB.

(iii) To find the true inclination with the V.P., draw an arc with a as centre and radius equal to AB, cutting the locus of b_1 in b_2. Join a with b_2. $ø$ is the true inclination of AB with the V.P.

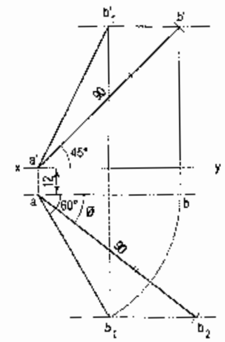


Fig. 10-39

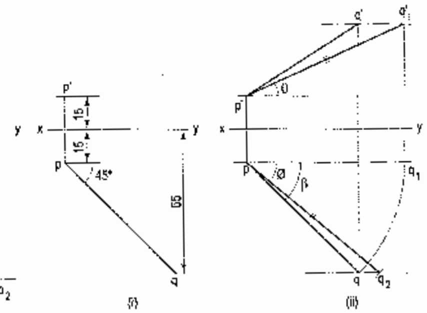


Fig. 10-40

Problem 10-15. (fig. 10-40): *Incomplete projections of a line PQ, inclined at 30° to the H.P. are given in fig. 10-40(i). Complete the projections and determine the true length of PQ and its inclination with the V.P.*

(i) Turn the top view pq [fig. 10-40(ii)] to a position pq_1, so that it is parallel to xy. Through p', draw a line making an angle θ (equal to 30°) with xy and cutting the projector through q_1 at q'_1. $p'q'_1$ is the front view of PQ.

(ii) Through q'_1, draw a line parallel to xy and cutting the projector through

We have seen that the line representing the true length obtained by the trapezoid method, intersects the top view or the top view-produced, at the H.T. at an angle equal to the true inclination of the line with the V.P.

(i) Hence, at the ends a and b, draw perpendiculars to ab on its opposite sides (as one end is below the H.P. and the other end above it). Through the H.T., draw a line making angle θ (equal to 40°) with ab and cutting the perpendiculars at A_1 and B_1, as shown. A_1B_1 is the true length of AB. aA_1 and bB_1 are the distances of the ends A and B respectively from the H.P.

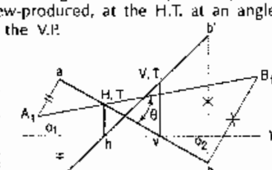


Fig. 10-41

(ii) Project a and b to a' and b', making $a'o_1$ equal to aA_1 and $b'o_2$ equal to bB_1. $a'b'$ is the front view of AB. Through v, the point of intersection between ab and xy, draw a projector cutting $a'b'$ at the V.T. of the line.

Problem 10-17. (fig. 10-42): *A line AB, 90 mm long, is inclined at 30° to the H.P. Its end A is 12 mm above the H.P. and 20 mm in front of the V.P. Its front view measures 65 mm. Draw the top view of AB and determine its inclination with the V.P.*

(i) Mark a and a' the projections of the end A. Through a', draw a line ab' 90 mm long and making an angle of 30° with xy.

(ii) With a' as centre and radius equal to 65 mm, draw an arc cutting the path of b' at b'_1. $a'b'_1$ is the front view of AB.

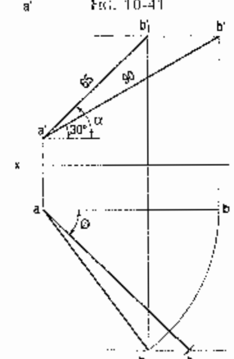


Fig. 10-42

(iii) Project b' to b, so that ab is parallel to xy. ab is the length of AB in the top view.

(iv) With a as centre and radius equal to ab, draw an arc cutting the projector through b_1 at b_1. Join a with b_1. ab_1 is the required top view.

Determine $ø$ as described in problem 10-14.

(ii) Similarly, draw perpendiculars to $p'q'$. viz. $p'P_2$ equal to po and $q'Q_2$ equal to qo and on opposite sides of $p'q'$. P_2Q_2 is the true length. $ø$ is the true inclination of PQ with the V.P. and the point where P_2Q_2 cuts $p'q'$ is the V.T. of PQ.

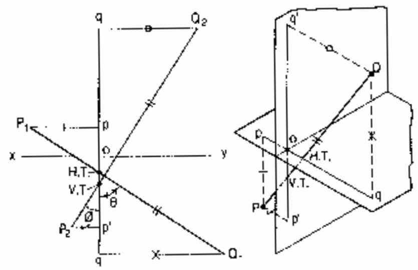
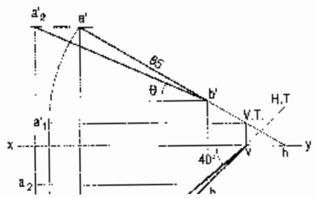


Fig. 10-43

Problem 10-19. (fig. 10-44): *A line AB, inclined at 40° to the V.P., has its ends 50 mm and 20 mm above the H.P. The length of its front view is 65 mm and its V.T. is 10 mm above the H.P. Determine the true length of AB, its inclination with the H.P. and its H.T.*

(i) Draw the front view $a'b'$ as per given positions of A and B and the given length.

(ii) Draw a line parallel to and 10 mm above xy. This line will contain the V.T. Produce $a'b'$ to cut this line at the V.T. Draw a projector through V.T. to v on xy.



(iii) Assuming a' V.T. to be the front view of a line which makes 40° angle with the V.P. and whose one end v is in the V.P., let us determine its true length.

(iv) Keeping V.T. fixed, turn the end a' to a'_1 so that the line becomes parallel to xy. Through v, draw a line making an angle of 40°

Produce $a'b'$ to meet xy at h. Draw a projector through h to cut ab-produced, at the H.T. of the line.

Problem 10-20. (fig. 10-45): *The front view a'b' and the H.T. of a line AB, inclined at 23° to the H.P. are given in fig. 10-45(i). Determine the true length of AB, its inclination with the V.P. and its V.T.*

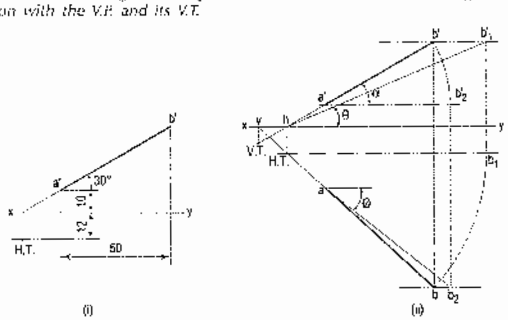


Fig. 10-45

Consider that hb' is the front view of a line inclined at 23° to the H.P. and the top view of whose one end is in H.T.

(i) Through h [fig. 10-45(ii)], draw a line making an angle of θ = 23° with xy and cutting the locus of B in the front view in b'_1. hb'_1 is the true length of the line whose length in the top view is H.T. b_1.

(ii) With H.T. as centre and radius equal to H.T. b_1, draw an arc cutting the projector through b' at b. H.T. b is the top view and hb' is the front view of a line which contains AB.

(iii) Therefore, through a', draw a projector cutting H.T. b at a. ab is the top view of AB.

Obtain the true length ab_2 (of AB) and its inclination $ø$ with the V.P. by making $a'b'$ parallel to xy.

(ii) Draw an equilateral triangle *abc* of 50 mm side with one side parallel to and below *xy*. Project the front view *a'b'c'* at the height *h* above *xy*. Determine the lengths of the other two legs in the top view as described below.

(iii) With *b'* as centre and radius equal to 163 mm, draw an arc cutting *xy* in q'_1. Similarly with *a'* and *c'* as centre and radius equal to 150 mm and 175 mm, draw an arc cutting *xy* in p'_1 and r'_1 respectively ap_1, bq_1 and cr_1 are the lengths of the three legs in the top view and α and β respectively are their inclinations with the floor (H.P.).

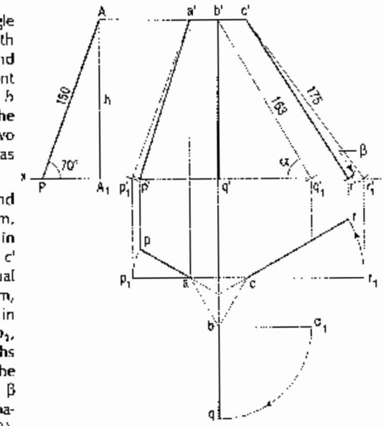
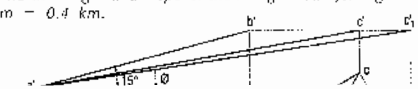


Fig. 10-46

(iv) The legs in the top view are to be inclined at 120° to each other and to meet at a point, if produced. Therefore, draw lines bisecting the angles of the triangle, making *ap* equal to PA_1, *bq* equal to bq_1 and *cr* equal to cr_1, thus completing the top view.

(v) Project *p*,*q* and *r* to *p'*,*q* and *r'* respectively on *xy*. Complete the front view by drawing lines *a'p'*, *b'q'* and *c'r'*.

Problem 10-22. (fig. 10-47): *A straight road going uphill from a point A, due east to another point B, is 4 km long and has a slope of 15°. Another straight road from B, due 30° east of north, to a point C is also 4 km long but is on ground level. Determine the length and slope of the straight road joining the points A and C. Scale, 10 mm = 0.4 km.*



(i) Mark any point *a'*. Draw a line *a'b'*, 100 mm long, to the right of *a'* and inclined upwards at 15° to the horizontal (to represent the road from *A* to *B*). Project its top view *ab* keeping it horizontal.

(ii) As the road from *B* to C is on ground level, the top view *bc* will be equal to 100 mm and inclined at (90° + 30°) i.e. 120° to *ab*.

(iii) From *b*, draw a line *bc*, 100 mm long and making 120° angle with *ab*. Project *c* to *c'* making *b'c'* horizontal. *a'c'* and *ac* are the front view and the top view respectively of the road from *A* to *C*,

Determine the true length $a'c'_1$ and the angle ø as shown, which are respectively the length and slope of the road from *A* to *C*.

Problem 10-23. (fig. 10-48): *Two lines AB and AC make an angle of 120° between them in their front view and top view. AB is parallel to both the H.P. and the V.P. Determine the real angle between AB and AC.*

Draw any line *b'a'* parallel to and above *xy*, and another line *a'c'* of any length making 120° angle with *b'a'*. Join *b'* with *c'*.

(i) Project the top view *ba* parallel to *xy* and the top view *ac*, making 120° angle with *ba*. Join *b* with *c*. *b'a* or *ba* is the true length of *AB*. Determine the true lengths of *AC* and *BC*, viz. $a'c'_1$ and $b'c'_2$, as shown.

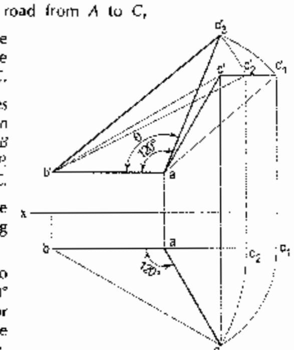
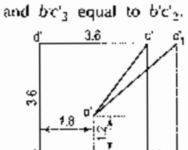


Fig. 10-48

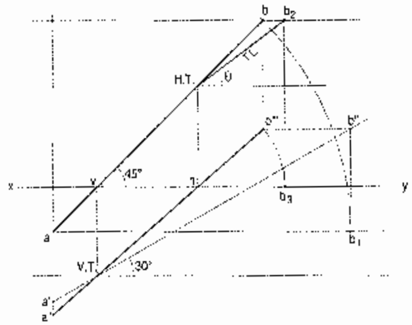
(ii) Draw a triangle $a'b'c'_3$ making $a'c'_3$ equal to $a'c'_1$ and $b'c'_3$ equal to $b'c'_2$. $\angle b'a'c'_3$ is the real angle between *AB* and *AC*.

Problem 10-24. (fig. 10-49): *An object O is placed 1.2 m above the ground and in the centre of a room 4.2 m × 3.6 m × 3.6 m high. Determine graphically its distance from one of the corners between the roof and two adjacent walls. Scale, 10 mm = 0.5 m.*



Problem 10-25. *The straight line AB is inclined at 30° to H.P., while its top view at 45° to a line xy. The end A is 20 mm in front of the V.P. and it is below the H.P. The end B is 75 mm behind the V.P. and it is above the H.P. Draw the projections of the line when its V.T. is 40 mm below. Find the true length of the portion of the straight line which is in the second quadrant and locate its H.T.*

Refer to fig. 10-50.



T.L. = 50 mm. ∠V.P., θ = 37°

Fig. 10-50

(i) Mark the points *a* (top view of *A*) and *b* (top view of *B*) at the distances of 20 mm and 75 mm below and above *xy* respectively.

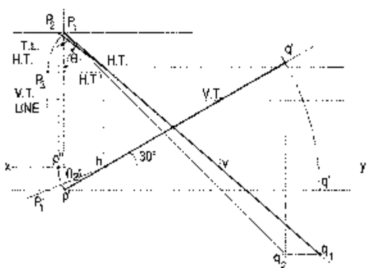
(ii) Through the point *a*, draw a line at 45° intersecting *xy* and the path of *b* at *v* and *b* respectively as shown.

(iii) Construct a line containing V.T. 40 mm below *xy*. Draw perpendicular from *v* to the line V.T.

(iv) With *a* as centre and radius equal to *ab*, draw an arc which intersects at b_1 a line drawn from *a* parallel to *xy*. From V.T. draw a line at 30° intersecting the projector of b_1 at *b"*. From *b"*, draw *b"b'"* parallel to *xy* to intersect projector of *b* at *b'"*. Join V.T. *b'"*. Produce it to meet the projector from *a* at

(i) Draw lines containing H.T. and V.T. at 45 mm and 30 mm above *xy* respectively. Mark point *p'* at 10 mm below line *xy*. Draw *pq'* at 30° from *p'* intersecting *xy* at *h* and line V.T. at V.T. From *h*, draw perpendicular to line H.T. to locate H.T.

(ii) Draw perpendicular from V.T. to intersect *xy* at *v*. Join *v* H.T. and produce to intersect the projector of *p'* at p_1. Draw $p_1 q_1$ of 150 mm representing true length of the line in top view. From *p'*, draw line parallel to *xy* representing front view of the line *PQ*. Draw projector from q_1 to cut the line drawn from *p'* at *q'*.



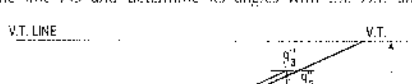
T.L. = 25 mm. ∠V.P., θ_1 = 37° ∠V.P., θ_2 = 22°

Fig. 10-51

(iii) Keeping *p'* fixed, turn *p'q"* such that it cuts the line drawn from *p* at *q'*. From q_1 draw line parallel to *xy* which intersects the vertical projector drawn from *q'* at q_2. Join P_1q_2. This is the required projection.

(iv) Keeping *h* fixed, rotate *hp* and make it parallel to *xy*. From *P'* draw projector intersecting the path of p_1 at p_2. H.T. p_2 is true-length of the line. Similarly keeping H.T.' fixed, turn H.T.' p_1 to make it parallel to *xy* as shown. From P_3, draw projector to intersect the horizontal line drawn from $P'P'_1$. Measure angle xhp'_1. This is the required angle with H.P.

Problem 10-27. (fig. 10-52): *The end P of a line PQ 130 mm long, is 33 mm in front of the V.P. The H.T. of the line is 40 mm in front of the V.P. and the V.T. is 50 mm above the H.P. The distance between H.T. and V.T. is 110 mm. Draw the projections of the line PQ and determine its angles with the H.P. and the V.P.*

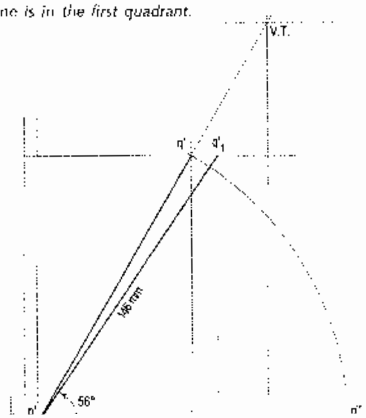


(i) Mark p below xy at a distance of 55 mm. Draw lines containing H.T. and V.T. at 40 mm below and 50 mm above xy respectively. Construct projectors through H.T. and V.T. 110 mm apart intersecting xy at h and v respectively.

(ii) Draw perpendiculars from h and v intersecting the lines containing H.T. and V.T. Join H.T. v and produce to cut the line drawn from point P as shown. Join h V.T. and extend further to intersect the projector drawn from P at P''_2.

(iii) Mark true length 130 mm on H.T.v. Let it be pq. Draw projector from q cutting xy at q'_1. With p'_1 as centre and radius equal to $p'_1q'_1$, draw an arc cutting a horizontal line drawn from q''_2 at q'''_3. Join pq_1 and $p''_2q'''_3$, are the required projections. $\theta_1 = 25.5°$ and $\theta_2 = 21°$ are the measured angles.

Problem 10-28. (fig. 10-53): *The distance between the end projectors of a line AB is 70 mm and the projectors through the traces are 110 mm apart. The end of a line is 10 mm above H.P. If the top view and the front view of the line make 30° and 60° with xy line respectively, draw the projections of the line and determine (i) the traces, (ii) the angles with the H.P. and the V.P., (iii) the true length of the line. Assume that the line is in the first quadrant.*



(i) Draw two vertical lines 110 mm apart representing projectors through the traces of the line. Mark intersection of these projectors h and v on xy as shown.

(ii) From v and h, draw lines at 30° and 60°.

(iii) Mark p', 10 mm above xy. Draw two vertical projectors at 70 mm apart keeping equal distance from the projectors through traces. $p'q'$ and pq represent front view and top view of the line as shown.

(iv) Keeping p fixed, turn pq to position pq_1. From q_1, draw a vertical projector intersecting the path of q' at q'_1. Join $p'q'_1$. This is the true length of the line. Measure angle $q''p'q'_1$ with the horizontal line as shown. This is the angle made by the line with the H.P. Similarly rotate $p'q'$ making it parallel to xy as shown.

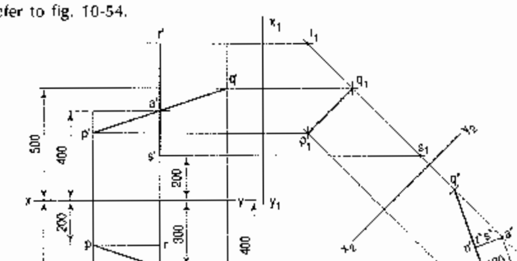
Draw a vertical projector from q'' to intersect the path of q at q_2. Measure the angle q_1pq_2 with the horizontal line. This is the angle made by the line with V.P.

Note: Problem 10-29 and problem 10-31 are solved by using auxiliary plane method.

Problem 10-29. *Two pipes PQ and RS seem to intersect at a and a in front view and top view as shown in fig. 10-54. The point A is 400 mm above H.P. and 300 mm in front of a wall.*

Neglecting the thickness of the pipes, determine the clearance between the pipes.

Refer to fig. 10-54.



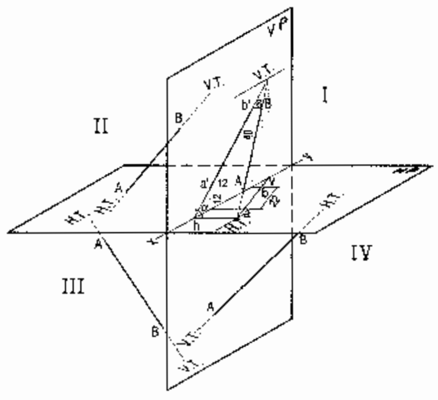
(iii) Mark an auxiliary reference line x_2y_2 perpendicular to the line r_1s_1 for obtaining the point view of the line. Draw an auxiliary front view as shown. Note that the distances of p'', q'', r'' and s'' from x_2y_2 are equal to the distances of p', q', r' and s' from x_1y_1.

(iv) a'' n' represents clearance between two pipes which is approximately 130 mm.

Problem 10-30. *The end projectors of line AB are 22 mm apart. A is 12 mm in front of the V.P. and 12 mm above the H.P. The point B 6 mm in front of the V.P. and 40 mm above the H.P. Locate the H.T. and the V.T. of the line and also determine its inclinations with the V.P. and the H.P.*

If the line AB is shifted to II, III and IV quadrants as shown in fig. 10-55 (assume that the distances of A and B from the projection-planes are same as the first quadrant), draw the projections of line and locate the traces.

The solution of first part of problem is shown in pictorial view. For the second part of the problem, the locations of the line in the respective quadrants are shown in fig. 10-55.



(i) Draw two end projectors of the line PQ at 80 mm apart.

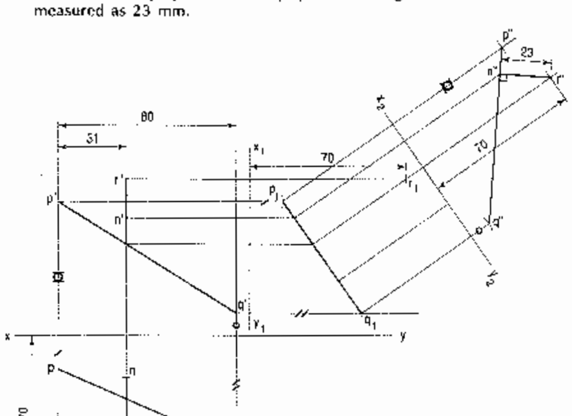
(ii) Mark the front view p' and the top view p at 60 mm and 15 mm from xy on the end projector of P. Similarly mark q' and q at 10 mm and 50 mm from xy on the end projector of Q.

(iii) Draw a vertical line at 31 mm away from $p'p$ towards $q'q$. Mark the position of R in the top view r and the front view r' at 70 mm from xy as shown.

(iv) Draw x_1y_1 perpendicular to xy as shown. Draw projectors from p', q' and r' on x_1y_1. Transfer the distances 15 mm, 50 mm and 70 mm of p, q and r from xy to the new top view p_1, q_1 and r_1 from x_1y_1.

(v) Draw another reference line x_2y_2 for the new front view parallel to p_1q_1. Transfer the distances 60 mm, 10 mm and 70 mm of p', q' and r' from xy to the new front view p'', q'' and r'' from x_2y_2.

(vi) From r'', draw perpendicular to $p''q''$ intersecting at n'' as shown which is measured as 23 mm.



Refer to fig. 10-57.

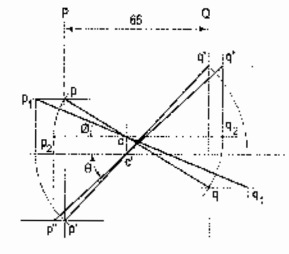


FIG. 10-57

(i) Draw the end projectors of the line PQ 65 mm apart. Mark the projection of ends P and Q according to given distances. $p'q'$ and pq are the front view and the top view respectively.

(ii) Mark the front view of point c in the line xy because it is lying in the H.P. Extend the projection line from c' to c on the top view pq.

(iii) Keeping c fixed, turn cp to cp_2 making parallel to xy.

(iv) Project p_2 to p''. Join $c'p''$. This is the true distance of the line cp. Similarly turn cq to cq_2 making it parallel to xy. Project q_2 to q'' join $c'q''$. This represents the true distance of the line cq.

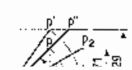
(v) Measure angles θ and ϕ as shown.

Problem 10-33. (fig. 10-58): *The distance between the end-projectors of a line PQ is 50 mm. A point P is 29 mm above H.P. and 20.71 mm behind V.P. While a point Q is 42 mm below H.P. and 30 mm in front of V.P.*

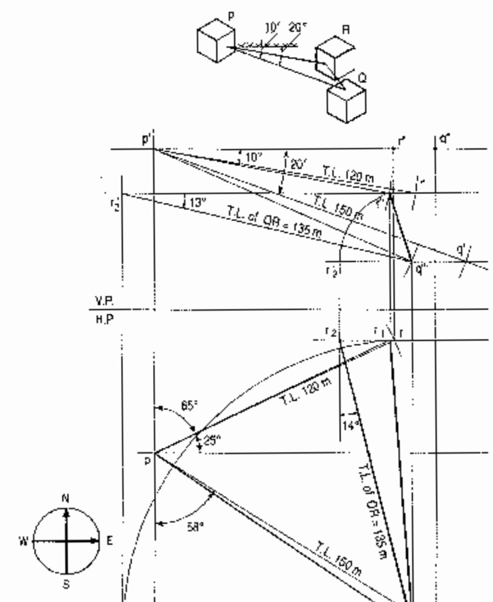
Draw the projections of the line and determine the true length and the true inclinations of line with H.P. and V.P.

(i) Draw the end-projectors 50 mm apart. Mark p' and p, the front view and the top view of the end P at 29 mm and 20.71 mm respectively. Similarly mark q and q' at 42 mm and 30 mm on the end-projector Q as shown. Join $p'q'$ and pq. They are intersecting xy at r. Mark paths of p', q', p and q parallel to xy.

(ii) With centre r and radius rp', draw an arc intersecting xy at p''. Through p'', draw projector cutting the path of p at p_2. Similarly with the same centre and radius rq', draw an arc intersecting xy at q''. Through q'', draw projector cutting the path of q at q_2. Join p_2q_2 which represents true length. Measure ϕ angle made by p_2q_2 with xy



Problem 10-34. (fig. 10-59): *Two pipes emerge from a common tank. The pipe PQ is 150 metre long and bears S 58° E on a downward slope of 20°. The pipe PR is 120 metre long and bears N 65° E on a downward slope of 10°. Determine the length of pipe required to connect Q and R. Take scale 1 mm = 1 m.*



(v) Draw a projector from q to intersect the horizontal line drawn from p' at q''. $p'q''$ is the front view of PQ. With p' as centre and radius equal to $p'q''$, draw an arc intersecting the path of q' at q''. Join $p'q''$ and draw a projector from q' cutting the path of q at q_1. Then $p'q'''$ and pq_1 are required projection. Similarly obtain the projection of pr'' and pr_1 for the line PR as shown. Join $r''q'''$ and r_1q_1. With centre q''' and a radius $q'''r'''$, draw an arc intersecting the path of q'' at r'_2. Draw a projector from r'_2 cutting the path of r at r_2. Join q_1r_2 and measure its true length and angle.

(vi) With centre q_1 and radius q_1r_1, draw an arc intersecting the path of q at q_2. Draw a projector from q_2 cutting the path of r' at r_3. Join $q'r'_3$ and measure its true length and angle.

(vii) QR = 135 m is the measured true length and S 13 E at downward slope of 13° is the measured angle.

Note: Depression or front view angles are seen in front view while bearing angles are seen in top view.

Problem 10-35. (fig. 10-60): *The projectors of two points P and Q are 70 mm apart. The point P is 25 mm behind the V.P. and 30 mm below the H.P. The point Q is 40 mm above the H.P. and 15 mm infront of the V.P. Find the third point S which is in the H.P. and infront of the V.P. such that its distance from point P is 90 mm and that from Q is 60 mm.*

(i) Draw xy line.

(ii) Draw the projectors of P and Q 70 mm apart.

(iii) Mark on the projector of the point p the front view and top view of the point p at 25 mm and 30 mm from xy respectively, say p' and p. Similarly on the projector of the point Q, mark the front view q' and the top view q for given distance from the xy.

(iv) Join $p'q'$ and pq. They are the front view and the top view of the line PQ.

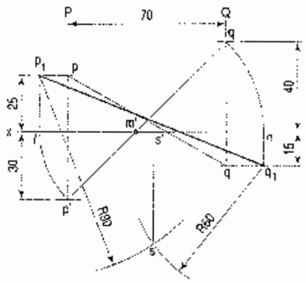


FIG. 10-60

Problem 10-36. (fig. 10-61): *Two unequal lines PQ and PR meeting at P makes an angle of 130° between them in their front view and top view. Line PQ is parallel and 6 mm away from both the principal planes. Assume the front view length of PQ and PR 50 mm and 60 mm respectively. Determine real angle between them.*

(i) Mark reference line xy. Draw at convinent distance above and below two parallel lines to the xy representing the front view and top view of PQ as shown. At the point P' construct angle of 130° with the length of $p'q'$ and $p'r'$ of 50 mm and 60 mm respectively.

(ii) Draw projector from r to intersect the line at angle of 130° at p in the top view of pq.

(iii) Make pr and qr parallel to xy line and project above xy to intersect the path of r' at r'' and r''' respectively.

Join $p'r'''$ and qr''. They are true length of the line PR and the line QR.

(iv) Construct triangle with sides PQ = 50 mm, $PR = p'r'''$ and $QR = q'r'$ as shown. Measure angle $\angle QPR$ equal and it is 120° approximately.

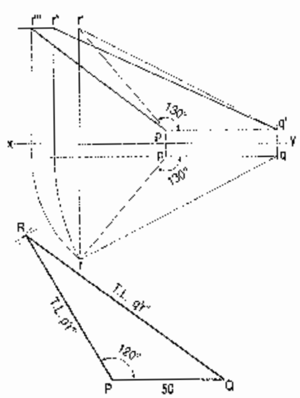
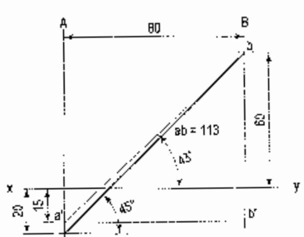


FIG. 10-61

Problem 10-37. (fig. 10-62): *The distance between end projectors of a straight line AB is 80 mm. The point A is 15 mm below the H.P. and 20 mm infront of the V.P. B is 60 mm behind the V.P. Draw projections of the line if it is inclined at 45° to V.P. Determine also true length and inclination with the H.P.*



Problem 10·38. (fig. 10·63): *Two mangoes on a tree are respectively 2.0 m and 3.5 m above the ground and 1.5 m and 2.0 m away from 0.2 m thick compound wall, but on the opposite sides of it. The distance between the mangoes, measured along the ground and parallel to the wall is 2.7 m. Determine the real distance between the mangoes. Take scale 1 m = 10 mm.*

(i) Pictorial view is shown for understanding purpose.

(ii) Draw reference line (ground line) *xy*. Mark two parallel lines as end-projectors at 2.7 m (27 mm) apart.

(iii) Let *P* be mango behind the wall and *Q* be infront of the wall.

(iv) Mark *P'* and *P* along projector *P* to given distances. Similarly mark *q'* and *q* for given distances on the projector *Q*.

(v) Join the point *p* and the point *q*, the point *p'* and the point *q'*. Then *pq* and *p'q'* are projections of *PQ*.

(vi) Rotates *pq* taking *q* as centre, make it parallel to the ground line *xy*, intersecting at the poin P_1. Draw the projector from p_1. Draw line parallel to the ground line *xy* from *p'*, intersecting at *p"*.

(vii) Join *p"q'*. The line *p'q'* is true distance between mangoes *P* and *Q*. It is approximately 4.8 m.

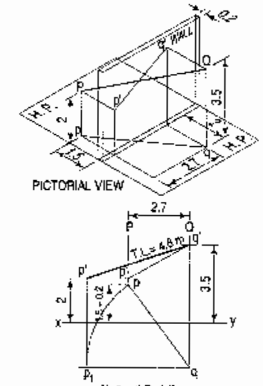
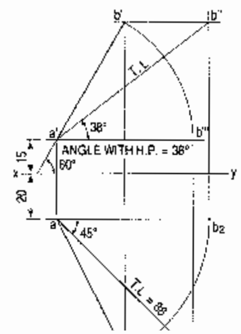


FIG. 10·63

Problem 10·39. (fig. 10·64): *The front view of straight line AB is 50 mm long and is inclined at 60° to the reference line xy. The end point A is 15 mm above H.P. and 20 mm infront of V.P. Draw the projections of a line AB if it is inclined at 45° to the V.P. and is situated in the first quadrant*



(iii) Mark the point in the V.P. at distance 1 m (= 10 mm) from midpoint *m*. It is the front view of the light bulb, say *b'*.

(iv) From *xy* line at 0.3 m (i.e. 3 mm) on the projector passing through *b'* mark the point *b* (top view).

(v) Consider adjacent wall right side. Mark *s'* front view of the switch at 1.5 m (i.e. 15 mm) above *xy* line and on the same line mark *s* (top view of switch) at 4 m away from *xy*.

(vi) Join *b's'* and *bs* which are the front view and the top view of the line.

(vii) *s* as centre and *bs* as radius, draw the arc to intersect a parallel line passing through *s* at b_1. From b_1, draw projector to intersect a parallel line to *xy* drawn from *b'* at *b"*. Join *sb"*.

(viii) Line *s'b'* shows shortest distance between the switch and the bulb. Here it is approximately 5 m.

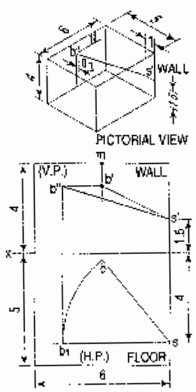
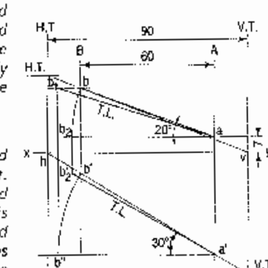


FIG. 10·65

Problem 10·41. (fig. 10·66): *The distance between end projectors of a line AB are 60 mm apart, while the projectors passing from H.T. and V.T. are 90 mm apart. The H.T. is 35 mm behind the V.P., the V.T. is 55 mm below the H.P. The point A is 7 mm behind the V.P. Find graphically true length of the line and inclinations with the H.P. and the V.P.*

See fig. 10·66 which is self-explanatory.

Problem 10·42. (fig. 10·67): *A line CD is inclined at 30° to the H.P. and it is in the first quadrant. The end C is 15 mm above the H.P. while the end D is in the V.P. The mid point M of of the line is 40 mm above H.P. The distance between the end projectors of the line is 70 mm. Draw the projections*



(vi) The path of *D* will intersect the projector of *D* at *d"*. Join *c'd"*. It is front view of *CD*.

(vii) With *c'* as centre and radius equal to *c'd"*, draw an arc cutting a line drawn parallel to *xy* from *c'* at *d'"*. Project *d'"* to cut a line drawn with *c* as centre and *c'd'* (true length) as radius, at d_3. From d_3, draw a line parallel to *xy*, representing path of *D* in top view.

(viii) Project *d"* to cut path of *D* in top view at d_4. Join cd_4. It is top view of *CD*.

(ix) The results are shown in fig. 10·67.

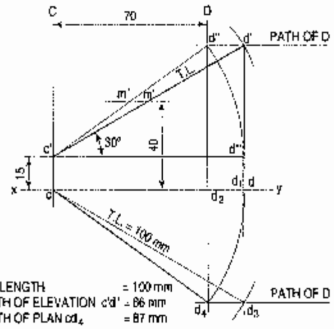
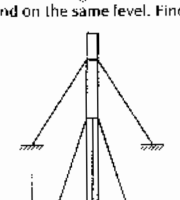


FIG. 10·67

EXERCISES 10(b)

1. A line *AB*, 75 mm long, is inclined at 45° to the H.P. and 30° to the V.P. Its end *B* is in the H.P. and 40 mm in front of the V.P. Draw its projections and determine its traces.
2. Draw the projections of a line *AB*, 90 mm long, its mid-point *M* being 50 mm above the H.P. and 40 mm in front of the V.P. The end *A* is 20 mm above the H.P. and 10 mm in front of the V.P. Show the traces and the inclinations of the line with the H.P. and the V.P.
3. The front view of a 125 mm long line *PQ* measures 75 mm and its top view measures 100 mm. Its end *Q* and the mid-point *M* are in the first quadrant, *M* being 20 mm from both the planes. Draw the projections of the line *PQ*.
4. A line *AB*, 75 mm long is in the second quadrant with the end *A* in the H.P. and the end *B* in the V.P. The line is inclined at 30° to the H.P. and at 45° to the V.P. Draw the projections of *AB* and determine its traces.
5. The end *A* of a line *AB* is in the H.P. and 25 mm behind the V.P. The end *B* is in the V.P. and 50 mm above the H.P. The distance between the end projectors is 75 mm. Draw the projections of *AB* and determine its true

9. The front view of a line *AB* measures 65 mm and makes an angle of 45° with *xy*. *A* is in the H.P. and the V.T. of the line is 15 mm below the H.P. The line is inclined at 30° to the V.P. Draw the projections of *AB* and find its true length and inclination with the H.P. Also locate its H.T.
10. A room is 4.8 m × 4.2 m × 3.6 m high. Determine graphically the distance between a top corner and the bottom corner diagonally opposite to it.
11. A line *AB* is in the first quadrant. Its end *A* and *B* are 20 mm and 60 mm in front of the V.P. respectively. The distance between the end projectors is 75 mm. The line is inclined at 30° to the H.P. and its H.T. is 10 mm above *xy*. Draw the projections of *AB* and determine its true length and the V.T.
12. Two oranges on a tree are respectively 1.8 m and 3 m above the ground, and 1.2 m and 2.1 m from a 0.3 m thick wall, but on the opposite sides of it. The distance between the oranges, measured along the ground and parallel to the wall is 2.7 m. Determine the real distance between the oranges.
13. Draw an isosceles triangle *abc* of base *ab* 40 mm and altitude 75 mm with *a* in *xy* and *ab* inclined at 45° to *xy*. The figure is the top view of a triangle whose corners *A*, *B* and *C* are respectively 75 mm, 25 mm and 50 mm above the H.P. Determine the true shape of the triangle and the inclination of the side *AB* with the two planes.
14. Three points *A*, *B* and *C* are 7.5 m above the ground level, on the ground level and 9 m below the ground level respectively. They are connected by roads with each other and are seen at angles of depression of 10°, 15° and 30° respectively from a point *O* on a hill 30 m above the ground level. *A* is due north-east, *B* is due north and *C* is due south-east of *O*. Find the lengths of the connecting roads.
15. A pipe-line from a point *A*, running due north-east has a downward gradient of 1 in 5. Another point *B* is 12 m away from and due east of *A* and on the same level. Find the length and slope of a pipe-line from *B* which runs due 15° east of north and meets the pipe-line from *A*.
16. The guy ropes of two poles 12 m apart, are attached to a point 15 m above the ground on the corner of a building. The points of attachment on the poles are 7.5 m and 4.5 m above the ground and the ropes make 45° and 30° respectively with the ground. Draw the projections and find the distances of the poles from the building and the lengths of the guy ropes.



Chapter 11 PROJECTIONS ON AUXILIARY PLANES

11-0. INTRODUCTION

Two views of an object, viz. the front view and the top view (projected on the principal planes of projection), are sometimes not sufficient to convey all the information regarding the object. Additional views, called *auxiliary views*, are therefore, projected on other planes known as *auxiliary planes*. These views are often found necessary in technical drawings. Auxiliary views may also be used for determining

(i) the true length of a line,

(ii) the point-view of a line,

(iii) the edge-view of a plane,

(iv) the true size and form of a plane etc.

They are thus very useful in finding solutions of problems in practical solid geometry.

This chapter deals with the following topics:

1. Types of auxiliary planes and views.
2. Projection of a point on an auxiliary plane.
3. Projections of lines and planes by the use of auxiliary planes.
4. To determine true length of a line.
5. To obtain point-view of a line and edge-view of a plane.
6. To determine true shape of a plane figure.

11-1. TYPES OF AUXILIARY PLANES AND VIEWS

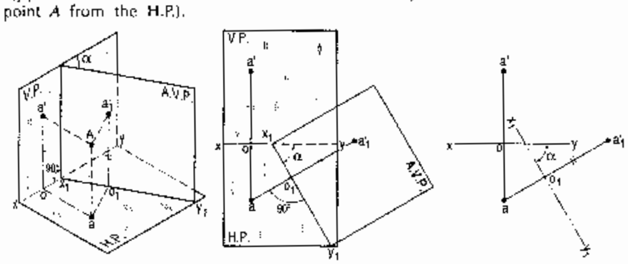
11-2. PROJECTION OF A POINT ON AN AUXILIARY PLANE

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 25 for the projection of a point on an auxiliary plane.

(1) Projection of a point on an auxiliary vertical plane:

A point *A* [fig. 11-1(i)] is situated in front of the V.P. and above the H.P. A.V.P. is the auxiliary vertical plane inclined at an angle α to the V.P. The H.P. and the A.V.P. meet at right angles in the line x_1y_1.

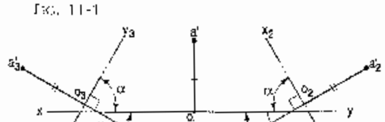
a' and a are respectively, the front view and the top view of the point *A*. a'_1 is the auxiliary front view obtained by drawing a projector Aa'_1 perpendicular to the A.V.P. It can be clearly seen that a'_1o_1 (the distance of the auxiliary front view a'_1 from x_1y_1) = a'o (the distance of the front view a' from *xy*) = *Aa* (the distance of the point *A* from the H.P.).



(i) (ii) (iii)

Fig. 11-1

Fig. 11-1(ii) shows the V.P. and the A.V.P. rotated about the H.P. to which they are perpendicular. The line of intersection x_1y_1 between the A.V.P. and the H.P.,



19. Three guy ropes *AB*, *CD* and *EF* are tied at points *A*, *C* and *E* on a vertical post 15 m long at heights of 14 m, 12 m and 10 m respectively from the ground. The lower ends of the ropes are tied to hooks at points *B*, *D* and *F* on the ground level. If the points *B*, *D* and *F* lie at the corners of an equilateral triangle of 9 m long sides and if the post is situated at the centre of this triangle, determine graphically the length of each rope and its inclination with the ground. Assume the thickness of the post and the ropes to be equal to that of a line.
20. A line *AB*, 80 mm long, makes an angle of 60° with the H.P. and lies in an auxiliary vertical plane (A.V.P.), which makes an angle of 45° with the V.P. Its end *A* is 10 mm away from both the H.P. and the V.P.

    Draw the projections of *AB* and determine (i) its true inclination with the V.P. and (ii) its traces.
21. A line *PQ* is 75 mm long and lies in an auxiliary inclined plane (A.I.P.) which makes an angle of 45° with the H.P. The front view of the line measures 55 mm and the end *P* is in the V.P. and 20 mm above the H.P.

    Draw the projections of *PQ* and find (i) its inclinations with both the planes and (ii) its traces.
22. A line *AB*, 80 mm long, makes an angle of 30° with the V.P. and lies in a plane perpendicular to both the H.P. and the V.P. Its end *A* is in the H.P. and the end *B* is in the V.P. Draw its projections and show its traces.
23. The front view of a line makes an angle of 30° with xy. The H.T. of the line is 45 mm in front of the V.P., while its V.T. is 30 mm below the H.P. One end of the line is 10 mm above the H.P. and the other end is 100 mm in front of the V.P.

    Draw the projections of the line and determine (i) its true length, and (ii) its inclinations with the H.P. and the V.P.
24. A room is 6 m × 5 m × 3.5 m high. An electric bracket light is above the centre of the longer wall and 1 m below the ceiling. The bulb is 0.3 m away from the wall. The switch for the light is on an adjacent wall, 1.5 m above the floor and 1 m away from the other longer wall. Find graphically the shortest distance between the bulb and the switch.
25. Three lines oa, ob and oc are respectively 25 mm, 45 mm and 65 mm long, each making 120° angles with the other two and the shortest line being vertical. The figure is the top view of the three rods *OA*, *OB* and *OC* whose ends *A*, *B* and *C* are on the ground, while *O* is 100 mm above it. Draw the front view and determine the length of each rod and its inclination with the ground.
26. The projectors of the ends of a line PQ are 90 mm apart. P is 20 mm above

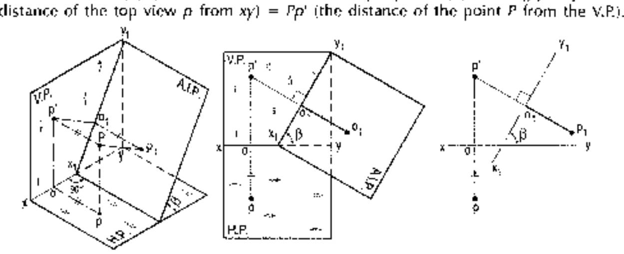
28. Two pegs *A* and *B* are fixed in each of the two adjacent side walls (of a rectangular room) which meet in a corner. Peg *A* is 1.5 m above the floor, 1.2 m from the side wall and is protruding 0.3 m from the wall. Peg *B* is 2 m above the floor, 1 m from the other side wall and is also protruding 0.3 m from the wall. Find the distance between the ends of the pegs.
29. Two objects *A* and *B*, 10 m above and 7 m below the ground level respectively, are observed from the top of a tower 35 m high from the ground. Both the objects make an angle of depression of 45° with the horizon. The horizontal distance between *A* and *B* is 20 m. Draw to scale 1:250, the projections of the objects and the tower and find (a) the true distance between *A* and *B*, and (b) the angle of depression of another object *C* situated on the ground midway between *A* and *B*.
30. A room measures 8 m long, 5 m wide and 4 m high. An electric point hangs in the centre of the ceiling and 1 m below it. A thin straight wire connects the point to a switch kept in one of the corners of the room and 2 m above the floor. Draw the projections of the wire, and find the length of the wire and its slope-angle with the floor.
31. A rectangular tank 4 m high is strengthened by four stay rods one at each corner, connecting the top corner to a point in the bottom 0.7 m and 1.2 m from the sides of the tank. Find graphically the length of the rod required and the angle it makes with the surface of the tank.
32. Three vertical poles *AB*, *CD* and *EF* are respectively 5, 8 and 12 metres long. Their ends *B*, *D* and *F* are on the ground and lie at the corners of an equilateral triangle of 10 metres long sides. Determine graphically the distance between the top ends of the poles, viz. *AC*, *CE* and *EA*.
33. The front view of a line *AB* measures 70 mm and makes an angle of 45° with *xy*. *A* is in the H.P. and the V.T. of the line is 15 mm below the H.P. The line is inclined at 30° to the V.P. Draw the projections of *AB*, and find its true length, inclination with the H.P. and its H.T.
34. A line *AB* measures 100 mm. The projectors through its V.T. and the end *A* are 40 mm apart. The point *A* is 30 mm below the H.P. and 20 mm behind the V.P. The V.T. is 10 mm above the H.P. Draw the projections of the line and determine its H.T. and inclinations with the H.P. and the V.P.
35. A horizontal wooden platform is 3.5 m long and 2 m wide. It is suspended from a hook by means of chains attached at its four corners. The hook is situated vertically above the centre of the platform and at a distance of 5 m above it. Determine graphically the length of each chain and the angle which

The new reference line making the angle α with xy, can be drawn in four different positions, as shown in fig. 11-2 by lines x_1y_1, x_2y_2 etc. All the front views are projected from the top view a and their distances from their respective reference lines are equal, i.e. $a'_1o_1 = a'_2o_2 ..... = a'o$.

(2) Projection of a point on an auxiliary inclined plane:

A point P [fig. 11-3(i)] is situated above the H.P. and in front of the V.P. A.I.P. is an auxiliary inclined plane making an angle β with the H.P. It meets the V.P. at right angles and in a line x_1y_1.

p' and p are respectively the front view and the top view of the point P. p_1 is the auxiliary top view obtained by drawing the projector Pp_1 perpendicular to the A.I.P. It can be seen that p_1o_1 (the distance of the auxiliary top view p_1 from x_1y_1) $= po$ (the distance of the top view p from xy) $= Pp'$ (the distance of the point P from the V.P.).



(i) (ii) (iii)

Fig. 11-3

The H.P. and the A.I.P. are then rotated about the V.P. to which they are perpendicular [fig. 11-3(ii)]. x_1y_1, the line of intersection between the V.P. and the A.I.P. makes the angle β with xy. The line joining the front view p' and the auxiliary top view p_1 is at right angles to x_1y_1 and intersects it at o_1. Note that $p_1o_1 = po$.

To draw the orthographic views [fig. 11-3(iii)], draw xy and mark p' and p. Draw x_1y_1 making the angle β with xy.

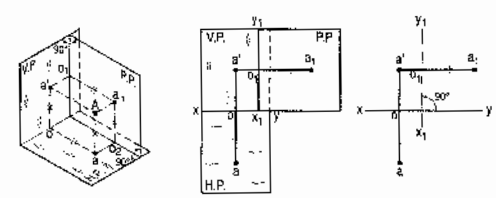
Through the front view p', draw a projector $p'p_1$ perpendicular to and intersecting x_1y_1 at o_1 and such that $p_1o_1 = po$. p_1 is the required auxiliary front view.

If the inclination of the A.V.P. with the V.P. is increased so that $\alpha = 90°$, the A.V.P. will be perpendicular to both the planes. Similarly, if the inclination of the A.I.P. with the H.P. is increased so that $\beta = 90°$, it will also be perpendicular to both the H.P. and the V.P. *This plane is called the profile plane* (P.P.). It may be rotated about any one of the two principal planes. The view on this plane can, therefore, be projected from either the top view or the front view and named accordingly.

(3) Projection of a point on an auxiliary plane perpendicular to both the principal planes:

In fig. 11-5(i), A is a point, P.P. is an auxiliary plane perpendicular to the H.P. and the V.P. a_1 is the auxiliary view projected on the P.P. It can be seen that $a_1o_2 = ao = Aa$ (the distance of A from the H.P.). Also $a_1o_1 = ao = Aa'$ (the distance of A from the V.P.).

Fig. 11-5(ii) shows the P.P. rotated about the V.P. a_1 lies on the projector drawn through the front view a' and perpendicular to the line of intersection between the V.P. and the P.P.

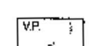


(i) (ii) (iii)

Fig. 11-5

It is thus projected from the front view and hence, called the auxiliary top view. In technical drawings, this view is generally termed as the *side view, end view or end front view*. Note that $a_1o_1 = ao$.

Note that, when seen from the left, the new reference line and the side view



General conclusions:

(i) *The auxiliary top view* of a point lies on a line drawn through the front view, perpendicular to the new reference line (x_1y_1) and at a distance from it, equal to the distance of the first top view from its own reference line (xy).

(ii) *The auxiliary front view* of a point lies on a line drawn through the top view, perpendicular to the new reference line (x_1y_1) and at a distance from it, equal to the distance of the first front view from its own reference line (xy).

(iii) The distances of all the front views of the same point (projected from the same top view) from their respective reference lines are equal.

(iv) The distances of all the top views of the same point (projected from the same front view) from their respective reference lines are equal.

Problem 11-1. (fig. 11-7 and fig. 11-8): *The projections of a line AB are given. Draw (i) an auxiliary front view of the line on an A.V.P. inclined at 60° to the V.P. and (ii) an auxiliary top view on an A.I.P. making an angle of 75° with the H.P.*

Let ab and $a'b'$ be the given projections.

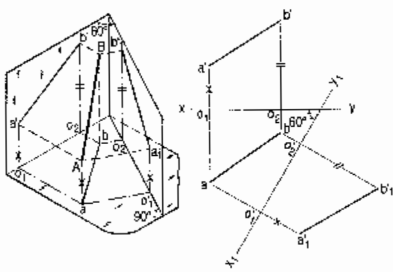


Fig. 11-7

(i) Draw a new reference line x_1y_1, inclined at 60° to xy to represent the A.V.P. (fig. 11-7).

(ii) Project the auxiliary front view $a'_1b'_1$ from the top view ab, by making $a'_1o'_1$ equal to $a'o_1$, and $b'_1o'_2$ equal to $b'o_2$.

(iii) Similarly, draw x_2y_2 for the A.I.P. inclined at 75° to xy (fig. 11-8).

(iv) Project the auxiliary top view a_2b_2 from the front view $a'b'$, making $a_2o''_1$ equal to ao_1 and $b_2o''_2$ equal to bo_2.

11-3. PROJECTIONS OF LINES AND PLANES BY THE USE OF AUXILIARY PLANES

Projections of lines and planes at given inclinations to one or both the planes may also be obtained by the use of auxiliary planes. The method adopted is called the *alteration or change-of-reference-line method.*

The line, in its initial position, is assumed to be parallel to both the planes of projection. Then, instead of making the line inclined to one of the planes, an auxiliary plane inclined to the line is assumed, i.e. a new reference line is drawn and the view is projected on it.

In case of a plane, it is kept parallel to one of the planes of projection in the initial stage, the required views being obtained by projecting it on new reference lines.

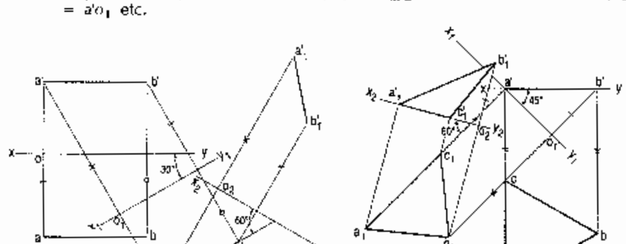
Problem 11-2. (fig. 11-9): *A line AB, 50 mm long, is inclined at 30° to the H.P. and its top view makes an angle of 60° with the V.P. Draw its projections.*

(i) Draw the projections ab and $a'b'$, assuming AB to be parallel to both the planes.

(ii) Project a new top view a_1b_1 on a new reference line x_1y_1 inclined at 30° to $a'b'$. a_1b_1 is still parallel to x_1y_1.

(iii) Draw the another reference line x_2y_2 to represent an A.V.P. inclined at 60° to the top view a_1b_1.

(iv) Project the required front view $a'_1b'_1$ on x_2y_2. Note that $a_1o_1 = ao$, $a'_1o_2 = a'o_1$ etc.



(iii) Project the new top view $a_1b_1c_1$. Again draw a new reference line x_2y_2 inclined at 60° to the line a_1c_1 (which is to make 60° angle with the V.P.).

(iv) Project the final front view $a'_1b'_1c'_1$ on x_2y_2. Note that $a'_1c'_1$ is in x_2y_2.

11-4. TO DETERMINE TRUE LENGTH OF A LINE

We have seen that the true length of a line and its inclinations with the planes of projection can be determined by making each of its projections parallel to *xy* (chapter 10).

Instead of changing the position of the projection, that of the plane may be altered, i.e. a new reference line representing an auxiliary plane may be drawn parallel to the projection. The auxiliary projection on that reference line will show the true length and true inclination of the line with the other plane.

Problem 11-4. (fig. 11-11): *The projections of a line AB are given. To determine its true length and true inclinations with the reference planes.*

Let *ab* and *a'b'* be the given projections of *AB*.

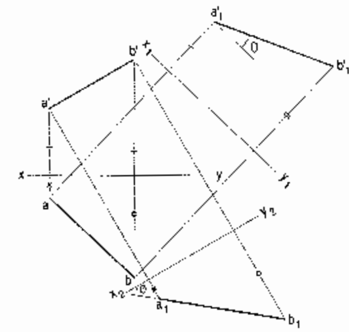


FIG. 11-11

(i) Draw a reference line x_1y_1 to represent an A.V.P. parallel to *ab*, the top view.

(ii) Project the auxiliary front view $a'_1b'_1$ which is the true length of *AB*. θ is its inclination with the H.P.

(iii) Produce $a'_1b'_1$ to meet *xy* at *v* and x_1y_1 at *h*. The H.T. will be on the top view *ab*-produced, so that oH.T. = o_1h. The V.T. is on the front view *a'b'*-produced, so that oV.T. = o_1v.

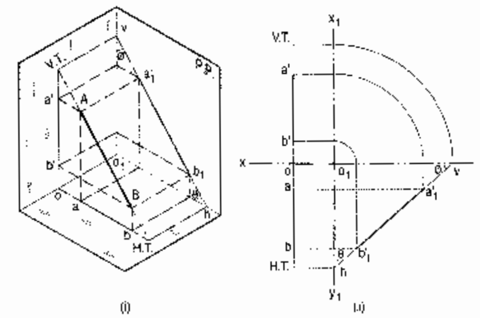


FIG. 11-12

The distances of the ends of the line from x_1y_1 are kept equal to their respective distances above *xy* by drawing lines inclined at 45° as shown.

11-5. TO OBTAIN POINT-VIEW OF A LINE AND EDGE-VIEW OF A PLANE

We have seen in chapter 10 that when a line is perpendicular to a reference plane, its projection on that plane is a point; while its projection on the other reference plane shows its true length. In other words, the projection of the view of a line showing its true length, on an auxiliary plane perpendicular to that view will be a point.

Similarly, a plane will be seen as a line, when it is projected on a plane, perpendicular to the true length of any one of its elements. The projection of the

When considering the side view, x_1y_1 is the edge-view of the V.P. and *xy* is that of the H.P. The point *o* is the side view or the point-view of the line of intersection of the V.P. and the H.P., i.e. x_1y_1 and *xy*. The line joining any point on $p'_1q'_1$, with *o* will show the shortest distance of that point from *xy*.

(ii) Find the mid-point a'_1 of $p'_1q'_1$ and join it with *o*. oa'_1 is the distance of the mid-point of *PQ* from *xy*.

(iii) From *o*, draw a line *ob* perpendicular to $p'_1q'_1$. *ob* is the shortest distance of *PQ* from *xy*. It will be perpendicular to both *PQ* and *xy*.

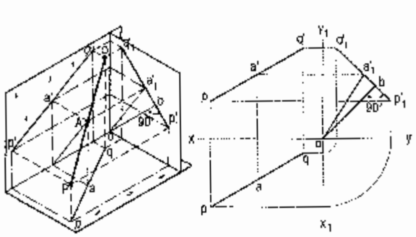


FIG. 11-13

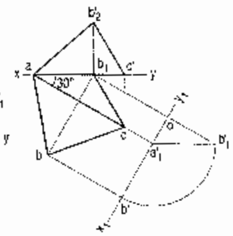


FIG. 11-14

Problem 11-7. (fig. 11-14): *An isosceles triangle ABC, base 60 mm and altitude 40 mm has its base AC in the H.P. and inclined at 30° to the V.P. The corners A and B are in the V.P. Draw its projections.*

Assume the triangle to be lying in the H.P. with the base *AC* inclined at 30° to the V.P. and *A* in the V.P. Its true shape will be seen in the top view.

(i) Therefore, in the top view, draw *ac* 60 mm long and inclined at 30° to *xy* and complete the triangle *abc*.

(ii) Project *c* to *c'* on *xy*. When the triangle is tilted about the edge *AC*, so that the corner *B* is in the V.P., in the top view the point *b* will move along a line perpendicular to *ac*, to a point b_1 in *xy*. The distance of the front view of *B* below *xy* may now be determined by means of an auxiliary plane.

11-6. TO DETERMINE TRUE SHAPE OF A PLANE FIGURE

The true shape of any plane figure may be determined by means of its projections on auxiliary planes, as illustrated in problems 11-8 and 11-9.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 26 for the following problem.

Problem 11-8. (fig. 11-15): *Projections of a pentagon resting on the ground on one of its sides are given. Determine the true shape of the pentagon.*

ae is the true length of the side because it is parallel to the H.P.

(i) Draw a reference line x_1y_1 perpendicular to *ae*. Project an auxiliary front view on it. It will give a point-view a'_1 and e'_1 of *ae* and an edge-view $a'_1c'_1$ of the pentagon.

(ii) Draw another reference line x_2y_2 parallel to a_1c_1 and project an auxiliary top view $a_1b_1c_1d_1e_1$, which will be the true shape of the pentagon.

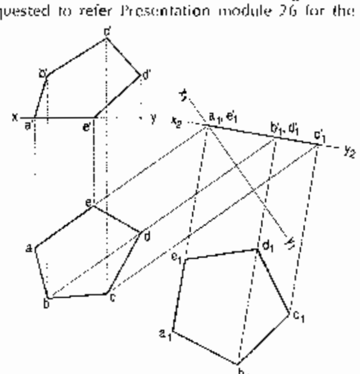
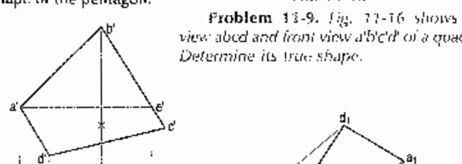


FIG. 11-15

Problem 11-9. (fig. 11-16 shows the top view *abcd* and front view *a'b'c'd'* of a quadrilateral. Determine its true shape.



(i) Through any corner, say a', draw a line parallel to xy and meeting $b'c'$ at e'.

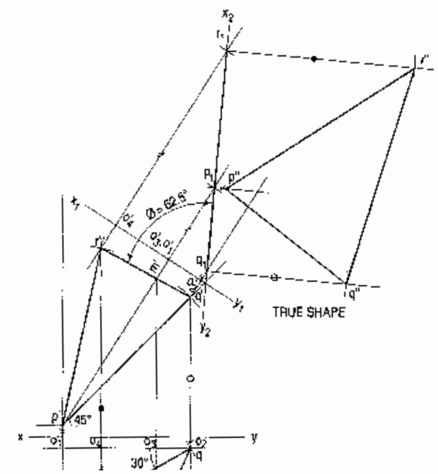
(ii) Project e' to e on the line bc in the top view. ae is the true length of the element AE.

(iii) Draw a reference line x_1y_1 perpendicular to ae. Project a new front view from the top view. It is a line $d'_1b'_1$.

(iv) Again, draw another reference line x_2y_2 parallel to the line-view $d'_1b'_1$ and project on it a new top view $a_1b_1c_1d_1$ which will show the true shape of the quadrilateral.

Note that $b'_1o_1 = b'o$, $b'_1o_2 = bo_1$ etc.

Problem 11-10. (fig. 11-17): *The projections of a triangular plate PQR appear as under:*



(a) *Top view : pq makes 30° with xy.*

qr = 95 mm. The corner q is 5 mm in front of the V.P.

(b) *Front view : p'q' = 60 mm; q'r' = 15 mm and r'p' = 80 mm.*

p'q' makes an angle of 45° with xy. The corner P of the plate is 5 mm above the H.P.

Draw the projections of the plate and determine true shape of the triangular plate.

(i) Mark xy. Draw top view and front view from the given dimensions.

(ii) Mark a line pm in the top view parallel to xy. Draw the projection of pm in the front view $p'm'$ as shown.

(iii) Select x_1y_1 perpendicular to $p'm'$ and project new top view taking the distances o_1p, o_4r and o_2q from the top view.

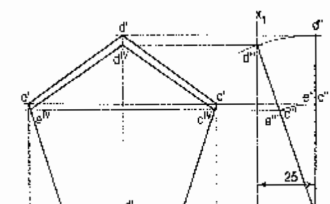
(iv) Select x_2y_2 and draw new front view as shown in fig. 11-17.

(v) Measure angle ϕ.

Problem 11-11. *A regular pentagon of 30 mm side is resting on one of its sides on the H.P. having that side parallel to and 25 mm in front of V.P. It is tilted about that side so that its highest corner rests in the V.P. Draw the projections of the pentagon.*

(i) Keep the plane of pentagon parallel to V.P. Draw the front view and top view as shown in fig. 11-18.

(ii) Project $a'b'c'd'e'$ on the line parallel to and 25 mm behind x_1y_1. Taking a'' as a center, tilt $a''d''$ such that d'' touches x_1y_1 at d'''. Complete the projections as shown in fig. **11-18.**



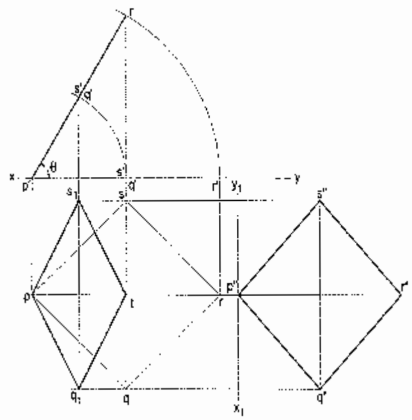


FIG. 11-19

(i) Assuming that the square plate is equally inclined with a vertical plane, draw its top view and front view as shown in fig. 11-19.

(ii) Raise r' so that the diagonal qs becomes twice the diagonal pt. Draw the top view p, q_1, t and s_1. Measure angle θ.

(iii) Draw new reference line x_1y_1 parallel to s_1q_1. Project new front view, keeping the same distances of points p', q', r' and s' from xy.

(iv) Measure angle θ.

EXERCISES 11

Solve the following exercises by applying the method of projections on auxiliary planes:

5. Determine the true shape of the figure, the top view of which is a regular pentagon of 35 mm sides, having one side inclined at 30° to xy and whose front view is a straight line making an angle of 45° to xy.

6. An equilateral triangle ABC of sides 75 mm long has its side AB in the V.P. and inclined at 60° to the H.P. Its plane makes an angle of 45° with the V.P. Draw its projections.

7. An isosceles triangle PQR having the base PQ 50 mm long and altitude 75 mm has its corners P, Q, and R 25 mm, 50 mm and 75 mm respectively above the ground. Draw its projections.

8. A thin regular pentagonal plate of 60 mm long edges has one of its edges in the H.P. and perpendicular to the V.P. while its farthest corner is 60 mm above the H.P. Draw the projections of the plate. Project another front view on an A.V.P. making an angle of 45° with the V.P.

9. A thin composite plate consists of a square of 70 mm long sides with an additional semi-circle constructed on CD as diameter. The side AB is vertical and the surface of the plate makes an angle of 45° with the V.P. Draw its projections. Project another top view on an A.I.P. making an angle of 30° with the side AB.

10. A 60° set-square of 125 mm longest side is so kept that the longest side is in the H.P. making an angle of 30° with the V.P. and the set-square itself inclined at 45° to the H.P. Draw the projections of the set-square.

11. A plane figure is composed of an equilateral triangle ABC and a semi-circle on AC as diameter. The length of the side AB is 50 mm and is parallel to the V.P. The corner B is 20 mm behind the V.P. and 15 mm below the H.P. The plane of the figure is inclined at 45° to the H.P. Draw the projections of the plane figure.

12. An equilateral triangle ABC having side length as 50 mm is suspended from a point O on the side AB 15 mm from A in such a way that the plane of the triangle makes an angle of 60° with the V.P. The point O is 20 mm below the H.P. and 40 mm behind the V.P. Draw the projections of the triangle.

13. A hexagonal plate of side 40 mm, is resting on a corner in V.P. with its surface making an angle of 30° with the V.P. The front view of the diagonal passing through that corner is inclined at 45° to the line xy. Draw the projections

12-0. INTRODUCTION

Plane figures or surfaces have only two dimensions, viz. length and breadth. They do not have thickness. A plane figure may be assumed to be contained by a plane, and its projections can be drawn, if the position of that plane with respect to the principal planes of projection is known.

In this chapter, we shall discuss the following topics:

1. Types of planes and their projections.
2. Traces of planes.

12-1. TYPES OF PLANES

Planes may be divided into two main types:

(1) Perpendicular planes.
(2) Oblique planes.

(1) **Perpendicular planes:** These planes can be divided into the following sub-types:

(i) Perpendicular to both the reference planes.
(ii) Perpendicular to one plane and parallel to the other.
(iii) Perpendicular to one plane and inclined to the other.

(i) ***Perpendicular to both the reference planes*** (fig. 12-1): A square *ABCD* is perpendicular to both the planes. Its H.T. and V.T. are in a straight line perpendicular to *xy*.

The front view *b'c'* and the top view *ab* of the square are both lines coinciding with the V.T. and the H.T. respectively.

(ii) ***Perpendicular to one plane and parallel to the other plane:***

(a) Plane, perpendicular to the H.P. and parallel to the V.P. [fig. 12-2(i)].

A triangle *PQR* is perpendicular to the H.P. and is parallel to the V.P. Its H.T. is parallel to *xy*. It has no V.T.

The front view *p'q'r'* shows the exact shape and size of the triangle. The top view *pqr* is a line parallel to *xy*. It coincides with the H.T.

(b) Plane, perpendicular to the V.P. and parallel to the H.P. [fig. 12-2(ii)].

A square *ABCD* is perpendicular to the V.P. and parallel to the H.P. Its V.T. is parallel to *xy*. It has no H.T.

The top view *abcd* shows the true shape and true size of the square. The front view *a'b'* is a line, parallel to *xy*. It coincides with the V.T.

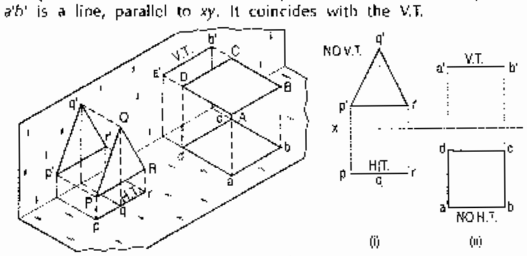


Fig. 12-2

(iii) ***Perpendicular to one plane and inclined to the other plane:***

(a) Plane, perpendicular to the H.P. and inclined to the V.P. (fig. 12-3).

A square *ABCD* is perpendicular to the H.P. and inclined at an angle ø to the V.P. Its V.T. is perpendicular to *xy*. Its H.T. is inclined at ø to *xy*.

Its top view *ab* is a line inclined at ø to *xy*. The front view *a'b'c'd'* is smaller than *ABCD*.

(b) Plane, perpendicular to the V.P. and inclined to the H.P. (fig. 12-4).

A square *ABCD* is perpendicular to the V.P. and inclined at an angle θ to the H.P. Its H.T. is perpendicular to *xy*. Its V.T. makes the angle θ with *xy*. Its front view *a'b'* is a line inclined at θ to *xy*. The top view *abcd* is a rectangle which is smaller than the square *ABCD*.

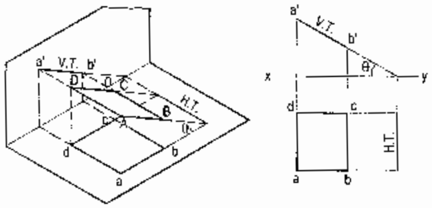


Fig. 12-4

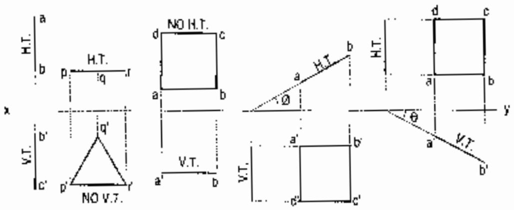


Fig. 12-5

Fig. 12-5 shows the projections and the traces of all these perpendicular planes by third-angle projection method.

(2) **Oblique planes:** Planes which are inclined to both the reference planes are called *oblique planes*. Representation of oblique planes by their traces is too advanced to be included in this book.

A few problems on the projections of plane figures inclined to both the reference planes are however, illustrated at the end of the chapter. They will prove to be of

12-3. GENERAL CONCLUSIONS

(1) **Traces:**

(a) When a plane is perpendicular to both the reference planes, its traces lie on a straight line perpendicular to *xy*.

(b) When a plane is perpendicular to one of the reference planes, its trace upon the other plane is perpendicular to *xy* (except when it is parallel to the other plane).

(c) When a plane is parallel to a reference plane, it has no trace on that plane. Its trace on the other reference plane, to which it is perpendicular, is parallel to *xy*.

(d) When a plane is inclined to the H.P. and perpendicular to the V.P., its inclination is shown by the angle which its V.T. makes with *xy*. When it is inclined to the V.P. and perpendicular to the H.P., its inclination is shown by the angle which its H.T. makes with *xy*.

(e) When a plane has two traces, they, produced if necessary, intersect in *xy* (except when both are parallel to *xy* as in case of some oblique planes).

(2) **Projections:**

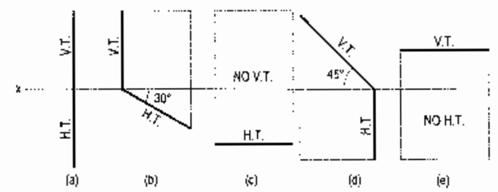
(a) When a plane is perpendicular to a reference plane, its projection on that plane is a straight line.

(b) When a plane is parallel to a reference plane, its projection on that plane shows its true shape and size.

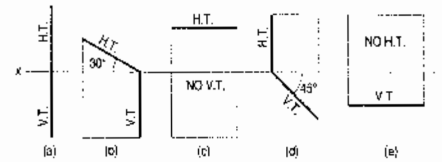
(c) When a plane is perpendicular to one of the reference planes and inclined to the other, its inclination is shown by the angle which its projection on the plane to which it is perpendicular, makes with *xy*. Its projection on the plane to which it is inclined, is smaller than the plane itself.

Problem 12-1. *Show by means of traces, each of the following planes:*

(a) *Perpendicular to the H.P. and the V.P.*
(b) *Perpendicular to the H.P. and inclined at 30° to the V.P.*
(c) *Parallel to and 40 mm away from the V.P.*



(First-angle projection)
FIG. 12-6



(Third-angle projection)
FIG. 12-7

12-4. PROJECTIONS OF PLANES PARALLEL TO ONE OF THE REFERENCE PLANES

The projection of a plane on the reference plane parallel to it will show its true shape. Hence, beginning should be made by drawing that view. The other view which will be a line, should then be projected from it.

(1) **When the plane is parallel to the H.P.:** The top view should be drawn first and the front view projected from it.

Problem 12-2. (fig. 12-8): *An equilateral triangle of 50 mm side has its V.T. parallel to and 25 mm above xy. It has no H.T. Draw its projections when one of its sides is inclined at 45° to the V.P.*

As the V.T. is parallel to xy and as there is no H.T.

Problem 12-3. (fig. 12-9): *A square ABCD of 40 mm side has a corner on the H.P. and 20 mm in front of the V.P. All the sides of the square are equally inclined to the H.P. and parallel to the V.P. Draw its projections and show its traces.*

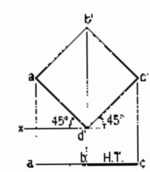


FIG. 12-9

As all the sides are parallel to the V.P., the surface of the square also is parallel to it. The front view will show the true shape and position of the square.

(i) Draw a square *a'b'c'd'* in the front view with one corner in *xy* and all its sides inclined at 45° to *xy*.

(ii) Project the top view keeping the line *ac* parallel to *xy* and 30 mm below it. The top view is its H.T. It has no V.T.

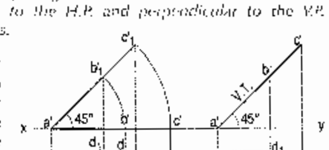
12-5. PROJECTIONS OF PLANES INCLINED TO ONE REFERENCE PLANE AND PERPENDICULAR TO THE OTHER

When a plane is inclined to a reference plane, its projections may be obtained in two stages. In the initial stage, the plane is assumed to be parallel to that reference plane to which it has to be made inclined. It is then tilted to the required inclination in the second stage.

(1) **Plane, inclined to the H.P. and perpendicular to the V.P.:** When the plane is inclined to the H.P. and perpendicular to the V.P. in the initial stage, it is assumed to be parallel to the H.P. Its top view will show the true shape. The front view will be a line parallel to *xy*. The plane is then tilted so that it is inclined to the H.P. The new front view will be inclined to *xy* at the true inclination. In the top view the corners will move along their respective paths (parallel to *xy*).

Problem 12-4. (fig. 12-10): *A regular pentagon of 25 mm side has one side on the ground. Its plane is inclined at 45° to the H.P. and perpendicular to the V.P. Draw its projections and show its traces.*

Assuming it to be parallel to the H.P.



(i) Draw the pentagon in the top view with one side perpendicular to *xy* [fig. 12-10(i)]. Project the front view. It will be the line

(2) **Plane, inclined to the V.P. and perpendicular to the H.P.:** In the initial stage, the plane may be assumed to be parallel to the V.P. and then tilted to the required position in the next stage. The projections are drawn as illustrated in the next problem.

Problem 12-5. (fig. 12-11): *Draw the projections of a circle of 50 mm diameter, having its plane vertical and inclined at 30° to the V.P. Its centre is 30 mm above the H.P. and 20 mm in front of the V.P. Show also its traces.*

A circle has no corners to project one view from another. However, a number of points, say twelve, equal distances apart, may be marked on its circumference.

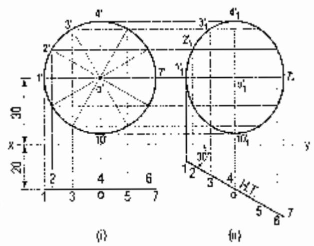


FIG. 12-11

(i) Assuming the circle to be parallel to the V.P., draw its projections. The front view will be a circle [fig. 12-11(i)], having its centre 30 mm above *xy*. The top view will be a line, parallel to and 20 mm below *xy*.

(ii) Divide the circumference into twelve equal parts (with a 30°-60° set-square) and mark the points as shown. Project these points in the top view. The centre O will coincide with the point 4.

(iii) When the circle is tilted, so as to make 30° angle with the V.P., its top view will become inclined at 30° to *xy*. In the front view all the points will move along their respective paths (parallel to *xy*). Reproduce the top view keeping the centre *o* at the same distance, viz. 20 mm from *xy* and inclined at 30° to *xy* [fig. 12-11(ii)].

(iv) For the final front view, project all the points upwards from this top view and horizontally from the first front view. Draw a freehand curve through the twelve points $1'_1$, $2'_1$ etc. This curve will be an ellipse.

12-6. PROJECTIONS OF OBLIQUE PLANES

When a plane has its surface inclined to one plane and an edge or a diameter or a diagonal parallel to that plane and inclined to the other plane, its projections are drawn in three stages.

(1) If the surface of the plane is inclined to the H.P. and an edge (or a diameter

If an edge is in the H.P. or on the ground, in the initial position, the plane is assumed to be lying in the H.P. or on the ground, with the edge perpendicular to the V.P. *If a corner is in the H.P. or on the ground, the line joining that corner with the centre of the plane is kept parallel to the V.P.*

(2) Similarly, if the surface of the plane is inclined to the V.P. and an edge (or a diameter or a diagonal) is parallel to the V.P. and inclined to the H.P.,

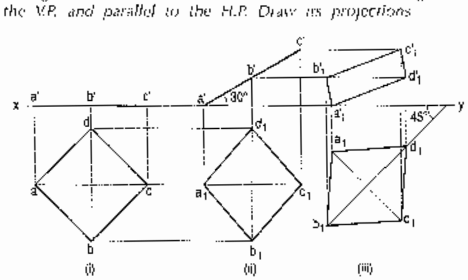
(i) in the initial position, the plane is assumed to be parallel to the V.P. and an edge perpendicular to the H.P.

(ii) It is then tilted so as to make the required angle with the V.P. Its top view in this position will be a line, while its front view will be smaller in size.

(iii) When the plane is turned to the required inclination with the H.P., only the position of the front view will change. Its shape and size will not be affected. In the final top view, the corresponding distances of all the corners from *xy* will remain the same as in the second top view.

If an edge is in the V.P., in the initial position, the plane is assumed to be lying in the V.P. with an edge perpendicular to the H.P. *If a corner is in the V.P., the line joining that corner with centre of the plane is kept parallel to the H.P.*

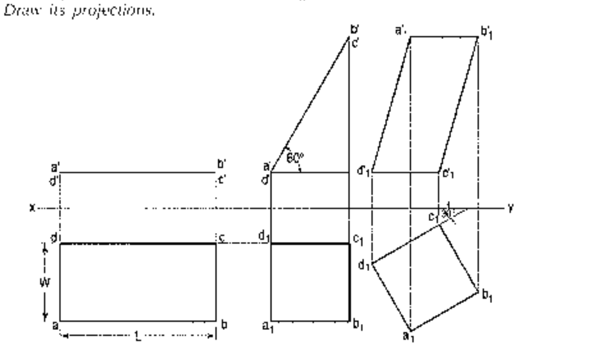
Problem 12-6. (fig. 12-12): *A square ABCD of 50 mm side has its corner A in the H.P., its diagonal AC inclined at 30° to the H.P. and the diagonal BD inclined at 45° to the V.P. and parallel to the H.P. Draw its projections.*



(iii) Reproduce the top view so that b_1d_1 is inclined at 45° to *xy*. Project the final front view upwards from this top view and horizontally from the second front view.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 27 for the following problem.

Problem 12-7. (Fig. 12-13): *A rectangular plane surface of size L × W is positioned in the first quadrant and is inclined at an angle of 60° with the H.P. and 30° with the V.P. Draw its projections.*



STEP 1 (i) STEP 2 (ii) STEP 3 (iii)

FIG. 12-13

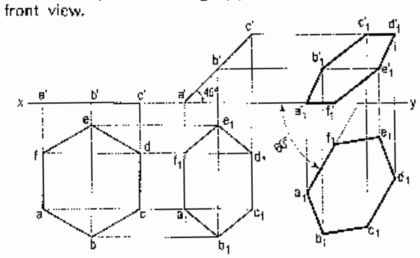
(i) The plane is first assumed to be parallel to H.P. with its shorter edge perpendicular to V.P. In this position, true shape and size of the plane is given by its projection on H.P. The front view will be a true line parallel to the reference line *xy*.

(ii) Rotate the front view projection by 60° (the angle of inclination of plane with H.P.) as shown in Step 2 of fig. 12-13(ii). Draw vertical lines from the ends of line *a'd'* and *b'c'* to intersect horizontal lines drawn from the top view *abcd*

(i) Draw the hexagon in the top view with one side perpendicular to *xy*. Project the front view *a'c'* in *xy*.

(ii) Draw *a'c'* inclined at 45° to *xy* keeping *a'* or *c'* in *xy* and project the second top view.

(iii) Reproduce this top view making a_1f_1 inclined at 60° to *xy* and project the final front view.

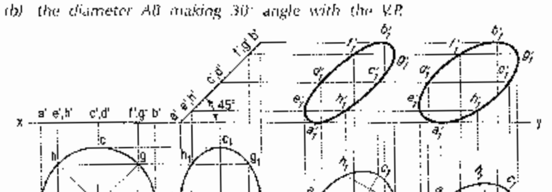


(i) (ii) (iii)

FIG. 12-14

Problem 12-9. (fig. 12-15): *Draw the projections of a circle of 50 mm diameter resting in the H.P. on a point A on the circumference, its plane inclined at 45° to the H.P. and*

(a) *the top view of the diameter AB making 30° angle with the V.P.;*
(b) *the diameter AB making 30° angle with the V.P.*

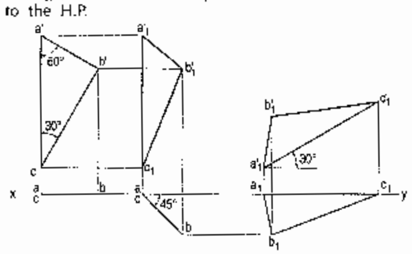


(b) If the diameter *AB*, which makes 45° angle with the H.P., is inclined at 30° to the V.P. also, its top view a_1b_1 will make an angle greater than 30° with *xy*. This apparent angle of inclination is determined as described below.

Draw any line a_1b_2 equal to *AB* and inclined at 30° to *xy* [fig. 12-15(iv)]. With a_1 as centre and radius equal to the top view of *AB*, viz. a_1b_1, draw an arc cutting *rs* (the path of *B* in the top view) at b_3. Draw the line joining a_1 with b_3, and around it, reproduce the second top view. Project the final front view. It is evident that a_1b_3 is inclined to *xy* at an angle θ which is greater than 30°.

Problem 12-10. (fig. 12-16): *A thin 30°-60° set-square has its longest edge in the V.P. and inclined at 30° to the H.P. Its surface makes an angle of 45° with the V.P. Draw its projections.*

In the initial stage, assume the set-square to be in the V.P. with its hypotenuse perpendicular to the H.P.



(i) (ii) (iii)

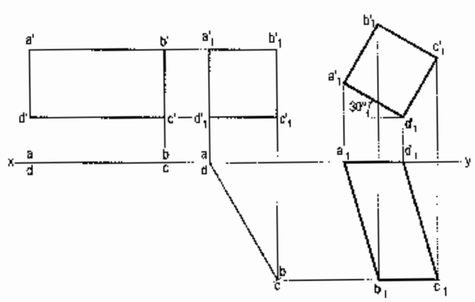
FIG. 12-16

(i) Draw the front view *a'b'c'* and project the top view *ac* in *xy*.

(ii) Tilt *ac* around the end *a* so that it makes 45° angle with *xy* and project the front view $a'_1b'_1c'_1$.

(iii) Reproduce the second front view $a'_1b'_1c'_1$ so that $a'_1b'_1$ makes an angle of 30° with *xy*. Project the final top view $a_1b_1c_1$.

Problem 12-11. (fig. 12-17): *A thin rectangular plate of sides 60 mm × 30 mm has its shorter side in the V.P. and inclined at 30° to the H.P. Project its top view if its front view is a square of 30 mm long sides.*

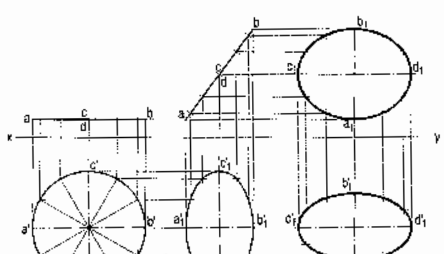


(i) (ii) (iii)

FIG. 12-17

Problem 12-12. (fig. 12-18): *A circular plate of negligible thickness and 50 mm diameter appears as an ellipse in the front view, having its major axis 50 mm long and minor axis 30 mm long. Draw its top view when the major axis of the ellipse is horizontal.*

As the plate is seen as an ellipse in the front view, its surface must be inclined to the V.P.



Problem 12-13. *Fig. 12-19 shows a thin plate of negligible thickness. It rests on its PQ edge with its plane perpendicular to V.P. and inclined 40° to the H.P. Draw its projections.*

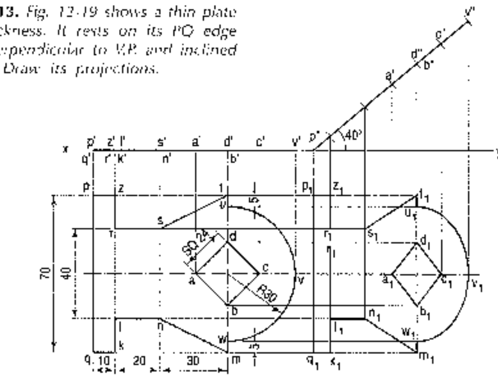


FIG. 12-19

(i) Keep the plane of plate in the H.P. and draw the projections as shown.

(ii) Tilt front view at p'' making an angle of 40°.

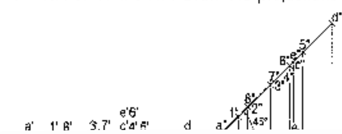
(iii) Project p'', a'', d'', c'', v'' etc. in the top view. Draw horizontal projectors intersecting previously drawn projectors from the front view. Join by smooth curve to complete the top view.

Problem 12-14. (fig. 12-20): *A pentagonal plate of 45 mm side has a circular hole of 40 mm diameter in its centre. The plane stands on one of its sides on the H.P. with its plane perpendicular to V.P. and 45° inclined to the H.P. Draw the projections.*

(i) Keep the plane of plate in the horizontal plane.

(ii) Draw top view and front view as shown.

(iii) Tilt the front view a'' ... d'' at a'' making an



Problem 12-15. (fig. 12-21): *A thin circular plate of 70 mm diameter is resting on its circumference such that its plane is inclined 60° to the H.P. and 30° to the V.P. Draw the projections of the plate.*

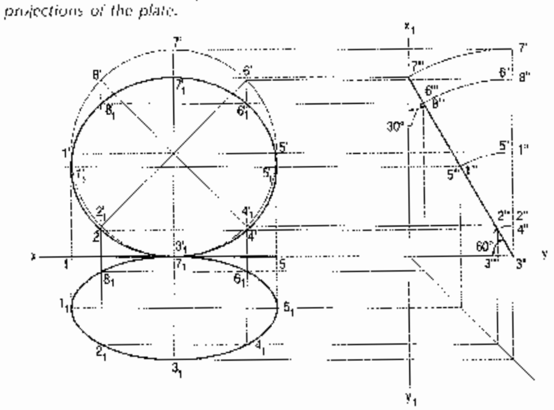


FIG. 12-21

(i) Draw the projection of the plate keeping its plane parallel to the V.P. as shown in fig. 12-21.

(ii) Mark a reference line x_1y_1 perpendicular to xy line to represent the auxiliary plane which is at right angle to both the H.P. and the V.P.

(iii) Divide the front view in eight parts and mark the points 1', 2' ....8'. Project these points on the side view as 1", 2" ....8".

(iv) Tilt the side view 3" 7" such that it touches the x_1y_1 line and also makes 60° with the xy line.

(v) Complete the projection as shown in fig. 12-21.

(iv) PR and QS are lying in H.P. pr and qs are true length. As the plane of the rhombus is inclined to H.P., the top view of the rhombus is going to be a square. But diagonal qs does not change in the length as it is perpendicular to V.P.

(v) Draw the projectors from the points p, q and r, s parallel to the xy. From q_1 and s_1 draw square $p_1\ q_1\ r_1\ s_1$ such that $s_1\ q_1 = p_1\ r_1$ as shown in fig. 12-22.

(vi) Draw vertical projectors from p_1, q_1, r_1 and s_1.

(vii) Projector of p_1 intersects at p'' in xy line. Taking p'' as centre and the radius equal to 60 mm ($p'r'$), draw the arc to intersect the vertical projectors of r_1 at r''. Join $p''r''$. Measure angle of $p''r''$ with xy line.

(viii) Tilt diagonal p_1r_1 at 30° with xy and reproduce square $p_2q_2r_2s_2$. Draw vertical projectors from p_2, q_2, r_2 and s_2 to intersect the horizontal projectors from p'', q'', r'' and s'' at p''', q''', r''' and s'''. Join the points p''', q''', r''' and s''' as shown.

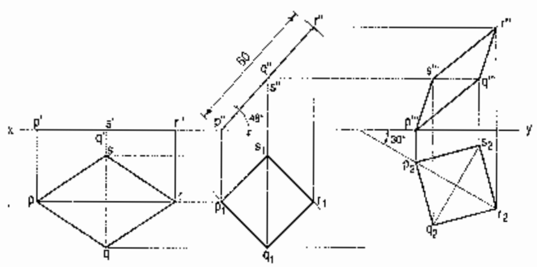


FIG. 12-22

EXERCISES 12

1. Draw an equilateral triangle of 75 mm side and inscribe a circle in it. Draw the projections of the figure, when its plane is vertical and inclined at 30° to the V.P. and one of the sides of the triangle is inclined at 45° to the H.P.

5. Draw a regular hexagon of 40 mm side, with its two sides vertical. Draw a circle of 40 mm diameter in its centre. The figure represents a hexagonal plate with a hole in it and having its surface parallel to the V.P. Draw its projections when the surface is vertical and inclined at 30° to the V.P. Assume the thickness of the plate to be equal to that of a line.
6. Draw the projections of a circle of 75 mm diameter having the end A of the diameter AB in the H.P., the end B in the V.P., and the surface inclined at 30° to the H.P. and at 60° to the V.P.
7. A semi-circular plate of 80 mm diameter has its straight edge in the V.P. and inclined at 45° to the H.P. The surface of the plate makes an angle of 30° with the V.P. Draw its projections.
8. The top view of a plate, the surface of which is perpendicular to the V.P. and inclined at 60° to the H.P. is a circle of 60 mm diameter. Draw its three views.
9. A plate having shape of an isosceles triangle has base 50 mm long and altitude 70 mm. It is so placed that in the front view it is seen as an equilateral triangle of 50 mm sides and one side inclined at 45° to xy. Draw its top view.
10. Draw a rhombus of diagonals 100 mm and 60 mm long, with the longer diagonal horizontal. The figure is the top view of a square of 100 mm long diagonals, with a corner on the ground. Draw its front view and determine the angle which its surface makes with the ground.
11. A composite plate of negligible thickness is made-up of a rectangle 60 mm × 40 mm, and a semi-circle on its longer side. Draw its projections when the longer side is parallel to the H.P. and inclined at 45° to the V.P., the surface of the plate making 30° angle with the H.P.
12. A 60° set-square of 125 mm longest side is so kept that the longest side is in the H.P. making an angle of 30° with the V.P. and the set-square itself inclined at 45° to the H.P. Draw the projections of the set-square.
13. A plane figure is composed of an equilateral triangle ABC and a semi-circle on AC as diameter. The length of the side AB is 50 mm and is parallel to the V.P. The corner B is 20 mm behind the V.P. and 15 mm below the H.P. The plane of the figure is inclined at 45° to the H.P. Draw the projections of the

Chapter 13

PROJECTIONS OF SOLIDS

13-0. INTRODUCTION

A solid has three dimensions, viz. length, breadth and thickness. To represent a solid on a flat surface having only length and breadth, at least two orthographic views are necessary. Sometimes, additional views projected on auxiliary planes become necessary to make the description of a solid complete.

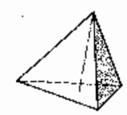
This chapter deals with the following topics:

1. Types of solids.
2. Projections of solids in simple positions.
   (a) Axis perpendicular to the H.P.
   (b) Axis perpendicular to the V.P.
   (c) Axis parallel to both the H.P. and the V.P.
3. Projections of solids with axes inclined to one of the reference planes and parallel to the other.
   (a) Axis inclined to the V.P. and parallel to the H.P.
   (b) Axis inclined to the H.P. and parallel to the V.P.
4. Projections of solids with axes inclined to both the H.P. and the V.P.
5. Projections of spheres.

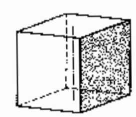
13-1. TYPES OF SOLIDS

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the

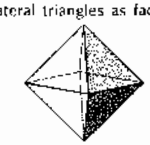
(iii) *Octahedron* (fig. 13-3): It has eight equal equilateral triangles as faces.



Tetrahedron
FIG. 13-1



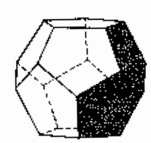
Cube
FIG. 13-2



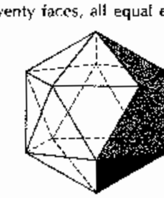
Octahedron
FIG. 13-3

(iv) *Dodecahedron* (fig. 13-4): It has twelve equal and regular pentagons as faces.

(v) *Icosahedron* (fig. 13-5): It has twenty faces, all equal equilateral triangles.



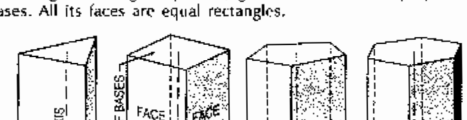
Dodecahedron
FIG. 13-4



Icosahedron
FIG. 13-5

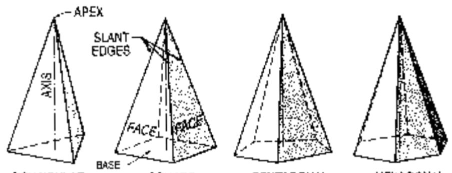
(vi) *Prism:* This is a polyhedron having two equal and similar faces called its ends or bases, parallel to each other and joined by other faces which are parallelograms. The imaginary line joining the centres of the bases is called the axis.

A right and regular prism (fig. 13-6) has its axis perpendicular to the bases. All its faces are equal rectangles.



Oblique prisms and pyramids have their axes inclined to their bases.

Prisms and pyramids are named according to the shape of their bases, as triangular, square, pentagonal, hexagonal etc.



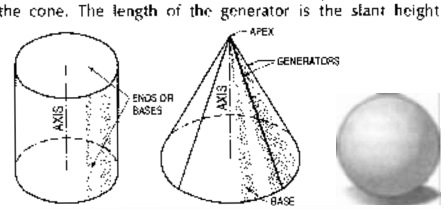
Pyramids
FIG. 13-7

(2) **Solids of revolution:**

(i) *Cylinder* (fig. 13-8): A *right circular cylinder* is a solid generated by the revolution of a rectangle about one of its sides which remains fixed. It has two equal circular bases. The line joining the centres of the bases is the axis. It is perpendicular to the bases.

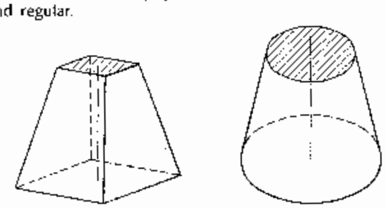
(ii) *Cone* (fig. 13-9): A *right circular cone* is a solid generated by the revolution of a right-angled triangle about one of its perpendicular sides which is fixed.

It has one circular base. Its axis joins the apex with the centre of the base to which it is perpendicular. Straight lines drawn from the apex to the circumference of the base-circle are all equal and are called *generators* of the cone. The length of the generator is the slant height of the cone.



(v) *Truncated:* When a solid is cut by a plane inclined to the base it is said to be *truncated.*

In this book mostly right and regular solids are dealt with. Hence, when a solid is named without any qualification, it should be understood as being right and regular.



Frustums
FIG. 13-11

13-2. PROJECTIONS OF SOLIDS IN SIMPLE POSITIONS

A solid in simple position may have its axis perpendicular to one reference plane or parallel to both. When the axis is perpendicular to one reference plane, it is parallel to the other. Also, when the axis of a solid is perpendicular to a plane, its base will be parallel to that plane. We have already seen that when a plane is parallel to a reference plane, its projection on that plane shows its true shape and size.

Therefore, the projection of a solid on the plane to which its axis is perpendicular, will show the true shape and size of its base.

Hence, when the axis is perpendicular to the ground, i.e. to the H.P., the top view should be drawn first and the front view projected from it.

When the axis is perpendicular to the V.P., beginning should be made with the front view. The top view should then be projected from it.

When the axis is parallel to both the H.P. and the V.P., neither the top view nor the front view will show the actual shape of the base. In this case, the projection of the solid on an auxiliary plane perpendicular to both the planes, viz. the side view must be drawn first. The front view and the top view are then projected from the sides perpendicular to *xy*. Name the corners as shown, thus completing the top view. The corners *d*, *e* and *f* are hidden and coincide with the top corners *a*, *b* and *c* respectively.

(ii) Project the front view, which will be a rectangle. Name the corners. The line *b'e'* coincides with *a'd'*.

Problem 13-2. (fig. 13-13): *Draw the projections of a pentagonal pyramid, base 30 mm edge and axis 50 mm long, having its base on the H.P. and an edge of the base parallel to the V.P. Also draw its side view.*

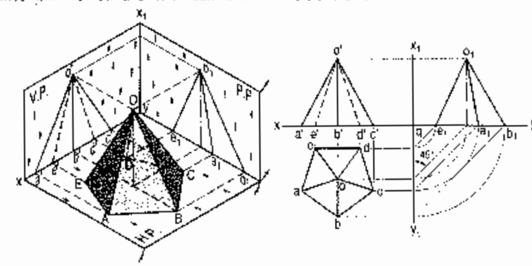


Fig. 13-13

(i) Assume the side *DE* which is nearer the V.P., to be parallel to the V.P. as shown in the pictorial view.

(ii) In the top view, draw a regular pentagon *abcde* with *ed* parallel to and nearer *xy*. Locate its centre *o* and join it with the corners to indicate the slant edges.

(iii) Through *o*, project the axis in the front view and mark the apex *o'*, 50 mm above *xy*. Project all the corners of the base on *xy*. Draw lines *o'a'*, *o'b'* and *o'c'* to show the visible edges. Show *o'd'* and *o'e'* for the hidden edges as dashed lines.

(iv) For the side view looking from the left, draw a new reference line x_1y_1 perpendicular to *xy* and to the right of the front view. Project the side view on it, horizontally from the front view as shown. The respective distances of all the points in the side view from x_1y_1, should be equal to their distances in the top view from *xy*. This is done systematically as

(i) Draw a circle of 40 mm diameter in the top view and project the front view which will be a rectangle [fig. 13-14(ii)].

(ii) Draw the top view [fig. 13-14(iii)]. Through the centre o, project the apex o', 50 mm above *xy*. Complete the triangle in the front view as shown.

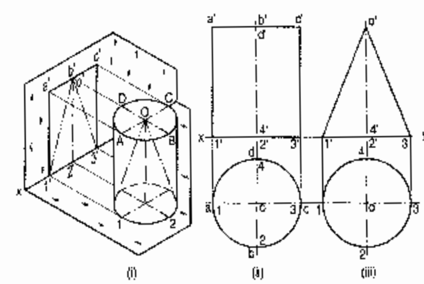
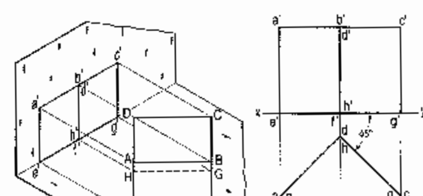


Fig. 13-14

In the pictorial view [fig. 13-14(i)], the cone is shown as contained by the cylinder.

Problem 13-4. (fig. 13-15): *A cube of 50 mm long edges is resting on the H.P. with its vertical faces equally inclined to the V.P. Draw its projections.*



(i) In the top view, draw a line *af* 30 mm long and inclined at 45° to *xy*. Construct a regular hexagon on *af*. Mark its centre *o* and complete the top view by drawing lines joining it with the corners.

(ii) Project up the front view as described in problem 13-2, showing the line *o'e'* and *o'f'* for hidden edges as dashed lines.

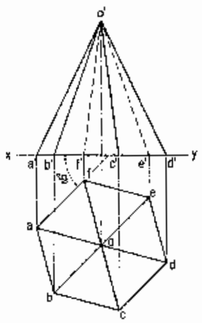


Fig. 13-16

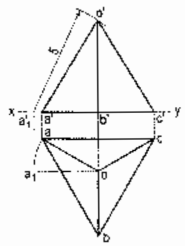


Fig. 13-17

Problem 13-6. (fig. 13-17): *A tetrahedron of 5 cm long edges is resting on the H.P. on one of its faces, with an edge of that face parallel to the V.P. Draw its projections and measure the distance of its apex from the ground.*

All the four faces of the tetrahedron are equal equilateral triangles of 5 cm side.

(i) Draw an equilateral triangle *abc* in the top view with one side, say *ac*, parallel to *xy*. Locate its centre *o* and join it with the corners.

(ii) In the front view, the corners *a'*, *b'* and *c'* will be in *xy*. The apex *o'* will lie on the projector through *o* so that its true distance from the corners of the base is equal to 5 cm.

(iii) To locate *o'*, make *oa* (or *ob* or *oc*) parallel to *xy*. Project a_1 to a'_1 on *xy*. With a'_1 as centre and radius equal to 5 cm cut the projector through *o* in *o'*. Draw lines *o'a'*, *o'b'* and *o'c'* to complete the front view. *o'b'* will be the distance of the apex from the ground.

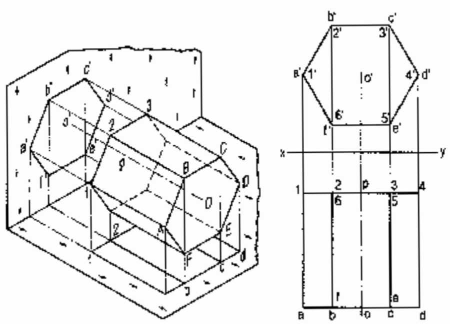
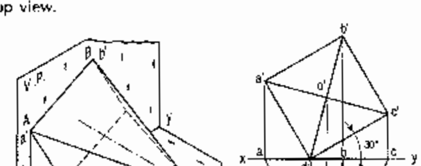


Fig. 13-18

Problem 13-8. (fig. 13-19): *A square pyramid, base 40 mm side and axis 65 mm long, has its base in the V.P. One edge of the base is inclined at 30° to the H.P. and a corner contained by that edge is on the H.P. Draw its projections.*

(i) Draw a square in the front view with the corner *d'* in *xy* and the side *d'c'* inclined at 30° to it. Locate the centre *o'* and join it with the corners of the square.

(ii) Project down all the corners in *xy* (because the base is in the V.P.). Mark the apex *o* on a projector through *o'*. Draw lines for the slant edges and complete the top view.



As the axis is parallel to both the planes, begin with the side view.

(i) Draw an equilateral triangle representing the side view, with one side in xy.

(ii) Project the front view horizontally from this triangle.

(iii) Project down the top view from the front view and the side view, as shown.

This problem can also be solved in two stages as explained in the next article.

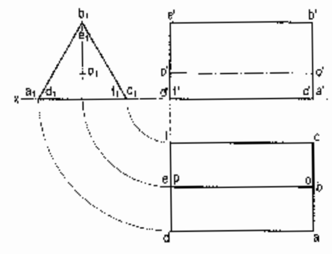


FIG. 13-20

EXERCISES 13(a)

Draw the projections of the following solids, situated in their respective positions, taking a side of the base 40 mm long or the diameter of the base 50 mm long and the axis 65 mm long.

1. A hexagonal pyramid, base on the H.P. and a side of the base parallel to and 25 mm in front of the V.P.
2. A square prism, base on the H.P., a side of the base inclined at 30° to the V.P. and the axis 50 mm in front of the V.P.
3. A triangular pyramid, base on the H.P. and an edge of the base inclined at 45° to the V.P.; the apex 40 mm in front of the V.P.
4. A cylinder, axis perpendicular to the V.P. and 40 mm above the H.P., one end 20 mm in front of the V.P.
5. A pentagonal prism, a rectangular face parallel to and 10 mm above the H.P., axis perpendicular to the V.P. and one base in the V.P.
6. A square pyramid, all edges of the base equally inclined to the H.P. and the axis parallel to and 50 mm away from both the H.P. and the V.P.
7. A cone, apex in the H.P. axis vertical and 40 mm in front of the V.P.
8. A pentagonal pyramid, base in the V.P. and an edge of the base in the H.P.

13-3. PROJECTIONS OF SOLIDS WITH AXES INCLINED

Moreover

(i) if the solid has an edge of its base parallel to the H.P. or in the H.P. or on the ground, that edge should be kept perpendicular to the V.P.; if the edge of the base is parallel to the V.P. or in the V.P., it should be kept perpendicular to the H.P.

(ii) If the solid has a corner of its base in the H.P. or on the ground, the sides of the base containing that corner should be kept equally inclined to the V.P.; if the corner is in the V.P., they should be kept equally inclined to the H.P.

(2) Having drawn the projections of the solid in its simple position, the final projections may be obtained by one of the following *two* methods:

(i) Alteration of position: The position of one of the views is altered as required and the other view projected from it.

(ii) Alteration of reference line or auxiliary plane: A new reference line is drawn according to the required conditions, to represent an auxiliary plane and the final view projected on it.

In the first method, the reproduction of a view accurately in the altered position is likely to take considerable time, specially, when the solid has curved surfaces or too many edges and corners. In such cases, it is easier and more convenient to adopt the second method. Sufficient care must however be taken in transferring the distances of various points from their respective reference lines.

After determining the positions of all the points for the corners in the final view, difficulty is often felt in completing the view correctly. The following sequence for joining the corners may be adopted:

(a) Draw the lines for the edges of the visible base. The base, which (compared to the other base) is further away from xy in one view, will be fully visible in the other view.

(b) Draw the lines for the longer edges. The lines which pass through the figure of the visible base should be dashed lines.

(c) Draw the lines for the edges of the other base.

It should always be remembered that, when two lines representing the edges cross each other, one of them must be hidden and should therefore be drawn as a dashed line.

Draw the pentagon in the front view with one side in xy and project the top view [fig. 13-21(i)].

The shape and size of the figure in the top view will not change, so long as the prism has its face on the H.P. The respective distances of all the corners in the front view from xy will also remain constant.

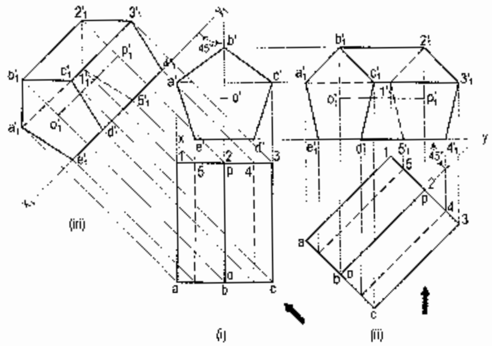


FIG. 13-21

Method I: [fig. 13-21(ii)]:

(i) Alter the position of the top view, i.e. reproduce it so that the axis is inclined at 45° to xy. Project all the points upwards from this top view and horizontally from the first front view, e.g. a vertical from a intersecting a horizontal from a' at a point a'_1.

(ii) Complete the pentagon $a'_1b'_1c'_1d'_1e'_1$ for the fully visible end of the prism. Next, draw the lines for the longer edges and finally, draw the lines for the edges of the other end. Note carefully that the lines $a'_11'_1$, $1'_12'_1$ and $1'_15'_1$ are dashed lines. $e'_15'_1$ is also hidden but it coincides with other visible lines.

Method II: [fig. 13-21(iii)]:

(i) Draw a new reference line x_1y_1, making 45° angle with the top view of the axis, to represent an auxiliary vertical plane.

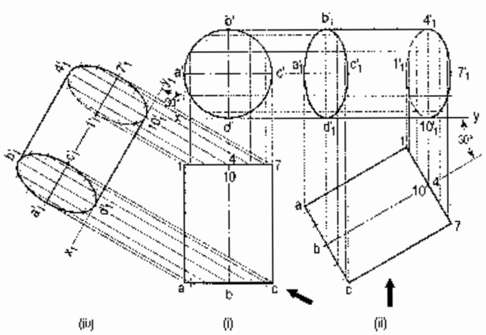


FIG. 13-22

13-3-2. AXIS INCLINED TO THE H.P. AND PARALLEL TO THE V.P.

Problem 13-12. (fig. 13-23): *A hexagonal pyramid, base 25 mm side and axis 50 mm long, has an edge of its base on the ground. Its axis is inclined at 30° to the ground and parallel to the V.P. Draw its projections.*

In the initial position assume the axis to be perpendicular to the H.P.

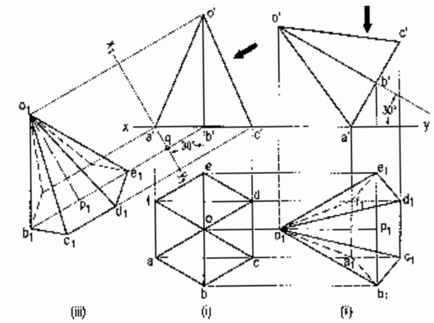
Draw the projections with the base in xy and its one edge perpendicular to the V.P. [fig. 13-23(i)].

If the pyramid is now tilted about the edge AF (or CD) the axis will become inclined to the H.P. but will remain parallel to the V.P. The distances of all the corners from the V.P. will remain constant.

The front view will not be affected except in its position in relation to xy. The new top view will have its corners at same distances from xy, as before.

Method I: [fig. 13-23(ii)]:

(i) Reproduce the front view so that the axis makes 30° angle with xy and the



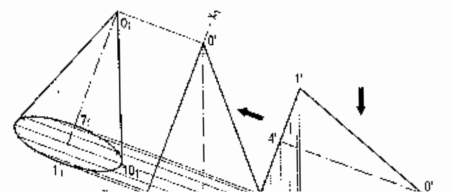
(iii) (i) (ii)

FIG. 13-23

Problem 13-13. (fig. 13-24): *Draw the projections of a cone, base 75 mm diameter and axis 100 mm long, lying on the H.P. on one of its generators with the axis parallel to the V.P.*

(i) **Assuming the cone to be resting on its base on the ground, draw its projections.**

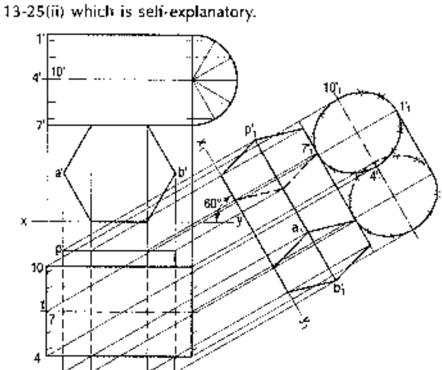
(ii) **Re-draw the front view so that the line o'7' (or o'1') is in *xy*. Project the required top view as shown. The lines from o_1 should be tangents to the ellipse.**



The top view obtained by auxiliary-plane method is shown in fig. **13-24(ii). The** new reference line x_1y_1 is so drawn as to contain the generator o'1' instead of o'7' (for sake of convenience). **The** cone is thus lying on the generator o'1'. Note that $1'1_1$ = **1'1**, $o'o_1$ = 4'o etc. Also note that the base is fully visible in both the methods.

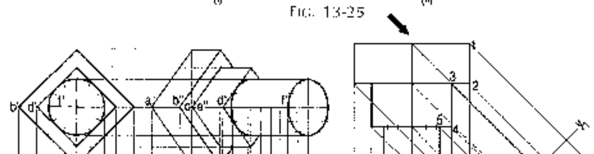
Problem 13-14. *The projections of a cylinder resting centrally on a hexagonal prism are given in fig. 13-25(i). Draw its auxiliary front view on a reference line inclined at 60° to xy.*

See fig. 13-25(ii) which is self-explanatory.



(i) (ii)

FIG. 13-25



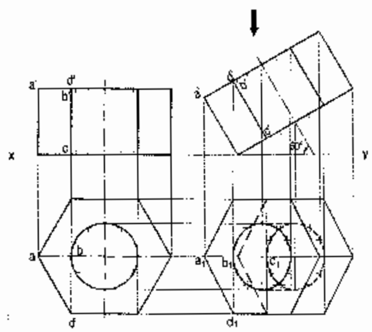
Problem 13-15. (fig. 13-26 and fig. 13-27): *A square headed bolt 25 mm diameter, 125 mm long and having a square neck has its axis parallel to the H.P. and inclined at 45° to the V.P.*

All the faces of **the** square head are equally inclined to the H.P. Draw its **projections** neglecting the threads and chamfer.

See fig. 13-26. The projections are obtained by the change-of-position method. The **length of the bolt** is taken shorter.

Fig. 13-27 shows the views in third-angle projection, obtained by the auxiliary-plane *method*.

Problem 13-16. (fig. 13-28): *A hexagonal prism, base 40 mm side and height 40 mm has a hole of 40 mm diameter drilled centrally through its ends. Draw its projections when it is resting on one of its corners on the H.P. with its axis inclined at 60° to the H.P. and two of its faces parallel to the V.P.*



(i) (ii)

FIG. 13-28

(i) **Begin with the top view and project up the front view assuming the axis to be vertical.**

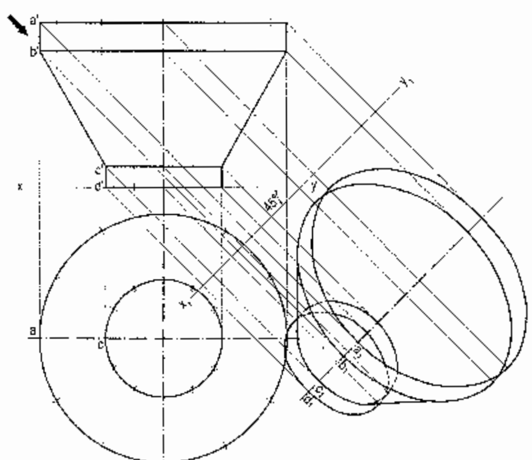


FIG. 13-29

13-4. PROJECTIONS OF SOLIDS WITH AXES INCLINED TO BOTH THE H.P. AND THE V.P.

The projections of a solid with its axis inclined to both the planes are drawn in three stages:

(i) Simple position

(ii) Axis inclined to one plane and parallel to the other

(iii) Final position.

The second and final positions may be obtained either by the alteration of the

Again, assume the prism to be turned so that the edge on which it rests, makes an angle of 30° with the V.P., keeping the inclination of the axis with the ground constant. The shape and size of the second top view will remain the same; only its position will change. In the front view, the distances of all the corners from xy will remain the same as in the second front view.

(iii) Therefore, reproduce the second top view making f_1g_1 inclined at 30° to *xy*. Project the final front view upwards from this top view and horizontally from the second front view, e.g. a vertical from a_1 and a horizontal from a' intersecting at a'_1. As the top end is further away from *xy* in the top view it will be fully visible in the front view. Complete the front view showing the hidden edges by dashed lines.

(iv) The second top view may be turned in the opposite direction as shown. In this position, the lower end of the prism, viz. $e'_1f'_1g'_1h'_1$ will be fully visible in the front view.

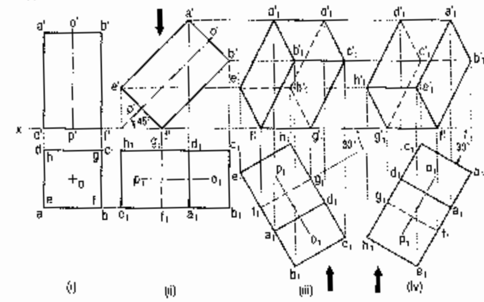
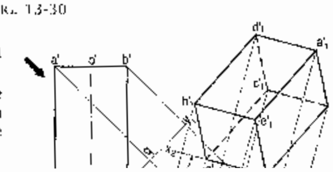


FIG. 13-30

Method II: (fig. 13-31):

(i) Draw the top view and the front view in simple position.

(ii) Through f', draw a new reference line x_1y_1 making 45° angle with the axis. On it, project the auxiliary top view.



Note: The new reference line satisfying the required conditions may be drawn in various positions, as explained in chapter 11.

Problem 13-19. (fig. 13-32): *Draw the projections of a cone, base 45 mm diameter and axis 50 mm long, when it is resting on the ground on a point on its base circle with (a) the axis making an angle of 30° with the H.P. and 45° with the V.P.; (b) the axis making an angle of 30° with the H.P. and its top view making 45° with the V.P.*

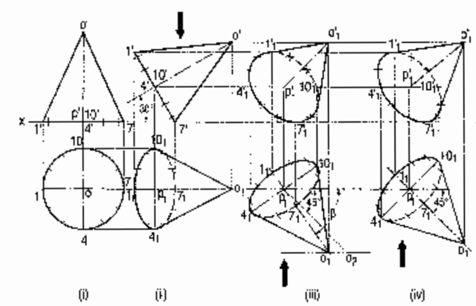


FIG. 13-32

(i) Draw the top view and the front view of the cone with the base on the ground.

(ii) Tilt the front view so that the axis makes 30° angle with *xy*. Project the second top view.

(a) In order that the axis may make an angle of 45° with the V.P., let us determine the apparent angle of inclination which the top view of the axis, viz. o_1p_1 should make with *xy* and which will be greater than 45°.

(iii) Mark any point p_1 below *xy*. Draw a line p_1o_2 equal to the true length of the axis, viz. o'p', and inclined at 45° to *xy*. With p_1 as centre and radius equal to p_1o_1 (the length of the top view of the axis) draw an arc cutting

(i) In the initial position, assume the pyramid as having its base in the V.P. and an edge of the base perpendicular to the H.P. The front view will have to be drawn first and the top view projected from it.

(ii) Change the position of the top view so that the line o1 (for the face o1 5) is in *xy*. Project the second front view.

(iii) Tilt this front view so that the line $1'_15'_1$ makes 30° angle with *xy*. Project the final top view. Note that the base is not visible in the top view as it is nearer *xy* in the front view.

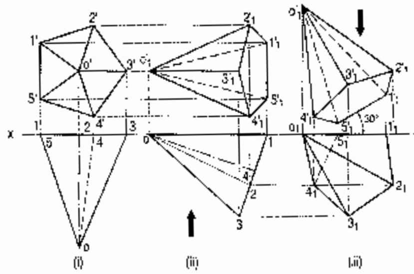
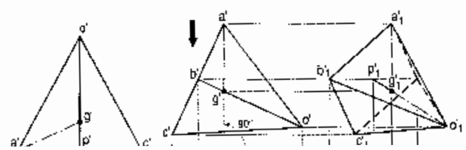


FIG. 13-33

Problem 13-21. (fig. 13-34): *A square pyramid, base 38 mm side and axis 50 mm long, is freely suspended from one of the corners of its base. Draw its projections, when the axis as a vertical plane makes an angle of 45° with the V.P. When a pyramid is suspended freely from a corner of its base, the imaginary line joining that corner with the centre of gravity of the pyramid will be vertical.*



The centre of gravity of a pyramid lies on its axis and at a distance equal to ¼ of the length of the axis from the base.

Assume the pyramid to be suspended from the corner *A* of the base.

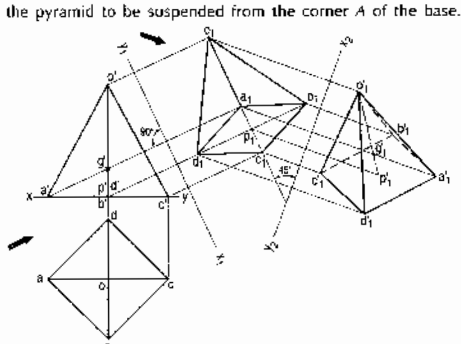


FIG. 13-35

In the initial position, the pyramid should be kept with its base on the ground and the line joining *A* with the centre of gravity *G*, parallel to the V.P. In the top view, *g* will coincide with *o* the top view of the axis.

(i) Draw a square *abcd* (in the top view) with *ag*, i.e. *ao* parallel to *xy*. Project the front view. Making *g'* at a distance equal to ¼ of the axis from *xy*. Join a' with *g'*.

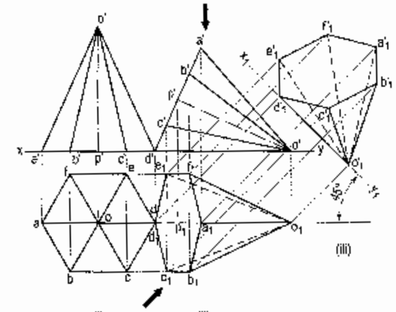
(ii) Tilt the front view so that a'g' is perpendicular to *xy* and project the top view. The axis will still remain parallel to the V.P.

(iii) Reproduce this top view so that o_1p_1 (the top view of the axis) is inclined at 45° to *xy*. The axis as a vertical plane will thus be making 45° angle with the V.P. Project the final front view.

Fig. 13-35 shows the projections obtained by the change-of-reference-line method.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the

(iii) Draw a new reference line x_1y_1 making 45° angle with o_1d_1 (the top view of the axis) and project the final front view.

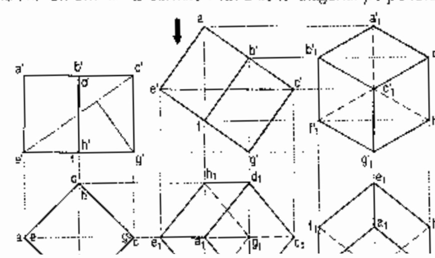


(i) (ii) (iii)

FIG. 13-36

The problem is thus solved by combination of the change-of-position and change-of-reference-line methods.

Problem 13-23. (fig. 13-37): *Draw the projections of a cube of 25 mm long edges resting on the H.P on one of its corners with a solid diagonal perpendicular to the V.P.*



(ii) Tilt the front view about the corner g' so that the line $e'c'$ becomes parallel to xy. Project the second top view. The solid diagonal CE is now parallel to both the H.P. and the V.P.

(iii) Reproduce the second top view so that the top view of the solid diagonal, viz. e_1c_1 is perpendicular to xy. Project the required front view.

Problem 13-24. (fig. 13-38): *A triangular prism, base 40 mm side and axis 50 mm long, is lying on the H.P. on one of its rectangular faces with the axis perpendicular to the V.P. A cone, base 40 mm diameter and axis 50 mm long, is resting on the H.P. and is leaning centrally on a face of the prism, with its axis parallel to the V.P. Draw the projections of the solids and project another front view on a reference line making 60° angle with xy.*

It will first be necessary to draw the cone with its base on the H.P. to determine the length of its generator and to project the top view.

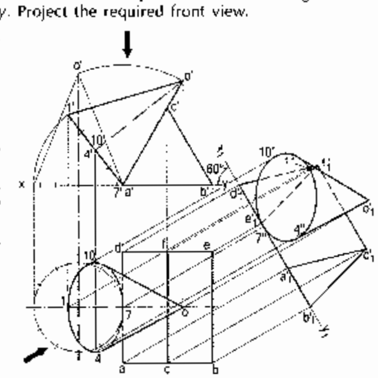


FIG. 13-38

Next, draw a triangle $a'b'c'$ for the prism and a triangle $o'1'7'$ for the cone as shown by the construction lines. Project the top view. Draw a reference line x_1y_1 and project the required front view as shown.

Problem 13-25. *A pentagonal prism is resting on one of the corners of its base on the H.P. The longer edge containing that corner is inclined at 45° to the H.P. The axis of the prism makes an angle of 30° to the V.P. Draw the projections of the solid.*

Also, draw the projections of the solid when the top view of axis is inclined at 30° to xy. Take the side of base 45 mm and height 70 mm.

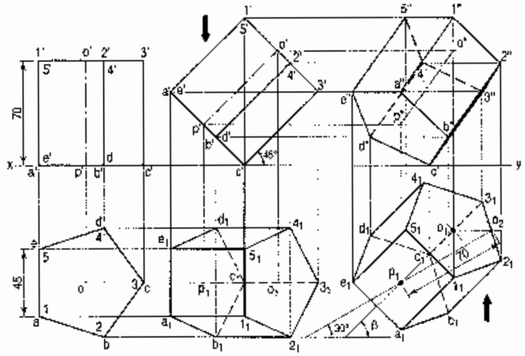
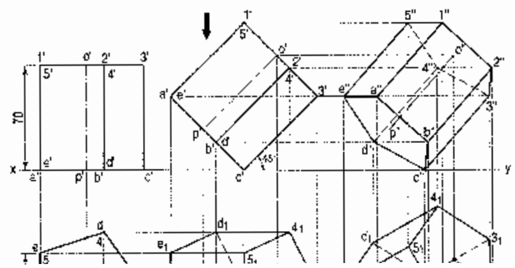


FIG. 13-39(i)

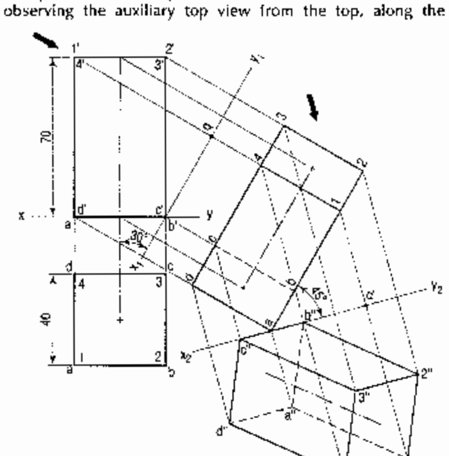
(v) When the top view of axis makes an angle of 30° with the V.P., it is evident that p_1o_1 is inclined at 30° to xy. Hence, reproduce the top view and the front view as shown in fig. 13-39(ii).



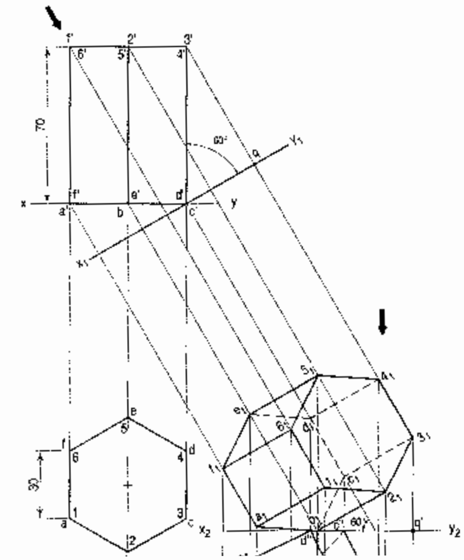
(i) In the initial position assume the axis of the prism to be perpendicular to the H.P. Draw the projections as shown.

(ii) Draw a new reference line x_1y_1 making an angle of 30° with the front view of the axis, to represent an auxiliary horizontal plane. Draw projectors from a', b' c', d' and 1', 2', 3', 4' perpendicular to x_1y_1 and on them, mark these points keeping the distance of each point from x_1y_1 equal to its distance from xy in the top view. Join the points as shown.

(iii) Draw another reference line x_2y_2 inclined at 45° to the line $a1$ (or $b2$). From the auxiliary top view, project the required new front view, keeping the distance of each point from x_2y_2 equal to its distance from x_1y_1, i.e. $q'1' = q1'$ etc. Join the points as shown. Note that the view is obtained by observing the auxiliary top view from the top, along the projectors.



(iii) Draw another reference line x_2y_2 inclined at 60° to the edge of base c_1d_1. From the auxiliary top view, project the required new front view, keeping the distance of each point from x_2y_2, equal to its distance from x_1y_1 i.e. $q3' = q'3''$ etc. Join the points as shown. It should be noted that the edge of base away from x_2y_2 will be observed as full lines and nearest lines from x_2y_2 will be dotted lines. i.e. $c''d''$, $d''e''$ and $e''f''$ are full lines while $f''a''$, $a''b''$ and $b''c'$ are dotted lines. Note that the view is drawn by observing the auxiliary top view from the top along the projectors.

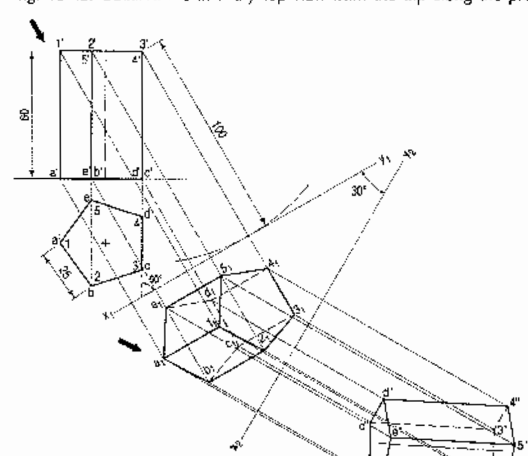


Problem 13-28. *A regular pentagonal prism lies with its axis inclined at 60° to the H.P. and 30° to the V.P. The prism is 60 mm long and has a face width of 25 mm. The nearest corner is 10 mm away from the V.P. and the farthest shorter edge is 100 mm from the H.P. Draw the projections of the solid.*

(i) Draw initial position of the prism as shown in fig. 13-42.

(ii) With 4' as centre and radius equal to 100 mm, draw an arc. Mark tangent to the arc making 60° with the axis as shown. This is a new reference line x_1y_1. Project the required new top view.

(iii) Draw another reference line x_2y_2 inclined at 30° angle to the axis of new top view. Project the various points to obtain new front view as shown in fig. 13-42. Observe the auxiliary top view from the top along the projectors.



(iii) Draw another reference line x_2y_2 parallel to the slant edge o_1c_1 or o_1b_1. Project new front view as shown. Observe auxiliary top view from the base a, b, c, d, o along projectors.

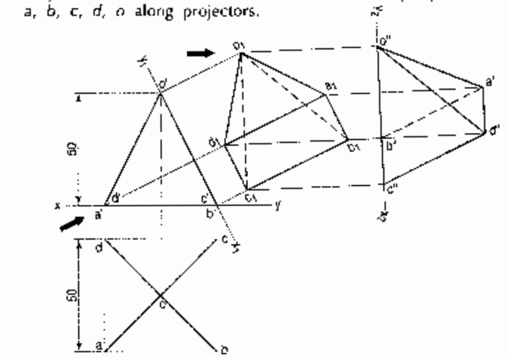
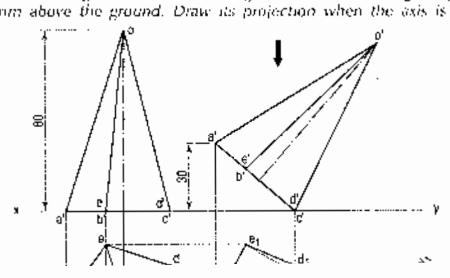


FIG. 13-43

Problem 13-30. *A regular pentagonal pyramid, base 30 mm side and height 80 mm rests on one edge of its base on the ground so that the highest point in the base is 30 mm above the ground. Draw its projection when the axis is parallel to the V.P.*



Draw another front view on a reference line inclined at 30° to the edge on which it is resting so that the base is visible.

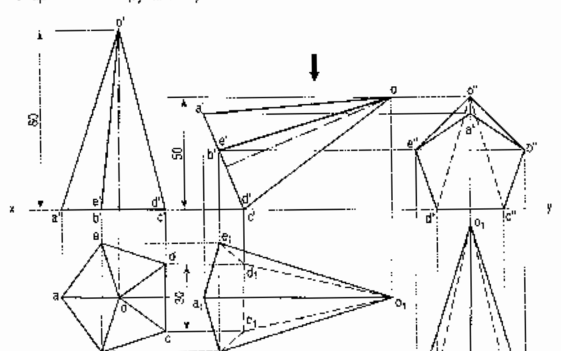
(i) Draw top view and front view in simple position assuming the axis of the pyramid perpendicular to the H.P.

(ii) Draw a parallel line at a distance of 30 mm from xy. Mark the point c' on the line xy and reproduce the front view as shown fig. 13-44.

(iii) Project points a', b', c' etc. and obtain new top view keeping distance of points a_1, b_1, c_1 etc. from xy equal to distance of a, b, c, etc. from the line xy.

(iv) Draw another reference line x_1y_1 making an angle of 30° with the side of base c_1d_1 and obtain a new front view as shown. Note that the base is visible. Observe from the base a, b, c, d, e along the projectors.

Problem 13-31. *A regular pentagonal pyramid with the sides of its base 30 mm and height 80 mm rests on an edge of the base. The base is tilted until its apex is 50 mm above the level of the edge of the base on which it rests. Draw the projection of the pyramid when the edge on which it rests, is parallel to the V.P. and the apex of the pyramid points towards V.P.*



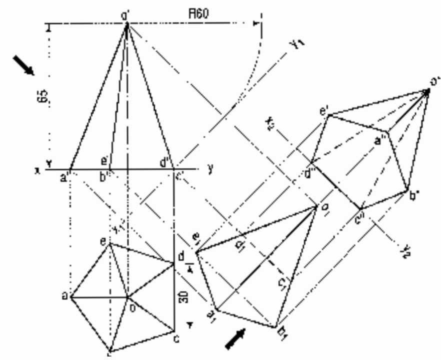
(iii) Redraw the top view keeping c_1d_1 parallel to *xy*. Project the points a_1, b_1, c_1 etc. vertically from the new top view and horizontal projectors from the points *a'*, *b'*, *c'* etc. of the front view. Join the intersection points of both the projectors in the correct sequence as shown.

Problem 13-32. *A right regular pentagonal pyramid, with the sides of the base 30 mm and height 65 mm rests on the edge of its base on the horizontal plane, the base being tilted until the vertex is at 60 mm above the H.P. Draw the projections of the pyramid when the edge on which it rests, is made parallel to FRP. Assuming the pyramid to be resting on its base on the horizontal plane, draw its projections keeping one of the sides of the base perpendicular to xy.*

Method I: Changing position of reference line [fig. 13-46(i)]:

(i) With *o'* as centre and radius equal to 60 mm, draw an arc. Draw the tangent to the arc passing through *c'* or *d'*. This is a new reference line x_1y_1. Project the required top view.

(ii) Draw another reference line x_2y_2 parallel to c_1d_1. Project new front view as shown. Observe auxiliary top view from the base *a*, *b*, *c*, *d*, *e* along the projectors.



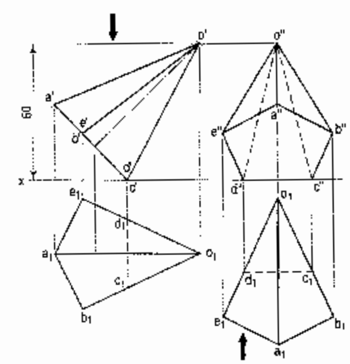
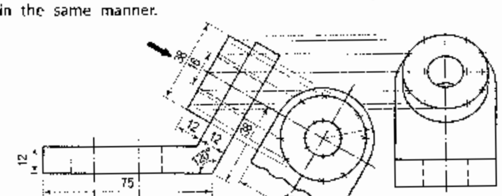


FIG. 13-46(ii)

Problem 13-33. *The front view, part top view and part auxiliary view of a casting are given in fig. 13-47(i). Project its side view.*

See fig. 13-47(ii).

The construction for the ellipse for 38 mm diameter circle has been shown in detail. Horizontal distances are taken from the auxiliary view. Other ellipses are drawn in the same manner.



A flat circular surface is formed when a sphere is cut by a plane. A hemisphere (i.e. a sphere cut by a plane passing through its centre) has a flat circular face of diameter equal to that of the sphere.

When it is placed on the ground on its flat face, its front view is a semi-circle, while its top view is a circle [fig. 13-49(i)].

When the flat face is inclined to the H.P. or the ground and is perpendicular to the V.P. it is seen as an ellipse (partly hidden) in the top view [fig. 13-49(ii)], while the contour of the hemisphere is shown by the arc of the circle drawn with radius equal to that of the sphere.

Fig. 13-50 shows the projections of a sphere, a small portion of which is cut off by a plane. Its flat face is perpendicular to the H.P. and inclined to the V.P. An ellipse is seen in the front view within the circle for the sphere.

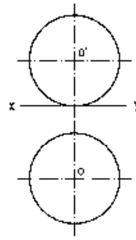
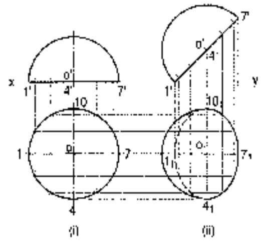


FIG. 13-48



(i) (ii)

FIG. 13-49

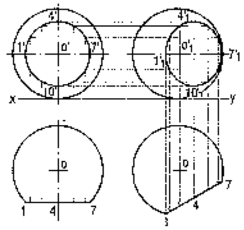
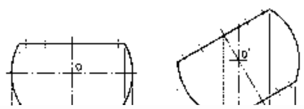


FIG. 13-50

When the flat face of a cut sphere is perpendicular to the V.P. and inclined to the H.P., its projections can be drawn as described in problem 13-34.

Problem 13-34. (fig. 13-51): *A brass flower-vase is spherical in shape with flat, circular top 35 cm diameter and bottom 25 cm diameter and parallel to each other. The greatest diameter is 40 cm. Draw the projections of the vase*



(1) Spheres in contact with each other: Projections of two equal spheres resting on the ground and in contact with each other, with the line joining their centres parallel to the V.P., are shown in fig. 13-52.

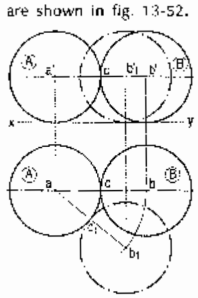


FIG. 13-52

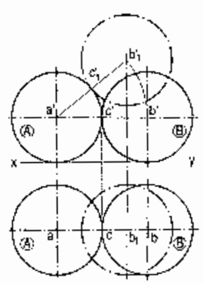


FIG. 13-53

As the spheres are equal in size, the line joining their centres is parallel to the ground also. Hence, both ab and a'b' show the true length of that line (i.e. equal to the sum of the two radii or the diameter of the spheres). The point of contact between the two spheres is also visible in each view.

If the position of one of the spheres, say sphere *B*, is changed so that the line joining their centres is inclined to the V.P., in the front view, the centre *b'* will move along the line *a'b'* to b'_1. The true length of the line joining the centres and the point of contact are now seen in the top view only.

When the sphere *B* is so moved that it remains in contact with the sphere *A* and the line joining their centres is parallel to the V.P., but inclined to the ground (fig. 13-53), the true length of that line and the point of contact are visible in the front view only.

Problem 13-35. (fig. 13-54): *Three equal spheres of 38 mm diameter are resting on the ground so that each touches the other two and the line joining the centres of two of them is parallel to the V.P.*

A fourth sphere of 50 mm diameter is placed on top of the three spheres so

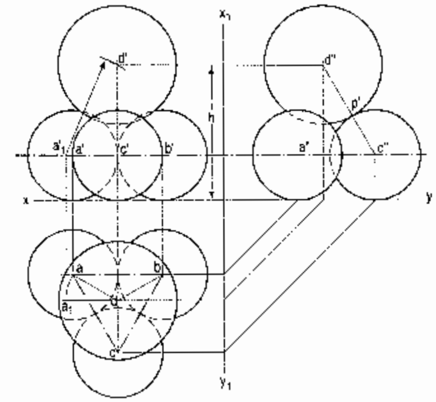


FIG. 13-54

But as none of the lines *da*, *db* or *dc* is parallel to *xy*, their front views will not show their true lengths. Therefore, to locate the position of the centre of the top sphere in the front view,

(i) make one of the lines, say *da*, parallel to *xy*;

(ii) project a_1 to a'_1 on the path of *a'* and

(iii) with a'_1 as centre and radius equal to 45 mm, draw an arc cutting the projector through *d* at the required point *d'*. With *d'* as centre and radius equal to 25 mm, draw the required circle which will be partly hidden as shown. *h* is the distance of the centre of the sphere from the ground.

(iv) Project the side view. As *c'd'* is parallel to the new reference line, *c"d"* will be equal to 45 mm and the point of contact *p'* between the spheres having centres *c* and *d* will be visible.

(2) Unequal spheres: When two unequal spheres are on the ground and are in contact with each other, their point of contact and the true length of the line joining

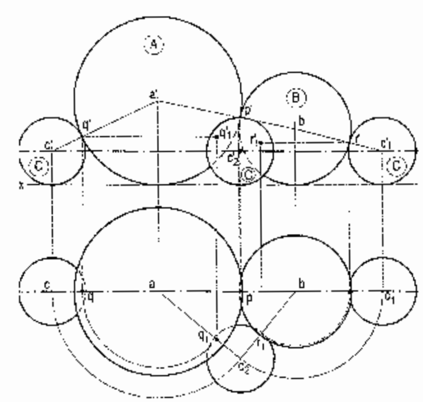


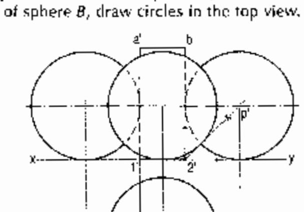
FIG. 13-55

(ii) Project the centres and obtain points a and *b* on a line parallel to *xy* in top view. With *a* as centre and radius equal to 37.5 mm of sphere *A*, and with *b* as centre and radius equal to 25 mm of sphere *B*, draw circles in the top view.

(iii) Similarly, draw the views of sphere C in contact with spheres *A* and *B*.

(iv) With a as centre and radius equal to *ac*, and with *b* as centre and radius equal to bc_1, draw arcs intersecting each other at c_2. With c_2 centre draw top view of the sphere C.

(v) Draw the projector through c_2 to cut the path of *c'* at c'_2. Then c'_2 is the



(i) Draw the front and top views of the prism. In the top view, draw diagonals of the square (intersecting each other at *o*) and produce them on both sides.

(ii) Draw the bisectors of angles *bce* and *cbf* intersecting each other at *p*. From *p*, draw a perpendicular *pq* to *bc*. Then *pq* is the required radius of the sphere and *p* is the centre of the circle for the sphere.

(iii) Obtain the other three centres in the same manner. Or, with *o* as centre and radius equal to *op*, draw a circle to cut the centre lines through *o* at the required centres. Draw the four circles.

(iv) Draw a bisector of angle *b'2'y* intersecting the projector through *p* at *p'*. Then *p'* is the centre of the sphere in the front view. The centres for the other circles will lie on the horizontal line through *p'*. Project their exact positions from the top view and draw the circles.

Problem 13-38. (fig. 13-57): *Six equal spheres are resting on the ground, each touching other two spheres and a triangular face of a hexagonal pyramid resting on its base on the ground.*

Draw the projections of the solids when a side of the base of the pyramid is perpendicular to the V.P.

Determine the diameter of each sphere. Base of the pyramid 20 mm side; axis 50 mm long.

(i) Draw the projections of the pyramid in the required position. Assuming the solid to be a prism, locate the positions of the centre of one sphere (viz. *p* and *p'*) in the two views.

(ii) Draw a line joining *p'* with *a'* (the centre of the base) which coincides with 2'. The centre of the required sphere will lie on this line. Draw a bisector of angle *o'3'y* cutting *a'p'* at *c'*. Draw a line *c'q'* perpendicular to *xy*.

(iii) With *c'* as centre and radius *c'q'*, draw one of the required circles.

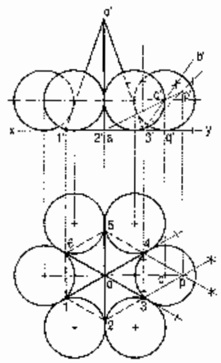
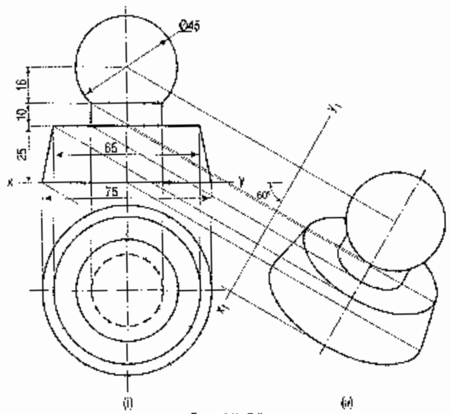


FIG. 13-57


(i) (ii)
FIG. 13-58

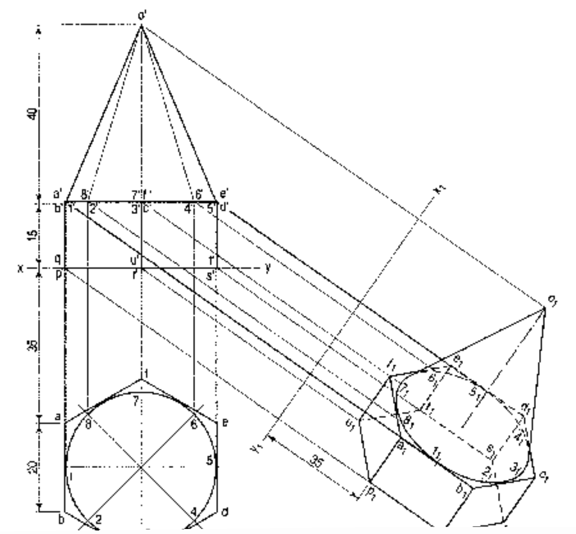
Problem 13-40. (fig. 13-59): *A vertical hexagonal prism of base side 20 mm and thickness 15 mm has one side of hexagon perpendicular to the V.P. A right cone of 34 mm diameter and height 40 mm is placed on the top face of prism such that the base of cone touches top surface of prism while the axes of both coincide. Draw the front view and top view of the combined object. Draw also projections when axes of combined solid is inclined at 35° with auxiliary plane.*

(i) Draw the top view of hexagonal prism keeping one of sides perpendicular to *xy*. (i.e. *ab* or *cd*). Project above *xy* line and draw the front view of prism of height 15 mm.

(ii) Inscribe circle in the top view touching sides of the prism. Project it in the front view and mark the height of the cone as shown.

(iii) Draw auxiliary x_1y_1 inclined at 35° with the axes of the combined solids.

(ii) Project the front view marking height of cylindrical disc and frustum of the pyramid 10 mm and 60 mm respectively.
(iii) Draw a line at angle of 30° with xy. (As axis is inclined with H.P., its inclination observed in the front view).
(iv) Reproduce the front view considering inclined line as axes of the combined solids.
(v) Draw the vertical projectors from various points of the front view.
(vi) Draw horizontal projectors to intersect respective vertical projectors. Obtain the auxiliary top view as shown.



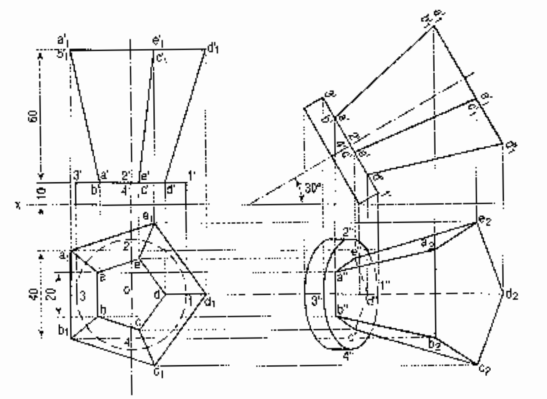
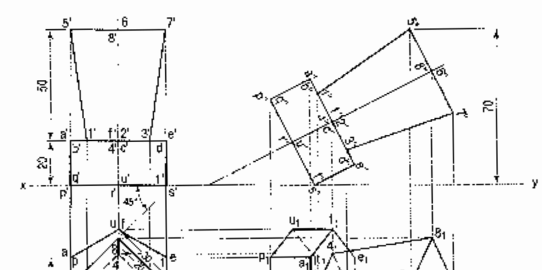


FIG. 13-60



(v) Draw from the top view horizontal projectors to intersect respective projectors drawn from the new front view.
(vi) Complete the top view as shown.

EXERCISES 13(b)

1. A rectangular block 75 mm × 50 mm × 25 mm thick has a hole of 30 mm diameter drilled centrally through its largest faces. Draw the projections when the block has its 50 mm long edge parallel to the H.P. and perpendicular to the V.P. and has the axis of the hole inclined at 60° to the H.P.
2. Draw the projections of a square pyramid having one of its triangular faces in the V.P. and the axis parallel to and 40 mm above the H.P. Base 30 mm side; axis 75 mm long.
3. A cylindrical block, 75 mm diameter and 25 mm thick, has a hexagonal hole of 25 mm side, cut centrally through its flat faces. Draw three views of the block when it has its flat faces vertical and inclined at 30° to the V.P. and two faces of the hole parallel to the H.P.
4. Draw three views of an earthen flower pot, 25 cm diameter at the top, 15 cm diameter at the bottom, 30 cm high and 2.5 cm thick, when its axis makes an angle of 30° with the vertical.
5. A tetrahedron of 75 mm long edges has one edge parallel to the H.P. and inclined at 45° to the V.P. while a face containing that edge is vertical. Draw its projections.
6. A hexagonal prism, base 30 mm side and axis 75 mm long, has an edge of the base parallel to the H.P. and inclined at 45° to the V.P. Its axis makes an angle of 60° with the H.P. Draw its projections.
7. A pentagonal prism is resting on a corner of its base on the ground with a longer edge containing that corner inclined at 45° to the H.P. and the vertical plane containing that edge and the axis inclined at 30° to the V.P. Draw its projections. Base 40 mm side; height 65 mm.
8. Draw three views of a cone, base 50 mm diameter and axis 75 mm long, having one of its generators in the V.P. and inclined at 30° to the H.P., the apex being in the H.P.
9. A square pyramid, base 40 mm side and axis 90 mm long, has a triangular face on the ground and the vertical plane containing the axis makes an angle of 45° with the V.P. Draw its projections.
10. A frustum of a pentagonal pyramid, base 50 mm side, top 25 mm side and

13. A line sketch (in two views) of a shed with a curved roof is given in fig. 13-62. Draw its front view on an auxiliary vertical plane inclined at 60° to the V.P. All dimensions are in metres. Scale, 10 mm = 0.5 m.
14. The front view of a hexagonal pyramid [base 25 mm side] having one of its triangular faces resting centrally on a triangular face of a square pyramid [base 50 mm side and axis 50 mm long] is given in fig. 13-63. The plane containing the two axes is parallel to the V.P. Draw the top view of the solids. From this top view, project a front view on a reference line x_1y_1 inclined at 30° to xy; (ii) from the given front view, project another top view on a reference line x_2y_2 inclined at 45° to xy.

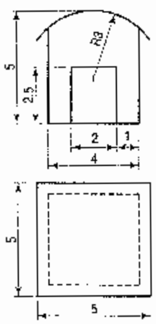


FIG. 13-62

15. A cube of 50 mm long edges is resting on the ground with its vertical faces equally inclined to the V.P. A hexagonal pyramid, base 25 mm side and axis 50 mm long, is placed centrally on top of the cube so that their axes are in a straight line and two edges of its base parallel to the V.P. Draw the front and top views of the solids. Project another top view on an A.I.P. making an angle of 45° with the H.P. From this top view project another front view on an auxiliary vertical plane inclined at 30° to the top view of the combined axis.

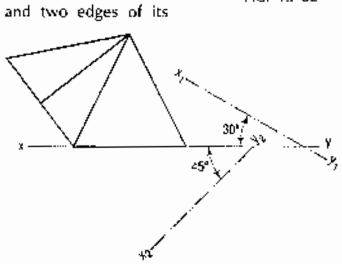
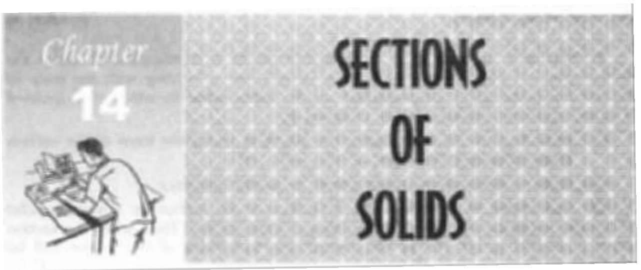


FIG. 13-63

16. Four equal spheres of 25 mm diameter are resting on the ground, each touching the other two spheres, so that a line joining the centres of two touching spheres is inclined at 30° to the V.P. A fifth sphere of 30 mm diameter is placed centrally on top of the four spheres, thus forming a pile. Draw the projections of the spheres and measure the height of the centre of



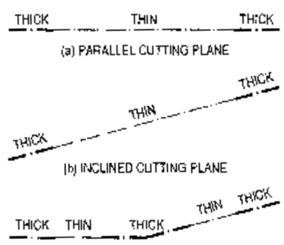
Chapter 14 SECTIONS OF SOLIDS

14-0. INTRODUCTION

Invisible features of an object are shown by dotted lines in their projected views. But when such features are too many, these lines make the views more complicated and difficult to interpret. In such cases, it is customary to imagine the object as being cut through or *sectioned* by planes. The part of the object between the cutting plane and the observer is assumed to be removed and the view is then shown *in section*.

The imaginary plane is called a section *plane* or a *cutting plane*. The surface produced by cutting the object by the section plane is called the *section*. It is indicated by thin section lines uniformly spaced and inclined at 45°.

The projection of the section along with the remaining portion of the object is called a *sectional view*. Sometimes, only the word section is also used to denote a sectional view.



(1) Section planes: Section planes are generally perpendicular planes. They may be perpendicular to one of the reference planes and either perpendicular, parallel or inclined to the other plane. They are usually described by their traces. It is important to remember that the projection of a section plane, on the plane

(2) Sections: The projection of the section on the reference plane to which the section plane is perpendicular, will be a straight line coinciding with the trace of the section plane on it. Its projection on the other plane to which it is inclined is called *apparent section*. This is obtained by

(i) projecting on the other plane, the points at which the trace of the section plane intersects the edges of the solid and

(ii) drawing lines joining these points in proper sequence.

(3) True shape of a section: The projection of the section on a plane parallel to the section plane will show the true shape of the section. Thus, when the section plane is parallel to the H.P. or the ground, the true shape of the section will be seen in *sectional top view*. When it is parallel to the V.P., the true shape will be visible in the *sectional front view*.

But when the section plane is inclined, the section has to be projected on an auxiliary plane parallel to the section plane, to obtain its true shape. When the section plane is perpendicular to both the reference planes, the sectional side view will show the true shape of the section. In this chapter sections of different solids are explained in stages by means of typical problems as follows:

1. Sections of prisms
2. Sections of pyramids
3. Sections of cylinders
4. Sections of cones
5. Sections of spheres.

14-1. SECTIONS OF PRISMS

These are illustrated according to the position of the section plane with reference to the principal planes as follows:

(1) Section plane parallel to the V.P.
(2) Section plane parallel to the H.P.
(3) Section plane perpendicular to the H.P. and inclined to the V.P.
(4) Section plane perpendicular to the V.P. and inclined to the H.P.

(1) Section plane parallel to the V.P.

Problem 14-1. (fig. 14-2): *A cube of 35 mm long edges is resting on the H.P.*

20. Four equal spheres are resting on the ground, each touching the other two spheres and a triangular face of a square pyramid, having base 25 mm side and axis 50 mm long. Draw their projections and find the diameter of the spheres.
21. One of the body diagonals of a cube of 45 mm edge is parallel to the H.P. and inclined at 45° to the V.P. Draw the front view and the top view of the cube.
22. A pentagonal pyramid, base 40 mm side and height 75 mm rests on one edge of its base on the ground so that the highest point in the base is 25 mm above the ground. Draw its projections when the axis is parallel to the V.P. Draw another front view on a reference line inclined at 30° to the edge on which it is resting, and so that the base is visible.
23. A thin lamp shade in the form of a frustum of a cone has its larger end 200 mm diameter, smaller end 75 mm diameter and height 150 mm. Draw its three views when it is lying on its side on the ground and the axis parallel to the V.P.
24. A bucket made of tin sheet has its top 200 mm diameter and bottom 125 mm diameter with a circular ring 40 mm wide attached at the bottom. The total height of the bucket is 250 mm. Draw its projections when its axis makes an angle of 60° with the vertical.
25. A hexagonal pyramid, side of the base 25 mm long and height 70 mm, has one of its triangular faces perpendicular to the H.P. and inclined at 45° to the V.P. The base-side of this triangular face is parallel to the H.P. Draw its projections.
26. A pentagonal pyramid has an edge of the base in the V.P. and inclined at 30° to the H.P., while the triangular face containing that edge makes an angle of 45° with the V.P. Draw three views of the pyramid. Length of the side of the base is 30 mm, while that of the axis is 80 mm.
27. A square pyramid, base 40 mm side and axis 75 mm long is placed on the ground on one of its slant edges, so that the vertical plane passing through that edge and the axis makes an angle of 30° with the V.P. Draw its three views.
28. A hexagonal prism, side of base 40 mm and height 50 mm is lying on the ground on one of its bases with a vertical face perpendicular to the V.P. A tetrahedron is placed on the prism so that the corners of one of its faces coincide with the alternate corners of the top surface of the prism. Draw the projections of the solids. Project another top view on an auxiliary inclined plane making 45° with the H.P.
29. A square duct is in the form of a frustum of a square pyramid. The sides of top and bottom are 150 mm and 100 mm respectively and its length is

32. A bucket, 300 mm diameter at the top and 225 mm diameter at the bottom has a circular ring 225 mm diameter and 50 mm wide attached at the bottom. The total height of the bucket is 300 mm. Draw the projections of the bucket when its axis is inclined at 60° to the H.P. and as a vertical plane makes an angle of 45° with the V.P. Assume the thickness of the plate of the bucket to be equal to that of a line.
33. The vertex-angle of the cone just touching the edges of a vertical hexagonal pyramid 125 mm in height is 45°. Draw the projections of the pyramid on a 45° inclined plane when the former is truncated by a plane making 45° with the axis and bisecting the axis.
34. A knob of a machine handle consists of 15 mm diameter × 150 mm long cylindrical portion and 40 mm diameter spherical portion. The centre of the sphere lies on the axis of the cylindrical portion. Draw the projections if its axis is inclined at 45° to the horizontal plane.
35. Six equal spheres rest on the ground in contact with each other and also with the slanting faces of a regular upright hexagonal pyramid, 25 mm edge of base and 125 mm length of axis. Draw the projections and find the diameter of the sphere.
36. A cylinder, 100 mm diameter and 150 mm long, has a rectangular slot 50 mm × 30 mm cut through it. The axis of the slot bisects the axis of the cylinder at right angles and the 50 mm side of the slot makes an angle of 60° with the base of the cylinder. Draw three views of the cylinder.
37. A very thin glass shade for a table lamp is the portion of a sphere 125 mm diameter included between two parallel planes at 15 mm and 55 mm from the centre, making the height 70 mm. If the axis of the shade is inclined at 30° to the vertical, obtain the projections of the shade.
38. A cone frustum, base 75 mm diameter, top 35 mm diameter and height 65 mm has a hole of 30 mm diameter drilled through it so that the axis of the hole coincides with that of the cone. It is resting on its base on the ground and is cut by a section plane perpendicular to the V.P., parallel to an end generator and passing through the top end of the axis. Draw sectional top view and sectional side view of the frustum.
39. Three vertical poles *AB*, *CD* and *EF* are respectively 5, 8 and 12 metres long. Their ends *B*, *D* and *F* are on the ground and lie at the corners of an equilateral triangle of 10 metres long sides. Determine graphically the distance

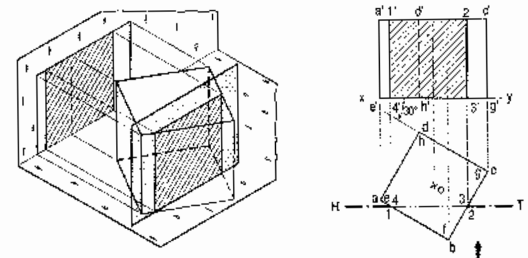
(ii) Name the points at which the edges are cut, viz. *ab* at 1, *bc* at 2, *gf* at 3 and *fe* at 4.

(iii) Project these points on the corresponding edges in the front view and join them in proper order.

As the section plane is parallel to the V.P., figure 1' 2' 3' 4' in the front view, shows the true shape of the section.

Show the views by dark but thin lines, leaving the lines for the cut-portion fainter.

(iv) Draw section lines in the rectangle for the section.

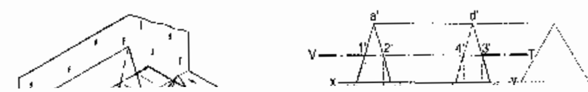


(i) (ii)

FIG. 14-2

(2) Section plane parallel to the H.P.

Problem 14-2. (fig. 14-3): *A triangular prism, base 30 mm side and axis 50 mm long, is lying on the H.P. on one of its rectangular faces with its axis inclined at 30° to the V.P. It is cut by a horizontal section plane, at a distance of 12 mm above the ground. Draw its front view and sectional top view.*



As the section plane is horizontal, i.e. parallel to the H.P., it is perpendicular to the V.P. Hence, the section will be seen as a line in the front view, coinciding with the V.T. of the section plane.

(i) Therefore, draw a line V.T. in the front view to represent the section plane, parallel to *xy* and 12 mm above it.

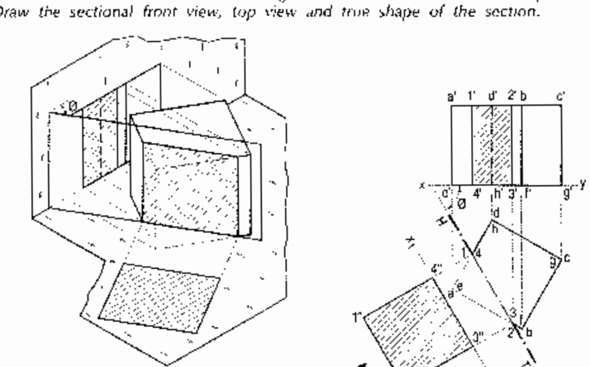
(ii) Name in correct sequence, points at which the edges are cut viz. *a'b'* at 1', *a'c'* at 2', *d'f'* at 3' and *d'e'* at 4'.

(iii) Project these points on the corresponding lines in the top view and complete the sectional top view by joining them in proper order.

As the section plane is parallel to the H.P., the figure 1 2 3 4 (in the top view) is the true shape of the section.

(3) Section plane perpendicular to the H.P. and inclined to the V.P.

Problem 14-3. (fig. 14-4): *A cube in the same position as in problem 14-1, is cut by a section plane, inclined at 60° to the V.P. and perpendicular to the H.P., so that the face which makes 60° angle with the V.P. is cut in two equal halves. Draw the sectional front view, top view and true shape of the section.*



The true shape of the section will be seen when it is projected on an auxiliary vertical plane, parallel to the section plane.

(iii) Therefore, draw a new reference line x_1y_1 parallel to the H.T. and project the section on it. The distances of the points from x_1y_1 should be taken equal to their corresponding distances from *xy* in the front view. Thus 4' and 3' will be on x_1y_1. 1" 4" and 2" 3" will be equal to 1' 4' and 2' 3 respectively. Complete the rectangle 1" 2" 3" 4" which is the true shape of the section and draw section lines in it.

(4) Section plane perpendicular to the V.P. and inclined to the H.P.

Problem 14-4. (fig. 14-5): *A cube in the same position as in problem 14-1 is cut by a section plane, perpendicular to the V.P., inclined at 45° to the H.P. and passing through the top end of the axis. (i) Draw its front view, sectional top view and true shape of the section. (ii) Project another top view on an auxiliary plane, parallel to the section plane.*

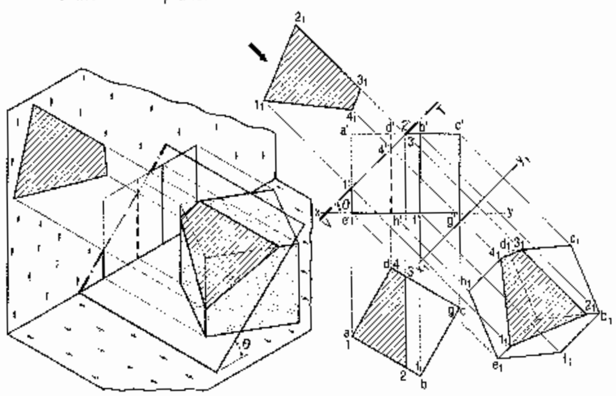


FIG. 14-5

The distances of all the points from the V.T. should be taken equal to their corresponding distances from *xy* in the top view, e.g. $1_11' = e'1$, $4_14' = b'4$ etc.

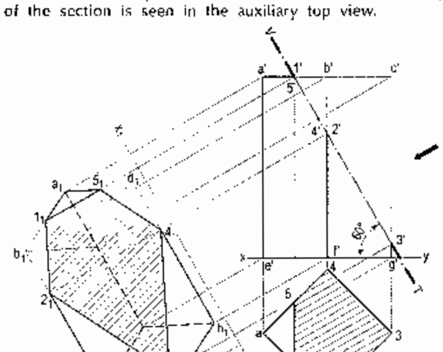
(iv) To project an auxiliary sectional top view of the cube, draw a new reference line x_1y_1, parallel to the V.T. The whole cube may first be projected and the points for the section may then be projected on the corresponding lines for the edges. Join these points in correct sequence and obtain the required top view.

(v) Draw section lines in the cut-surface, in the views where it is seen. Keep the lines for the removed edges thin and fainter.

Additional problems on sections of prisms:

Problem 14-5. (fig. 14-6): *A square prism, base 40 mm side, axis 80 mm long, has its base on the H.P. and its faces equally inclined to the V.P. It is cut by a plane, perpendicular to the V.P., inclined at 60° to the H.P. and passing through a point on the axis, 55 mm above the H.P. Draw its front view, sectional top view and another top view on an A.I.P. parallel to the section plane.*

The problem is similar to problem 14-4 and needs no further explanation. The true shape of the section is seen in the auxiliary top view.



(ii) Project them on the corresponding lines in the front view. The positions of points 4 and 5 cannot be located directly. Hence, project them on the first top view to 4_1 on *ef* and 5_1 on *ed*. From this top view, obtain their positions $4'_1$ and $5'_1$ on the corresponding lines in the first front view. As the two front views are identical, these points can now be transferred to the second front view by making e'4' equal to $e'4'_1$ and e'5' equal to $e'5'_1$. 4' and 5' are the projections of points 4 and 5 respectively. Complete the sectional front view as shown.

(iii) Obtain the true shape of the section on x_1y_1 as explained in problem 14-3, making o"1" equal to o'1', etc.

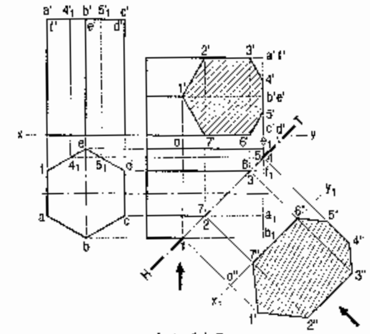
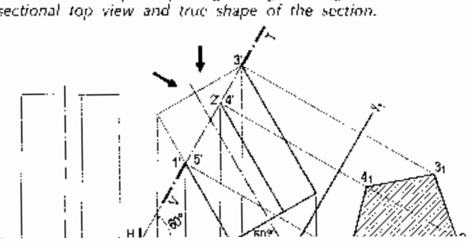


FIG. 14-7

Problem 14-7. (fig. 14-8): *A pentagonal prism, base 28 mm side and height 65 mm has an edge of its base on the H.P. and the axis parallel to the V.P. and inclined at 60° to the H.P. A section plane, having its H.T. perpendicular to xy, and the V.T. inclined at 60° to xy and passing through the highest corner, cuts the prism. Draw the sectional top view and true shape of the section.*



(i) Draw the projections of the prism in the required position.

(ii) Draw the line V.T. passing through the highest corner 3 and inclined at 60° to *xy*. A perpendicular to *xy* through *V* will be the H.T. of the section plane.

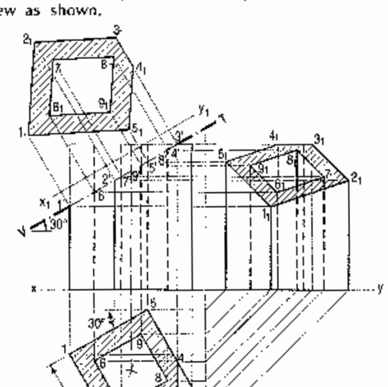
(iii) Project the sectional top view and the true shape of the section, as shown in the figure.

Problem 14-8. (fig. 14-9): *A hollow square prism, base 40 mm side (outside), height 65 mm and thickness 8 mm is resting on its base on the H.P. with a vertical face inclined at 30° to the V.P. A section plane, inclined at 30° to the H.P., perpendicular to the V.P. and passing through the axis at a point 12 mm from its top end, cuts the prism. Draw its sectional top view, sectional side view and true shape of the section.*

(i) Draw the projections of the prism in the given position, showing the hidden edges by dashed lines.

(ii) Draw a line V.T. for the cutting plane and mark points at which the inside and outside edges are cut.

(iii) Project the sectional top view, true shape of the section and the sectional side view as shown.



(1) Section plane parallel to the base of the pyramid.

Problem 14-9. (fig. 14-10): *A pentagonal pyramid, base 30 mm side and axis 65 mm long, has its base horizontal and an edge of the base parallel to the V.P. A horizontal section plane cuts it at a distance of 25 mm above the base. Draw its front view and sectional top view.*

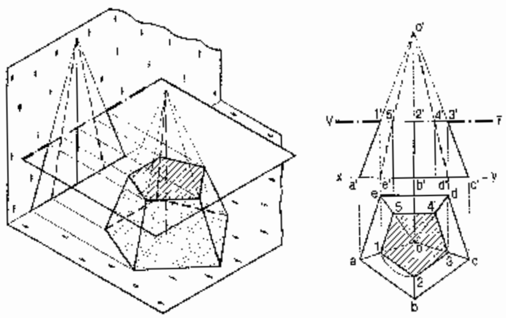


FIG. 14-10

(i) Draw the projections of the pyramid in the required position and show a line V.T. for the section plane, parallel to and 25 mm above the base.
All the five slant edges are cut.

(ii) Project the points at which they are cut, on the corresponding edges in the top view. The point 2' cannot be projected directly as the line *ob* is perpendicular to *xy*. But it is quite evident from the projections of other points that the lines of the section in the top view, viz. 3-4, 4-5 and 5-1 are parallel to the edges of the base in their respective faces and that the points 1, 3, 4 and 5 are equidistant from o.

(iii) Hence, line 1-2 also will be parallel to *ab* and o2 will be equal to o1, o3 etc. Therefore, with o as centre and radius o1, draw an arc cutting *ob* at a point 2 which will be the projection of 2'. Complete the sectional top view in which the true shape of the section, viz. the pentagon 1, 2, 3, 4 and 5

(i) Draw the projections of the pyramid in the required position and show a line **H.T.** (for the cutting plane) in the top view parallel to *xy* and 6 mm from the axis.

(ii) Project points **1**, 2 and 3 (at which the edges are cut) on corresponding edges in the front view and join them. Figure 1' 2' 3' shows the true shape of the section.

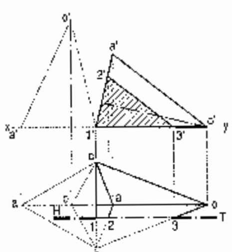


FIG. 14-11

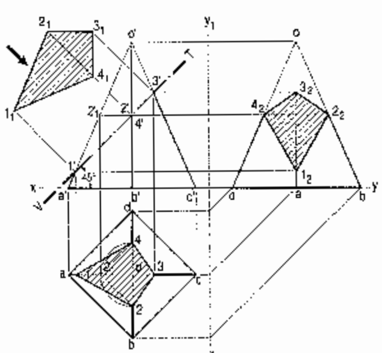


FIG. 14-12

(3) Section plane perpendicular to the V.P. and inclined to the H.P.

Problem 14-11. (fig. 14-12): *A square pyramid, base 40 mm side and axis 65 mm long, has its base on the H.P. and all the edges of the base equally inclined to the V.P. It is cut by a section plane, perpendicular to the V.P., inclined at 45° to the H.P. and bisecting the axis. Draw its sectional top view, sectional side view and true shape of the section.*

(i) Draw the projections of the pyramid in the required position. The section plane will be seen as a line in the front view. Hence, draw a line V.T.

(4) Section plane perpendicular to the H.P. and inclined to the V.P.

Problem 14-12. (fig. 14-13): *A pentagonal pyramid has its base on the H.P. and the edge of the base nearer the V.P., parallel to it. A vertical section plane, inclined at 45° to the V.P., cuts the pyramid at a distance of 6 mm from the axis. Draw the top view, sectional front view and the auxiliary front view on an A.V.P. parallel to the section plane. Base of the pyramid 30 mm side; axis 50 mm long.*

The section plane will be seen as a line in the top view. It is to be at a distance of 6 mm from the axis.

(i) Hence, draw a circle with o as centre and radius equal to 6 mm.

(ii) Draw a line H.T., tangent to this circle and inclined at 45° to *xy*. It can be drawn in four different positions, of which any one may be selected.

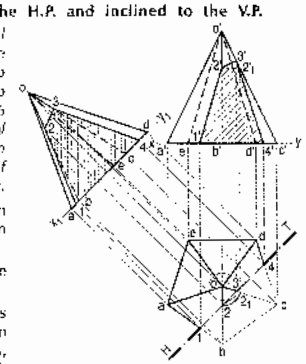


FIG. 14-13

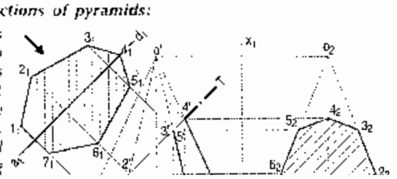
(iii) Project points 1, 2 etc. from the top view to the corresponding edges in the front view. Here again, point 2 cannot be projected directly. The process shown in problem 14-11 must be reversed. With centre *o* and radius *o*2 draw an arc cutting any one of the slant edges, say *oc* at 2_1. Project 2_1 to $2'_1$ on *o'c'*.

(iv) Through $2'_1$, draw a line parallel to the base, cutting *o'b'* at 2'. Then 2' is the required point. Complete the view. It will show the apparent section.

(v) Draw a reference line x_1y_1 parallel to the H.T. and project an auxiliary sectional front view which will show the true shape of the section also.

Additional problems on sections of pyramids:

Problem 14-13. (fig. 14-14): *A hexagonal pyramid, base 30 mm side and axis 65 mm long, is resting on its base on the H.P. with two edges parallel to the V.P. It is cut by a section plane, perpendicular to the V.P. inclined at 45° to the H.P. and intersecting*



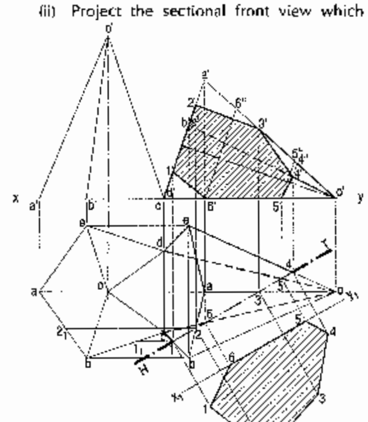
The true shape may be drawn on the V.T. as a new reference line or around the centre line a_1d_1, drawn parallel to the V.T. as shown.

The distances of the points 1_1, 2_1 etc. from $a_1 d_1$ are taken equal to the distances of points 1, 2 etc. from the line *ad* (which is parallel to *xy*).

Problem 14-14. (fig. 14-15): *A pentagonal pyramid, base 30 mm side and axis 60 mm long, is lying on one of its triangular faces on the H.P. with the axis parallel to the V.P. A vertical section plane, whose H.T. bisects the top view of the axis and makes an angle of 30° with the reference line, cuts the pyramid, removing its top part. Draw the top view, sectional front view, true shape of the section and development of the surface of the remaining portion of the pyramid.*

(i) Draw the H.T. of the section plane and name the points at which the edges are cut, in correct sequence, i.e. mark the visible edges first and then the hidden edges.

(ii) Project the sectional front view which will show the apparent section.



(iii) Obtain the true shape of the section on x_1y_1 as a new reference line drawn parallel to the H.T.

Development (fig. 14-16): The line *o'a'* shows the true length of the slant edge.

(i) With any point O as centre and radius *o'a'*, draw an arc and construct the development of the whole pyramid. Mark points on it, taking the positions of 1 and 2 from the first top view and those of other points by projecting them on the true-length-line *o'a'*.

(ii) Draw lines joining these points and complete the development as shown in

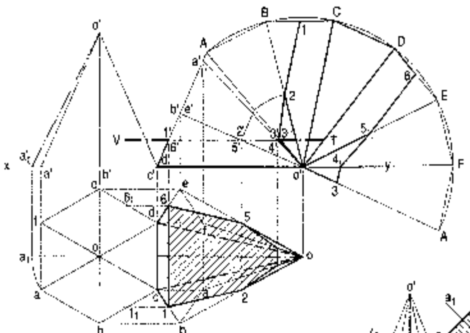


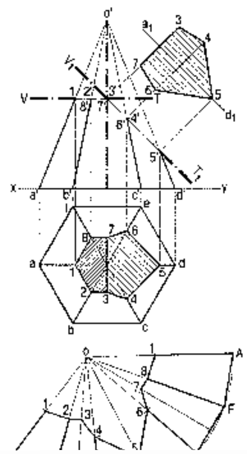
FIG. 14-17

Development: None of the edges shows the true length of the slant edge.

(i) Hence, determine the true length $o'a'_1$ and draw the development of the whole pyramid.

(ii) Locate positions of the points 1 and 6 by projecting them on the first top view and positions of other points by drawing lines through them, parallel to the base and upto the true length line *o'A*.

(iii) Mark these points on the development and complete it as shown.



Problem 14-16. (fig. 14-18): *A hexagonal pyramid, base 30 mm side and axis 75 mm long, resting on its base on the H.P. with two of its edges parallel to the V.P. is cut by two section planes, both perpendicular to the V.P. The horizontal section plane cuts the axis at a point 35 mm from the apex. The*

14-3. SECTIONS OF CYLINDERS

We shall now learn the following three cases. They are

(1) Section plane parallel to the base
(2) Section plane parallel to the axis
(3) Section plane inclined to the base.

(1) Section plane parallel to the base: When a cylinder is cut by a section plane parallel to the base, the true shape of the section is a circle of the same diameter.

(2) Section plane parallel to the axis: When a cylinder is cut by a section plane parallel to the axis, the true shape of the section is a rectangle, the sides of which are respectively equal to the length of the axis and the length of the section plane within the cylinder (fig. 14-19). When the section plane contains the axis, the rectangle will be of the maximum size.

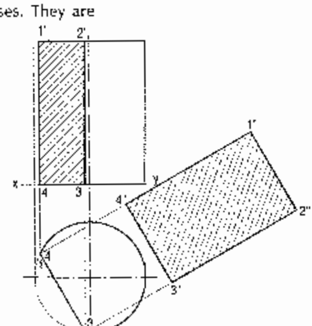
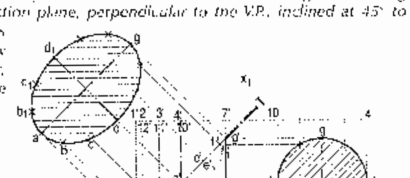


FIG. 14-19

(3) Section plane inclined to the base:

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 31 for the following problem.

Problem 14-17. (fig. 14-20): *A cylinder of 40 mm diameter, 60 mm height and having its axis vertical, is cut by a section plane, perpendicular to the V.P., inclined at 45° to the H.P. and intersecting the axis 32 mm above the base. Draw its front view, sectional top view, sectional side view and true shape of the section.*



As the cylinder has no edges, a number of lines representing the generators may be assumed on its curved surface by dividing the base-circle into, say 12 equal parts.

(i) Name the points at which these lines are cut by the V.T. In the top view, these points lie on the circle and hence, the same circle is the top view of the section. The width of the section at any point, say c', will be equal to the length of the chord cc_1 in the top view.

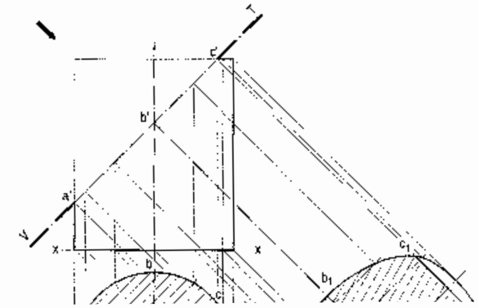
(ii) The true shape of the section may be drawn around the centre line ag drawn parallel to V.T. as shown. It is an ellipse the major axis of which is equal to the length of the section plane viz. $a'g'$, and the minor axis equal to the diameter of the cylinder viz. dd_1.

(iii) Project the sectional side view as shown. The section will be seen as a circle because the section plane makes 45° angle with xy.

Additional problems on sections of cylinders:

Problem 14-18. (fig. 14-21): *A cylinder 50 mm diameter and 60 mm long, is resting on its base on the ground. It is cut by a section plane perpendicular to the V.P., the V.T. of which cuts the axis at a point 40 mm from the base and makes an angle of 45° with the H.P. Draw its front view, sectional top view and another sectional top view on an A.I.P. parallel to the section plane.*

In this case, the top end of the cylinder is also cut. Hence, the true shape of the section is a part of an ellipse as shown in the auxiliary top view.



Problem 14-19. (fig. 14-22): *A cylinder, 55 mm diameter and 65 mm long, has its axis parallel to both the H.P. and the V.P. It is cut by a vertical section plane inclined at 30° to the V.P., so that the axis is cut at a point 30 mm from one of its ends and both the bases of the cylinder are partly cut. Draw its sectional front view and true shape of the section.*

Draw the projections of the cylinder and a line H.T. for the section plane. Project the points at which the bases and the lines are cut. The points on the bases cannot be projected directly. Therefore, project them

(i) To the first top view i.e. a to a_1 and e to e_1.

(ii) Then to the first front view, i.e. a_1 to a'_1 and e_1 to e'_1.

(iii) Finally, transfer them to the second front view to a' and e' each, at two places as shown.

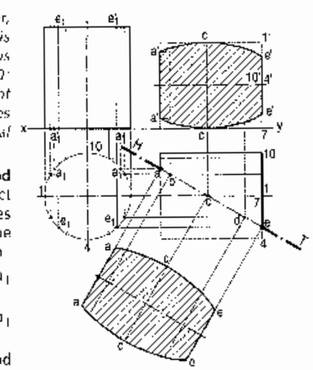
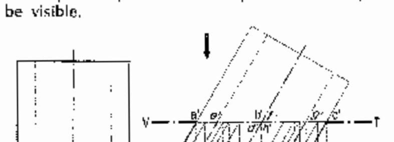


Fig. 14-22

(iv) Draw the true shape of the section either on a new reference line or symmetrically around the centre line and making aa equal to $a'a'$, cc equal to $c'c'$ etc.

Problem 14-20. (fig. 14-23): *A hollow cylinder, 50 mm outside diameter, axis 70 mm long and thickness 8 mm has its axis parallel to the V.P. and inclined at 30° to the vertical. It is cut in two equal halves by a horizontal section plane. Draw its sectional top view.*

The figure is self-explanatory. Note that a part of the ellipse for the inside bottom will also be visible.



14-4. SECTIONS OF CONES

This is discussed in details as follows:

(1) Section plane parallel to the base of the cone.

(2) Section plane passing through the apex of the cone.

(3) Section plane inclined to the base of the cone at an angle smaller than the angle of inclination of the generators with the base.

(4) Section plane parallel to a generator of the cone.

(5) Section plane inclined to the base of the cone at an angle greater than the angle of inclination of the generators with the base.

(1) Section plane parallel to the base of the cone:

The cone resting on the H.P. on its base [fig. 14-24(i)] is cut by a section plane parallel to the base. The true shape of the section is shown by the circle in the top view, whose diameter is equal to the length of the section viz. $a'a'$. The width of the section at any point, say b', is equal to the length of the chord bb_1.

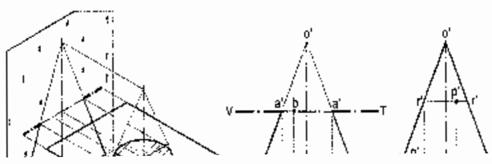
Problem 14-21. [fig. 14-24(ii)]: *To locate the position in the top view of any given point p' in the front view of the above cone.*

Method I:

(i) Through p', draw a line $r'r'$ parallel to the base.

(ii) With o as centre and diameter equal to $r'r'$, draw a circle in the top view.

(iii) Project p' to points p and p_1 on this circle. p is the top view of p'. p_1 is the top view of another point p'_1 on the back side of the cone and coinciding with p'. The chord pp_1 shows the width of the horizontal section of the cone at the point p'. This method may be called the *circle method*.



Method II:

When the position of a point in the top view say q is given, its front view q can be determined by reversing the above process.

(i) With centre o and radius oq, draw a circle cutting the horizontal centre line at s.

(ii) Through s, draw a projector cutting the slant side $o'1'$ at s'.

(iii) Draw the line $s's'$ parallel to the base, intersecting a projector through q at the required point q'.

(2) Section plane passing through the apex of the cone:

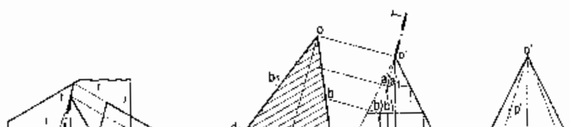
Problem 14-22. [fig. 14-25(i)]: *A cone, diameter of base 50 mm and axis 50 mm long is resting on its base on the H.P. It is cut by a section plane perpendicular to the V.P., inclined at 75° to the H.P. and passing through the apex. Draw its front view, sectional top view and true shape of the section.*

Draw the projections of the cone and on it, show the line V.T. for the section plane.

Mark a number of points a', b' etc. on the V.T. and project them to points a, b etc. in the top view by the circle method. It will be found that these points lie on a straight line through o.

Thus, od is the top view of the line or generator $o'd'$ and triangle odd_1 is the top view of the section. The width of the section at any point b' on the section is the line bb_1, obtained by projecting b on this triangle. This method is called the generator method.

Project the true shape of the section. It is an isosceles triangle, the base of which is equal to the length of the chord on the base-circle and the altitude is equal to the length of the section plane within the cone.



Problem 14-23. [fig. 14-25(ii)]: *To determine by generator method, the position in the top view of a given point p' in the front view of the above cone*

Draw the line $o'p'$ and produce it to cut the base at r'. Project r' to points r and r_1 on the base-circle in the top view. Draw lines or and or_1. Thus, or is the top view of the generator $o'r'$, and or_1 that of the generator (at the back) which coincides with $o'r'$. Project p' to p and p_1 on or and or_1 respectively. Thus, p is the top view of p', and p_1 is the top view of another point on the other side of the cone and coinciding with p. The line pp_1 is the width of the horizon-section of the cone at p'.

The position in the front view of any point in the top view, say q, may be determined by reversing the process. Draw the line oq and produce it to cut the base-circle at s. Project s to s' on the base in the front view. Join o' with s'. Through, q, draw a projector to cut $o's'$ at the required point q'.

Sectional views of cones may be obtained by applying any one of the above two methods for locating the positions of points. The generator method is more suitable particularly when the cone is in inclined positions.

(3) Section plane inclined to the base of the cone at an angle smaller than the angle of inclination of the generators with the base:

Problem 14-24. *A cone, base 75 mm diameter and axis 80 mm long is resting on its base on the H.P. It is cut by a section plane perpendicular to the V.P., inclined at 45° to the H.P. and cutting the axis at a point 35 mm from the apex. Draw its front view, sectional top view, sectional side view and true shape of the section.*

Draw a line V.T. in the required position in the front view of the cone. The positions of points on this line and the width of section at each point can be determined by one of the methods explained in problem 14-21 and problem 14-23 and as described below.

(i) ***Generator method*** (fig. 14-26(i) and fig. 14-26(ii)):

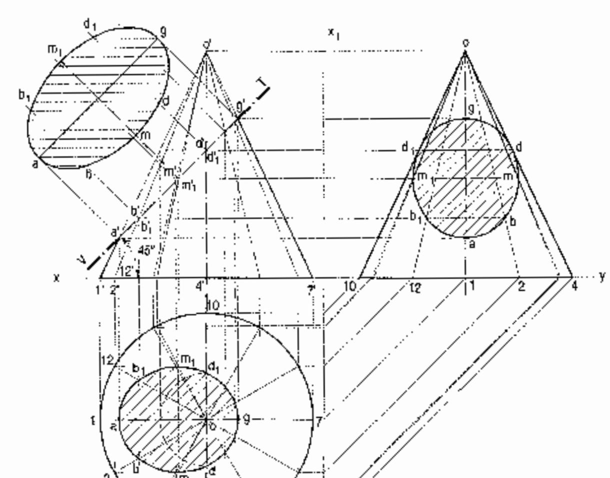
(a) Divide the base-circle into a number of equal parts, say 12. Draw lines (i.e. generators) joining these points with o. Project these points on the line representing the base in the front view.

(b) Draw lines $o'2'$, $o'3'$ etc. cutting the line for the section at points b', c' etc. Project these points on the ...

for the maximum width of the section at its centre should also be obtained. Mark m', the mid-point of the section and obtain the points m and m_1. Draw a smooth curve through these points.

(d) The true shape of the section may be obtained on the V.T. as a new reference line or symmetrically around the centre line ag, drawn parallel to the V.T. as shown. It is an ellipse whose major axis is equal to the length of the section and minor axis equal to the width of the section at its centre.

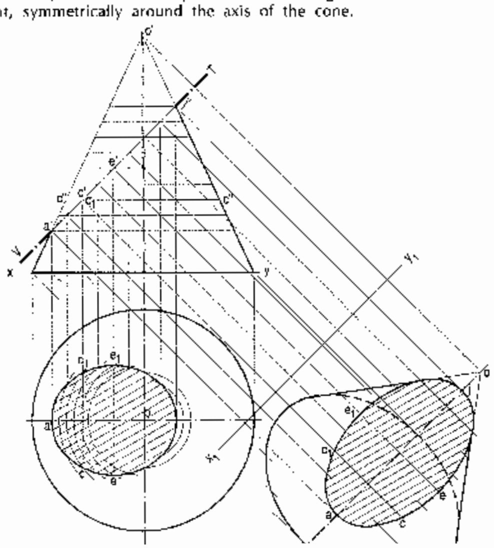
Draw the sectional side view by projecting the points on corresponding generators, as shown.



(c) Similarly, obtain all other points and draw a smooth curve through them. This curve will show the apparent section. The maximum width of the section will be at the mid-point e'. It is shown in the top view by the length of the chord joining e and e_1.

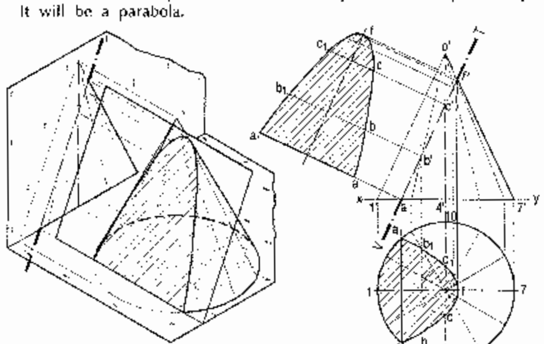
(d) Draw a reference line x_1y_1 parallel to the V.T. and project the true shape of the section. In the figure, the auxiliary sectional top view of the truncated cone is shown. It shows the true shape of the section.

The sectional side view (not shown in the figure) may be obtained by projecting all the division-points horizontally and then marking the width of the section at each point, symmetrically around the axis of the cone.



(ii) Draw the twelve generators in the top view and project them to the front view. All the generators except $o'1'$, $o'2'$ and o'-12 are cut by the section plane. Project the points at which they are cut, to the corresponding generators in the top view. The width of the section at the point where the base is cut will be the chord aa_1. Draw a curve through $a...f...a_1$. The figure enclosed between aa_1 and the curve is the apparent section.

(iii) Obtain the true shape of the section as explained in the previous problem. It will be a parabola.



(i) (ii)

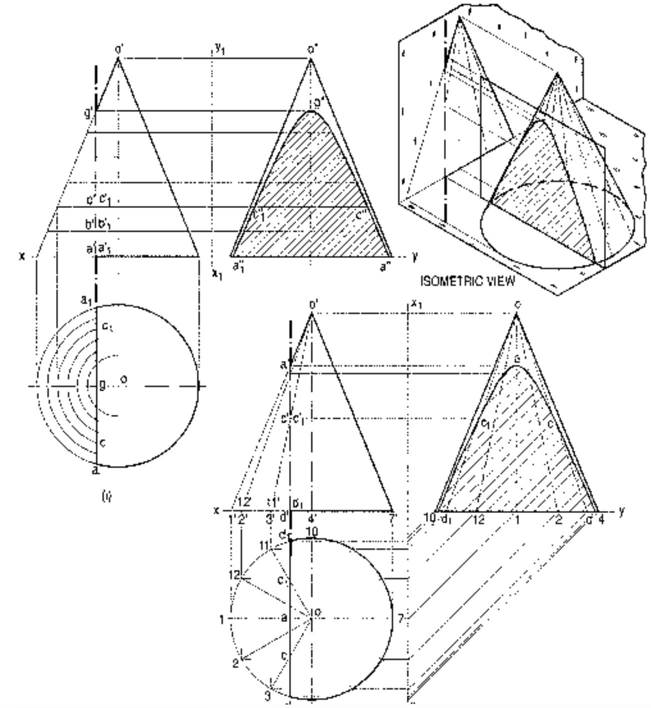
Fig. 14-28

(5) Section plane inclined to the base of the cone at an angle greater than the angle of inclination of the generators with the base:

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 32 for the following problem.

Problem 14-26. [fig. 14-29(i) and fig. 14-29(ii)]: *A cone, base 45 mm diameter* ...

Fig. 14-29(ii) shows the views obtained by the generator method.



For development, the true lengths of the cut-generators are obtained by drawing lines parallel to the base. Positions of points a and a_1 are determined by projecting them on the base-circle in the first top view.

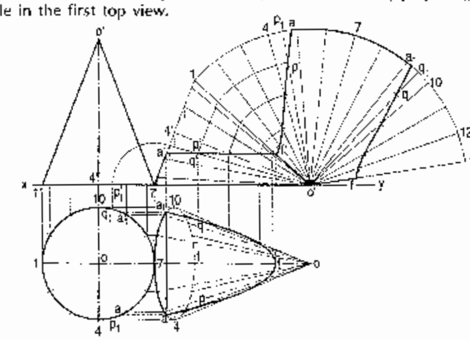
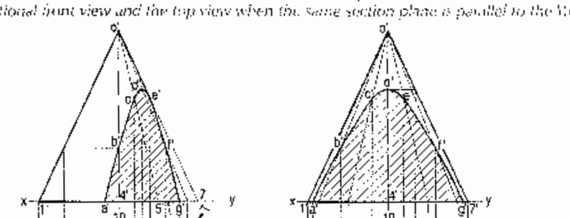


Fig. 14-30

Problem 14-28. (fig. 14-31): *A cone, base 70 mm diameter, axis 75 mm long and resting on its base on the H.P., is cut by a vertical section plane, the H.T. of which makes an angle of 60° with the reference line and is 12 mm away from the top view of the axis. (i) Draw the sectional front view and the true shape of the section. (ii) Also draw the sectional front view and the top view when the same section plane is parallel to the V.P.*



(i) Draw a circle with centre o and radius equal to **12** mm.

(ii) Draw a **line** for the section plane, tangent to this circle and **inclined at 60°** to xy [fig. 14-31(i)].

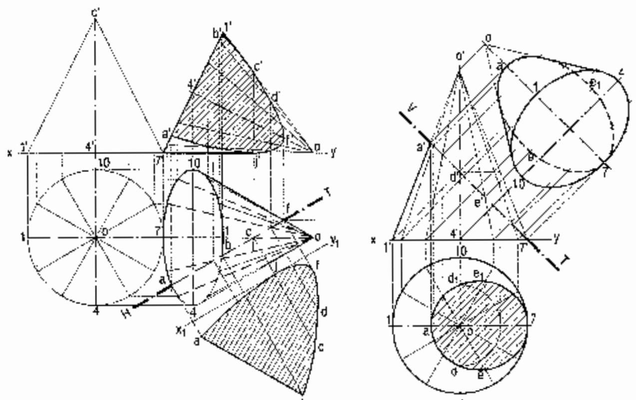
(iii) Project the front **view by** the generator method as shown. Note how **the** point f' is obtained.

Fig. 14-31(ii) shows the two views when the section **plane** is parallel to the V.P.

Problem 14-29. (fig. 14-32): *A cone, base 60 mm diameter and axis 60 mm long is lying on the H.P. on one of its generators with the axis parallel to the V.P. A vertical section plane parallel to the generator which is tangent to the ellipse (for the base) in the top view, cuts the cone bisecting the axis and removing a portion containing the apex. Draw its sectional front view and true shape of the section.*

(i) **Name** in correct sequence the points **at** which **the** base **and the** generators are cut **and** project them in the front view.

(ii) **Project** the true shape **of the** section on the new reference line $x_1 y_1$ drawn parallel to the H.T.



14-5. SECTIONS OF SPHERES

These are discussed in details as under.

(1) Section plane parallel to the H.P.
(2) Section plane parallel to the V.P.
(3) Section plane perpendicular to the V.P. and inclined to the H.P.
(4) Section plane perpendicular to the H.P. and inclined to the V.P.

(1) Section plane parallel to the H.P.: When a sphere is cut by a plane, **the** true shape of the section is always a circle.

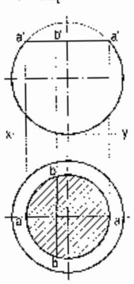
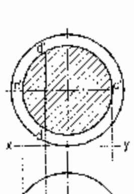
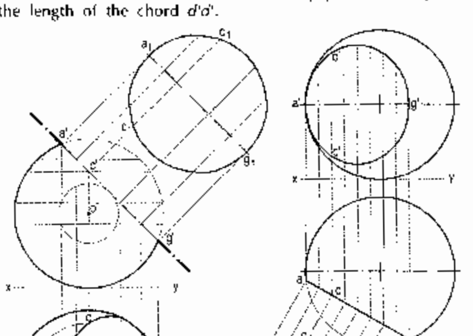


Fig. 14-34

The sphere in fig. 14-34 is cut by a horizontal section plane. The true shape of the section (seen in the top view) is a circle of diameter $a'a'$. The width of the section at any point say b', is equal to the **length** of the chord bb.

(2) Section plane parallel to the V.P.: When the sphere is cut by a section plane parallel to the V.P. (fig. 14-35), the true shape of the section, seen in the front view, is a circle of diameter cc. **The** width of section **at any** point d is equal to the **length of the chord** $d'd'$.





Draw a line (for the section plane) inclined at 45° to *xy* and tangent to the circle of 10 mm radius drawn with *o'* as centre. Mark a number of points on this line.

Method I:

(i) Find the width of section at each point in the top view as shown in fig. 14-34. For example, the chord *cc* is the width of section at the point *c'*.

(ii) Draw a curve through the points thus obtained. It will be an ellipse. The true shape of the section will be a circle of diameter a'g'.

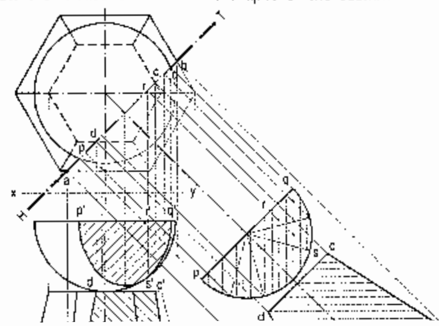
Method II:

It is known that the true shape of the section is a circle of diameter equal to a'g'. The width of section at any point say *c'* is equal to the chord c_1c_1 on this circle. Therefore, project *c'* to points c in the top view so that $cc = c_1c_1$. Similarly, obtain other points and draw the ellipse through them.

Fig. 14-37 shows the sectional front view and true shape of the section when the section plane is vertical and inclined to the V.P.

(4) Section plane perpendicular to the H.P. and inclined to the V.P.:

Problem 14-32. (fig. 14-38): *The projections of a hemisphere 50 mm diameter, placed centrally on the top of a frustum of a hexagonal pyramid, base 32 mm side, top 20 mm side and axis 50 mm long are given. Draw the sectional front view when the vertical section plane H.T. inclined at 45° to the V.P. and 10 mm from the axis, cuts them. Also draw the true shapes of the sections of both the solids.*



14-6. TYPICAL PROBLEMS OF SECTIONS OF SOLIDS

Problem 14-33. *A solid composed of a half-cone and a half-hexagonal pyramid is shown in fig. 14-39. It is cut by a section plane, which makes an angle of 30° with the base, is perpendicular to the V.P. and contains an edge of the base of the pyramid. Draw its sectional top view, true shape of the section and development of the surface of the remaining portion. Base of cone 60 mm diameter; axis 70 mm long.*

(i) Draw a line V.T. inclined at 30° to the base and passing through a'.

(ii) Project the sectional top view. Note how points b and b_1 are obtained. The true shape of the section will be partly elliptical.

(iii) Draw the development of the half-cone and half-pyramid and show the lines for the section in it.

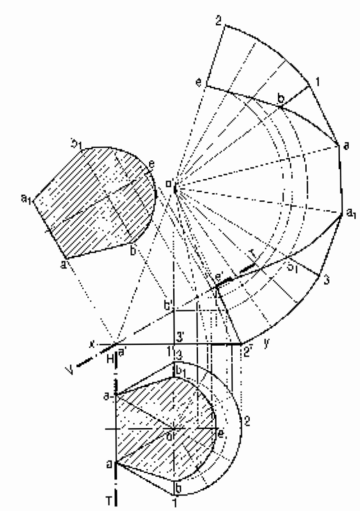
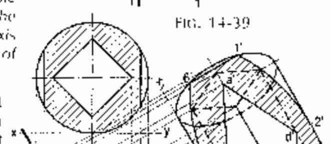


Fig. 14-39

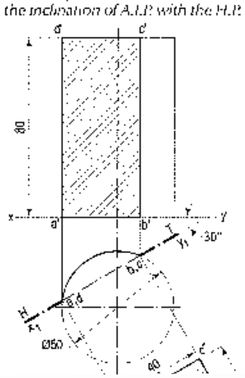
Problem 14-34. (fig. 14-40): *A cylinder, base 50 mm diameter and axis 75 mm long, has a square hole of 25 mm side cut through it so that the axis of the hole coincides with that of the cylinder. The cylinder is lying on the H.P. with the axis perpendicular to the V.P. and the faces of the hole equally inclined to the H.P.*

A vertical section plane, inclined at 60° to the V.P. cuts the cylinder in two equal halves. Project the front



of the hole will be visible within the section and hence, must be shown as full lines.

(iii) Complete the view by showing the section and the remaining portion of the cylinder with dark lines.



Problem 14-35. (fig. 14-41): *A square prism axis 110 mm long is resting on its base in the H.P. The edges of the base are equally inclined to V.P.*

The prism is cut by an A.I.P. passing through the mid-point of the axis in such a way that the true shape of the section is rhombus having diagonals of 100 mm and 50 mm. Draw the projections and determine the inclination of A.I.P. with the H.P.

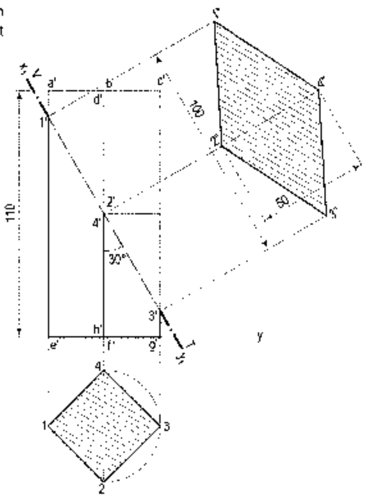


Fig. 14-41

(i) Draw the top view and the front view as shown.

(ii) Mark the mid-point of the axis in the front view.

(iii) With the mid-point of the axis as centre and radius equal to 50 mm (half of the longer diagonal i.e. 100 mm), draw an arc cutting

(i) Draw a top view and an front view of the cylinder.

(ii) Draw x_1y_1 at 30° to *xy* in such a way that the chord length in the top view is 40 mm. Project points 1, 2, 3 and 4 and draw the rectangle of 40 mm × 80 mm as shown.

Problem 14-37. (fig. 14-43): *A hexagonal pyramid, base 30 mm side and axis 70 mm long is resting on its slant edge of the face on the horizontal plane.*

A section plane, perpendicular to the V.P., inclined to the H.P. passes through the highest corner of the base and intersecting the axis at 25 mm from the base. Draw the projections of the solid and determine the inclination of the section plane with the H.P.

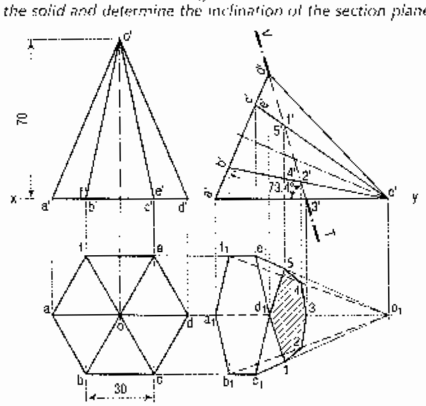


Fig. 14-43

(i) Draw the top view and the front view keeping one of the sides of the base parallel to *xy*.

(ii) With *a'* and *o'*, as centres and radii equal to *a'd'* and *o'd'* draw arcs intersecting each other at point *d'*. Draw a section plane passing through *d'* and point 25 mm away from the base along the axis as shown.

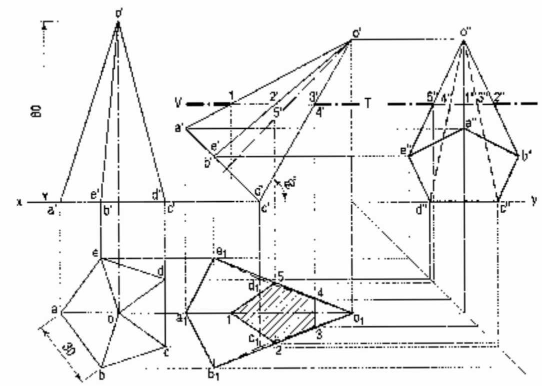
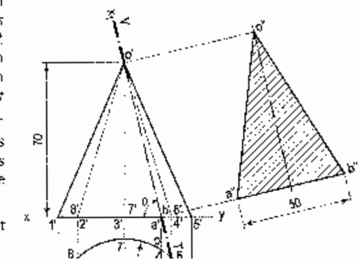


FIG. 14-44

Problem 14-39. (fig. 14-45): *A cone, diameter of the base 60 mm and axis 70 mm long is resting on its base on the H.P. It is cut by an A.I.P. so that the true shape of the section is an isosceles triangle having 50 mm base. Draw the top view, the front view and the true shape of the section.*



When a section plane passes through an apex of a cone and cuts the base of the cone, the true-shape of section is a triangle.

(i) Draw a top view and an front view as shown.

Problem 14-40. (fig. 14-46): *A square pyramid of 60 mm side of base and 70 mm length of axis is resting on its base on the H.P. having a side of base perpendicular to the V.P. It is cut by two cutting planes. One is parallel to its extreme right face and 10 mm away from it. While the other is parallel to the extreme left face.*

Both the cutting planes intersect each other on the axis of the pyramid. Draw the sectional top view, front view and the left hand side view.

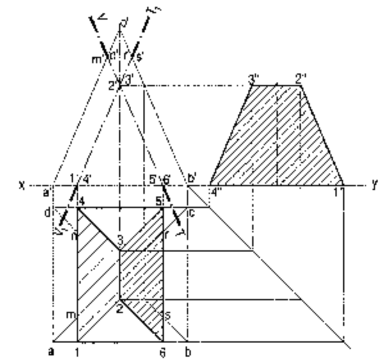


FIG. 14-46

(i) Draw the top view and the front view as shown.

(ii) Draw lines V.T. and V_1T_1 representing section planes in the front view intersecting at 2' and 3'.

(iii) Complete the projections. Note that the intersection points 2' and 3' are transferred on the slant edge o'b' and then projected in the top view.

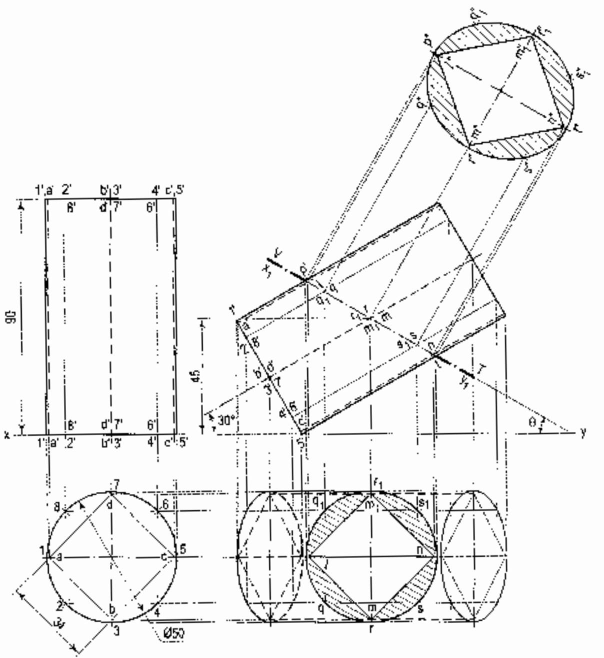


FIG. 14-47

Problem 14-42. (fig. 14-48): *A cylindrical disc of 46 mm diameter is resting on the H.P. and has height of 20 mm. A hexagonal prism of side 23 mm and height of 30 mm*

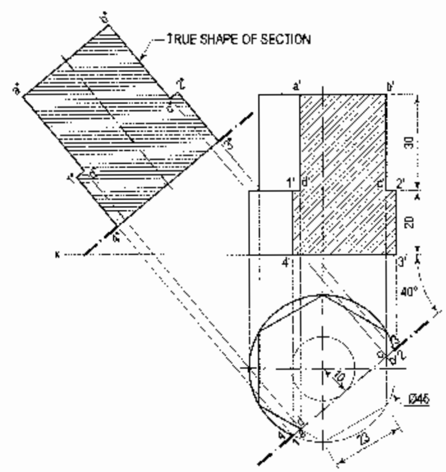
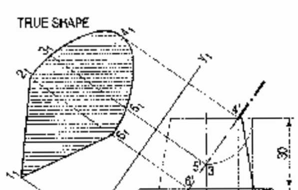


FIG. 14-48

Problem 14-43. (fig. 14-49): *A square prism of 40 mm side is resting on H.P. and has height of 30 mm. Its faces are equally inclined with the V.P. A frustum of cone having base diameter 40 mm and top 30 mm diameter with height 30 mm is kept on the prism such that axes of the both solids are coinciding. A sectional plane cuts the combined axes and inclined at 55 with H.P. passes through left corners of the*



(iv) Draw a new reference line x_1y_1 parallel to the section plane and project the section on it.

(v) The distances of the points from x_1y_1 should be taken equal to their corresponding distances from *xy* in the top view of combined solids.

Problem 14-44. (fig. 14-50): *A horizontal frustum of square pyramid having front square of 20 mm side and back square of 30 mm at length of 60 mm has axis perpendicular to the V.P. and the side of square is inclined to 45° with H.P. It is cut by section plane making 40° with V.P. and passing through a point on axis 30 mm from the surface of large square side. Draw projections of the frustum.*

(i) Mark point *b'* and construct the square a' b' c' d' with sides equally inclined to the *xy*. This is a front view of the frustum of square pyramid.

(ii) Project the top view such that the axis remains perpendicular to *xy* as shown in fig. 14-50.

(iii) Draw a section plane at distance of 20 mm along axis from large square at angle of 40° with *xy*.

(iv) Mark the points *p, q, r, s* and project them in the front view. Draw section lines in the front view for the section and complete the view.

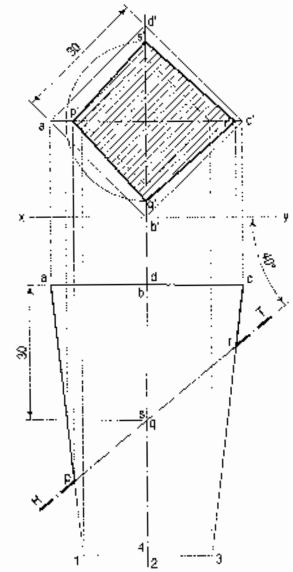


Fig. 14-50

EXERCISES 14

1. A cube of 50 mm long edges is resting on the H.P. with a vertical face inclined at 30° to the V.P. It is cut by a section plane, perpendicular to the V.P., inclined at 30° to the H.P. and passing through a point on the axis, 38 mm above the H.P. Draw the sectional top view, true shape of the section and development

plane, the H.T. of which makes an angle of 30° with *xy* and bisects the axis. Draw the sectional front view, top view and true shape of the section. Develop the surface of the remaining half of the prism.

4. A hollow square prism, base 50 mm side (outside), length 75 mm and thickness 9 mm is lying on the H.P. on one of its rectangular faces, with the axis inclined at 30° to the V.P. A section plane, parallel to the V.P. cuts the prism, intersecting the axis at a point 25 mm from one of its ends. Draw the top view and sectional front view of the prism.
5. A cylinder, 65 mm diameter and 90 mm long, has its axis parallel to the H.P. and inclined at 30° to the V.P. It is cut by a vertical section plane in such a way that the true shape of the section is an ellipse having the major axis 75 mm long. Draw its sectional front view and true shape of the section.
6. A cube of 65 mm long edges has its vertical faces equally inclined to the V.P. It is cut by a section plane, perpendicular to the V.P., so that the true shape of the section is a regular hexagon. Determine the inclination of the cutting plane with the H.P. and draw the sectional top view and true shape of the section.
7. A vertical hollow cylinder, outside diameter 60 mm, length 85 mm and thickness 9 mm is cut by two section planes which are normal to the V.P. and which intersect each other at the top end of the axis. The planes cut the cylinder on opposite sides of the axis and are inclined at 30° and 45° respectively to it. Draw the front view, sectional top view and auxiliary sectional top views on planes parallel to the respective section planes.
8. A square pyramid, base 50 mm side and axis 75 mm long, is resting on the H.P. on one of its triangular faces, the top view of the axis making an angle of 30° with the V.P. It is cut by a horizontal section plane, the V.T. of which intersects the axis at a point 6 mm from the base. Draw the front view, sectional top view and the development of the sectioned pyramid.
9. A pentagonal pyramid, base 30 mm side and axis 75 mm long, has its base horizontal and an edge of the base parallel to the V.P. It is cut by a section plane, perpendicular to the V.P., inclined at 60° to the H.P. and bisecting the axis. Draw the front view and the top view when the pyramid is tilted so that it lies on its cut-face on the ground with the axis parallel to the V.P. Show the shape of the section by dotted lines. Develop the surface of the truncated pyramid.
10. A tetrahedron of 65 mm long edges is lying on the H.P. on one of its faces,

cone through the mid-point of the axis. Draw the front view, sectional top view and an auxiliary top view on a plane parallel to the axis.

13. A cone, base 65 mm diameter and axis 75 mm long, is lying on the H.P. on one of its generators with the axis parallel to the V.P. A section plane which is parallel to the V.P. cuts the cone 6 mm away from the axis. Draw the sectional front view and development of the surface of the remaining portion of the cone.
14. The cone in above problem 13 is cut by a horizontal section plane passing through the centre of the base. Draw the sectional top view and another top view on an auxiliary plane parallel to the axis of the cone.
15. A hemisphere of 65 mm diameter, lying on the H.P. on its flat face, is cut by a vertical section plane inclined to the V.P. so that the semi-ellipse seen in the front view has its minor axis 45 mm long and half major axis 25 mm long. Draw the top view, sectional front view and true shape of the section.
16. The top view of a cylinder 75 mm diameter, 125 mm long, placed on top of the frustum of a cone, base 100 mm diameter, top 50 mm diameter and axis 125 mm long is shown in fig. 14-51. Both the solids are cut by a vertical section plane, the H.T. of which is 12 mm from the axis of the frustum and makes 30° angle with *xy*. Draw the sectional front view and true shape of the sections.

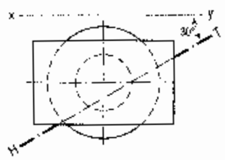
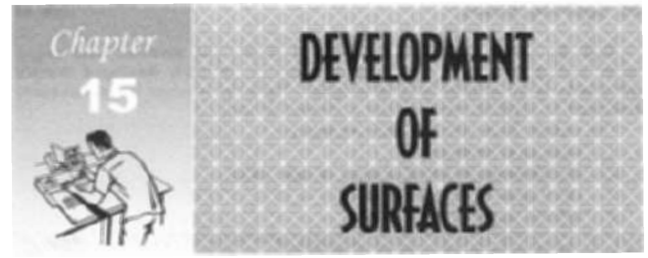


Fig. 14-51

17. A sphere of 75 mm diameter is cut by a section plane, perpendicular to the V.P. and inclined at 30° to the H.P. in such a way that the true shape of the section is a circle of 50 mm diameter. Draw its front view, sectional top view and sectional side view.
18. A frustum of a cone, base 75 mm diameter, top 50 mm diameter and axis 75 mm long, has a hole of 30 mm diameter drilled centrally through its flat faces. It is resting on its base on the H.P. and is cut by a section plane, the V.T. of which makes an angle of 60° with *xy* and bisects the axis. Draw its sectional top view and an auxiliary top view on a reference line parallel to the V.T., showing clearly the shape of the section.
19. A hexagonal prism, side of the base 25 mm long and axis 65 mm long is resting on an edge of the base on the H.P., its axis being inclined at 60° to the H.P. and parallel to the V.P. A section plane, inclined at 45° to the V.P. and normal to the H.P., cuts the prism and passes through a point on the

an angle of 30° with the H.P., normal to the V.P. and bisecting the axis. Draw its sectional top view and another top view on a plane parallel to the section.

22. *PQR* is an isosceles triangle having base *PR* horizontal and 50 mm long, and altitude 50 mm. A point *A* is taken on *PR* at a distance of 15 mm from *P* and a straight line *AB* is drawn parallel to *PQ* cutting *QR* at *B*. If *AB* is regarded as the V.T. of an inclined plane perpendicular to the V.P., cutting a cone of which *PQR* is the front view, draw the sectional top view, sectional side view and true shape of the section.
23. A cone of 55 mm diameter and 75 mm height is resting on the H.P. on one of its generators in such a way that, the generator is parallel to the V.P. It is cut by a plane parallel to the V.P. and inclined at 90° to the H.P. and passing through a point 15 mm in front of its axis. Draw the sectional front view and the top view of the cone.
24. The true section of a vertical square prism cut by an inclined plane is a rectangle of 75 mm × 40 mm. The plane cuts one of the side faces at a height of 40 mm from the base. Draw three views of the cut prism when it rests on the cut face on the H.P. with its axis remaining parallel to the V.P.
25. An equilateral triangular prism, base 50 mm side and height 100 mm is standing on the H.P. on its triangular face with one of the sides of that face inclined at 90° to the V.P. It is cut by an inclined plane in such a way that the true shape of the section is a trapezium of 50 mm and 12 mm parallel sides. Draw the projections and true shape of the section and find the angle which the cutting plane makes with the H.P.
26. A horizontal cylinder, 30 mm diameter and length 60 mm, is placed centrally on the top of a frustum of a cone, diameter of the base 45 mm, diameter of the top 25 mm and height 45 mm. Draw a sectional front view of the two solids on a vertical plane, distance 12 mm from the axis of the cone and making an angle of 60° with the axis of the cylinder.
27. A cone, base 75 mm diameter and axis 100 mm long, has its base on the H.P. A section plane, parallel to one of the end generators and perpendicular to the V.P., cuts the cone intersecting the axis at a point 75 mm from the base. Draw the sectional top view and project another top view on a plane parallel to the section plane, showing the shape of the section clearly.
28. A solid is made up of a cylinder, 30 mm diameter and 75 mm long, which joins



15-0. INTRODUCTION

Imagine that a solid is enclosed in a wrapper of thin material, such as paper. If this covering is opened out and laid on a flat plane, the flattened-out paper is the development of the solid. Thus, when surfaces of a solid are laid out on a plane, the figure obtained is called its development.

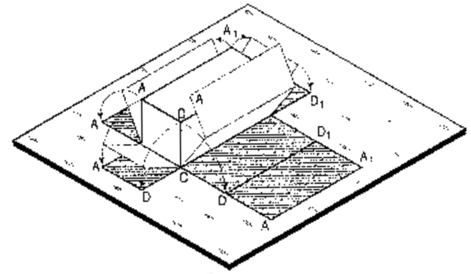


FIG. 15-1

Fig. 15-1 shows a square prism covered with paper in process of being opened out. Its development (fig. 15-2) consists of four equal rectangles for the faces and two similar squares for its ends. Each figure shows the true size and shape of the

Only the surfaces of polyhedra (such as prisms and pyramids) and single-curved surfaces (as of cones and cylinders) can be accurately developed. Warped and double-curved surfaces are undevelopable. These can however be approximately developed by dividing them up into a number of parts.

This chapter deals with the following topics:

1. Methods of development.
2. Developments of lateral surfaces of right solids.
3. Development of transition pieces.
4. Spheres (approximate method).

15-1. METHODS OF DEVELOPMENT

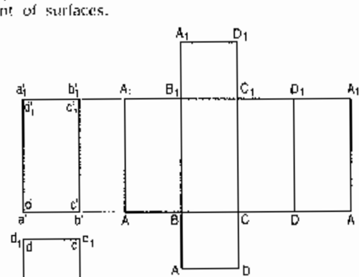
This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 33 for the methods of development of surfaces.

The following are the principal methods of development:

(1) **Parallel-line development:** It is employed in case of prisms and cylinders in which stretch-out-line principle is used. Lines *A-A* and A_1-A_1 in fig. 15-2 are called the stretch-out lines.

(2) **Radial-line development:** It is used for pyramids and cones in which the true length of the slant edge or the generator is used as radius.

(3) **Triangulation development:** This is used to develop transition pieces. This is simply a method of dividing a surface into a number of triangles and transferring them into the development.



PARALLEL-LINE DEVELOPMENT

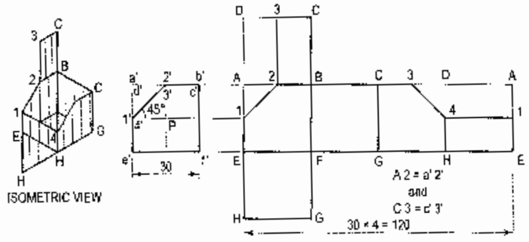
FIG. 15-2

(4) **Approximate method:** It is used to develop objects of double curved or

Problem 15-1. *Draw the development of the surface of the part P of the cube, the front view of which is shown in fig. 15-3(i).*

Name all the corners of the cube and also the points at which the edges are cut.

(i) Draw the stretch-out lines *A-A* and *E-E* directly in line with the front view, and assuming the cube to be whole, draw four squares for the vertical faces, one square for the top and another for the bottom as shown in fig. 15-3(ii).



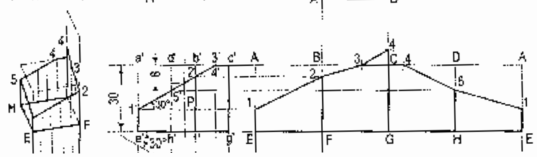
(i) CUBE (ii) DEVELOPEMENT OF CUBE

FIG. 15-3

(ii) Name all the corners. Draw a horizontal line through 1' to cut *AE* at 1 and *DH* at 4. *a' b'* is the true length of the edge. Hence, mark a point 2 on *AB* and 3 on *CD* such that *A 2 = a' 2'* amd *C 3 = c' 3'*. Mark the point 3 on *CD* in the top square also.

(iii) Draw lines 1-2, 2-3, 3-4 and 4-1, and complete the development as shown. Keep lines for the removed portion, viz. *A1*, *A2*, *3D*, *D4* and *DA* thin and fainter.

Problem 15-2. *Draw the development of the surface of the part P of the cube shown in two views in fig. 15-4(i).*



(i) Draw horizontal lines through points 1', 2' and 5' to cut *AE* in 1, *BF* in 2 and *DH* in 5 respectively. Lines *b'c'* and *c'd'* do not show the true lengths of the edges. The sides of the square in the top view show the true length. Therefore, mark points 3 in *BC* and 4 in *CD* such that *B3 = b3* and *C4 = c4*.

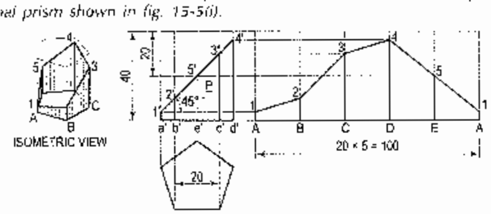
(ii) Draw lines joining 1, 2, 3 etc. in correct sequence and complete the required development. Keep the lines for the removed part fainter.

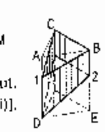
15-2-2. PRISMS

Development of the lateral surface of a prism consists of the same number of rectangles in contact as the number of the sides of the base of the prism. One side of the rectangle is equal to the length of the axis and the other side equal to the length of the side of the base.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 34 for the following problem.

Problem 15-3. *Draw the development of the lateral surface of the part P of the pentagonal prism shown in fig. 15-5(i).*





(i) PENTAGONAL PRISM (ii) DEVELOPEMENT OF PRISM

FIG. 15-5

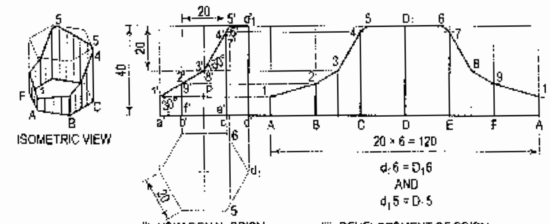
Name the corners of the prism and the points at which the edges are cut.

(i) Draw the development assuming the prism to be whole [fig. 15-5(ii)]. It is made up of five equal rectangles.

(ii) Draw horizontal lines through points 1', 2' etc. to cut the lines

Problem 15-5. *Draw the development of the lateral surface of the part P of the hexagonal prism shown in fig. 15-7(i).*

Name the points at which the edges are cut and draw the development assuming the prism to be whole [fig. 15-7(ii)].



(i) HEXAGONAL PRISM   (ii) DEVELOPEMENT OF PRISM

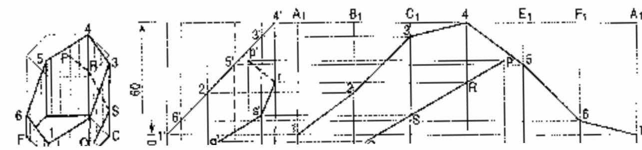
FIG. 15-7

(i) Obtain all the points except 5 and 6 by drawing horizontal lines. Note that points 3 and 8 lie on vertical lines drawn through the mid-points of BC and EF.

(ii) Mark points 5 and 6 such that $5D_1 = 5d_1$ and $D_16 = d_16$.

(iii) Draw lines joining points 1, 2, 3 etc. in correct sequence and complete the required development as shown.

Problem 15-6. *Draw the development of the lateral surface of the truncated prism shown in fig. 15-8(i). Also, draw the front view of the line joining the points P and Q (whose projections p, p' and q, q' are given) along the surface of the prism by the shortest distance.*



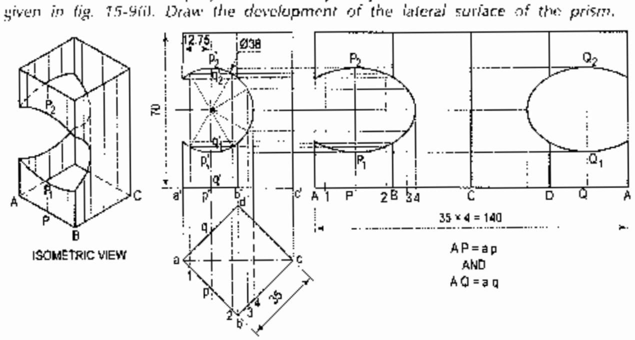
Draw the required development [fig. 15-8(ii)] as explained in problem 15-3.

(i) Mark a point p_1 on DE and q_1 on BC such that $Dp_1 = dp$ and $Bq_1 = bq$. Draw verticals through points p_1 and q_1, and on them, obtain points P and Q by drawing horizontal lines through points p' and q'.

(ii) Draw a straight line joining P with Q. Then PQ shows the shortest distance between them. To draw this line in the front view, the process must be reversed. Let PQ cut the line $D4$ at R and $C3$ at S.

(iii) Draw horizontals through R and S cutting $d'4'$ at r' and $c'3'$ at s'. Draw lines $p'r'$, $r's'$ and $s'q'$ which show the front view of the line PQ. Note that $p'r'$ is a hidden line.

Problem 15-7. *The projections of a square prism with a hole drilled in it are given in fig. 15-9(i). Draw the development of the lateral surface of the prism.*



(i) SQUARE PRISM   (ii) DEVELOPEMENT OF PRISM

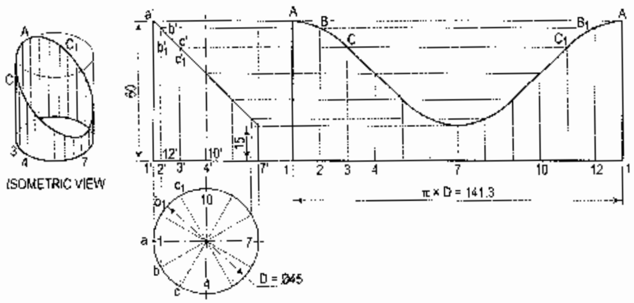
FIG. 15-9

(i) Mark a number of points on the circle for the hole. Draw the development of the whole prism [fig. 15-9(ii)] and locate the positions of these points on it.

(ii) For example, to locate points p'_1 and p'_2 and points q'_1 and q'_2 which coincide with them in the front view, draw a perpendicular through them

(i) Divide the circle in the top view into twelve equal parts. Project the division points to the front view and draw the generators. Mark points a', b' and b'_1, c' and c'_1 etc. in which the generators are cut.

(ii) Draw the development of the lateral surface of the whole cylinder along with the generators [fig. 15-10(ii)]. The length of the line 1-1 is equal to $\pi \times D$ (circumference of the circle). This length can also be marked approximately by stepping off with a bow divider, twelve divisions, each equal to the chord-length ab. (The length thus obtained is about 1% shorter than the exact length; but this is permitted in drawing work.)

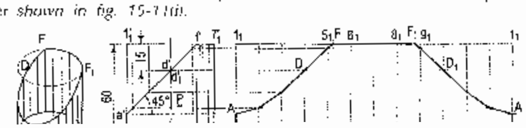


(i) TRUNCATED CYLINDER   (ii) DEVELOPEMENT OF CYLINDER

FIG. 15-10

(iii) Draw horizontal lines through points a', b' and b'_1 etc. to cut the corresponding generators in points A, B and B_1 etc. Draw a smooth curve through the points thus obtained. The figure 1-A-A-1 is the required development.

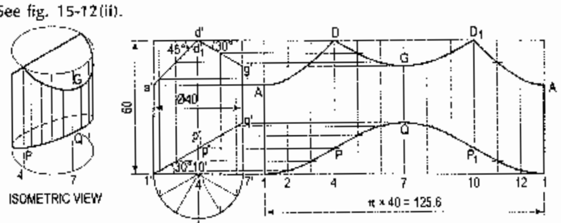
Problem 15-9. *Draw the development of the lateral surface of the part P of the cylinder shown in fig. 15-11(i).*



Draw the development as explained in problem 15-8. Positions of the points at which the upper end of the cylinder is cut should be obtained from the top view. Mark these points, viz. F and F_1 on the line 1_1-1_1 between points 5_1 and 6_1 and between 8_1 and 9_1 in such a way that $6_1F = 6_1f$ and $8_1F_1 = 8_1f_1$. Draw curves FA and F_1A passing through these points and complete the required development as shown.

Problem 15-10. *Draw the development of the lateral surface of the cylinder cut by three planes as shown in fig. 15-12(i).*

See fig. 15-12(ii).

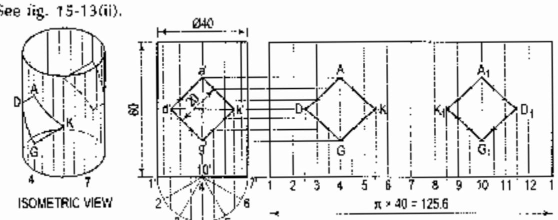


(i) CYLINDER CUT BY 3 PLANES   (ii) DEVELOPEMENT OF CUT CYLINDER

FIG. 15-12

Problem 15-11. (fig. 15-13(ii)): *Draw the development of the lateral surface of the cylinder having a square hole in it as shown in fig. 15-13(i)*

See fig. 15-13(ii).



Parts *A* and *C* are similar and are in the form of cylinders truncated at one end only. The part *A* and care as is shown in fig 15-15(ii) and fig. 15-15(iv) are developed on a stretch-out line drawn directly in line with its base. The twelve divisions are obtained from the semi-circle drawn on the base as diameter. The part *B* is truncated at both the ends. It is developed on a stretch-out line drawn through *h* and at right angles to its axis *xy* as shown in fig 15-15(iii).

As the curves of the part *B* are exactly similar to those of *A* and *C*, the three developments may also be drawn combined to minimize wastage on plate as shown in fig. 15-15(v).

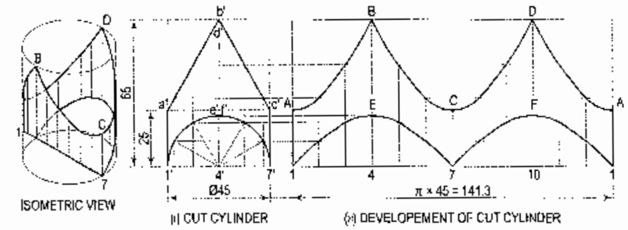
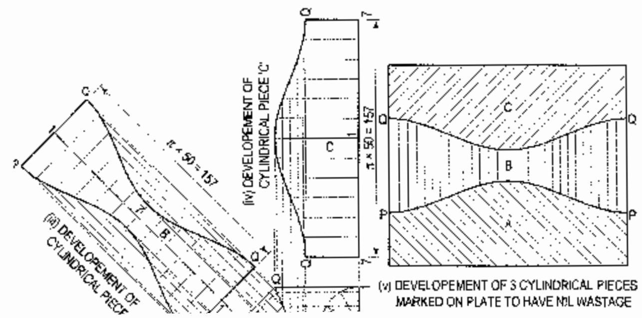


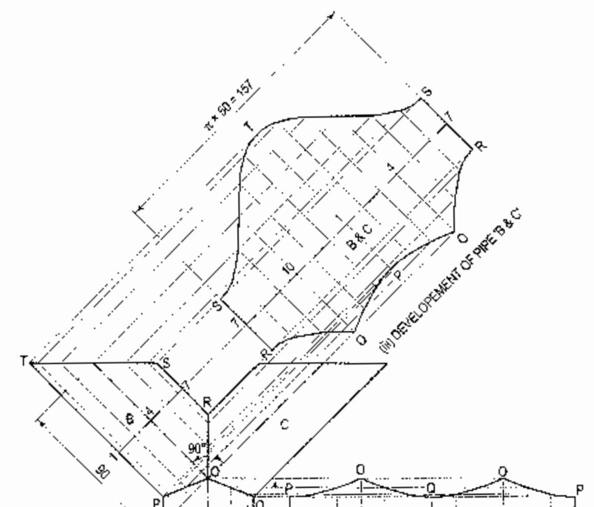
Fig. 15-14



Problem 15-14. *Three cylindrical pipes of 50 mm diameter form a Y-piece as shown in the front view in fig. 15-16(i). Draw the development of the surface of each pipe.*

(i) Draw a semi-circle on the base of pipe *A* as diameter and obtain twelve divisions. Draw the development [fig. 15-16(ii)] as in the previous problem.

(ii) Draw any convenient line at right angles to the axis of the pipe *B* [fig. 15-16(iii)]. On this line as a stretch-out line, draw the development as shown. Pipes *B* and *C* are similar and hence, their developments will also be similar.



Note: The true length of a slant edge of pyramid can be measured from the front view, if the top view of that edge is parallel to *xy*; and it can be measured from the top view, if the slant edge is parallel to *xy* in the front view.

Method of drawing the development of the lateral surface of a pyramid:

(i) With any point O as centre and radius equal to the true length of the slant edge of the pyramid, draw an arc of the circle. With radius equal to the true length of the side of the base, step-off (on this arc) the same number of divisions as the number of sides of the base.

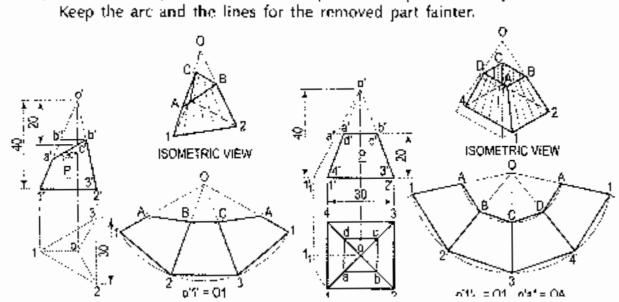
(ii) Draw lines joining the division-points with each other in correct sequence and also with the centre for the arc. The figure thus formed (excluding the arc) is the development of the lateral surface of the pyramid.

Problem 15-15. *Draw the development of the lateral surface of the part P of the triangular pyramid shown in fig. 15-17(i). The line o'1' in the front view is the true length of the slant edge because it is parallel to xy in the top view. The true length of the side of the base is seen in the top view.*

(i) Draw the development of the lateral surface of the whole pyramid [fig. 15-17(ii)] as explained above. On O1 mark a point *A* such that *OA* = *o'a'*. *o'2'* (with which *o'3'* coincides) is not the true length of the slant edge.

(ii) Hence, through *b'*, draw a line parallel to the base and cutting *o' a'* at *b"*. *o'b"* is the true length of *o'b'* as well as *o'c'*. Mark a point *B* in *O2* and *C* in *O3* such that *OB* = *OC* = *o'b"*.

(iii) Draw lines *AB*, *BC* and *CA* and complete the required development as shown. Keep the arc and the lines for the removed part fainter.



(ii) With *O* as centre and radius $o'1'_1$, draw an arc and obtain the development of the lateral surface of the whole pyramid [fig. 15-18(ii)].

(iii) With centre *O* and radius *o' a*, draw an arc cutting *O1*, *O2* etc. at points *A*, *B* etc. respectively.

(iv) Draw lines *AB*, *BC*, *CD* and *DA* and complete the required development. Note that these lines are respectively parallel to lines 1-2, 2-3 etc.

Problem 15-17. *Draw the development of the lateral surface of the part P of the square pyramid shown in fig. 15-19(i).*

Draw the top view of the pyramid and determine the true length $o'1'_1$ of the slant edges as explained in problem 15-16. On this line, obtain the true lengths *o a"* and *o'b"*.

(i) Draw the development of the lateral surface of the whole pyramid [fig. 15-19(ii)].

(ii) Mark a point *A* in *O1* and *D* in *O4* such that *OA* = *OD* = *o'a"*. Similarly, mark *B* in *O2* and *C* in *O3* such that *OB* = *OC* = *o'b"*. Draw lines *AB*, *BC* etc. and complete the required development as shown.

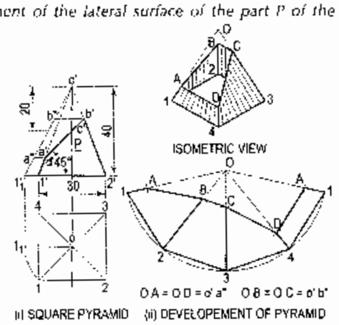
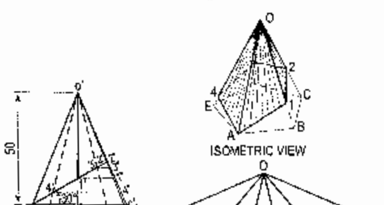


Fig. 15-19

Problem 15-18. *Draw the development of the lateral surface of the pentagonal pyramid, the lower part of which is removed as shown in fig. 15-20(i).*

None of the lines in the front view shows the true length of the slant edges. Hence, draw the top view and determine the true length $o'c'_1$. Through points



Problem 15-19. *Draw the development of the lateral surface of the part P of the pentagonal pyramid shown in fig. 15-21(i).*

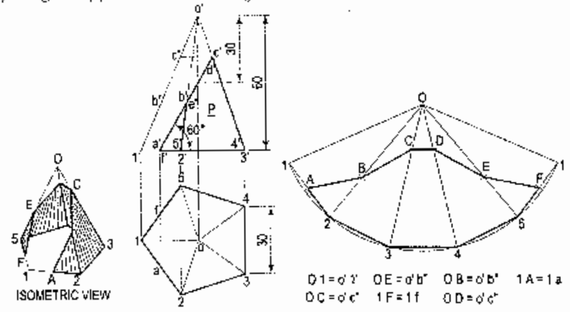


Fig. 15-21

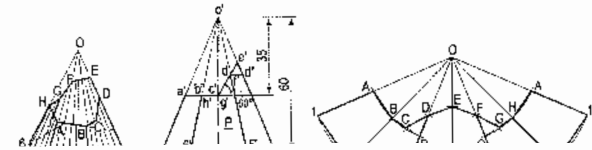
The line o'1' shows the true length of the slant edges. On it, obtain true lengths o'b'' and o'c''. Two edges of the base are also cut.

(i) Draw the top view and obtain the true lengths 1a and 1f as shown. Draw the development of the lateral surface of the whole pyramid.

(ii) Obtain points *B*, *C*, *D* and *E* as explained in problem 15-18. Mark a point *A* in 1-2 and *F* in 5-1 such that 1*A* = 1a and 1*F* = 1f.

(iii) Draw lines joining points *A*, *B*, *C* etc. and complete the required development.

Problem 15-20. *Draw the development of the lateral surface of the part P of the hexagonal pyramid shown in fig. 15-22(i).*

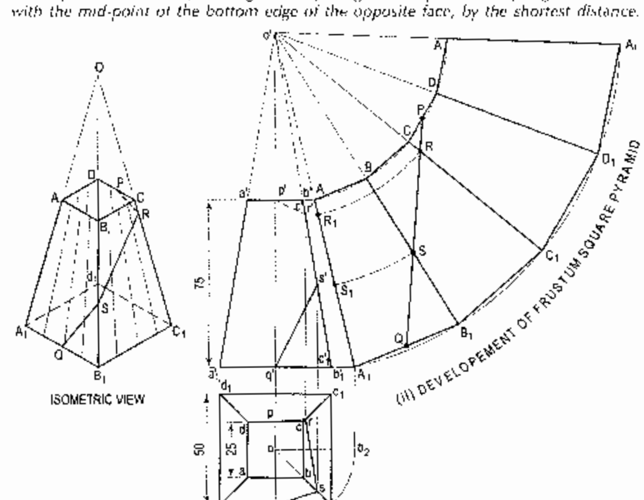


Lines o'1 and o'4' show the true length of the slant edges. Draw the development of the lateral surface of the whole pyramid [fig. 15-22(ii)]. Obtain the development of the left-half of the pyramid as explained in problem 15-16 and that of the right-half as explained in problem 15-15.

Note that the points C and G are the mid-points of the lines *BR* and *HQ* respectively.

Problem 15-21. (fig. 15-23): *A frustum of a square pyramid has its base 50 mm side, top 25 mm side and height 75 mm. Draw the development of its lateral surface.*

Also, draw the projections of the frustum (when its axis is vertical and a side of its base is parallel to the V.P.), showing the line joining the mid-point of a top edge of one face with the mid-point of the bottom edge of the opposite face, by the shortest distance.



15-2-5. CONE

The development of the curved surface of a cone is a sector of a circle, the radius and the length of the arc of which are respectively equal to the slant height and the circumference of the base-circle of the cone.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 35 for the following problem.

Problem 15-22. *Draw the development of the lateral surface of the truncated cone shown in fig. 15-24(i).*

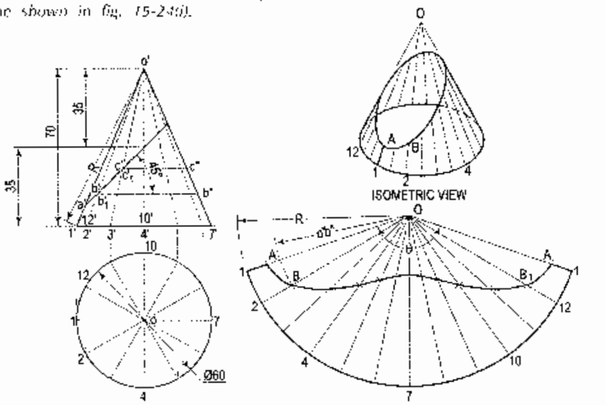


Fig. 15-24

Assuming the cone to be whole, let us draw its development.

(i) Draw the base-circle in the top view and divide it into twelve equal parts.

(ii) With any point O as centre and radius equal to o'1' or o'7', draw an arc of the circle [fig. 15-24(ii)]. The length of this arc should be equal to the

(v) Join the division-points with *O*, thus completing the development of the whole cone with twelve generators shown in it [fig. 15-24(ii)].

(vi) The truncated portion of the cone may be deducted from this development by marking the positions of points at which generators are cut and then drawing a curve through them. For example, generators o'2' and o'12' in the front view are cut at points b' and b'₁ which coincide with each other. The true length of o' b' may be obtained by drawing a line through b', parallel to the base and cutting o'7' at b''. Then o'b'' is the true length of o'b'.

(vii) Mark points *B* and B_1 on generators O2 and O-12 respectively, such that $OB = OB_1$ = o' b''. Locate all points in the same way and draw a smooth curve through them. The figure enclosed this curve and the arc is the development of the truncated cone.

Problem 15-23. *Draw the development of the lateral surface of the part P of the cone shown in fig. 15-25(i).*

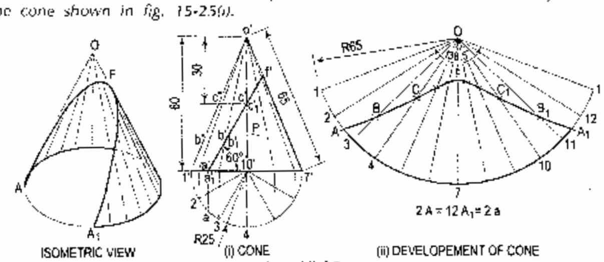
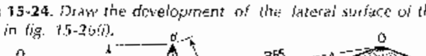


Fig. 15-25

Draw the development as explained in problem 15-22 [fig. 15-25(ii)]. For the points at which the base of the cone is cut, mark points *A* and A_1 on the arcs 2-3 and 11-12 respectively, such that $A2 = A_1\text{-}12$ = a2. Draw the curve passing through the points *A*, *B*, *C* etc. The figure enclosed between this curve and the arc $A\text{-}A_1$ is the required development.

Problem 15-24. *Draw the development of the lateral surface of the part P of the cone shown in fig. 15-26(i).*



Problem 15-25. *Draw the development of the lateral surface of the part P of the cone shown in fig. 15-27(i).*

Draw the development of the lateral surface of the whole cone [fig. 15-27(ii)]. With O as centre and radius o'q, draw the arc QQ cutting O_1 at Q.

Obtain the curve for the lower part as explained in problem 15-22. The figure enclosed between this curve and the arc QQ is the required development.

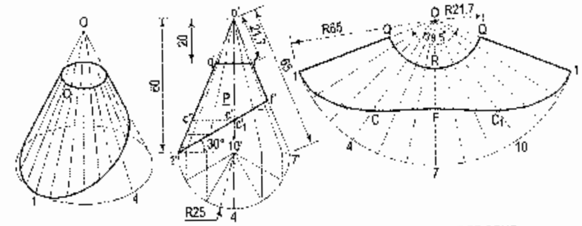


FIG. 15-27

Problem 15-26. *Draw the projections of a cone resting on the ground on its base and show on them, the shortest path by which a point P, starting from a point on the circumference of the base and moving around the cone will return to the same point. Base of cone 61 mm diameter; axis 75 mm long.*

(i) Draw the projections and the development of the surface of the cone showing all twelve generators (fig. 15-28). The development may be drawn attached to o'1'.

(ii) Assume that P starts from the point 1 (i.e. point 1' in the front view). Draw a straight line 1'1' on the development. This line shows the required shortest path.

To transfer this line to the front view the process adopted in problem 15-22 must be reversed. Let us take a point P_4 at which the path cuts the generator o'4. Mark a point P''_4 on o'1' such that $o'P''_4 = oP_4$. This can be done by drawing an arc with o' as centre and radius equal to $o'P_4$ cutting o'1'

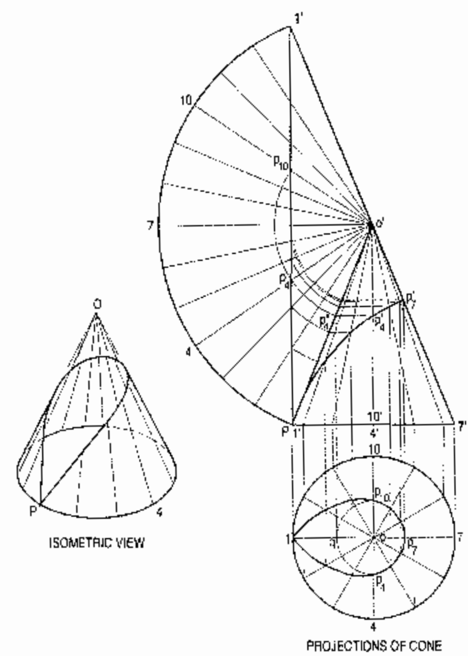


FIG. 15-28

Problem 15-27. (fig. 15-30): *Draw the development of the lateral surface of the*

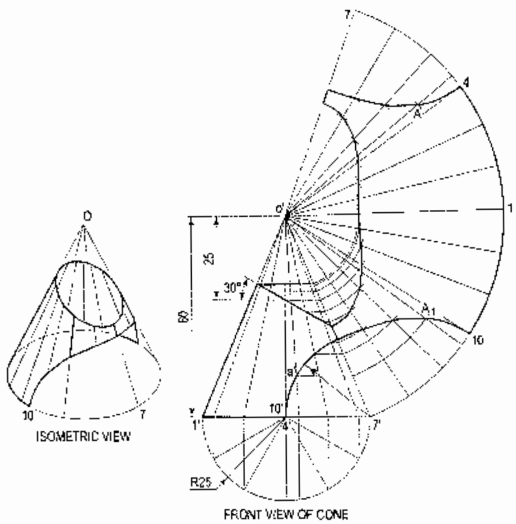
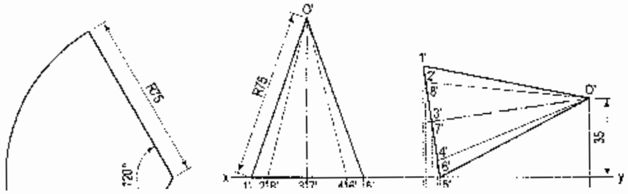


FIG. 15-29



(i) Determine the radius of the base circle of the cone using following formula:

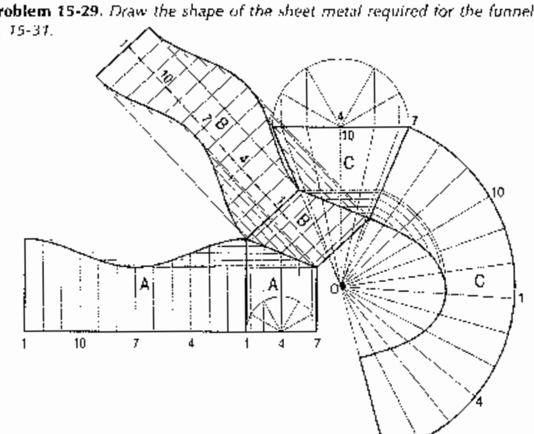
$$S = R.\ \theta = 2\ \pi\ r \quad \text{.......... (i)}$$

where S – The arc of circle
R – Radius of the arc
θ – Angle subtended by the arc at the centre
r – Radius of base circle of the cone.

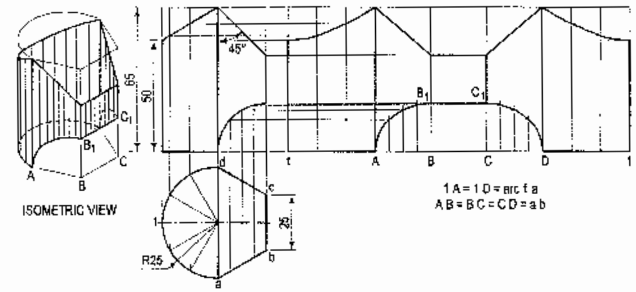
Substitute $R = 75$ mm, $\theta = \dfrac{\pi \times 120}{180}$ radian, we obtain
$r = 25$ mm.

(ii) Draw the circle of radius of 25 mm representing the top view of the cone.
(iii) Project the front view with the height equal to 75 mm.
(iv) Tilt the front view such that the apex is 35 mm above xy line.
(v) Complete the projection as shown in fig. 15-30.

Problem 15-29. *Draw the shape of the sheet metal required for the funnel shown in fig. 15-31.*



Draw perpendiculars at A, B etc. and at other intermediate points. Locate on them, positions of points at which they are cut and draw the curves and straight lines as shown.



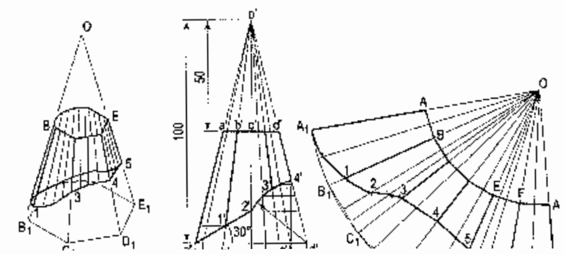
(i) TRUNCATED HALF CYLINDER AND CUT PRISM

(ii) DEVELOPEMENT OF TRUNCATED HALF CYLINDER AND CUT PRISM

FIG. 15-32

Problem 15-31. *Draw the development of the lateral surface of the solid shown in two views (drawn in first-angle projection) in fig. 15-33(i).*

The solid is made-up of portions of frusta of a cone and a hexagonal pyramid.



The slant height of the cone is equal to the slant edge of the pyramid.

(i) Therefore, with any point O as centre and radii $o'a'$ and $o'a'_1$, draw arcs [fig. 15-33(ii)].

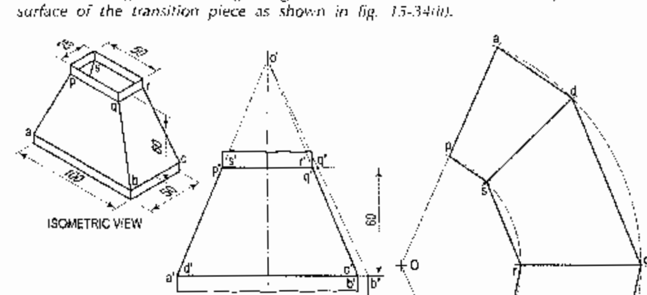
(ii) On the outer arc, step-off distances (i) A_1B_1 equal to the arc a_1b_1, (ii) B_1C_1, C_1D_1, D_1E_1 and E_1F_1, each equal to the side of the base, viz. b_1c_1 and (iii) F_1A_1 equal to the arc f_1a_1.

(iii) Join these points with O, cutting the inner arc at points A, B etc. Locate positions of various points as explained in problems 15-18 and 15-22 and complete the development as shown.

15-3. DEVELOPMENT OF TRANSITION PIECES

Pipes are used in many industries to convey hot or cold fluids. When two different sizes and shapes of pipes are joined using special pipe joint which is known as transition piece. In most cases, transition pieces are composed of plane surfaces and conical surfaces, the latter being developed by triangulation. The procedure of development of few transition pieces is illustrated in the following problems.

Problem 15-32. *In air-conditioning system a rectangular duct of 100 mm × 50 mm connects another rectangular duct of 50 mm × 25 mm through the transition piece as shown in fig. 15-34(i). Neglecting thickness of a metal sheet, develop the lateral surface of the transition piece as shown in fig. 15-34(ii).*



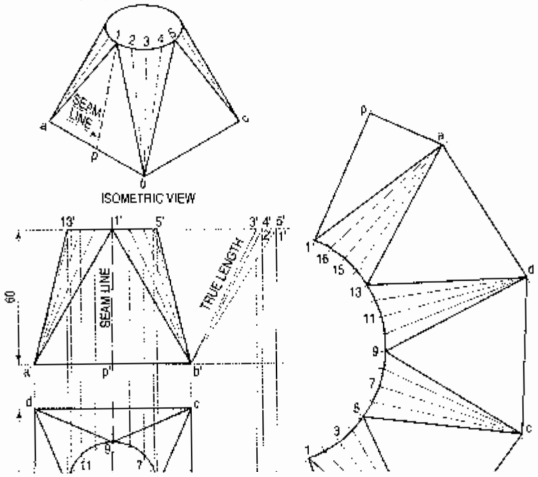
The transition piece is a frustum of a rectangular pyramid.

(i) Determine the position of the apex of the pyramid by extending $a'p'$ and $b'q'$ as shown. None of the lines in the front view shows the true length of the slant edge. Therefore, draw the top view and make any slant line parallel to xy and determine its true length $o'b''$.

(ii) With O as centre and radius ob'', draw an arc and obtain the development of a whole pyramid as shown.

(iii) With O as centre and radius $o'q''$, draw an arc cutting oa, ob, oc at points p, q, etc. respectively. Join them in sequence and complete the development as shown.

Problem 15-33. (fig. 15-35): *An air-conditioning duct of a square cross-section 70 mm × 70 mm connects a circular pipe of 40 mm diameter through the transition piece. Draw the projections and develop the lateral surface of the transition piece.*



(iii) Note that the transition piece is composed of four isosceles triangles and four conical surfaces. The seam is along line 1-*P*.

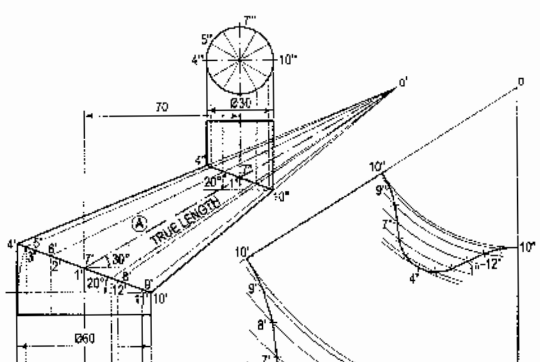
(iv) Begin the development from the seam line 1-*P* (1'-*P*'). As shown in fig. 15-35(ii) draw the right angle triangle 1-*P*-*b*, whose base *pb* is equal to half the side *ab* and whose hypotenuse 1-*b* is equal to the true length 1-*b*' of side 1-*b*.

(v) The conical surfaces are developed by the triangulation method as follows.

(vi) In the top view, join division of the circle 1, 2, 3 etc. with the corner *a*, *b*, *c* and *d*. Project them in the front view as shown. Obtain the true length of sides of each triangle as shown.

(vii) With *b* as centre and 2'*b*' (true length) radius draw an arc, cutting the arc drawn with 1' as centre and 1'2' as radius. Similarly, obtain the points 3', 4', 5' etc. Join them in the proper order as shown.

Problem 15-34. *A steam pipe bends at certain angle is connected by a transition piece as shown in fig. 15-36(i). Draw the development of lateral surface of the transition piece A.*



(i) Draw the top view and the front view. The transition piece is a truncated cone. The apex of the cone is determined by extending extreme generators 4' 4'' and 10' 10''. The projections of the base and the top of truncated cone are inclined to *xy*, therefore in the top view their projections do not show the true shapes.

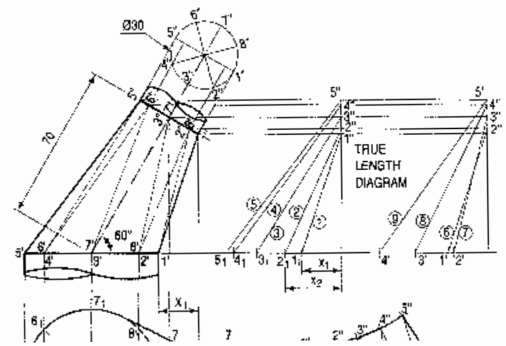
(The true-shape is an ellipse.) For approximate method of development, these projections in the top view can be taken as the true shape.

(ii) Draw the projections and the development of the cone showing all generators. Obtain the true length of generators.

(iii) With *O* as centre and radius *O*10', draw an arc of circle. Similarly draw the arcs of circle taking radii *O*9', *O*8' etc.

(iv) With 10' as centre and radius equal to 4-3 (a division of base circle in the top view), draw an arc cutting the previously drawn arc. Similarly obtain points 8', 7', 6' etc. Join them by smooth curve. Obtain the development of the top circle similar way by taking 4''5'' radius (a division of top circle).

Problem 15-35. *The orthographic projections of an exhaust pipe required for an engine is shown in fig. 15-37. Draw development of the transition connector by triangulation method.*



(i) Draw the given projections. Divide the circle of base in the top view into eight equal parts, say 1_1, 2_1. . . etc. Project them in the front view 1', 2'. . . etc. as shown.

(ii) Draw an auxiliary view of the top pipe as shown and divide it into eight equal parts. Number them 1'', 2'' . . . etc.

(iii) Form the triangles on the lateral surface as shown.

(iv) Determine true length of each side of a triangle as shown.

(v) Mark the length of $1''1_1$. With 1 as centre and radius equal to 1'2'' [line-(6)] draw an arc cutting the arc drawn with radius 1''2'' (division of auxiliary circle) and the centre as 1''. A half development is shown.

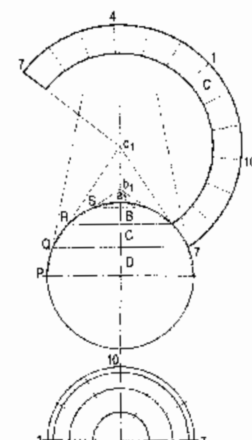
15-4. SPHERES (APPROXIMATE METHOD)

The surface of a sphere can be approximately developed by dividing it into a number of parts. The divisions may be made in two different ways:

(i) in zones (ii) in lunes.

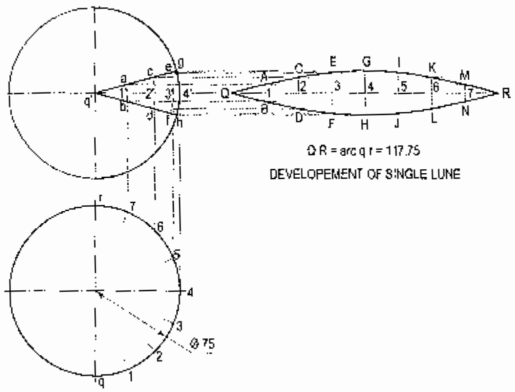
A *zone* is a portion of the sphere enclosed between two planes perpendicular to the axis. A *lune* is the portion between two planes which contain the axis of the sphere.

(1) Zone method: Fig. 15-38 shows the top half of a sphere divided into four zones of equal width. By joining the points *P*, *Q*, *R* etc. by straight lines, each zone becomes a cone frustum, except the upper-most zone which becomes a cone of small altitude.



Developments of these cone frusta and the upper cone will give the development of the half sphere. For example, take the zone *C*. It is a frustum of a cone whose vertex is at c_1. The surface of this frustum is shown developed in the front view. The length of the divisions on the arc is obtained from the top view. All the zones can be developed in the same manner.

Draw perpendiculars at each division-point and make *AB* and *MN* equal to *ab* at points 1 and 7, *CD* and *KL* equal to *cd* at points 2 and 6 etc. Draw smooth curves through points *Q*, *A*, *C* etc. The figure thus obtained will be the approximate development of one-twelfth of the surface of the sphere. Development of surfaces of some more solids cut by different planes, and solids with holes cut or drilled through them are treated in chapters 14 and 16.



Lune method
FIG. 15-39

EXERCISES 15

1. Draw the development of the lateral surface of the part *P* of each of the solids, the front views of which are shown in fig. 15-40 and described below.

2. Draw the development of the lateral surface of the part *P* of each of the cylinders, the front views of which are shown in fig. 15-41.

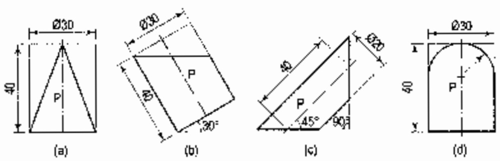


FIG. 15-41

3. Draw the development of the lateral surface of the part *P* of each of the pyramids, the front views of which are shown in fig. 15-42, and described below.

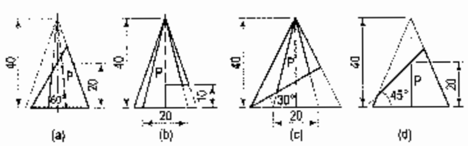


FIG. 15-42

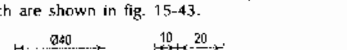
(a) A square pyramid, side of the base 20 mm long and one side of the base inclined at 30° to the V.P.

(b) A pentagonal pyramid, one side of the base parallel to the V.P.

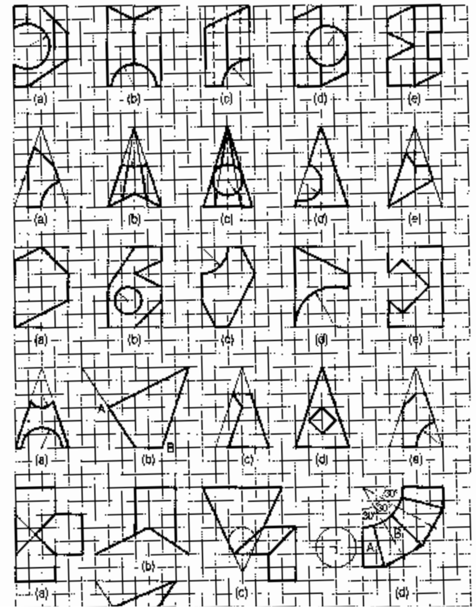
(c) A hexagonal pyramid, two sides of the base parallel to the V.P.

(d) A square pyramid, side of the base 20 mm long and all the sides of the base equally inclined to the V.P.

4. Draw the development of the lateral surface of the part *P* of each of the cones, front views of which are shown in fig. 15-43.

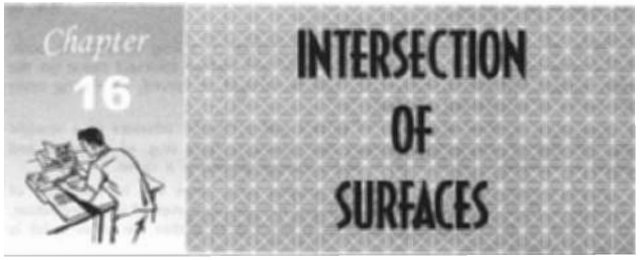


(a) A hexagonal prism having a face parallel to the V.P.
(b) A square prism, all faces equally inclined to the V.P.
(c) A pentagonal prism having a vertical face parallel to the V.P.
(d) A triangular prism having a vertical face parallel to the V.P.
(e) A hexagonal prism having two faces perpendicular to the V.P.



(a) A square pyramid having a side of base perpendicular to the V.P.
(b) A hexagonal pyramid having a side of base parallel to the V.P.
(c) A pentagonal pyramid having a side of base parallel to the V.P.
(d) A triangular pyramid having a side of base parallel to the V.P.
(e) A square pyramid having all sides of the base equally inclined to the V.P.

7. Draw the development of the surfaces of the portions of the cylinders shown in the third row.
8. Draw the development of the surfaces of the portions of the cones shown in the fourth row.
9. Refer to the fifth row, and
   (i) Draw the development of the pipes forming a Tee shown at (a).
   (ii) Draw the development of the cylindrical steel chimney erected on a roof [shown at (b)], assuming the squares to be of 30 cm side.
   (iii) Draw the development of the three parts of the funnel shown at (c).
   (iv) Develop parts *A* and *B* of the transition piece shown at (d).
10. Refer to the last row, and
   (i) Develop the surface of the conical buoy with a hemispherical top shown at (a).
   (ii) Determine the shape of the tin sheet required to prepare the can shown at (b).
   (iii) The development of the surface of a cylinder is given at (c). Draw the front view of the cylinder showing the line *AB* in it.
   (iv) The development of the surface of a cone is shown at (d). Draw the projections of the cone showing lines *AB*, *BC* and *CA* in each view.
11. A pipe 40 mm diameter and 120 mm long (along the axis) is welded to the vertical side of a tank. Show the development of the pipe, if it makes an angle of 60° with the side to which it is welded, the other end of the pipe making an angle of 30° with its own axis. Neglect thickness of the pipe.
12. The inside of a hopper of a floor mill is to be lined with tin sheet. The top and bottom of the hopper are regular pentagons with each side equal to 450 mm and 300 mm respectively (internally). The height of the hopper is 450 mm. Draw the shape to which the tin sheet is to be cut so as to fit in the hopper. Scale, 1:10.
13. A 50 mm cylinderical pipe



16-0. INTRODUCTION

The intersecting surfaces may be two plane surfaces or two curved surfaces of solids. The lateral surface of every solid taken as a whole is a curved surface. This surface may be made of only curved surface as in case of cylinders, cones etc. or of plane surfaces as in case of prisms, pyramids etc. In the former case, the problem is said to be on the intersection of surfaces and in the latter case, it is commonly known as the problem on interpenetration of solids. It may, however, be noted that when two solids meet or join or interpenetrate, it is the curved surfaces of the two that intersect each other. The latter problem also is, therefore, on the intersection of surfaces.

In this chapter, we shall learn about the intersection of surfaces as shown below:

1. Line of intersection
2. Methods of determining the line of intersection between surfaces of two interpenetrating solids
3. Intersection of two prisms
4. Intersection of cylinder and cylinder
5. Intersection of cylinder and prism
6. Intersection of cone and cylinder
7. Intersection of cone and prism
8. Intersection of cone and cone
9. Intersection of sphere and cylinder or prism.

16-1. LINE OF INTERSECTION

Thus, the line of intersection of the two surfaces is a line common to both. It is composed of points at which the lines of one surface intersect those on the other surface. The line of intersection may be straight or curved, depending upon the nature of intersecting surfaces.

Two plane surfaces (e.g. faces of prisms and pyramids) *intersect in a straight line. The line of intersection between two curved surfaces* (e.g. of cylinders and cones) *or between a plane surface and a curved surface is a curve.*

When a solid completely penetrates another solid, there will be two lines of intersection. These lines are, sometimes, called *the lines or curves of interpenetration*. The portion of the penetrating solid which lies hidden within the other solid is shown by dotted lines.

16-2. METHODS OF DETERMINING THE LINE OF INTERSECTION BETWEEN SURFACES OF TWO INTERPENETRATING SOLIDS

(1) Line method: A number of lines are drawn on the lateral surface of one of the solids and in the region of the line of intersection. Points of intersection of these lines with the surface of the other solid are then located. These points will obviously lie on the required line of intersection. They are more easily located from the view in which the lateral surface of the second solid appears edgewise (i.e. as a line). The curve drawn through these points will be the line of intersection.

(2) Cutting-plane method: The two solids are assumed to be cut by a series of cutting planes. The cutting planes may be vertical (i.e. perpendicular to the H.P.), edgewise (i.e. perpendicular to the V.P.) or oblique. The cutting planes are so selected as to cut the surface of one of the solids in straight lines and that of the other in straight lines or circles.

Each method is explained in detail while solving illustrative problems. Sound knowledge of projections of solids in various positions is quite essential while dealing with these problems.

16-3. INTERSECTION OF TWO PRISMS

Prisms have plane surfaces as their faces. The line of intersection between two

(i) Draw the projections of the prisms in the required position. The faces of the vertical prism are seen as lines in the top view. Hence, let us first locate the points of intersection in that view.

(ii) Lines 1-1 and 3-3 intersect the edge of the vertical prism in points p_1 and p_3 (coinciding with a). Lines 2-2 and 4-4 intersect the faces at p_2 and p_4 respectively. The exact positions of these points along the length of the prism may now be determined by projecting them on corresponding lines in the front view. For example, p_2 is projected to p'_2 on the line 2'2'. Note that p'_4 coincides with p'_2.

(iii) Draw lines $p'_1p'_2$ and $p'_2p'_3$. Lines $p'_1p'_4$ and $p'_3p'_4$ coincide with the front lines. These lines show the line of intersection. Lines $q'_1q'_2$ and $q'_2q'_3$ on the other side are obtained in the same manner. Note that the lines for the hidden portion of the edges are shown as dashed lines. The portions $p'_1p'_3$ and $q'_1q'_3$ of vertical edges a'a' and c'c' do not exist and hence, must be removed or kept fainter.

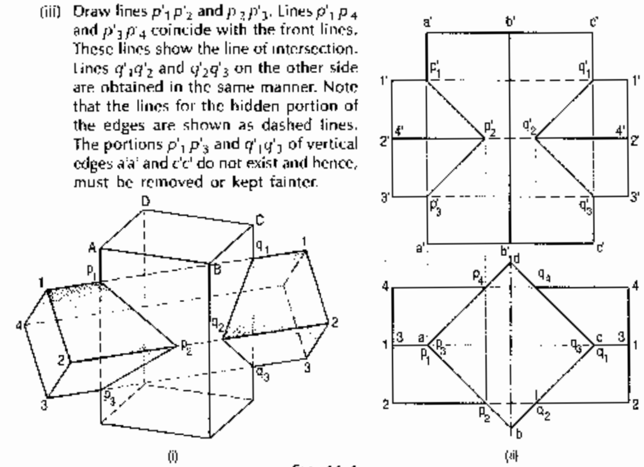
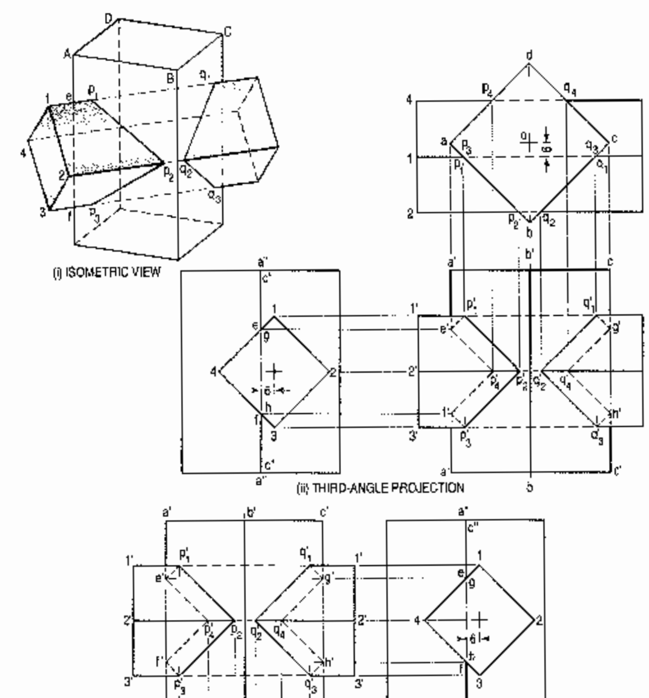


Fig. 16-1

Problem 16-2. (fig. 16-2): *A vertical square prism, base 50 mm side is completely penetrated by a horizontal square prism, base 35 mm side so that their axes are 6 mm apart. The axis of the horizontal prism is parallel to the V.P., while the faces of both prisms are equally inclined to the V.P. Draw the projections of the prisms*



(ii) Locate points (on the other side) at which the edges come out and also the two points g' and h' at which the edge c'c' is cut.

(iii) Draw lines joining these points. They will be exactly similar to lines $p'_1p'_2$ etc. on the left-hand side.

Problem 16-3. (fig. 16-3): *A vertical square prism, base 50 mm side and height 90 mm has a face inclined at 30° to the V.P. It is completely penetrated by another square prism, base 38 mm side and axis 100 mm long, faces of which are equally inclined to the V.P. The axes of the two prisms are parallel to the V.P. and bisect each other at right angles. Draw the projections showing lines of intersection.*

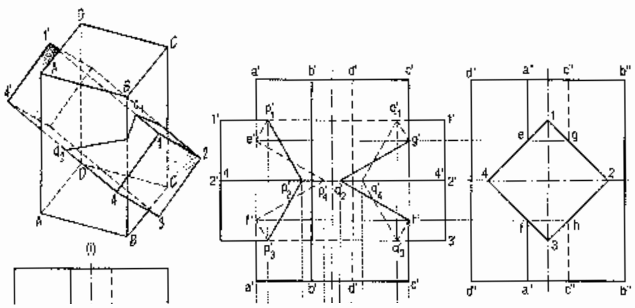
Adopt the same method as explained in problem 16-2.

(i) The edges 1-1 and 3-3 enter one face of the vertical prism and come out of its opposite face.

(ii) Obtain the points (from the top view) at which all edges intersect the faces and also the four key points (from the side view).

Note carefully the lines for visible and hidden edges, shown as full lines and dotted lines respectively.

Although the two axes are intersecting, the visible portions of the lines of intersection, when the penetrating prism enters and comes out differ because the penetrated prism has its faces inclined to the V.P.



Lines $p'_1p'_2$ and $p'_2p'_3$ are visible on the left side while q'_2g' and q'_2h' are visible on the right side. Edges a'e' and a'f' are partly hidden, while c'g' and h'c' are fully visible.

Fig. 16-3(b) shows the front view of the vertical prism, when the penetrating prism has been removed. Note that the edges of the back portions of the hole are partly visible.

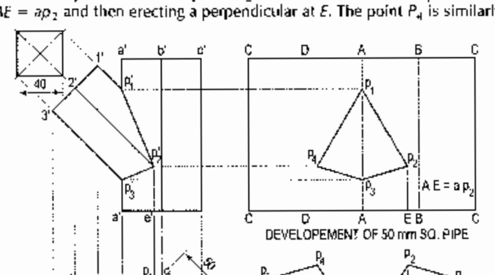
Problem 16-4. (fig. 16-4): *A square pipe of 50 mm side has a similar branch of 40 mm side. The axis of the main pipe is vertical and is intersected by the axis of the branch at an angle of 45°. All the faces of both the pipes are equally inclined to the V.P. Draw the projections of the pipes, showing lines of intersection. Also develop the surfaces of both the pipes.*

The line of intersection between the two pipes is obtained [fig. 16-4(i)] in the same manner as shown in problem 16-1. As the axes are intersecting, the edge a'a' is cut by the two edges of the branch at points p'_1 and p'_3. The other two edges of the branch enter the faces of the main pipe at points p'_2 and p'_4.

Developments of the surfaces of the two pipes are shown in fig. 16-4(ii).

(i) Heights of all the points for fig. 16-4(ii) are obtained from the front view, e.g. $P_1A = p'_1a'$, $P_11 = p'_11'$ etc.

(ii) The exact position of the point P_2 is located from the top view by making $AE = ap_2$ and then erecting a perpendicular at E. The point P_4 is similarly located.



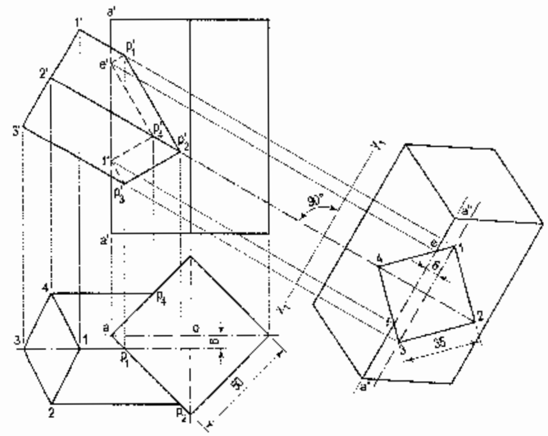


FIG. 16-5

(i) Obtain points of intersection of the edges of the inclined prism from the top view. For the points at which the edge a'a' of the vertical prism is cut, it will be necessary to project a view in which faces of the inclined prism will be seen as lines.

(ii) Therefore, project an auxiliary top view on a reference line x_1y_1 drawn perpendicular to the axis of the inclined prism.

(iii) Mark points e and f at which a"a" is pierced by the faces and project them to points e' and f' on the corresponding line a'a' in the front view. Draw straight lines joining the six points in correct sequence.

Problem 16-6. (fig. 16-6): *A square pyramid is of base sides 40 mm and height 55 mm. The sides of the base are equally inclined with the V.P. It is penetrated by a horizontal triangular prism of sides 40 mm and 70 mm axis long. The axis is perpendicular to the V.P. 25 mm above the base of the pyramid and 8 mm away from the axis of the pyramid. Assume that one of the faces of the prism is vertical and passes through the pyramid. Draw the front view, top view and side-view showing the intersection curve.*

(i) Draw the projections of the square pyramid and triangular prism in the required position.

(ii) In the front view, the edges 1'–1', ... prism, intersects the faces of the vertical pyramid at P'_1 ... and P'_6, respectively.

(iii) Project points P'_1, ... in the ... section point P_1, P_2, q_2, P_3, P_4, q_4, P_5, q_5, and P_6.

(iv) Similarly take projections from ... and complete the side view.

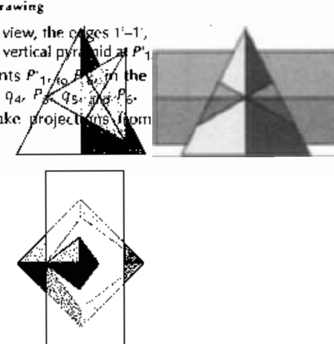
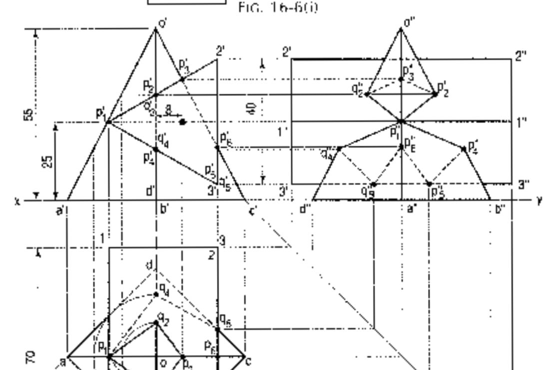


FIG. 16-6(i)



(i) Draw the projections of the square pyramid and triangular prism in the required position.

(ii) In the front view, draw lines o'e', o'b', o'g' and o'h passing through 1', 2', 3 and intersecting points respectively.

(iii) As the axes are intersecting, the edges o'b' and o'd' are cut by the two edges of the horizontal prism at P'_2, q'_2, P'_4 and q'_4.

(iv) The third edge of the horizontal prism enters the faces of vertical prism at P_3, q'_3, P'_5 and q'_5.

(v) Project these points in the top view and obtain the intersecting points P_1, P_2, P_3, P_4, P_5, q_1, q_2, q_3, q_4 and q_5.

(vi) Take projections from front view and top view and complete side view.

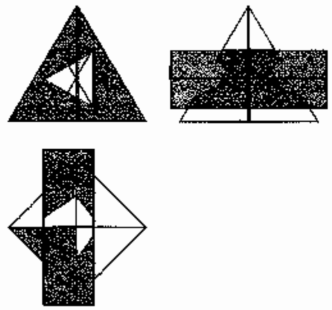
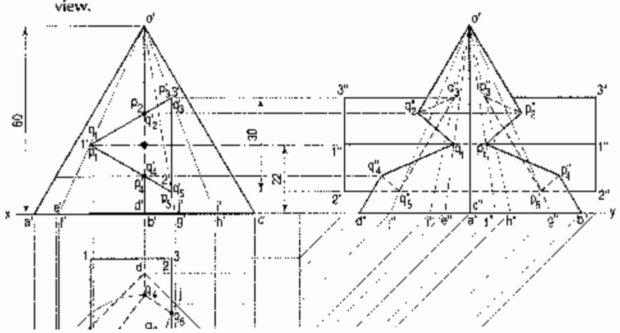


FIG. 16-7(i)



16-4. INTERSECTION OF CYLINDER AND CYLINDER

As cylinders have their lateral surfaces curved, the line of intersection between them will also be curved. Points on this line may be located by any one of the two methods. For plotting an accurate curve, certain *critical or key points*, at which the curve changes direction, must also be located. *These are the points at which outermost or extreme lines of each cylinder pierce the surface of the other cylinder.* In prisms, vertices are the key points.

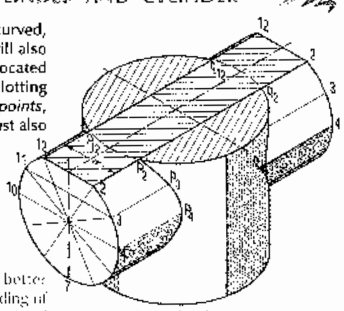
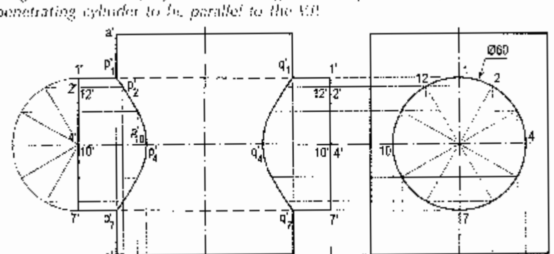


FIG. 16-8(i)

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 37 for the line of intersection.

Problem 16-8. (fig. 16-8): *A vertical cylinder of 80 mm diameter is completely penetrated by another cylinder of 60 mm diameter, their axes bisecting each other at right angles. Draw their projections showing curves of penetration, assuming the axis of the penetrating cylinder to be parallel to the V.P.*



Draw the front view and the top view and show lines for twelve generators in the horizontal cylinder in both views.

(a) ***Line method:***

(i) Mark points p_1, p_2 etc. at which lines 1-1, 2-2 etc. intersect the circle (showing the surface of the vertical cylinder) in the top view and project them to p'_1, p'_2 etc. on corresponding lines 1'1', 2'2' etc. in the front view.

(ii) Draw the required curves on both sides of the axis through points thus located. Hidden portions of the curves coincide with the visible portions. Points p'_1, p'_4, p'_7 and p'_{10} are the key points where the curve changes direction.

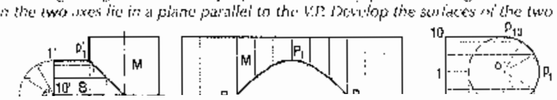
(b) *Cutting-plane method:* It will be seen that in this problem, there is practically no difference between the line method and the cutting-plane method. But the latter method proves more useful in solving problems in which none of the projections shows a line-view of the surface of a solid. Assume a series of horizontal cutting planes passing through the lines on the horizontal cylinder and cutting both cylinders.

Sections of the horizontal cylinder will be rectangles, while those of the vertical cylinder will always be circles of the same diameter as its own. Points at which sides of the rectangles intersect the circle will lie on the curve of intersection. For example, let a horizontal section plane through points 2 and 12 [fig. 16-8(i)].

In the front view, it will be seen as a line coinciding with the line 2' 2'. The section of the horizontal cylinder will be a rectangle of width w (i.e. the line 2-12). The section of the vertical cylinder will be a circle. Points p_2 and p_{12} at which the sides (2-2 and 12-12) of the rectangle cut the circle, lie on the curve. These points are first marked in the top view [fig. 16-8(ii)] and then projected to points p'_2 and p'_{12} on lines 2' 2' and 12'-12' in the front view. Points on the other side of the vertical axis are located in the same manner.

The problem may also be solved by assuming cutting planes to be vertical and parallel to both axes. They will be seen as lines in the top view and the side view. Sections of both cylinders will be rectangles and will be seen in their true sizes in the front view. Points at which sides of sections of one cylinder intersect sides of corresponding sections of the other, will lie on the curve of intersection.

Problem 16-9. (fig. 16-9): *A cylindrical pipe of 30 mm diameter has a similar branch of the same size. The axis of the main pipe is vertical and is intersected by that of the branch at right-angles. Draw the projections of the pipes, assuming suitable lengths, when the two axes lie in a plane parallel to the V.P. Develop the surfaces of the two pipes.*



Adopt the same method as explained in problem 16-8. The curve of intersection in the front view is seen as two straight lines meeting at right-angles [fig. 16-9(i)]. Developments of surfaces of the pipes are shown in fig. 16-9(ii).

Fig. 16-9(iii) shows in third-angle projection method, projections of the pipes of the same size joining at right-angles and forming an elbow. Note that the curve of intersection is seen as a straight line joining the two corners.

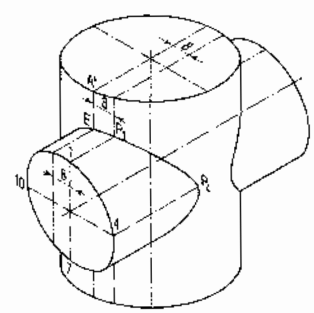
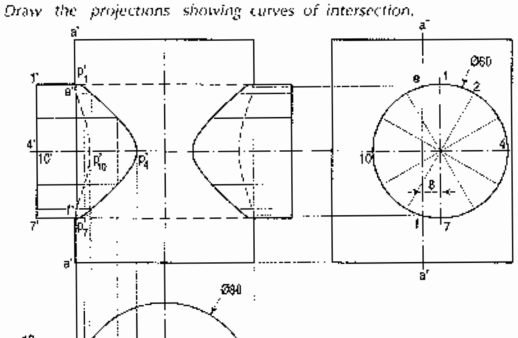


Fig. 16-10(i)

Problem 16-10. (fig. 16-10): *A vertical cylinder of 80 mm diameter is penetrated by another cylinder of 60 mm diameter, the axis of which is parallel to both the H.P. and the V.P. The two axes are 8 mm apart. Draw the projections showing curves of intersection.*



(iii) Project these points to e' and f' on the line a a'.

(iv) Draw the curve passing through all the points in correct sequence, showing the hidden portion by dotted lines. Plot a similar curve on the other side of the axis.

Problem 16-11. (fig. 16-11): *A vertical cylinder of 75 mm diameter is penetrated by another cylinder of the same size. The axis of the penetrating cylinder is parallel to both the H.P. and the V.P. and is 9 mm away from the axis of the vertical cylinder. Draw the projections showing curves of intersection.*

As the cylinders are of the same size and their axes are apart, a portion of the surface of the penetrating cylinder will be outside the vertical cylinder.

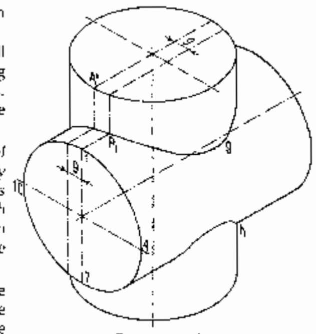
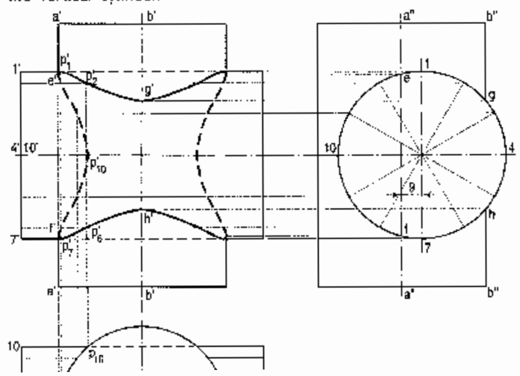


Fig. 16-11(i)



(ii) Locate key points e' and f' as shown in problem 16-10. In addition to these, mark two more key points g and h (in the side view) where the circle cuts the extreme line $b'b''$ of the vertical cylinder.

(iii) Project these points to g' and h' on the line $b'b'$ in the front view. Draw a curve through all the points, showing the hidden portion by dotted lines. Instead of two separate curves of intersection we have one continuous curve. Note that there are twelve key points in this curve.

Problem 16-12. (fig. 16-12): *A cylinder of 60 mm diameter, having its axis vertical is penetrated by another cylinder of 40 mm diameter. The axis of the penetrating cylinder is parallel to the V.P. and bisects the axis of the vertical cylinder, making an angle of 60° with it. Draw the projections showing curves of intersection.*

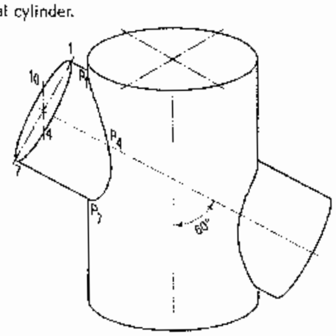
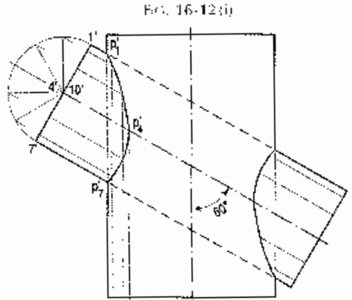


Fig. 16-12(i)

Draw the projections of the cylinders in the required position and proceed to locate the points on curves of intersection as shown in problem 16-8. The back and front curves will coincide with each other.

Problem 16-13. (fig. 16-13): *A vertical pipe of 60 mm diameter has a branch of 30 mm diameter. The axis of the branch is inclined at 45° to the ground, parallel to the V.P. and is 15 mm away from the axis of the main pipe. Draw the projections of the pipes*



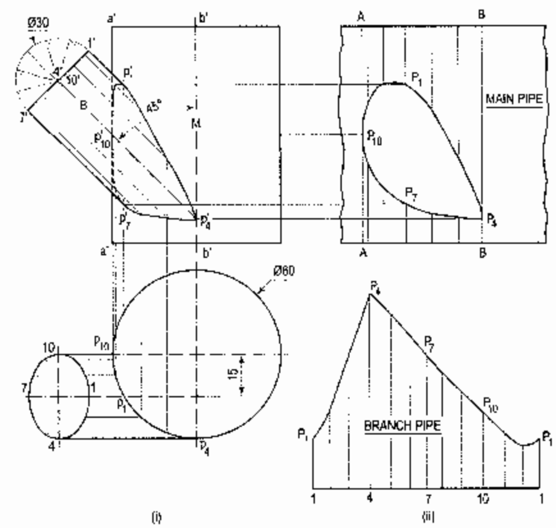


Fig. 16-13

Only a part of the development of the main pipe, just sufficient to show the shape of the hole in it, is shown in fig. 16-13(ii). Distances along the length of the stretch-out line are taken from the top view and positions of points are projected from the front view. In the development of the branch, the stretch-out line is divided into twelve equal parts and heights of points are taken from the front view. e.g. $4p_4 = 4'p'_4$ etc.

Problem 16-14. (fig. 16-14): *A cylindrical pipe of 30 mm diameter has a similar*

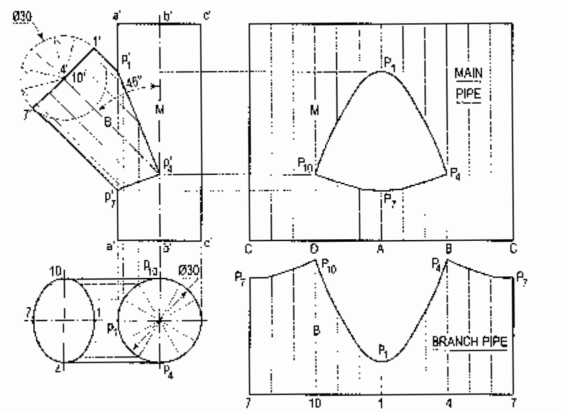
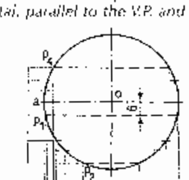


Fig. 16-14

16-5. INTERSECTION OF CYLINDER AND PRISM

Problem 16-15. (fig. 16-15): *A vertical cylinder of 60 mm diameter has a square hole of 30 mm sides cut through it. The axis of the hole is horizontal, parallel to the V.P. and 6 mm away from the axis of the cylinder. The faces of the hole are equally inclined to the H.P. and the V.P. Draw the projections of the cylinder showing the hole in it.*



(i) Draw three views of the cylinder showing the lines for the hole in given position. Project all the key points, i.e. points of intersection

Problem 16-16. (fig. 16-16): *A vertical cylinder of 60 mm diameter is penetrated by a horizontal square prism, base 40 mm side, the axis of which is parallel to the V.P. and 10 mm away from the axis of the cylinder. A face of the prism makes an angle of 30° with the H.P. Draw their projections, showing curves of intersection.*

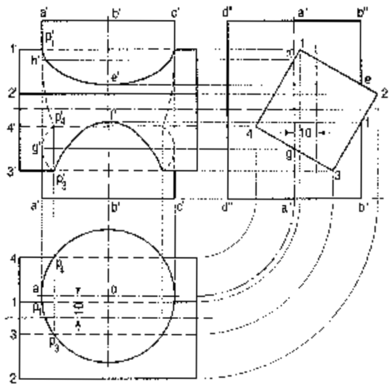


Fig. 16-16

(i) Draw the views in the required position. One longer edge of the prism will remain outside the cylinder. Project all the key points, viz. points of intersection of the edges of the prism with the cylinder and those of the extreme lines of the cylinder with the surface of the prism, as shown in the figure.

(ii) To obtain accurate shape of the curves, project few more intermediate points also. These are omitted from the figure. Draw the required curve of intersection through these points, taking precaution to show the hidden part by dashed lines.

Problem 16-17. (fig. 16-17): *A vertical square prism having its faces equally inclined to the V.P. is completely penetrated by*

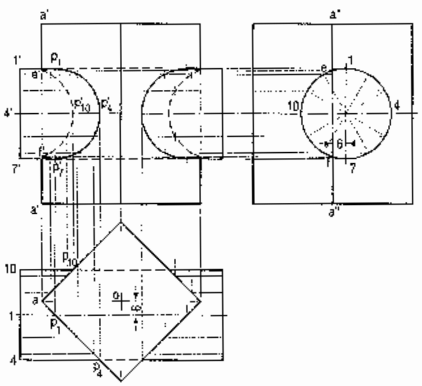
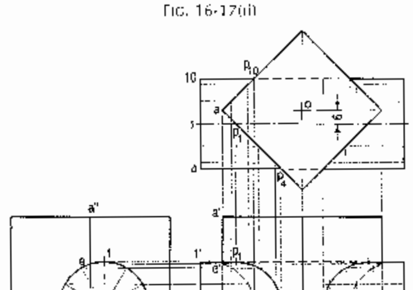


Fig. 16-17(ii)



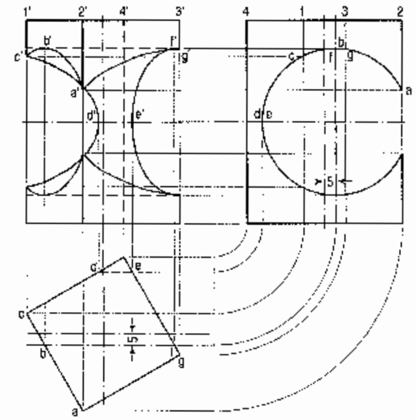


Fig. 16-18

(i) Draw the views and project all the key points as shown. Plot few intermediate points (between the key points) also.

(ii) Draw a curve joining the points in correct sequence. As it is a hole cut in the prism, the curve at the back will also be visible. Only a small portion of the curve will not be seen.

Problem 16-19. (fig. 16-19): *A connecting rod, 50 mm diameter, has a rectangular block 65 mm wide and 25 mm thick, forged at its end. The rod joins the block with a turned radius of 25 mm. Draw the projections of the rod showing curve of intersection.*

The rod increases in diameter as it approaches the block. This forms what is called a fillet of 25 mm radius. As the width of the block is not as large as the biggest diameter of the rod, a curve of intersection is formed. Points on the curve are found as shown below.

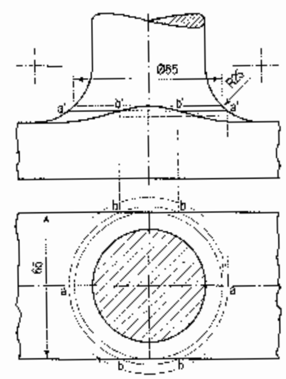


Fig. 16-19

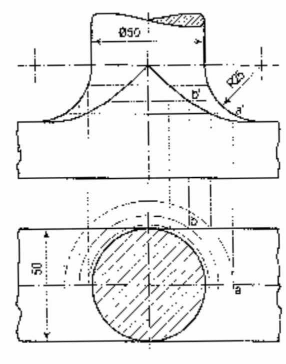


Fig. 16-20

Problem 16-20. *Draw the front view and the side view of the forked end of the connecting rod shown in fig. 16-21, showing the curve of intersection.*

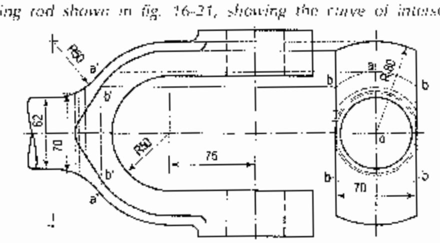


Fig. 16-21

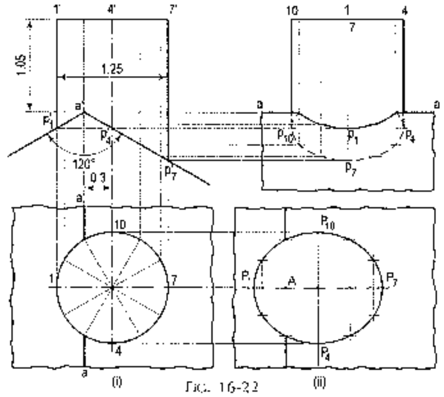


Fig. 16-22

(i) Draw the given views and project the side view.

(ii) To obtain points on the curve, draw lines on the surface of the chimney by dividing the circle (in the top view) into twelve equal parts. Project points at which these lines intersect the two lines for the roof in the front view to corresponding lines in the side view.

(iii) Draw a curve through the points thus obtained. The upper part of the curve will be hidden.

The real shape of the hole in the roof is shown above the side view. Horizontal distances are taken from the front view and widths are projected from the top view.

16-6. INTERSECTION OF CONE AND CYLINDER

Problem 16-22. *A vertical cone, diameter of base 75 mm and axis 100 mm long, is completely penetrated by a cylinder of 45 mm diameter. The axis of the cylinder is parallel to the H.P. and the V.P. and intersects the axis of the cone at a point 28 mm above the base. Draw the projections of the solids showing curves of intersection.*

This book is accompanied by a computer CD, which contains an audiovisual ...

In the front view, the cutting plane is seen as a line coinciding with 2'2'. Points p_2 and p_{12} when projected on the line 2' 2' (with which the line 12'-12 coincides) will give a point p'_2 (with which p'_{12} will coincide). Then p'_2 and p'_{12} are the points on the curve of intersection.

(iii) To obtain the points systematically, draw circles with centre o and diameters *dd*, *ee*, *ff* etc. cutting lines through 1, 2 and 12, 3 and 11 etc. at points p_1, p_2 and p_{12}, p_3 and p_{11} etc.

(iv) Project these points to the corresponding lines in the front view. Two more key points at which the curve changes direction must also be located. Their positions are determined from the side view. They are the points of nearest approach viz. m" and n" at which, lines drawn from the centre of the circle (i.e. the axis of the cylinder) and perpendicular to the extreme generators of the cone, cut the circle.

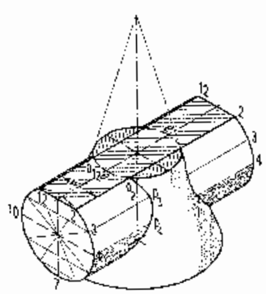
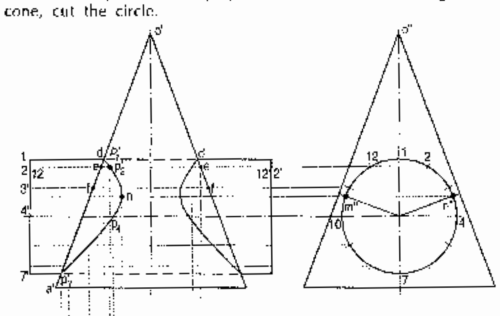


Fig. 16-23



(v) Project these points to m' and n' in the front view and to m and n in the top view on the corresponding lines. Draw curves through these points in both the views. The back curve in the front view will coincide with the front curve. In the top view a part of the curve will lie hidden and hence, it will be dotted. Draw similar curves on the right-hand side of the axis of the cone.

(b) ***Line method*** (fig. 16-25): The surface of the cylinder is seen as a circle in the side view.

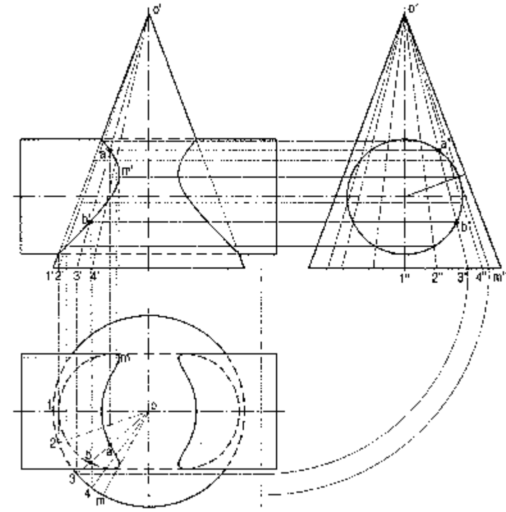
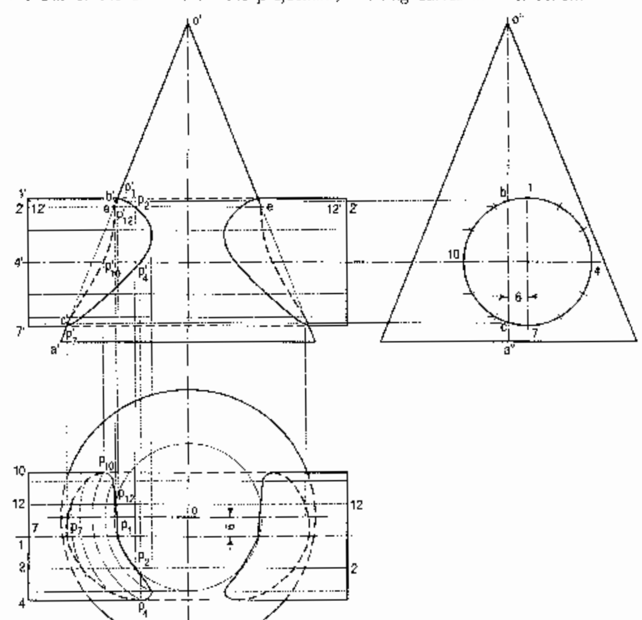


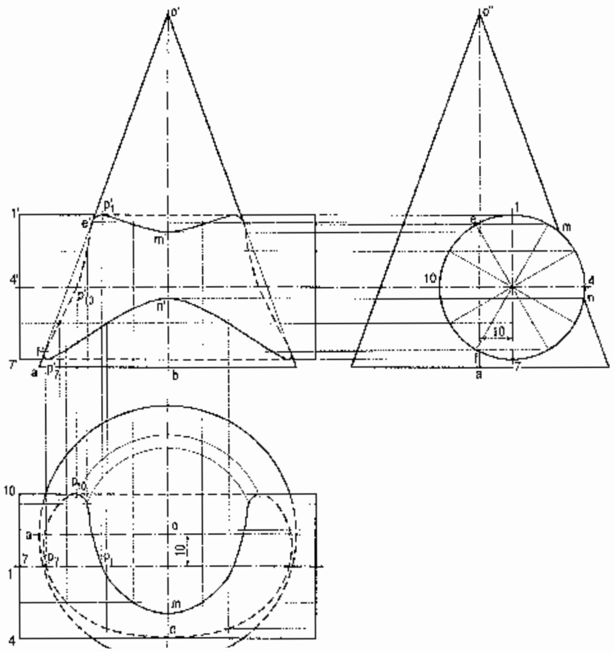
FIG. 16-25

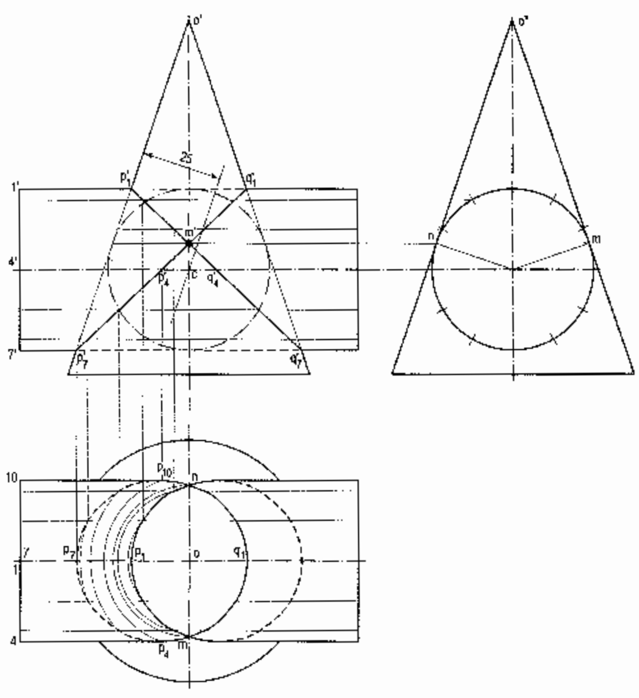
(i) Hence, draw a number of lines (representing generators of the cone) o"1", o"2" etc. in the region of the circle and symmetrical on both sides of the

Problem 16-23. (fig. 16-26): *A vertical cone, base 80 mm diameter, axis 100 mm long, is penetrated by a horizontal cylinder of 40 mm diameter, the axis of which is 25 mm above the base of the cone, parallel to the V.P. and 6 mm away from the axis of the cone. Draw the projections, showing curves of intersection.*



Problem 16-24. (fig. 16-27): *A vertical cone, base 80 mm diameter and axis 110 mm long is penetrated by a horizontal cylinder, 45 mm diameter. The axis of the cylinder is 25 mm above the base of the cone, is parallel to the V.P. and is 10 mm away from the axis of the cone. Draw the projections of the solids showing curves of intersection.*





16-7. INTERSECTION OF CONE AND PRISM

Problem 16-29. (fig. 16-33): *Draw an equilateral triangle of 100 mm side with one side horizontal. Draw a square of 35 mm side in its centre with its sides inclined at 45° to the base of the triangle. The figure shows the front view of a cone standing on its base on the ground and having a square hole cut through it. Draw three views of the cone.*

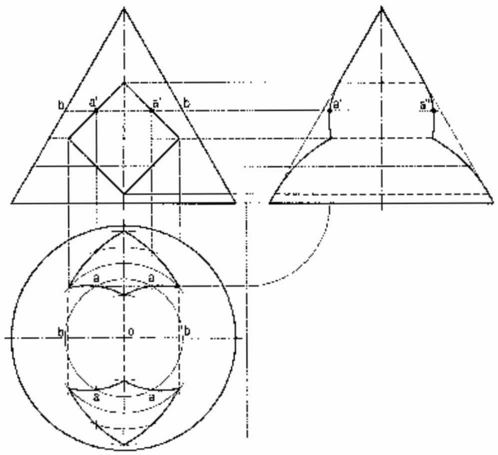


Fig. 16-33

(i) Project the top and side views from the given view. Assume the cone as cut by a horizontal cutting plane passing through points a'. The section of the cone will be a circle of diameter *bb*. The hole will be cut in two straight lines through points a' and perpendicular to the V.P.

(ii) Therefore, with centre o (the apex in the top view) and diameter *bb*, draw a circle cutting the projectors through a' at points a. Assume additional cutting planes, particularly those which pass through corners of the square and find other points. Draw curves through these points.

The method of locating points a'' in the side view is clearly indicated by construction lines. Obtain all points in the same manner.

Problem 15 ... *ical cone, base 80 mm diameter and axis 90 mm long, is ... prism of base 35 mm side. The axis of the prism is parallel ... n that of cone. Draw the projections when the plane contai... allel to the V.P. and the faces of the prism are equally incli...*

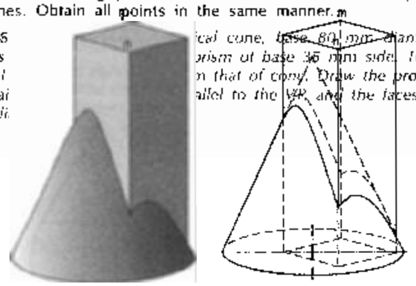
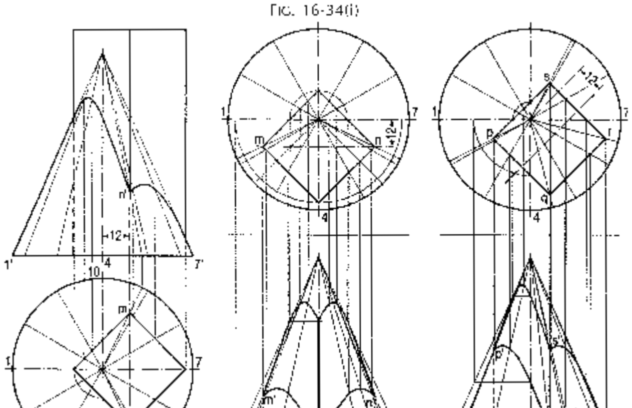


Fig. 16-34(i)

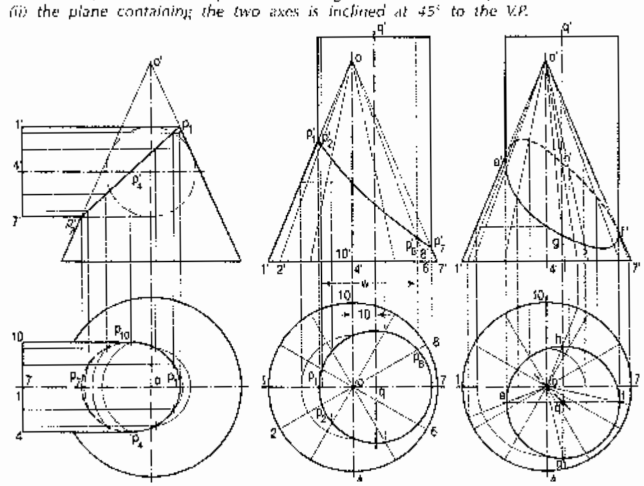


the total height of the funnel is 60 mm. Draw projections showing the curve of intersection when it is placed with its mouth on the ground and the two axes parallel to the V.P.

Draw the projection of the two parts. To form the funnel, the pipe must be extended beyond the centre line of the conical part. The points of intersection of the upper part of the pipe with the cone will therefore be on the right-hand side of the centre line.

The curve of intersection will be seen as a straight line in the front view and will be elliptical in the top view.

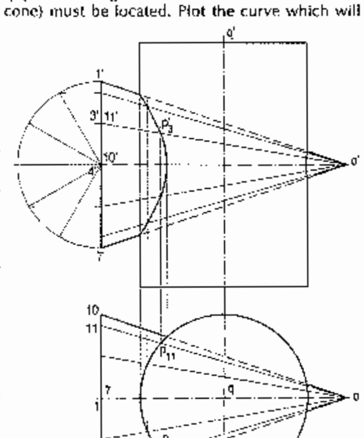
Problem 16-27. *A vertical cone, diameter of base 75 mm and axis 90 mm long is penetrated by a cylinder of 50 mm diameter, the axis of which is parallel to and 10 mm away from that of the cone. Draw the projections showing curves of intersection, when (i) the plane containing the two axes is parallel to the V.P.; (ii) the plane containing the two axes is inclined at 45° to the V.P.*



The cutting-plane method is exactly similar. Assume a series of vertical cutting planes passing through the apex. The sections of the cone will be triangles and those of the cylinder will be rectangles. Points of intersection between these sections will lie on the curve. For example, take a cutting plane coinciding with the line 2-8. In the front view, the section of the cone will be shown by triangle o'-2'-8', while that of the cylinder will be a rectangle of width *w*. Points p'_2 and p'_8 at which lines o'2' and o'8' cut the sides of the rectangle, lie on the curve of intersection.

(ii) As the plane containing the two axes makes an angle of 45° with the V.P., the centre *q* of the circle for the cylinder will lie on a line drawn through *o*, inclined at 45° to *xy* and 10 mm away from *o* (fig. 16-31).

Draw the projections and adopt the same method as in the case (i). In addition to the twelve points, four key points *e*, *f*, *g* and *h* (where the extreme lines of the cylinder intersect the cone) must be located. Plot the curve which will be partly hidden. If a hole is drilled through the cone instead of a cylinder penetrating it, the curve will be fully visible.



Problem 16-28. (fig. 16-32): *A vertical cylinder of 75 mm diameter is penetrated by a cone, base 75 mm diameter and axis 110 mm long, the two axes bisecting each other at right-angles. Draw the front view showing lines of intersections.*

(i) Divide the base circle of the cone into twelve equal parts and draw lines for the generators in both views. Assume a series of cutting planes perpendicular to the V.P. and passing through the apex. They will be seen as lines in the

16-8. INTERSECTION OF CONE AND CONE

Problem 16-31. (fig. 16-37): *A vertical cone, base 90 mm diameter and axis 90 mm long, is penetrated by another cone of base 75 mm diameter and height 100 mm. The axes of the two cones bisect each other at right-angles. Draw the front view showing curves of intersection, when the axis of the penetrating cone is parallel to the V.P.*

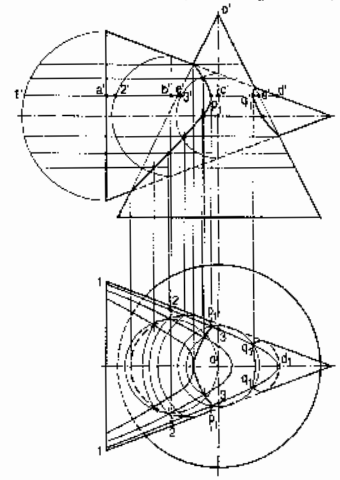


FIG. 16-37

(i) Assume a horizontal cutting plane coinciding with a line a'd'. The section of the vertical cone will be a circle of diameter ee. The section of the horizontal cone will be a hyperbola. The width of the hyperbola at the point a' will be equal to twice the length of the line a'1'; that at the point b' will be twice b'2' etc.

(ii) In the top view, mark points on the projector through a' and symmetrical on both sides of the horizontal axis, so that 1-1 = twice a'1'. Similarly, mark

16-9. INTERSECTION OF SPHERE AND CYLINDER OR PRISM

Problem 16-32. (fig. 16-38): *A hole of 50 mm diameter is drilled through a sphere of 75 mm diameter. The axis of the hole is 10 mm away from the centre of the sphere. Draw three views of the sphere when a vertical plane containing the centre of the sphere and the axis of the hole is inclined at 60° to the V.P.*

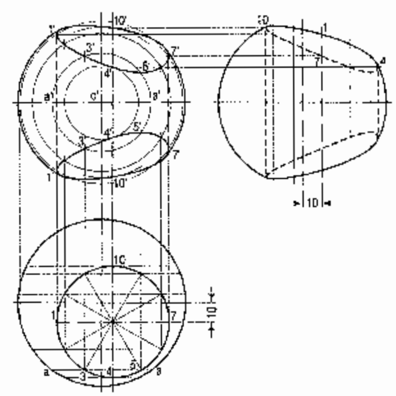


FIG. 16-38

(i) Draw the top view of the sphere and show the circle for the hole in the required position.

(ii) Project the front view and the side view. Divide the circle for the hole into twelve equal parts.

(iii) Assume a number of cutting planes parallel to the V.P. The sections of the sphere will be circles, while the hole will be cut in straight lines. Intersection

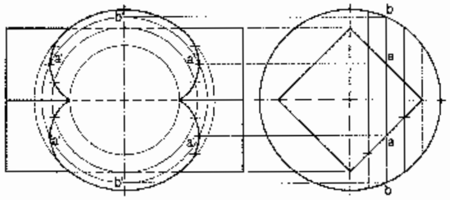


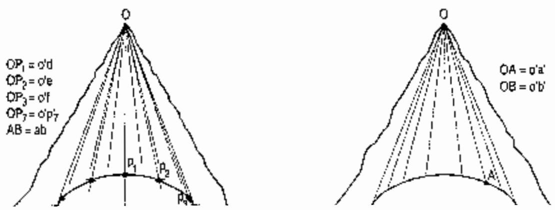
FIG. 16-39

(i) Draw the front view and project the side view. Assume a vertical cutting plane passing through, say points a. The section of the sphere will be a circle of diameter *bb*. It is cut by the section of the prism (a rectangle of width aa) at points a' as shown in the front view. Then points a' are on the curve of intersection.

(ii) Obtain more points together with the key points in the same manner and draw curves through them.

Problem 16-34. (fig. 16-40): *Draw the development of a portion of the surface of the cone given in problem 16-22, showing the hole in it.*

In fig. 16-40(i), the positions of points are taken from fig. 16-24, while in fig. 16-40(ii) they are obtained from fig. 16-25. In each case, distances along the arc are measured from the top view, while the distances of points (on the generators) from o are taken from the front view, after projecting them on the true length line.



EXERCISES 16

1. A vertical square prism, base 50 mm side has its faces equally inclined to the V.P. It is completely penetrated by another square prism of base 30 mm side, the axis of which is parallel to both the planes and is 6 mm away from the axis of the vertical prism. The faces of the horizontal prism also are equally inclined to the V.P. Draw the projections of the solids showing lines of intersection.
2. Two equal prisms whose ends are equilateral triangles of 40 mm side and axes 100 mm long, intersect at right angles. One face of each prism is on the ground. The axis of one of the prisms makes 30° with the V.P. Draw three views of the solids.
3. A square prism of base 50 mm side and height 125 mm stands on the ground with a side of the base inclined at 30° to the V.P. It is penetrated by a cylinder, 50 mm diameter and 125 mm long, whose axis is parallel to both the H.P. and the V.P. and bisects the axis of the prism. Draw the projections showing fully the curves of intersection.
4. A cylindrical boiler is 2 m in diameter and has a cylindrical dome 0.8 m diameter and 0.6 m high. The axis of the dome intersects the axis of the boiler. Draw three views of the arrangement. Develop the surface of the dome. Scale 1 cm = 0.2 m.
5. A vertical pipe, 75 mm diameter and 150 mm long, has two branches, one on each side. The horizontal branch is of 60 mm diameter while the other is of 50 mm diameter and inclined at 45° to the vertical. Assume the axis of 50 mm branch and the main pipe to be in the same plane, and that of 60 mm branch at 6 mm from the axis of the main pipe and parallel to the V.P. Draw the views of the pipe showing curves of intersection. Draw the developments of three pipes, assuming suitable lengths.
6. A cylinder of 75 mm diameter and 125 mm height, stands on its base on the ground. It is penetrated centrally by a cylinder, 50 mm diameter and 125 mm long, whose axis is parallel to the H.P. but inclined at 30° to the V.P. Draw the projections showing curves of intersection. Draw also the development of the penetrated cylinder.
7. A right circular cylinder of 75 mm diameter penetrates another of 100 mm diameter, their axes being at right angles to each other but 10 mm apart. Draw the projections of the curves of intersection on a plane parallel to the axes of the cylinders.

11. A cone frustum is 125 mm high, 85 mm diameter at the top and 115 mm diameter at the bottom. It is vertically placed and is completely penetrated by a horizontal cylinder 75 mm diameter and 125 mm long, the axis of which bisects the axis of the frustum. Draw the projections of the solids showing curves of intersection.
12. A conical funnel, 150 mm diameter at the mouth and 125 mm high has a pipe of 40 mm diameter attached at its apex. The length of the pipe is 100 mm and its axis is at right-angles to the axis of the funnel and in the same plane, with the outer side of the pipe in line with the apex of the funnel. Draw full size, the arrangement with sufficient number of views to show the joint.
13. A cone, 90 mm diameter of base, axis 110 mm long, stands on the ground and is completely penetrated by a cylinder, 50 mm diameter and 110 mm long. The axis of the cylinder is horizontal, parallel to the V.P. and passes through the axis of the cone, 75 mm from the apex. Draw the projections of both curves of intersection. Develop the surface of the cone.
14. A hole of 25 mm diameter is drilled in a cone having 75 mm diameter of base and 60 mm height. The axis of the hole is parallel to that of the cone and 6 mm away from it. Draw three views of the cone when a vertical plane containing the two axes is perpendicular to the V.P.
15. A conical hopper is fitted in vertical position on a horizontal pipe, 75 mm in diameter and 150 mm in length. The diameter of the hopper at the top is 110 mm and changes by 25 mm in every 25 mm of vertical distance. Draw the projections showing the curves of intersection if the top of the hopper is 70 mm above the axis of the pipe. Develop the surfaces of the hopper and the pipe.
16. A cylinder, 50 mm diameter of base and 100 mm height is centrally penetrated by a cone, 50 mm diameter of base and 75 mm height. The axis of the cylinder which is vertical, cuts the axis of the cone which is horizontal at 30 mm from the base of the cone. Draw the front view and the side view, showing curves of penetration.
17. A cone, base 75 mm diameter and axis 100 mm long, has an equilateral triangular hole of 40 mm side cut through it. The axis of the hole coincides with the axis of the cone. Draw three views of the cone when it is resting on its base on the ground with a face of the hole parallel to the V.P. Develop the surface of the cone.
18. A vertical cone, base 100 mm diameter and height 125 mm is penetrated by another cone, 50 mm diameter and axis 100 mm long. The axis of the penetrating cone is parallel to the H.P. and the V.P., 40 mm above the base and 10 mm from the axis of the vertical cone. It comes out equally on both sides of the cone. Draw

21. A rectangular slot for a cotter is cut in the tapering portion of a piston rod as shown in fig. 16-41. Draw three views of the rod, showing the curves of penetration in each view.
22. A frustum of a cone appears in the front view as a trapezium of 50 mm and 75 mm parallel sides, 90 mm apart. A cylindrical pipe joins the frustum and in the side view, the circle representing the pipe is found to touch the 50 mm side and the sides of the frustum. Draw three views of the frustum and the portion of the pipe joined as stated.

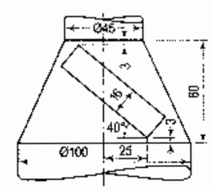


FIG. 16-41

23. In a circle of 50 mm radius, draw a square of 30 mm side symmetrically around its centre. The figure is the top view of a sphere completely penetrated by a 75 mm long square prism. From this top view, project a front view on a reference line *xy* parallel to a diagonal of the square. From this front view, project another top view on a reference line making 45° angle with the axis of the prism.
24. A square prism of 50 mm side of a base and 100 mm length of axis is resting on its base on the ground having a side of base at 30° to the V.P. It is completely penetrated by a horizontal square prism of 40 mm side of a base and 100 mm length of axis; the axis of which is parallel to the V.P. and bisects the axis of the vertical prism at right-angle. Draw the projections of the solids showing the lines of intersection when a face of the penetrating solid is at 30° to the H.P.
25. A vertical cylinder of 60 mm diameter is penetrated by a square prism of 35 mm side, the axis of which is inclined at 30° to the ground but parallel to the V.P. The faces of the prism are equally inclined to the V.P. and the axis of the prism is 10 mm in front of the axis of the cylinder. Draw the projections of the solids showing the curves of interpenetration.
26. A cone, diameter of base 70 mm and axis 70 mm long is kept on the ground on its base. A vertical hole of 50 mm is drilled through the cone in such a way that the axis of the hole is 10 mm away from that of the cone. The plane containing both axes is parallel to the V.P. Draw three views of the solids.

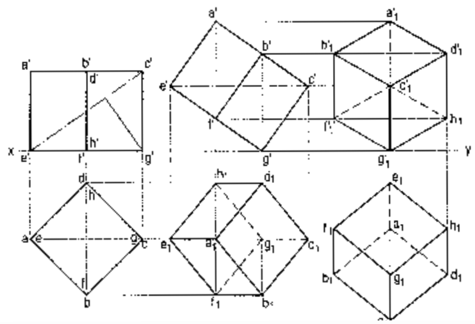
Chapter 17

ISOMETRIC PROJECTION

17-1. INTRODUCTION

Isometric projection is a type of pictorial projection in which the three dimensions of a solid are not only shown in one view, but their actual sizes can be measured directly from it.

If a cube is placed on one of its corners on the ground with a solid diagonal perpendicular to the V.P., the front view is the *isometric projection* of the cube. The step-by-step construction is shown in fig. 17-1.



(ii) Tilt the front view about the corner g' so that the line $e'c'$ becomes parallel to xy. Project the second top view. The solid diagonal CE is now parallel to both the H.P. and the V.P.

(iii) Reproduce the second top view so that the top view of the solid diagonal, viz. $e_1\ c_1$ is perpendicular to xy. Project the required front view.

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 39 for the introduction.

Fig. 17-2 shows the front view of the cube in the above position, with the corners named in capital letters. Its careful study will show that:

(a) All the faces of the cube are equally inclined to the V.P. and hence, they are seen as similar and equal rhombuses instead of squares.

(b) The three lines *CB*, *CD* and *CG* meeting at *C* and representing the three edges of the solid right-angle are also equally inclined to the V.P. and are therefore, equally foreshortened. They make equal angles of 120° with each other. The line *CG* being vertical, the other two lines *CB* and *CD* make 30° angle each, with the horizontal.

(c) All the other lines representing the edges of the cube are parallel to one or the other of the above three lines and are also equally foreshortened.

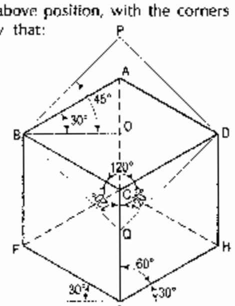


FIG. 17-2

(d) The diagonal *BD* of the top face is parallel to the V.P. and hence, retains its true length.

This chapter deals with various topics of isometric projection as shown below:

1. Isometric axes, lines and planes
2. Isometric scale
3. Isometric drawing or isometric view
4. Isometric graph.

17-2. ISOMETRIC AXES, LINES AND PLANES

17-6. ILLUSTRATIVE PROBLEMS

The procedure for drawing isometric views of planes, solids and objects of various shapes is explained in stages by means of illustrative problems.

In order that the construction of the view may be clearly understood, construction lines have not been erased. They are, however, drawn fainter than the outlines.

In an isometric view, lines for the hidden edges are generally not shown. In the solutions accompanying the problems, one or two arrows have been shown. They indicate the directions from which if the drawing is viewed, the given orthographic views would be obtained. Students need not show these arrows in their solutions.

17-6-1. ISOMETRIC DRAWING OF PLANES OR PLANE FIGURES

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 40 for the following problem.

Problem 17-1. *The front view of a square is given in fig. 17-7(i). Draw its isometric view.*

As the front view is a square, the surface of the square is vertical. In isometric view, vertical lines will be drawn vertical, while horizontal lines will be drawn inclined at 30° to the horizontal.

(i) Through any point *d*, draw a vertical line *da* = *DA* [fig. 17-7(ii)].

(ii) Again through *d*, draw a line *dc* = *DC* inclined at 30° to the horizontal and at 60° to *da*.

(iii) Complete the rhombus *abcd* which is the required isometric view. The view can also be drawn in direction of the other sloping axis as shown in fig. 17-7(iii).

Problem 17-2. *If fig. 17-7(i) is the top view of a square, draw its isometric view.*

As the top view is a square, the surface of the square is horizontal. In isometric view, all the sides will be drawn inclined at 30° to the horizontal.

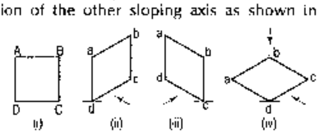


FIG. 17-7

(i) From any point *d* [fig. 17-7(iv)], draw two lines *da* and *dc* inclined at 30°

The surface of the triangle is vertical and the base *ab* is horizontal. *ab* will be drawn parallel to a sloping axis. The two sides of the triangle are inclined.

Hence they will not be drawn parallel to any isometric axis. In an isometric view, angles do not increase or decrease in any fixed proportion. They are drawn after determining the positions of the ends of the arms on isometric lines.

Therefore, enclose the triangle in the rectangle *ABQP*. Draw the isometric view *abqp* of the rectangle [fig. 17-9(ii)].

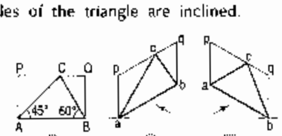


FIG. 17-9

Mark a point c in *pq* such that *pc* = *PC*. Draw the triangle *abc* which is the required isometric view. It can also be drawn in the other direction as shown in fig. 17-9(iii).

Problem 17-5. *The front view of a quadrilateral whose surface is parallel to the V.P. is shown in fig. 17-10(i). Draw its isometric view.*

Enclose the quadrilateral in a rectangle *ABEF*.

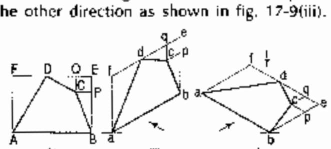


FIG. 17-10

(i) Draw lines *CP* and *CQ* parallel to the sides *FE* and *BE* respectively.

(ii) Draw the isometric view of the rectangle [fig. 17-10(ii)] and obtain the point *d* in *fe* as explained in problem 17-4. Draw the isometric view *cpeq* of the rectangle *CPEQ*.

(iii) Draw the quadrilateral *abcd* which is the required isometric view.

If the given view is the top view of a quadrilateral whose surface is horizontal, i.e. parallel to the H.P., its isometric view will be as shown in fig. 17-10(iii).

Problem 17-6. *If the view given in fig. 17-11(i) is*

(a) *the front view of a hexagon whose surface is parallel to the V.P. or*

(b) *the top view of the hexagon whose surface is horizontal, draw its isometric views.*

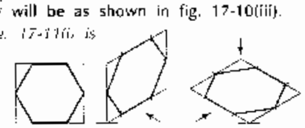


FIG. 17-11

(a) fig 17-11(ii). (b) fig 17-11(iii).

In both cases, the views can be drawn in the other direction also.

$$\text{In triangle } ABO,\ \frac{BA}{BO} = \frac{1}{\cos 30^\circ} = \frac{2}{\sqrt{3}}$$

$$\text{In triangle } PBO,\ \frac{BP}{BO} = \frac{1}{\cos 45^\circ} = \frac{\sqrt{2}}{1}$$

$$\frac{BA}{BP} = \frac{2}{\sqrt{3}} \times \frac{1}{\sqrt{2}} = \frac{\sqrt{2}}{\sqrt{3}} = 0.815$$

$$\text{The ratio, } \frac{\text{isometric length}}{\text{true length}} = \frac{BA}{BP} = \frac{\sqrt{2}}{\sqrt{3}} = 0.815 \text{ or } \frac{9}{11} \text{ (approx.).}$$

Thus, the isometric projection is reduced in the ratio $\sqrt{2} : \sqrt{3}$, i.e. *the isometric lengths are 0.815 of the true lengths.*

Therefore, while drawing an *isometric projection*, it is necessary to convert true lengths into isometric lengths for measuring and marking the sizes. This is conveniently done by constructing and making use of an isometric scale as shown below.

(a) Draw a horizontal line *BD* of any length (fig. 17-3). At the end *B*, draw lines *BA* and *BP*, such that ∠ *DBA* = 30° and ∠ *DBP* = 45°. Mark divisions of true length on the line *BP* and from each division-point, draw verticals to *BD* meeting *BA* at respective points. The divisions thus obtained on *BA* give lengths on isometric scale.

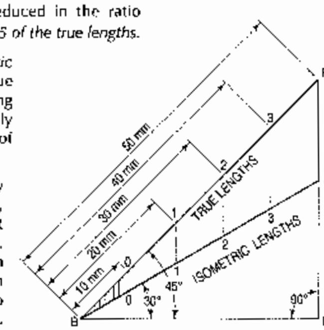
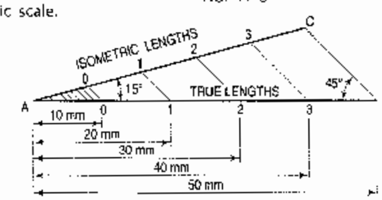


FIG. 17-3

(b) The same scale may also be drawn with divisions of natural scale on a horizontal line *AB* (fig. 17-4). At the ends *A* and *B*, draw lines *AC* and *BC* making 15° and 45° angles with *AB* respectively, and inter-



17-4. ISOMETRIC DRAWING OR ISOMETRIC VIEW

If the foreshortening of the isometric lines in an isometric projection is disregarded and instead, the true lengths are marked, the view obtained [fig. 17-5(iii)] will be exactly of the same shape but larger in proportion (about 22.5%) than that obtained by the use of the isometric scale [fig. 17-5(ii)]. Due to the ease in construction and the advantage of measuring the dimensions directly from the drawing, it has become a general practice to use the true scale instead of the isometric scale.

To avoid confusion, the view drawn with the true scale is called *isometric drawing* or *isometric view*, while that drawn with the use of isometric scale is called *isometric projection*.

Referring again to fig. 17-2, the axes *BC* and *CD* represent the sides of a right angle in horizontal position. Each of them together with the vertical axis *CG*, represents the right angle in vertical position. Hence, in isometric view of any rectangular solid resting on a face on the ground, each horizontal face will have its sides parallel to the two sloping axes; each vertical face will have its vertical sides parallel to the vertical axis and the other sides parallel to one of the sloping axes.

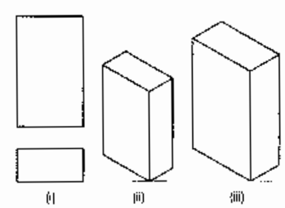
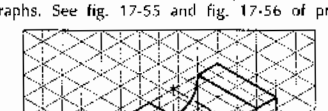


FIG. 17-5

In other words, the vertical edges are shown by vertical lines, while the horizontal edges are represented by lines, making 30° angles with the horizontal. These lines are very conveniently drawn with the T-square and a 30°-60° set-square or drafter.

17-5. ISOMETRIC GRAPH

An isometric graph as shown in fig. 17-6 facilitates the drawing of isometric view of an object. Students are advised to make practice for drawing of isometric view using such graphs. See fig. 17-55 and fig. 17-56 of problem 17-33.



Or, after determining the position of one point, draw through it, lines parallel to the sides of the rhombus and obtain the other three points. Draw a neat and smooth curve passing through the eight points viz. 1, 6, 2, 7 etc. The curve is the required isometric view. It is an ellipse.

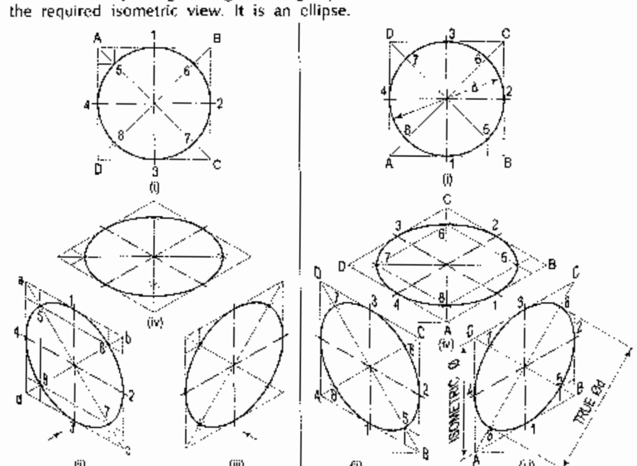


FIG. 17-12   FIG. 17-13

If the view given in fig. 17-12(i) is the top view of a circle whose surface is horizontal, its isometric view will be as shown in fig. 17-12(iv).

As the isometric views have been drawn with the true scale, the major axis of the ellipse is longer than the diameter of the circle.

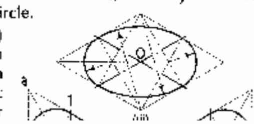


Fig. 17-13(ii), fig. 17-13(iii) and fig. 17-13(iv) show the isometric projection of the circle drawn with isometric scale. Note that when the length of the side of the rhombus is equal to the isometric diameter of the circle, the length of the major

lines will be drawn horizontal, while the other two will make 60°-angles with the horizontal. With centres *b* and *d*, draw arcs 3-4 and 1-2 respectively. With centres *p* and *q*, draw arcs 1-4 and 2-3 respectively and complete the required ellipse. Fig. 17-14(ii) shows the ellipse obtained in the rhombus drawn in the direction of the other sloping axis. Fig. 17-14(iii) shows the isometric view of the circle when its surface is horizontal.

The ellipse obtained by the four-centre method is not a true ellipse and differs considerably in size and shape from the ellipse plotted through points. But owing to the ease in construction and to avoid the labour of drawing freehand neat curves, this method is generally employed.

Problem 17-8. *To draw the isometric view of a circle of a given diameter, around a given point.*

Let O be the given point and *D* the diameter of the circle.

(a) When the surface of the circle is vertical [fig. 17-14(i)].

(i) Through *O*, draw a vertical centre line and another centre line inclined at 30° to the horizontal, i.e. parallel to a sloping isometric axis. On these lines, mark points 1, 2, 3 and 4 at a distance equal to 0.5*D* from *O*.

(ii) Through these points, draw lines parallel to the centre lines and obtain the rhombus *abcd* of sides equal to *D*.

(iii) Draw the required ellipse in this rhombus by the four-centre method.

By drawing the second centre line parallel to the other sloping axis, the isometric view is obtained in another position as shown in fig. 17-14(ii).

(b) When the surface of the circle is horizontal [fig. 17-14(iii)].

Through *O*, draw the two centre lines parallel to the two sloping isometric axes, i.e. inclined at 30° to the horizontal. Draw the required ellipse as explained in (a) above.

Note: This construction is very useful in drawing isometric views of circular holes in solids.

Problem 17-9. *Fig. 17-15(i) shows the front view of a semi-circle whose surface is parallel to the V.P. Draw its isometric view.*

(i) Enclose the semi-circle in a rectangle. Draw the isometric view of the rectangle [fig. 17-15(ii) and [fig. 17-15(iii)].

(ii) Using the four-centre method, draw the half-ellipse in it which is the required view. The centre for the longer arc may be obtained as shown or by completing the rhombus.

See fig. 17-17(ii) and fig. 17-17(iii).

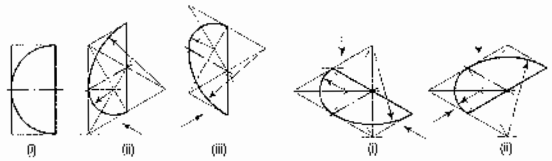


FIG. 17-17   FIG. 17-18

If the view shown in fig. 17-17(i) is the top view of a semi-circle whose surface is horizontal, its isometric view will be as shown in fig. 17-18(i) or fig. 17-18(ii).

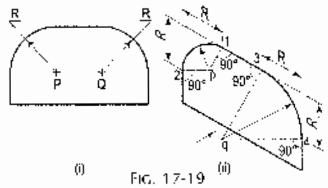


FIG. 17-19

Problem 17-11. *Fig. 17-19(i) shows the front view of a plane parallel to the V.P. Draw its isometric view.*

(i) The upper two corners of the plane are rounded with quarter circles. Enclose the plane in a rectangle.

(ii) Draw the isometric view of the rectangle. From the upper two corners of the parallelogram, mark points on the sides at a distance equal to *R*, the radius of the arcs. At these points erect perpendiculars to the respective sides to intersect each other at points *p* and *q*. With *p* and *q* as centres, and radii *p*1 and *q*3, draw the arcs and complete the required view.

It is interesting to note that although the arcs are of the same radius, they are drawn with different radii in their isometric views.

17-6-2. ISOMETRIC DRAWING OF PRISMS AND PYRAMIDS

We have seen that the isometric view of a cube is determined from its orthographic view in a particular position. The three edges of the solid right-angle of the cube are shown by lines parallel to the three isometric axes. A square prism or a rectangular prism also has solid right-angles. Hence, lines for its edges are also drawn parallel to the three isometric axes.

Problem 17-12. *Draw the isometric view of a square prism, side of the base 20 mm long and the axis 40 mm long, when its axis is (i) vertical and (ii) horizontal.*

(i) When the axis is vertical, the ends of the prism will be horizontal. Draw the isometric view (the rhombus 1-2-3-4) of the top end [fig. 17-20(i)]. Its sides will make 30°-angles with the horizontal. The length of the prism will be drawn in the third direction, i.e. vertical. Hence, from the corners of the rhombus, draw vertical lines 1-5, 2-6 and 3-7 of length equal to the length of the axis. The line 4-8 should not be drawn, as that edge will not be visible. Draw lines 5-6 and 6-7, thus completing the required isometric view. Lines 7-8 and 8-5 also should not be drawn. Beginning may also be made by drawing lines from the point 6 on the horizontal line and then proceeding upwards.

(ii) When the axis is horizontal, the ends will be vertical. The ends can be drawn in two ways as shown in fig. 17-20(ii) and fig. 17-20(iii). In each case, the length is shown in the direction of the third isometric axis.

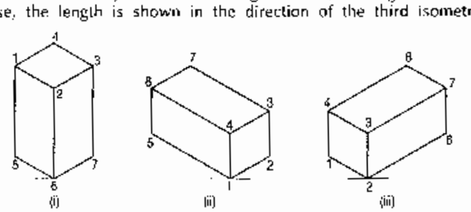
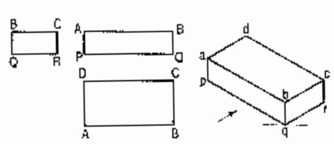


FIG. 17-20

Problem 17-13. *Three views of a block are given in fig. 17-21(i). Draw its isometric view.*



The block is in the form of a rectangular prism. Its shortest edges are vertical. Lines for these edges will be drawn vertical. Lines for all other edges which are horizontal, will be drawn inclined at 30° to the horizontal in direction of the two sloping axes as shown in fig. 17-21(ii).

Problem 17-14. *Three views of a block are given in fig. 17-22(i). Draw its isometric view.*

(i) Enclose the block in a rectangular box.

(ii) Draw the isometric view of the box [fig. 17-22(ii)].

(iii) Mark points *e* and *f* on the line *bc* such that $be = BE$ and $fc = FC$.

(iv) Complete the required view as shown.

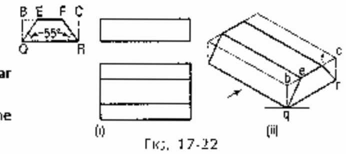


FIG. 17-22

Problem 17-15. *Draw the isometric view of the plate shown in three views in fig. 17-23(i).*

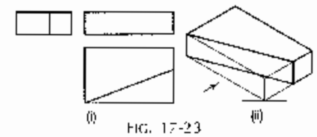


FIG. 17-23

Obtain the required view as explained in problem 17-14 and as shown in fig. 17-23(ii).

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 42 for the following problem.

Problem 17-16. *Draw the isometric view of the frustum of the hexagonal pyramid shown in fig. 17-24(i).*

(i) Enclose the front view and the top view in rectangles.

(ii) Draw the isometric view of the rectangular box [fig. 17-24(ii)]. Locate the six points of the base of the frustum on the sides of the bottom of the box. The upper six points on the top surface of the box are located by drawing isometric lines, e.g. *P*1 and *Q*1 intersecting at a point 1.

(iii) Join the corners and complete the isometric view as shown.

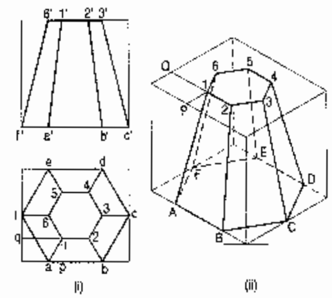


FIG. 17-24

(ii) Co-ordinate or Offset method: This method is adopted for objects in which

(i) Enclose the base (in the top view) in an oblong.

(ii) Draw an offset *oq* (i.e. *pq*) on the line *ab*.

(iii) Draw the isometric view of the oblong and locate the corners of the base in it [fig. 17-25(ii)].

(iv) Mark a point *Q* on the line *AB* such that $AQ = aq$. From *Q*, draw a line *QP* equal to *qo* and parallel to *2C*. At *P*, draw a vertical *OP* equal to *o'p'*.

(v) Join *O* with the corners of the base, thus completing the isometric view of the pyramid.

Fig. 17-25(iii) shows the isometric view of the same pyramid with its axis in horizontal position.

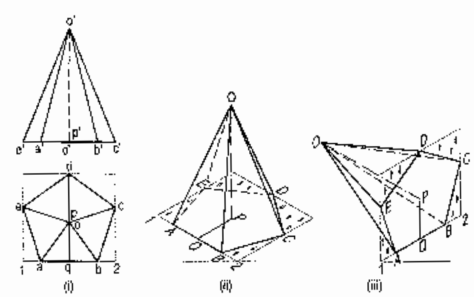


FIG. 17-25

Problem 17-18. *Draw the isometric view of the truncated triangular pyramid shown in fig. 17-26(i).*

(i) Draw the perpendiculars *d' x'*, *e y'* and *f z'* the front view and the offsets *dq*, *er* and *fc* in the top view.

17-6-3. ISOMETRIC DRAWING OF CYLINDERS

Problem 17-19. *Draw the isometric view of the cylinder shown in fig. 17-27(i).*

The axis of the cylinder is vertical, hence its ends are horizontal. Enclose the cylinder in a square prism.

Method I:

Draw the isometric view of the prism [fig. 17-27(ii)]. In the two rhombuses, draw the ellipses by the four-centre method. Draw two common tangents to the two ellipses. Erase the inner half of the lower ellipse and complete the required view.

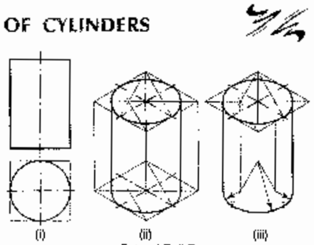


FIG. 17-27

Method II:

Draw the rhombus for the upper end of the prism [fig. 17-27(iii)] and in it, draw the ellipse by the four-centre method. From the centres for the arcs, draw vertical lines of length equal to the length of the axis, thus determining the centres for the lower ellipse. Draw the arcs for the half ellipse. Draw common tangents, thus completing the required view.

When the axis of the cylinder is horizontal, its isometric view is drawn by method I as shown in fig. 17-28(i).

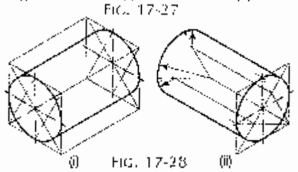


FIG. 17-28

Fig. 17-28(ii) shows the view drawn by method II, but the axis is shown sloping in the other direction.

Fig. 17-29 and fig. 17-30 respectively show the isometric views (drawn by method II) of a half-cylindrical disc with its axis in vertical and horizontal positions.

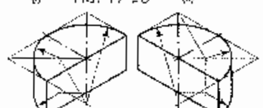


FIG. 17-29

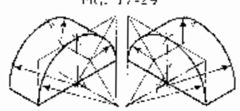


FIG. 17-30

17-6-4. ISOMETRIC DRAWING OF CONES

Problem 17-20. *Draw the isometric view of a cone, base 40 mm diameter*

Problem 17-21. *Draw the isometric view of the frustum of a cone shown in fig. 17-32(i).*

(i) Draw the ellipse for the base [fig. 17-32(ii)]. Draw the axis.

(ii) Around the top end of the axis, draw the ellipse for the top.

(iii) Draw common tangents, erase the unwanted part of the ellipse and complete the view as shown.

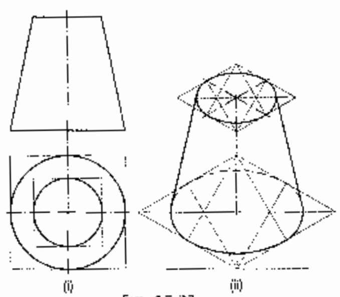
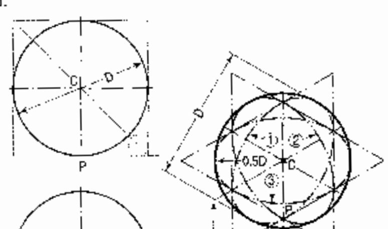


FIG. 17-32

17-6-5. ISOMETRIC DRAWING OF SPHERE

The orthographic view of a sphere seen from any direction is a circle of diameter equal to the diameter of the sphere. Hence, the isometric projection of a sphere is also a circle of the same diameter as explained below.

The front view and the top view of a sphere resting on the ground are shown in fig. 17-33(i). *C* is its centre, *D* is the diameter and *P* is the point of its contact with the ground.



Again, assume a horizontal section through the centre of the sphere. The isometric projection of this circle is shown by the ellipse 3, drawn in a horizontal position around the same centre C. In this case also, the distance of the outermost points on the ellipse from the centre C is equal to 0.5D.

Thus, it can be seen that in an isometric projection, the distances of all the points on the surface of a sphere from its centre, are equal to the radius of the sphere.

Hence, the isometric projection of a sphere is a circle whose diameter is equal to the true diameter of the sphere.

Also, the distance of the centre of the sphere from its point of contact with the ground is equal to the isometric radius of the sphere, viz. *CP*.

It is, therefore, of the utmost importance to note that, *isometric scale must invariably be used, while drawing isometric projections of solids in conjunction with spheres or having spherical parts.*

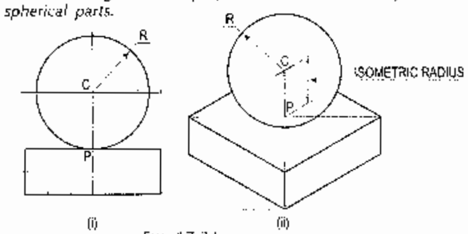


FIG. 17-34

Problem 17-22. *Draw the isometric projection of a sphere resting centrally on the top of a square prism, the front view of which is shown in fig. 17-34(i).*

(i) Draw the isometric projection (using isometric scale) of the square prism and locate the centre *P* of its top surface [fig. 17-34(ii)].

(ii) Draw a vertical at *P* and mark a point *C* on it, such that *PC* = the *isometric radius* of the sphere.

(iii) With *C* as centre and *radius equal to the radius of the sphere*, draw a circle which will be the isometric projection of the sphere.

17-7. TYPICAL PROBLEMS OF ISOMETRIC DRAWING

The solutions given in the following typical problems are mostly self-explanatory.

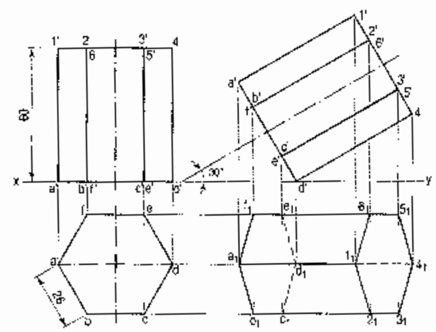


FIG. 17-35

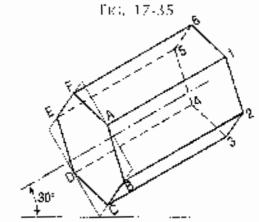
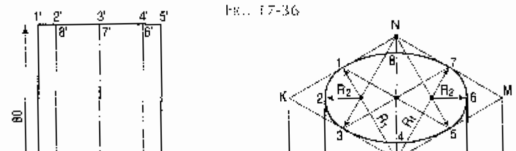


FIG. 17-36



Problem 17-24. (fig. 17-37): *A cylindrical block of base, 60 mm diameter and height 80 mm, standing on the H.P. with its axis perpendicular to the H.P. Draw its isometric view.*

The method shown in fig. 17-38 is self-explanatory.

Problem 17-25. *The projection of pentagonal pyramid is shown in fig. 17-39. Draw its isometric view.*

See fig. 17-40.

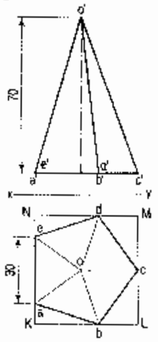


FIG. 17-39

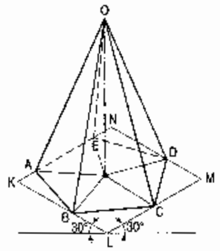
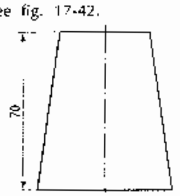
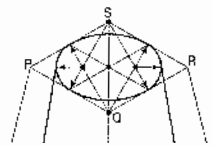


FIG. 17-40

Problem 17-26. *The projection of the frustum of the cone is shown in fig. 17-41. Draw its isometric view.*

See fig. 17-42.





Problem 17-27. *The orthographic projections of the object is shown in fig. 17-43. Draw the isometric view of the object.*

See fig. 17-44.

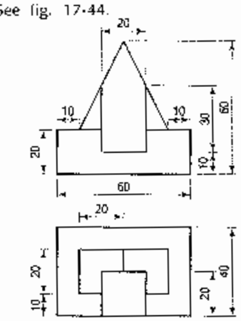


FIG. 17-43

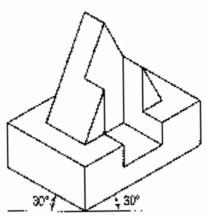
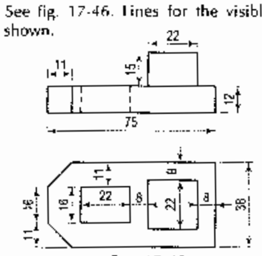
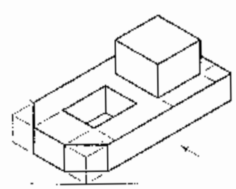


FIG. 17-44

Problem 17-28. *Draw the isometric view of the casting shown in two views in fig. 17-45.*

See fig. 17-46. Lines for the visible lower edges of the rectangular hole should be shown.





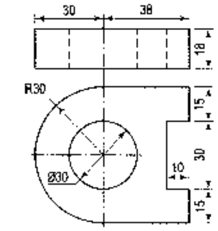


FIG. 17-47

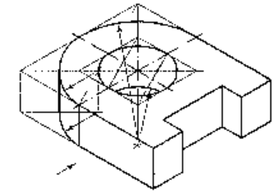
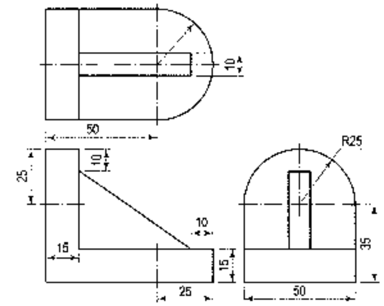


FIG. 17-48



(Third-angle projection)
FIG. 17-49

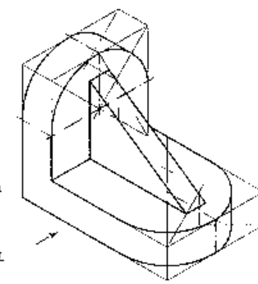
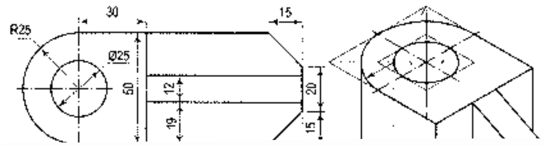


FIG. 17-50



Problem 17-32. *The front view of a board fitted with a letter H and mounted on a wooden post is given in fig. 17-53. Draw its isometric view, assuming the thickness of the board and of the letter to be equal to 3 cm. Scale, half full size. (All dimensions are given in centimeters.)*

See fig. 17-54.

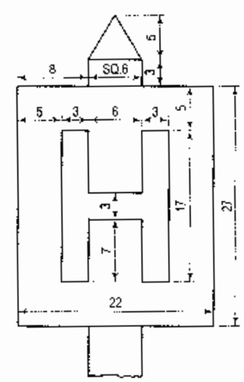


FIG. 17-53

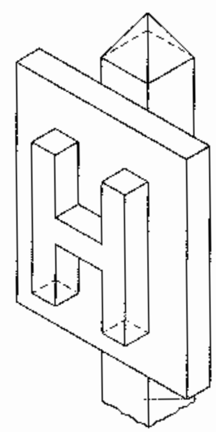


FIG. 17-54

Problem 17-33. *Draw the isometric view of the casting shown in two views in fig. 17-55.*

See fig. 17-56.

Problem 17-34. *Draw the isometric view of the model of steps, two views of which are shown in fig. 17-57.*

See fig. 17-58.

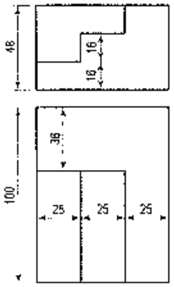


FIG. 17-57

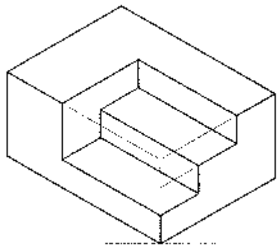


FIG. 17-58

Problem 17-35. *Two pieces of wood joined together by a dovetail joint are shown in two views in fig. 17-59. Draw the isometric view of the two pieces separated but in a position ready for fitting.*

See fig. 17-60.

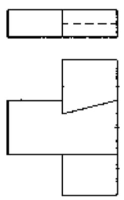


FIG. 17-59

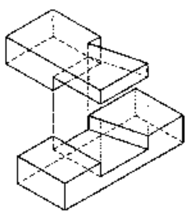


FIG. 17-60

(b) In this position, points *P*, *Q*, *R* etc. for the lid are located by enclosing the lid in the oblong and transferring the same on the isometric view as shown in fig. 17-62. The view is left incomplete to avoid congestion.

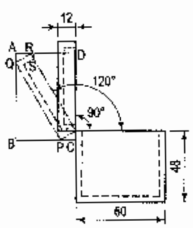


FIG. 17-61

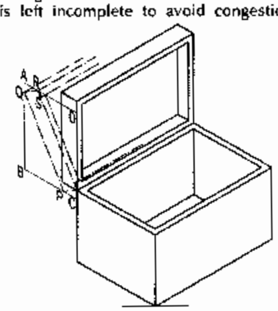
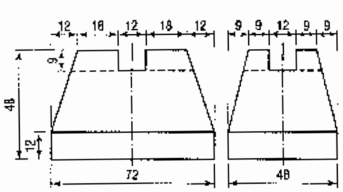
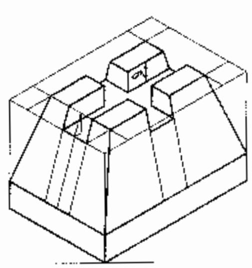


FIG. 17-62

Problem 17-37. *Two views of a cast-iron block are shown in fig. 17-63. Draw its isometric view.*

See fig. 17-64.





The points on the curve are located by co-ordinate method. The parallel curve is obtained by drawing lines in the third direction and equal to the thickness of the moulding.

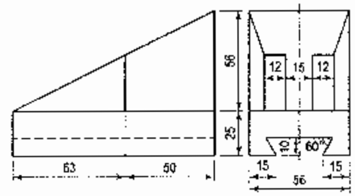


FIG. 17-65

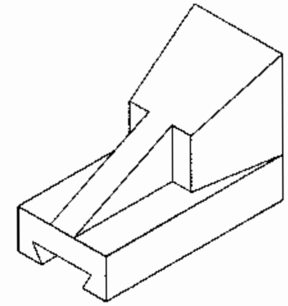
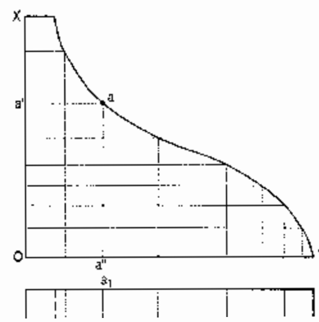
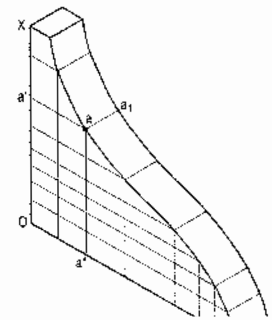


FIG. 17-66





The centre C of the sphere is at a distance equal to the isometric radius from the centre P of the top face of the cone frustum. *The circle for the sphere is drawn with the true radius.*

The ellipse for the section of the sphere is drawn within the rhombus constructed around the point Q on the axis.

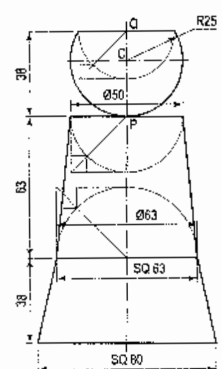


FIG. 17-69

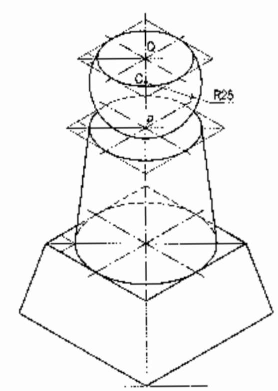
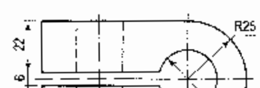


FIG. 17-70

Problem 17-41. *Draw the isometric view of the clamping piece shown in fig. 17-71.*

See fig. 17-72.



Problem 17-42. (fig. 17-73): *Draw the isometric view of a hexagonal nut for a 24 mm diameter bolt, assuming approximate dimensions. The threads may be neglected but chamfer must be shown.*

See fig. 17-74.

Problem 17-43. *Draw the isometric view of the paper-weight with spherical knob shown in fig. 17-75.*

See fig. 17-76. Isometric scale should be used for all dimensions except for the radius of the circle for the sphere.

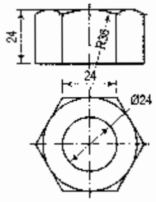


FIG. 17-73

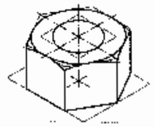


FIG. 17-74

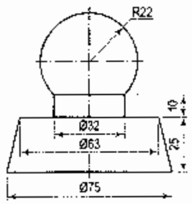


FIG. 17-75

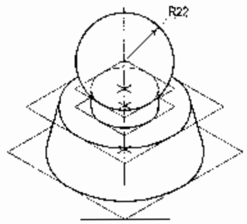


FIG. 17-76

Problem 17-44. (fig. 17-77): *Draw the isometric view of a square-headed bolt 24 mm diameter and 70 mm long, with a square neck 18 mm thick and a head, 40 mm square and 18 mm thick.*

See fig. 17-78.

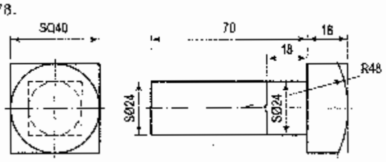


FIG. 17-77

Problem 17-45. *Draw the isometric view of the casting shown in fig. 17-79.*

See fig. 17-80.

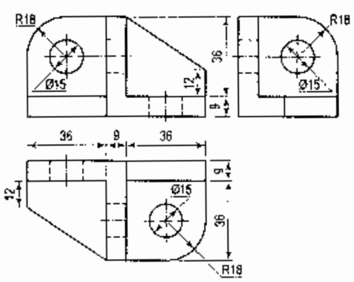


FIG. 17-79

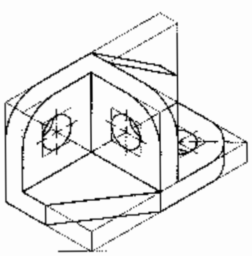


FIG. 17-80

Problem 17-46. *The projections of a casting are shown in fig. 17-81. Draw its isometric view.*

See fig. 17-82.

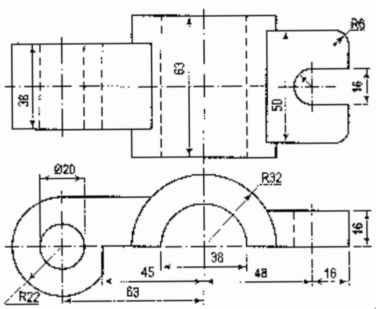


FIG. 17-81

Problem 17-47. *Draw the isometric view of the bracket shown in two views in fig. 17-83.*

See fig. 17-84.

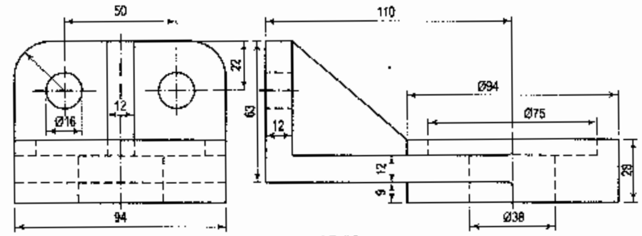
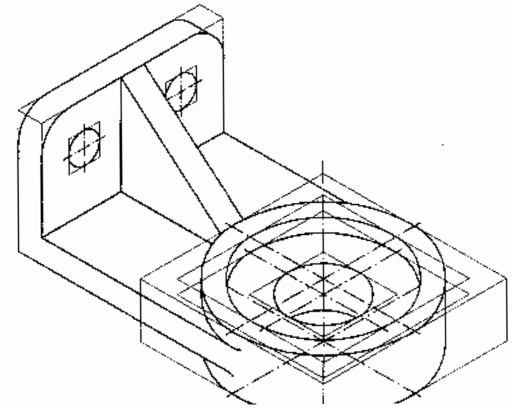


FIG. 17-83



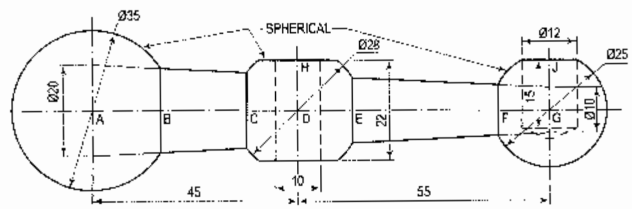


FIG. 17-85

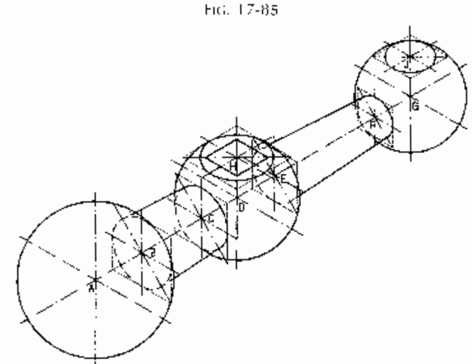


FIG. 17-86

(i) Draw an axis and mark on it the positions of points *A*, *B* etc.

(ii) At points *B*, *C*, *E* and *F*, draw ellipses for circular sections of the conical handle. Ellipses at *B* and *E* will be completely hidden.

(iii) With points *A*, *D* and *G* as centres, draw circles for the spheres, with their respective true radii.

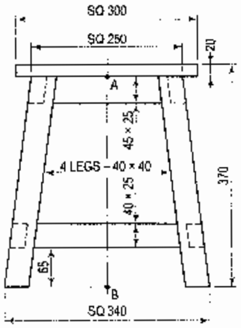


FIG. 17-87

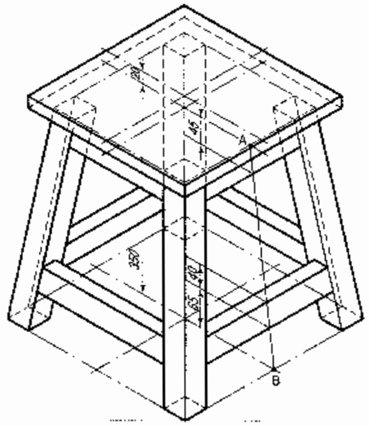
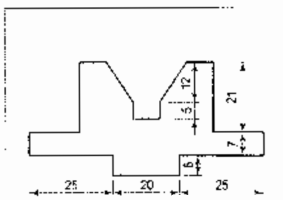
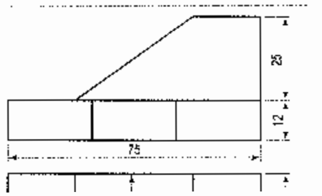


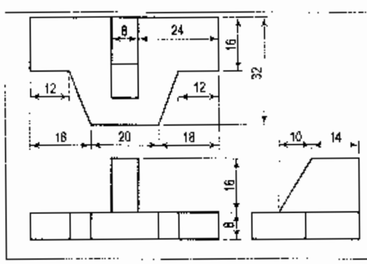
FIG. 17-88

EXERCISES 17

1. Projections of castings of various shapes are given in figs. 17-89 to 17-115. Draw the isometric view of each casting.







(Third-angle projection)
FIG. 17-91

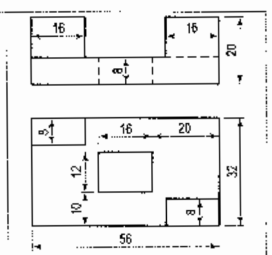


FIG. 17-92

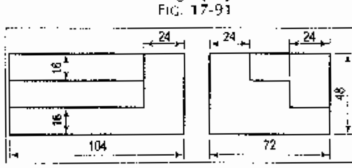


FIG. 17-93

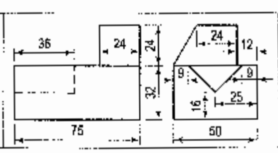
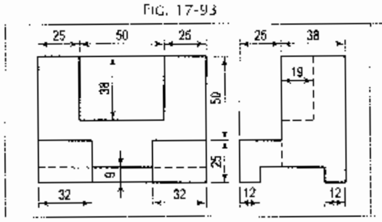
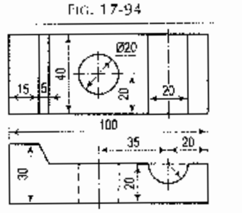


FIG. 17-94



(Third-angle projection)
FIG. 17-95



(Third-angle projection)
FIG. 17-96

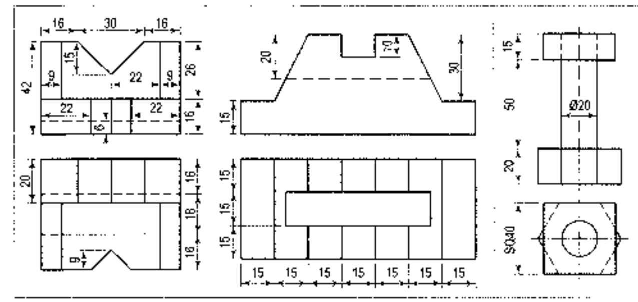


FIG. 17-99 FIG. 17-100 FIG. 17-101

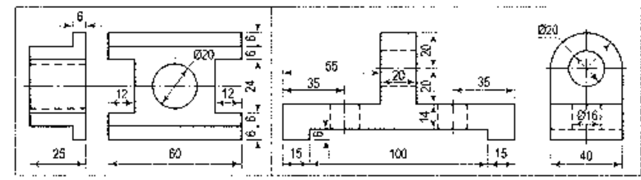
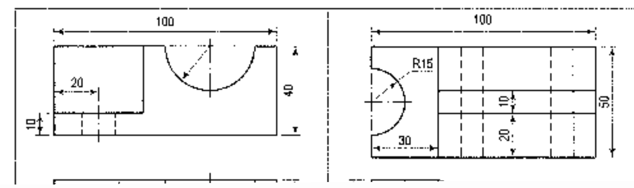


FIG. 17-102 FIG. 17-103



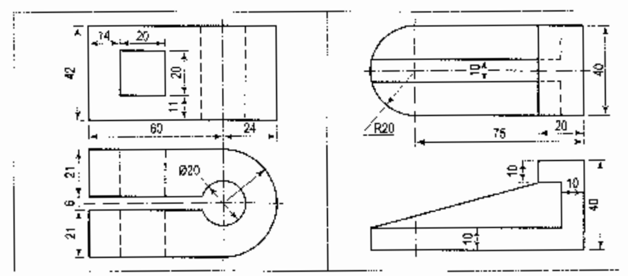


FIG. 17-106 (Third-angle projection) FIG. 17-107

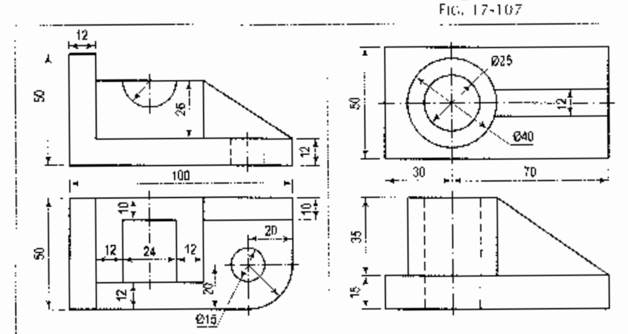
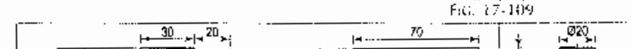
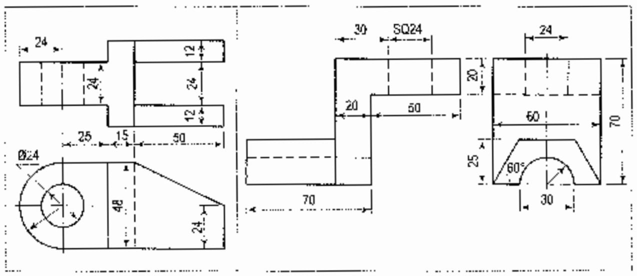


FIG. 17-108 (Third-angle projection) FIG. 17-109





(Third-angle projection) FIG. 17-112 FIG. 17-113

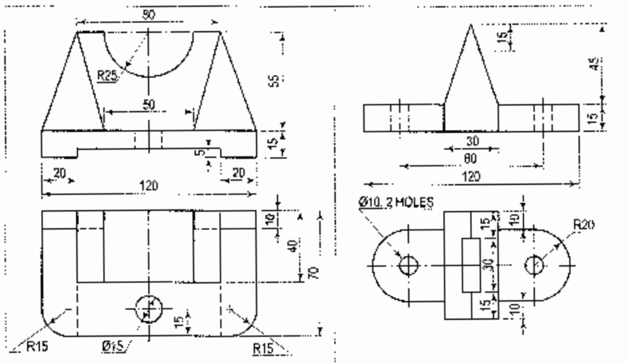


FIG. 17-114 FIG. 17-115

2. Assuming unit length to be equal to 10 mm, draw the isometric views of

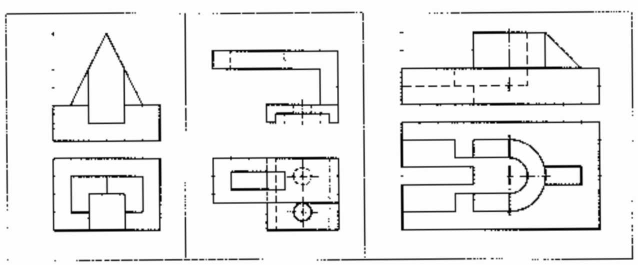
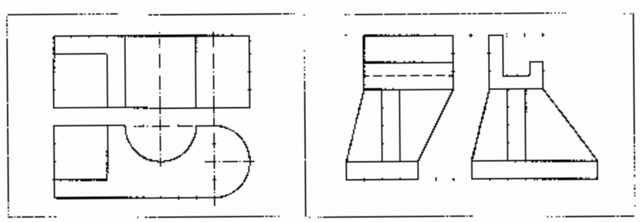
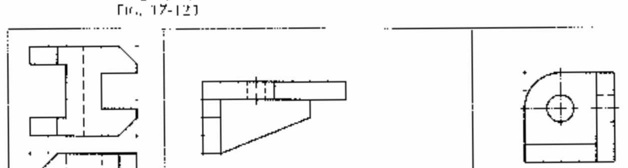
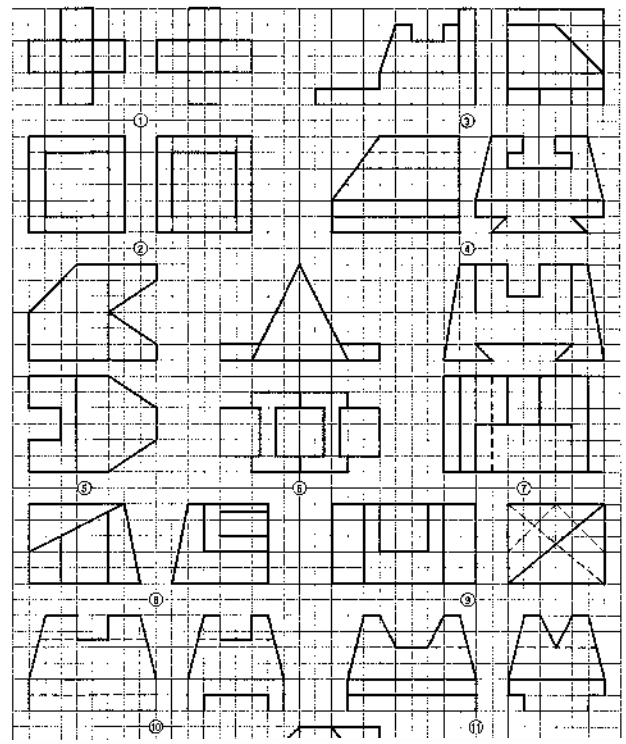


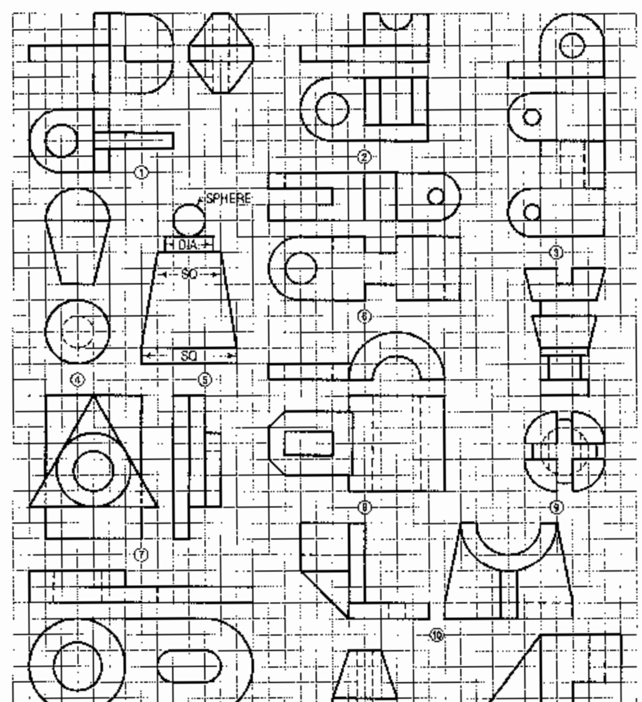
FIG. 17-118 FIG. 17-119 FIG. 17-120



(Third-angle projection) FIG. 17-121 FIG. 17-122

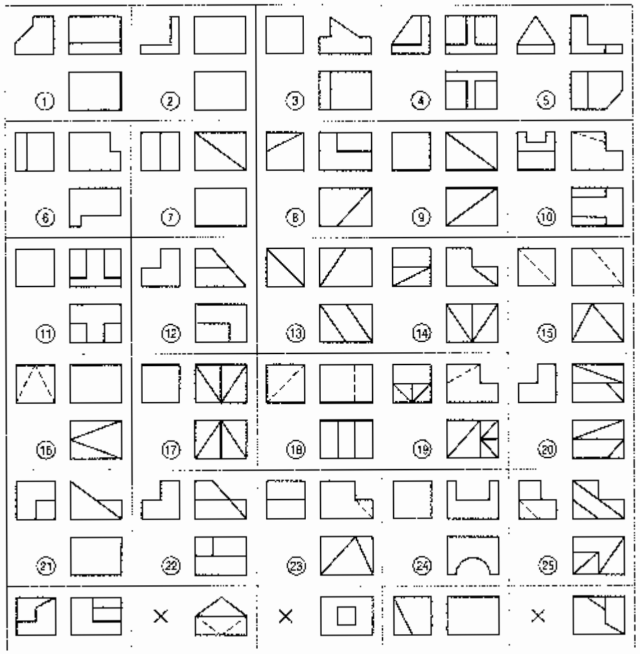




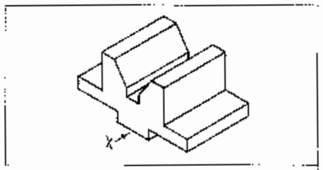


4. Orthographic views of 35 objects with either (i) a line or (ii) lines or (iii) a view missing are given in fig. 17-128. Complete the given views. Also draw freehand, the isometric view of each object.

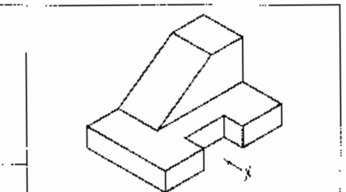
[*For answer see fig. 17-194.*]



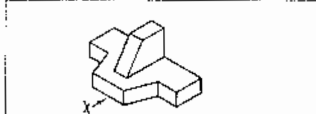
SOLUTIONS TO EXERCISES 17



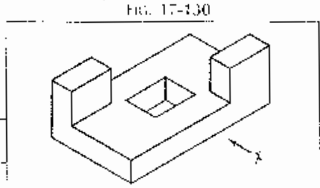
(Ex. 1, Fig. 17-89)
Fig. 17-129



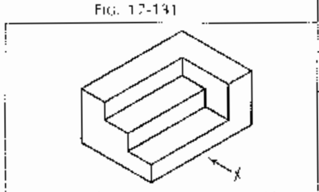
(Ex. 1, Fig. 17-90)
Fig. 17-130



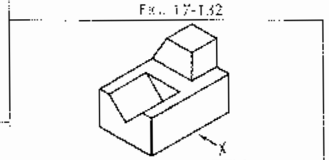
(Ex. 1, Fig. 17-91)
Fig. 17-131



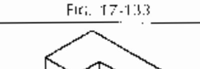
(Ex. 1, Fig. 17-92)
Fig. 17-132

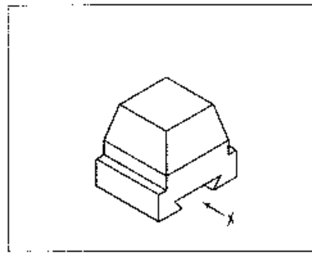


(Ex. 1, Fig. 17-93)
Fig. 17-133

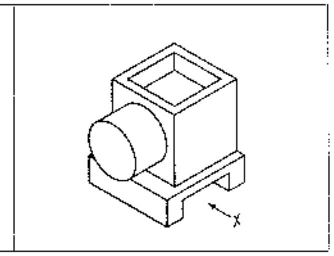


(Ex. 1, Fig. 17-94)
Fig. 17-134

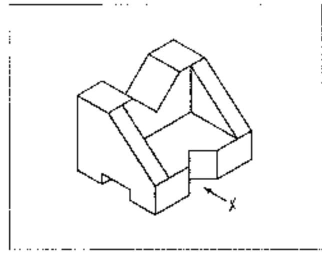




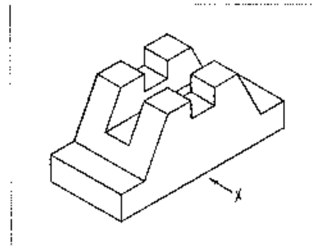
(Ex. 1. Fig. 17-97)
Fig. 17-137



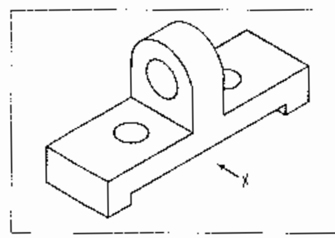
(Ex. 1. Fig. 17-98)
Fig. 17-138



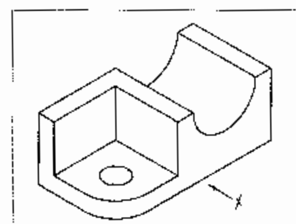
(Ex. 1. Fig. 17-99)
Fig. 17-139



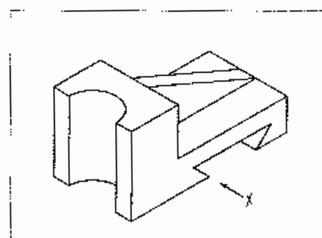
(Ex. 1. Fig. 17-100)
Fig. 17-140



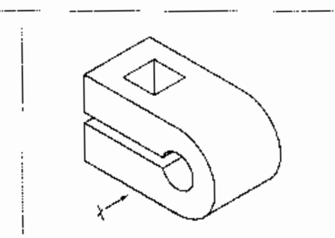
(Ex. 1. Fig. 17-103)
Fig. 17-143



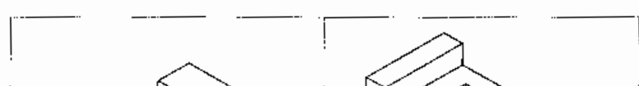
(Ex. 1. Fig. 17-104)
Fig. 17-144

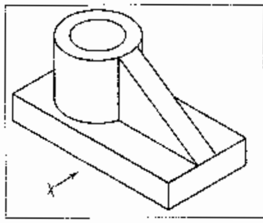


(Ex. 1. Fig. 17-105)
Fig. 17-145

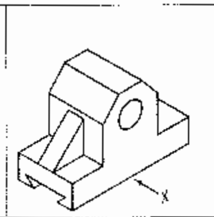


(Ex. 1. Fig. 17-106)
Fig. 17-146

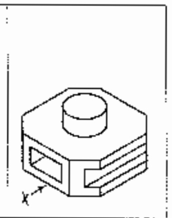




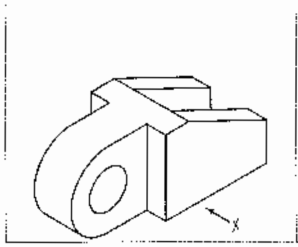
(Ex. 1. Fig. 17-109)
Fig. 17-149



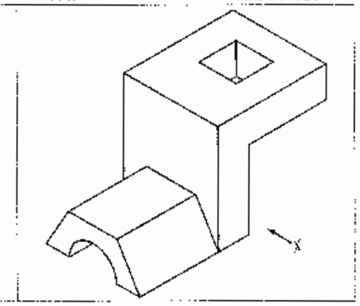
(Ex. 1. Fig. 17-110)
Fig. 17-150



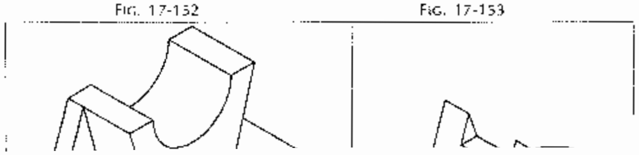
(Ex. 1. Fig. 17-111)
Fig. 17-151

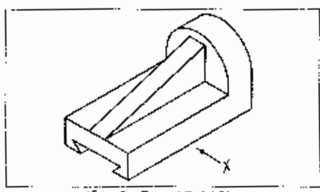


(Ex. 1. Fig. 17-112)
Fig. 17-152

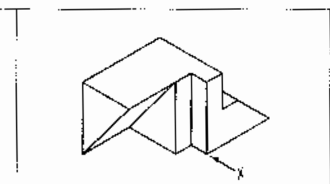


(Ex. 1. Fig. 17-113)
Fig. 17-153

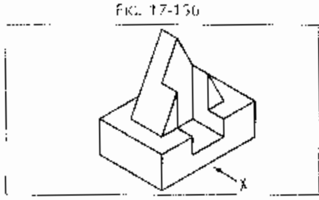




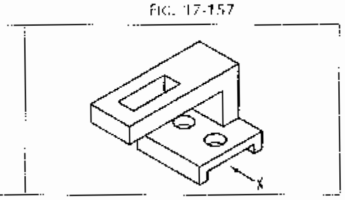
(Ex. 2. Fig. 17-116)
Fig. 17-156



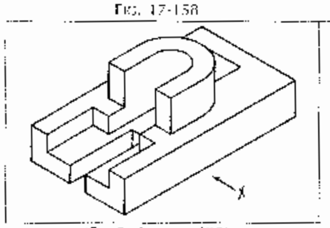
(Ex. 2. Fig. 17-117)
Fig. 17-157



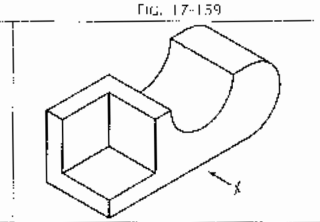
(Ex. 2. Fig. 17-118)
Fig. 17-158



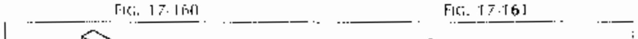
(Ex. 2. Fig. 17-119)
Fig. 17-159

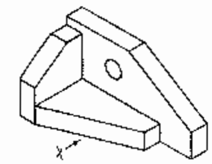


(Ex. 2. Fig. 17-120)
Fig. 17-160

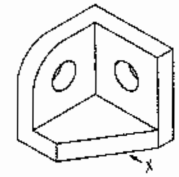


(Ex. 2. Fig. 17-121)
Fig. 17-161

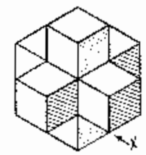




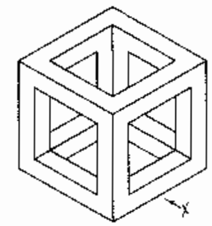
(Ex. 2. Fig. 17-124)
Fig. 17-164



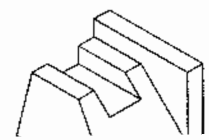
(Ex. 2. Fig. 17-125)
Fig. 17-165

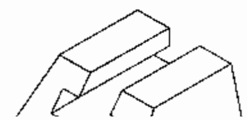


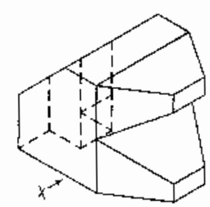
[Ex. 3. Fig. 17-126(1)]
Fig. 17-166



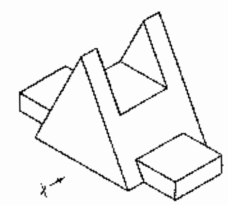
[Ex. 3. Fig. 17-126(2)]
Fig. 17-167



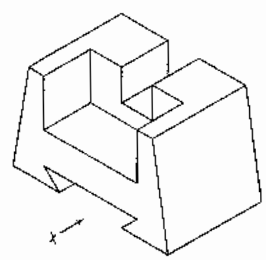




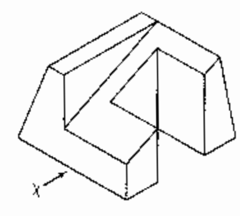
[Ex. 3. Fig. 17-126(5)]
Fig. 17-170



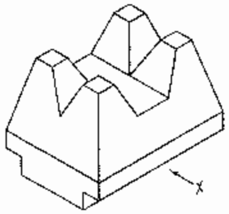
[Ex. 3. Fig. 17-126(6)]
Fig. 17-171



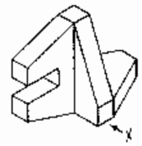
[Ex. 3. Fig. 17-126(7)]
Fig. 17-172



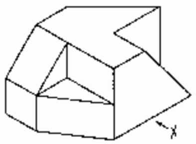
[Ex. 3. Fig. 17-126(8)]
Fig. 17-173



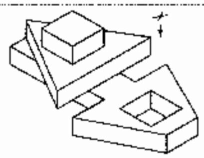
[Ex. 3. Fig. 17-126(11)]
Fig. 17-176



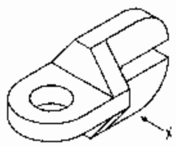
[Ex. 3. Fig. 17-126(12)]
Fig. 17-177



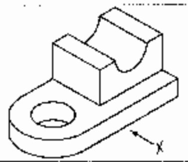
[Ex. 3. Fig. 17-126(13)]
Fig. 17-178



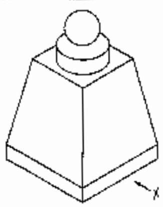
[Ex. 3. Fig. 17-126(14)]
Fig. 17-179



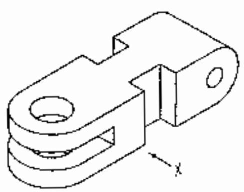
[Ex. 3. Fig. 17-127(1)]
Fig. 17-180



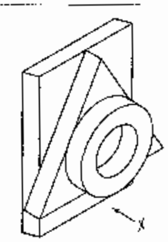
[Ex. 3. Fig. 17-127(2)]
Fig. 17-181



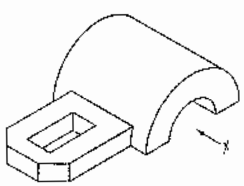
[Ex. 3. Fig. 17-127(5)]
Fig. 17-184



[Ex. 3. Fig. 17-127(6)]
Fig. 17-185



[Ex. 3. Fig. 17-127(7)]
Fig. 17-186



[Ex. 3. Fig. 17-127(8)]
Fig. 17-187

Chapter 18 OBLIQUE PROJECTION

18-1. INTRODUCTION

Pictorial projections are becoming popular due to the use of a computer in a modern drawing office. An oblique projection like isometric projection is another method of pictorial projection. The oblique projection represents three dimensional object on the projection plane by one view only. This type of drawing is useful for making an assembly of an object and provides directly a production drawing (working drawing) of the object for the manufacturing purpose.

This chapter deals with the following topics of oblique projection:

1. Principle of the oblique projection
2. The oblique projection and the isometric projection
3. Receding lines and receding angles
4. Types of the oblique projection
5. Rules for the choice of position of an object
6. Steps for drawing the oblique projection
7. Oblique projection of pyramid
8. Oblique projection of circle
9. Oblique projection of cylinder
10. Oblique projection of prism.

18-2. PRINCIPLE OF THE OBLIQUE PROJECTION

When an observer looks towards an object from infinity, the lines of sights (projectors)

The principal difference between the *oblique projection and the isometric projection* is that in case of the isometric projection all the three axes are inclined at an angle of 120° to each other whereas in the oblique projection third axis is inclined at an angle of 30° or 45° or 60° with respect to two perpendicular axes.

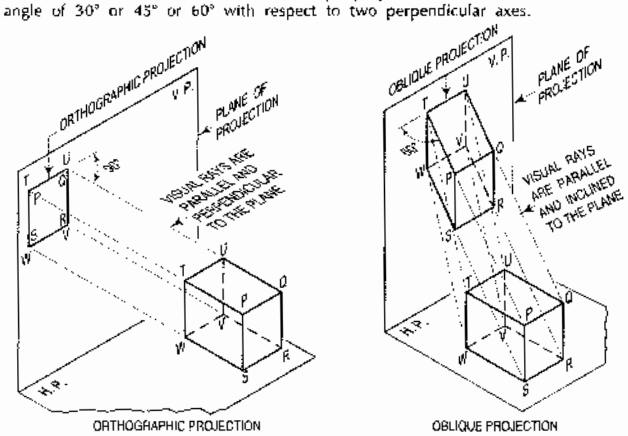


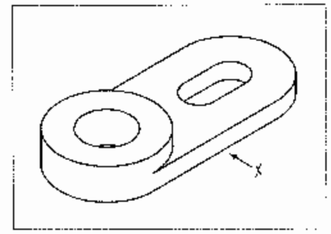
FIG. 18-1

18-3. THE OBLIQUE PROJECTION AND THE ISOMETRIC PROJECTION

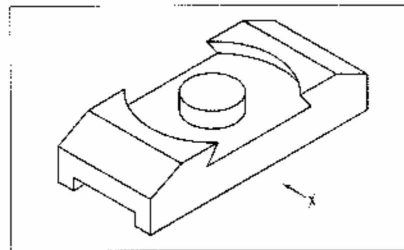
The difference between the oblique projection and the isometric projection is given in table 18-1.

TABLE 18-1

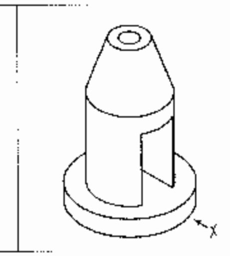
(i)	Projectors from an object are parallel	(i)	Projectors from an object are parallel



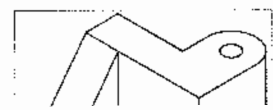
[Ex. 3. FIG. 17-127(11)]
FIG. 17-190

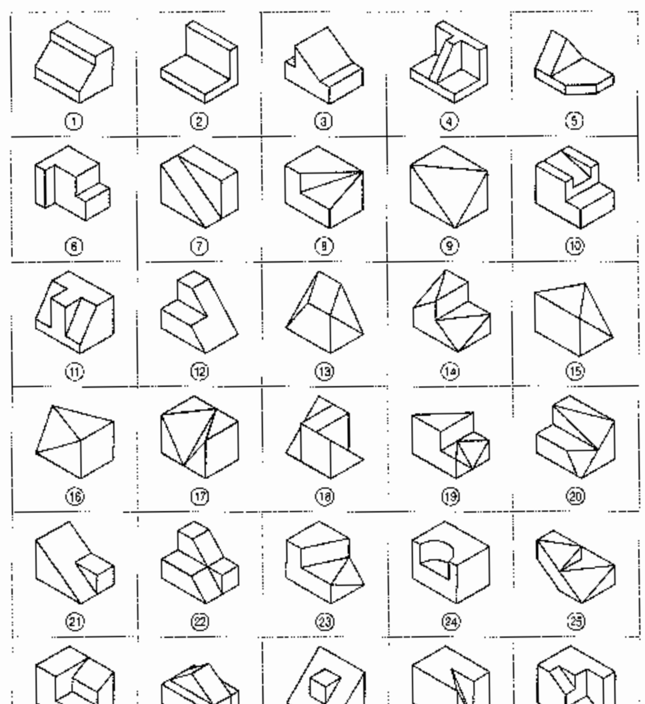


[Ex. 3. FIG. 17-127(12)]
FIG. 17-191



[Ex. 3. FIG. 17-127(13)]
FIG. 17-192





18-4. RECEDING LINES AND RECEDING ANGLES

In oblique projection, the faces of object which are perpendicular to the plane of projection are projected in the distorted shapes. The perpendicular edges of such planes are drawn at an angle of 30° or 45° or 60° with the horizontal. These inclined lines are known as the *receding lines* and their inclinations to the horizontal is known as *receding angles*.

The appearance of distortion of an object can be improved by shortening the length of the receding lines. Refer to fig. 18-3.

The receding lines may be inclined either upwards or downwards, or to the left or right depending upon the necessity to show the details of an object effectively. Refer fig. 18-2.

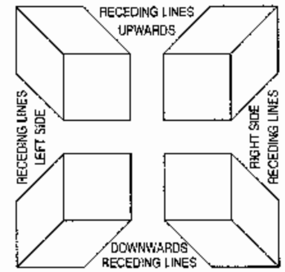


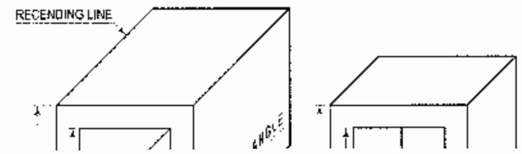
FIG. 18-2

18-5. TYPES OF THE OBLIQUE PROJECTION

The oblique projection is based on scales by which the receding lines are drawn.

(1) **Cavalier projection:** When the receding lines are drawn to full size scale and the projectors inclined at an angle of 30° or 45° or 60° to the plane of projection, such oblique projection is known as *cavalier projection*. Refer to fig. 18-3(i).

(2) **Cabinet projection:** If the receding lines are drawn to half size scale such oblique projection is known as the *cabinet projection*. Refer to fig. 18-3(ii).



18-6. RULES FOR THE CHOICE OF POSITION OF AN OBJECT

In oblique projection, the object is assumed to be placed with one face parallel to the plane of projection. Hence, that face appears in its true shape and size (fig. 18-4).

This gives two main dimensions of the object. The third dimension is shown by lines drawn at a convenient angle, generally 30° or 45° with the horizontal. To give a natural appearance, these lines are drawn $\frac{3}{4}$ or $\frac{1}{2}$ the actual lengths. Thus, in an oblique projection also, there are three axes — a vertical, a horizontal and a third, inclined at an angle of 30° or 45° with the horizontal.

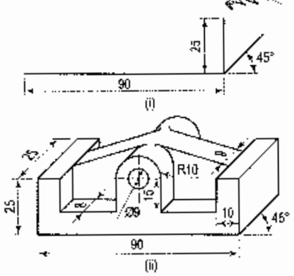


FIG. 18-4

Rectangular surfaces and circles parallel to the third axis are shown parallelograms and ellipses respectively. When an object has curved surfaces or long edges, the face containing such surfaces or edges is usually so placed that it may appear in its true shape. By doing so, the drawing is simplified and the amount of distortion is considerably reduced. Fig. 18-5 shows the guide with its longer edges parallel to the inclined axis. Comparing fig. 18-4 with this view, it can be seen that the former gives a clear idea of the shape of the guide. The choice of the position of an object should be such that minimum distortions of the object can occur. This can be achieved by observing the following rules:

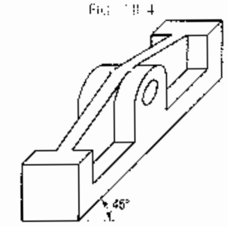
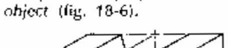


FIG. 18-5

Rule I. *Keep the longest dimension parallel to the plane of projection. This may reduce the distortion effect of the object* (fig. 18-6).

Rule II. *The face of an object containing essential contours (i.e. circles*



18-7. STEPS FOR DRAWING THE OBLIQUE PROJECTION

The steps for preparing an oblique projection from orthographic projections are illustrated in the following problem.

Problem 18-1. (fig. 18-8 and fig. 18-9): *The orthographic projections of a casting are given in fig. 18-8. Draw the oblique projection when the receding axis is inclined at an angle of 30° to the horizontal.*

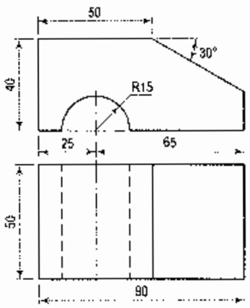
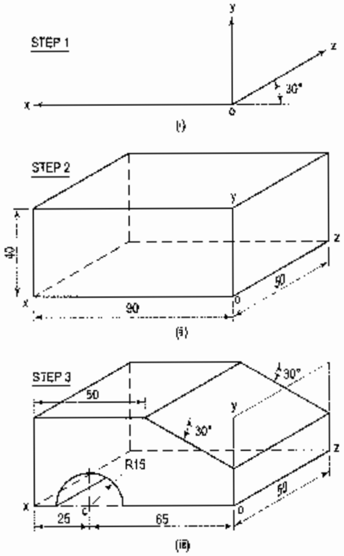


FIG. 18-8



(i) Mark the point o and draw *ox* and *oy* mutually perpendicular axes. Draw receding axis *oz* at an angle of 30° with the axis *ox* (horizontal). Fig. 18-9(i).

(ii) Construct a box by marking distances of 90 mm, 40 mm and 50 mm along the axes *ox*, *oy* and oz respectively as shown in fig. 18-9(ii).

(iii) Mark a centre c of semi-circle

18-8. OBLIQUE DRAWING OF PYRAMID

Problem 18-2. (fig. 18-10): *A frustum of a square pyramid has its base 30 mm, top 20 mm, side and height 40 mm. Draw the oblique projection of the pyramid when it rests on its base on the H.P. with one of the sides of the base perpendicular to the V.P.*

(i) Draw the front view and the top view of the frustum of the pyramid as per given conditions.

(ii) Draw axes *ox*, *oy* and *oz* as explained in problem 18-1 [steps (i) and (ii)].

(iii) Complete the projection as shown in fig. 18-10(ii).

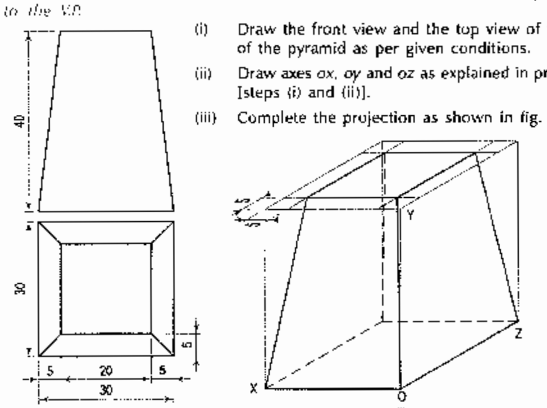


FIG. 18-10

18-9. OBLIQUE DRAWING OF CIRCLE

(1) **Offset method** (fig. 18-11):

(i) As shown in fig. 18-11, draw square to enclose circle in the front plane and divide the circle

(2) Four centre approximate method (fig. 18-12):

(i) Draw the rhombus *ABCD* in top and side plane with the length of side equal to the diameter of a circle.

(ii) Mark *P*, *Q*, *R* and *S* as the mid points of the respective sides.

(iii) From *P* and *Q*, draw line perpendicular to *AB* and *BC* respectively, such that they intersect at C_1.

(iv) Similarly draw perpendiculars from *R* and *S* to get C_2.

(v) Also mark C_3 and C_4 as the intersection points of perpendicular lines.

(vi) With C_1 and C_2 as centre and C_1P and C_2R as radius draw arc *PQ* and arc *RS* respectively.

(vii) Similarly with C_3 and C_4 as centre and C_3P and C_4R as radius draw arc *PS* and arc *RQ* respectively.

(viii) These four arcs forms the ellipse, which represents the circle in the oblique projection.

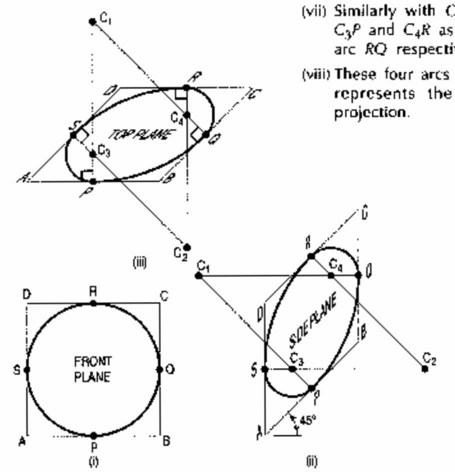


Fig. 18-12

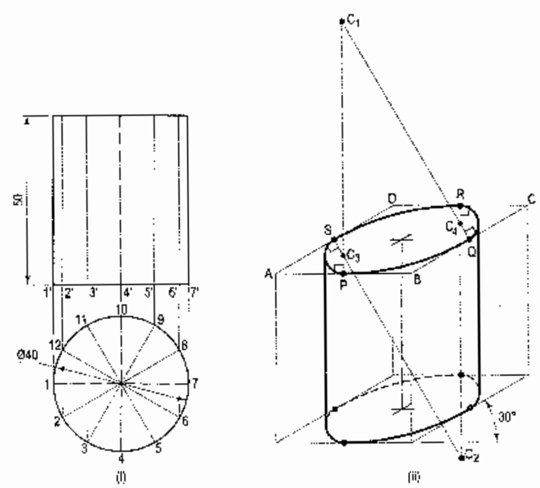


Fig. 18-13

18-11. OBLIQUE DRAWING OF PRISM

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 44 for the following problem.

Problem 18-4. *A hexagonal prism, base 30 mm side and axis 100 mm long, resting on its base on H.P. is cut by a section plane perpendicular to V.P. and makes the angle of 45° with the H.P. passes through a point on the axis 20 mm from*

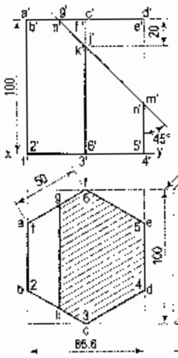


Fig. 18-14

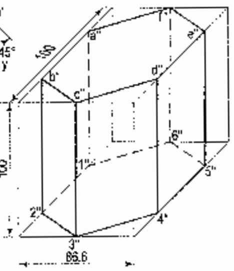


Fig. 18-15

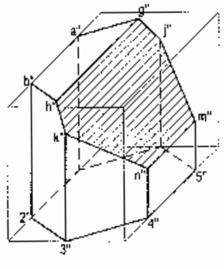
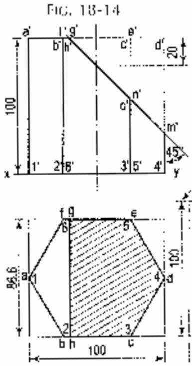
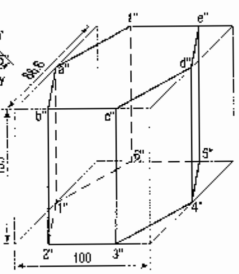
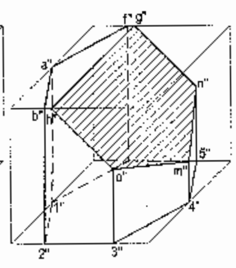


Fig. 18-16







(iii) Complete the development as shown in fig. 18-20(ii).

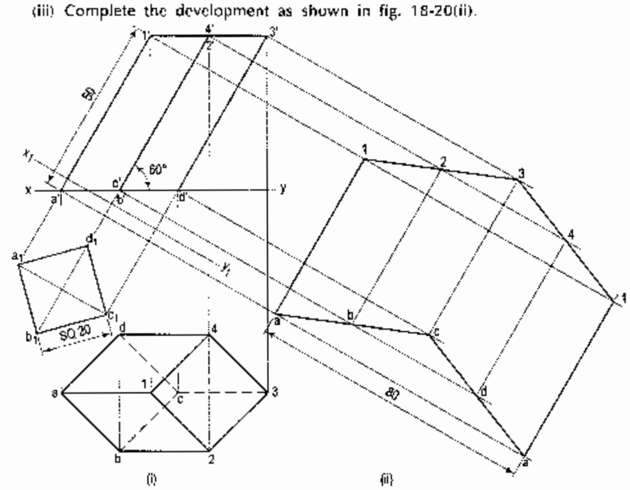
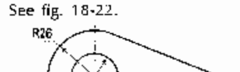


Fig. 18-20

18-12. TYPICAL PROBLEMS OF OBLIQUE PROJECTION

Problem 18-6. (fig. 18-21 and fig. 18-22): *The orthographic projections of a casting are shown in fig. 18-21. Draw the oblique projection when the receding axis is inclined at an angle of 30° with the horizontal.*

See fig. 18-22.



Problem 18-7. (fig. 18-23 and fig. 18-24): *The font view and sectional side view of a casting is shown in fig. 18-23. Draw the oblique projection when the receding axis is inclined at an angle of 45° with the horizontal.*

See fig. 18-24.

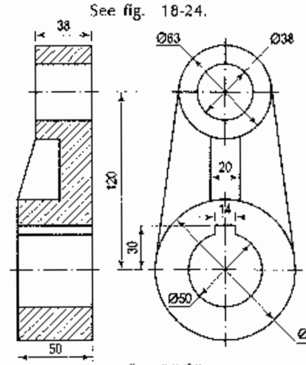


Fig. 18-23

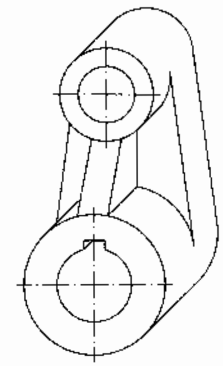


Fig. 18-24

EXERCISES 18

1. Differentiate clearly between the oblique projection and the isometric projection.
2. Explain the terms receding lines and receding angles.
3. Explain the rules pertaining to the choice of position for drawing oblique projection with minimum distortions.
4. Draw the oblique projection of a regular hexagonal prism, 25 mm side of the base and height 60 mm. When it rests on its base in the horizontal plane, the receding axis is inclined at an angle of 45°.
5. A right cylinder of 60 mm diameter and an axis 70 mm long has a co-axial through square hole of 20 mm side. Draw the oblique view when the cylinder rests on its base on the horizontal plane.
6. A cone of base 50 mm diameter and 60 mm long rests on its base on

9. Draw the oblique view of a square with a square pyramid placed on its top.
10. A frustum of a hexagonal pyramid of 25 mm side of the top and 30 mm side of the base, and height 60 mm rests with one of its base corners on the H.P. such that two of the base edges passing through the corner on which it rests make equal angle with the H.P. The axis of the pyramid is parallel to the H.P. and perpendicular to V.P. Draw the oblique projection by the cabinet method.
11. The orthographic projections of few objects are shown in fig. 18-25, fig. 18-26 and fig. 18-27. Draw the oblique projections.

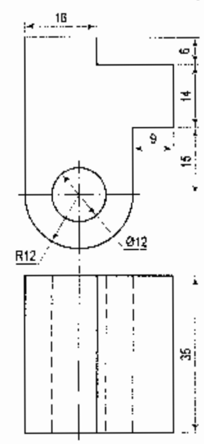


Fig. 18-25

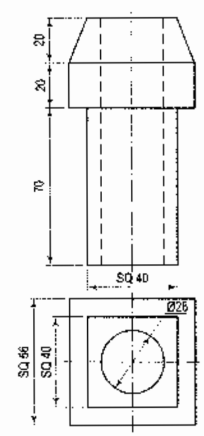
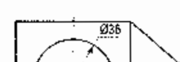
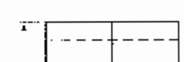


Fig. 18-26





Chapter 19 PERSPECTIVE PROJECTION

19-1. INTRODUCTION

Perspective projection or perspective drawing is the representation of an object on a plane surface, called the *picture plane*, as it would appear to the eye, when viewed from a fixed position.

It may also be defined as the figure formed on the picture plane when visual rays from the eye to the object cut the picture plane. Perspective is mainly used in architecture. By means of perspective, the architect is able to show how an object would appear when constructed.

It is essential to have full knowledge of the principles of orthographic projection (third-angle method) before the theory of perspective drawing can be studied.

In this chapter, we shall deal with the topics of perspective drawing as follows:

1. Principle of perspective projection
2. Definitions of perspective elements
3. Station point
4. Angle of vision
5. Picture plane
6. Methods of drawing perspective view
7. Types of perspective
8. Distance points
9. Measuring line or line of heights
10. Perspectives of circles and solids.

19-2. PRINCIPLE OF PERSPECTIVE PROJECTION

In perspective projection, the eye is assumed to be situated at a definite position relative to the object. The vertical plane, which (in perspective) is called the picture plane, is placed between the object and the eye.

Visual rays from the eye to the object converge to a point in the eye and are,

(1) **Ground plane** (GP): It is a horizontal plane on which the object is assumed to be situated.

(2) **Station point** (S): It is the point where the eye of the observer is located while viewing the object.

(3) **Picture plane** (PP): It is a vertical transparent plane located between the station point and the object which is to be viewed. It is the plane on which the perspective is formed. The front view of perspective elements and of the object (if necessary) is also projected on this plane.

(4) **Horizontal plane** (HP): This imaginary plane is at the level of the eye, i.e. the station point. It is a horizontal plane, above the ground plane and at right angles to the picture plane.

(5) **Auxiliary ground plane** (AGP): It is a horizontal plane placed above the horizon plane. The top view of the object and of the perspective elements is projected on this plane.

(6) **Ground line** (GL): The line of intersection of the picture plane with the ground plane is called the ground line.

(7) **Horizon line** (HL): It is the line in which the horizon plane intersects the picture plane. It is parallel to the ground line.

(8) **Perpendicular axis** (PA): It is the line drawn through the station point, perpendicular to the picture plane. It is, sometimes called the *Line of sight* or *Axis of vision*.

(9) **Centre of vision** (C): The point in which the perpendicular axis pierces the picture plane is called the centre of vision. It lies on the horizon line.

(10) **Central plane** (CP): It is an imaginary vertical plane, which passes through the station point and the centre of vision. It contains the perpendicular axis. It is perpendicular to both, the picture plane and the ground plane.

Fig. 19-2 shows the projections of the perspective elements. In the top view, the picture plane PP is seen as a horizontal line. The object X is above PP, while S the station point is below PP. The line SC is the perpendicular axis and represents the central plane also. The ground plane, the horizon plane and the auxiliary ground plane will be seen as rectangles, but are not shown. In the front view, lines GL (ground line) and HL (horizon line) represent respectively the ground plane and the horizon plane. The station point s' and the centre of vision c' coincide with each other on HL. The central plane CP is seen as a vertical line through s'. The picture plane will be seen as a rectangle, but is not shown. The perspective view (when drawn) will be seen above or around GL.

19-4. STATION POINT

The position of the station point is of great importance. Upon its position, the general appearance of the perspective depends. Hence, it should be so located as to view the object in the best manner.

For large objects such as buildings, the station point is usually taken at the eye level of a person of normal height as shown in fig. 19-1 i.e. about 1.8 metres. For small objects, the station point should be fixed at such a height as would give a good view of the top surface as well as side surfaces.

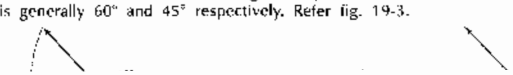
The distance of the station point from the picture plane, when taken equal to about twice the greatest dimension of the object, usually gives good view in the perspective.

For objects having heights and widths more or less equal, the location of the station point may be so fixed that the angle between the visual rays from the station point to the outer-most boundaries of the object is approximately 30°.

The station point should be so situated in front of the object that the central plane passes through the centre of interest of the object. It may not, necessarily, be placed in front of the exact middle of the object. Refer fig. 19-1.

19-5. ANGLE OF VISION

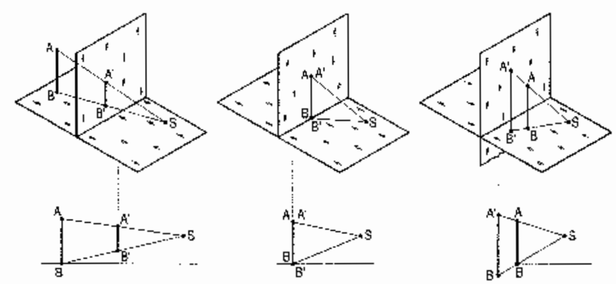
Angle of vision is angle subtended by eye in horizontal or vertical direction in which one can visualize the things clearly. Horizontal and vertical angle of vision is generally 60° and 45° respectively. Refer fig. 19-3.



19-6. PICTURE PLANE

The position of the picture plane relative to the object, determines the size of the perspective view. The perspective will show the object reduced in size when it is placed behind the picture plane. If the object is moved nearer the picture plane, the size of the perspective will increase. When the picture plane coincides with the object, the perspective of the object will be of its exact size. When the object is placed in front of the picture plane, its perspective, when projected back, will show the object enlarged in size.

In fig. 19-4(i), the line *AB* is behind the picture plane. Its perspective *A'B'* is shorter than *AB*. In fig. 19-4(ii), *AB* is in the picture plane; its perspective *A'B'* is equal to *AB* and coincides with it. Fig. 19-4(iii) shows the line *AB* placed in front of the picture plane; when projected back on the picture plane, its perspective *A B'* is longer than *AB*.



(i)   (ii)   (iii)

FIG. 19-4

19-7. METHODS OF DRAWING PERSPECTIVE VIEW

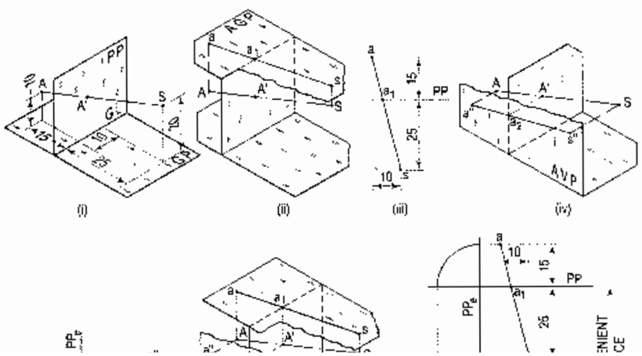
19-7-1. VISUAL-RAY METHOD

This method is explained by means of the following three illustrative problems:

Problem 19-1. (fig. 19-5): *A point A is situated 15 mm behind the picture plane and 10 mm above the ground plane. The station point S is 25 mm in front of the picture plane, 20 mm above the ground plane and lies in a central plane 10 mm to the right of the point. Draw the perspective view of the point A.*

The pictorial view of the ground plane, the picture plane, the given point and the station point in their respective positions is given in fig. 19-5(i). The visual ray *AS* from the station point *S* to the point *A* is also shown. It passes through the picture plane. To mark the perspective of *A*, the point *A'* at which *AS* pierces the picture plane should be located.

In fig. 19-5(ii), an auxiliary ground plane (AGP) is shown placed above the point *A*, and the visual ray *AS* is shown projected on it, as is the top view of *AS* and a_1 is the top view of the point *A'* at which *AS* pierces the picture plane. a_1 shows the position of the point *A'* along the length of the picture plane. When the auxiliary ground plane is revolved and brought in the same plane as that of the picture plane, the view will be as shown in fig. 19-5(iii).



view of *AS* and a_2 is the side view of *A'*. It shows the height of *A'* above the ground plane. Fig. 19-5(v) shows the orthographic view (side view) when *AVP* is revolved and brought in the same plane as that of the picture plane.

Fig. 19-5(vii) shows the top view [fig. 19-5(iii)] and the side view [fig. 19-5(v)] combined together. A horizontal line drawn through a_2 and intersecting the vertical line through a_1 gives the point *A'* which is the perspective view of the point *A*. It is quite clear from the pictorial view [fig. 19-5(vi)] that *A'* lies in the picture plane on the line *AS*.

Steps in drawing the perspective view of the point A [fig. 19-5(vii)]:

(i) Draw a horizontal line PP representing the picture plane in the top view.

(ii) Mark a, the top view of *A*, 15 mm above PP.

(iii) Draw a line (representing the central plane) perpendicular to PP and 10 mm to the right of *a*. On this line, mark s, the top view of the station point, 25 mm below PP.

(iv) Draw a line joining a with *s* and intersecting PP at a point a_1.

(v) At any convenient distance below PP, draw a horizontal line GL. It is the ground line and also represents the ground plane in the front view.

(vi) Draw a line HL parallel to and 20 mm above GL. It is the horizon line and also represents the horizon plane in the front view.

(vii) At any point on GL and to the left of *a*, draw a vertical line PP_e (representing the picture plane in the side view).

(viii) Mark a", the side view of *A*, 10 mm above GL and 15 mm to the left of PP_e.

(ix) Mark s", the side view of the station point, on HL and 25 mm to the right of PP_e.

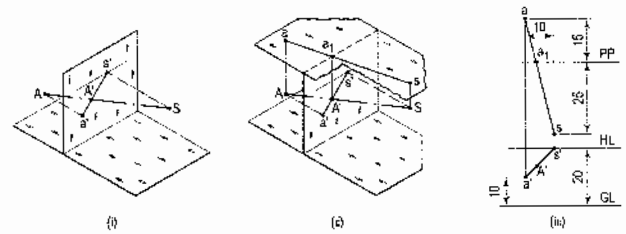
(x) Draw a line joining a" with *s*" and intersecting PP_e at a point a_2.

(xi) Through a_1, draw a vertical line. Through a_2, draw a horizontal line intersecting the vertical line at a point *A'*.

Then *A'* is the perspective view of the point *A*.

Alternative method: Instead of the side view of *AS*, its front view a's' may be projected on the picture plane (considering it as a vertical plane of projection) as shown in fig 19-6(i). The point *A'* must lie on this line *a's'*. It can be located by combining the top view and the front view as shown in fig. 19-6(ii) and fig. 19-6(iii), and as described below.

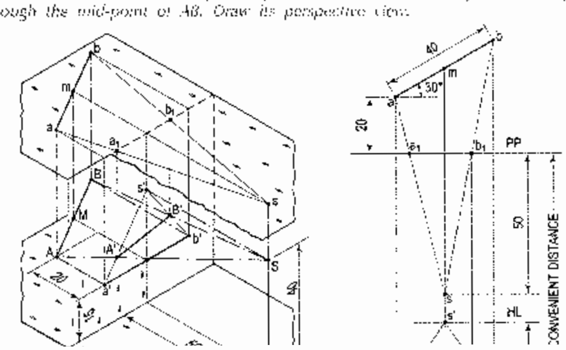
Perspective view of a straight line by the visual-ray method is drawn by first marking the perspectives of its ends which are points and then joining them.



(i) (ii) (iii)

FIG. 19-6

Problem 19-2. (fig. 19-7): *A straight line AB, 40 mm long, is parallel to and 15 mm above the ground plane, and inclined at 30° to the picture plane. The end A is 20 mm behind the picture plane. The station point is 40 mm above the ground plane, 50 mm in front of the picture plane and lies in a central plane which passes through the mid-point of AB. Draw its perspective view.*



(ii) Draw a vertical line through m, the mid-point of ab and on it mark s, the top view of the station point, 50 mm below PP.

(iii) Draw lines joining s with a and b, and intersecting **PP** at points a_1 and b_1 respectively.

(iv) Draw the ground line GL at any convenient distance below PP. Draw the horizon line **HL** parallel to and 40 mm above GL. Project s', the front view on HL.

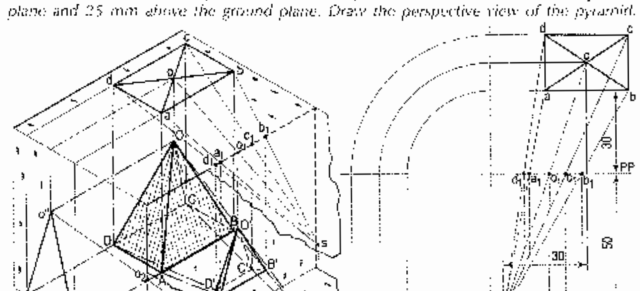
(v) From ab, project the front view $a'b'$, parallel to and 15 mm above GL. Draw lines joining s' with a' and b'.

(vi) Through a_1 and b_1, draw verticals to intersect $a's'$ and $b's'$ at points A' and B' respectively.

(vii) Join A' with B'. Then $A'B'$ is the required perspective view of AB.

The perspective can also be obtained with the aid of the side view instead of the front view. Perspective view of any solid (by visual-ray method) can similarly be drawn by first obtaining the perspective of each corner and then joining them in correct sequence, taking care to show the hidden edges by dashed lines.

Problem 19-3. (fig. 19-8 and fig. 19-9): *A rectangular pyramid, base 30 mm × 20 mm and axis 35 mm long, is placed on the ground plane on its base, with the longer edge of the base parallel to and 30 mm behind the picture plane. The central plane is 30 mm to the left of the apex and the station point is 50 mm in front of the picture plane and 25 mm above the ground plane. Draw the perspective view of the pyramid.*



In fig. 19-9, the perspective view is drawn by means of its top view and the front view. It partly overlaps the front view.

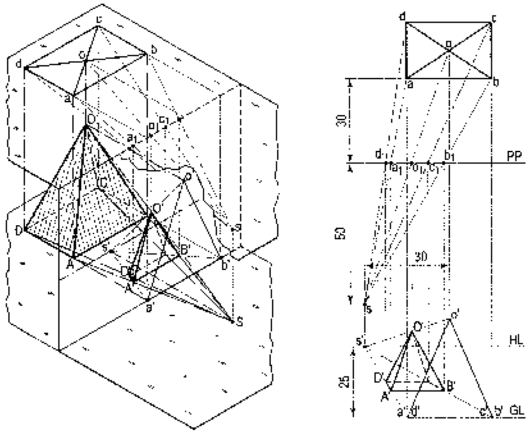


FIG. 19-9

19-7-2. VANISHING-POINT METHOD

Vanishing points: These are imaginary points infinite distance away from the station point. In practice, the point at which the visual ray from the eye to that infinitely distant vanishing point pierces the picture plane is referred to as the vanishing point.

If we stand between the rails of a long straight stretch of a railway track, it would appear as if the rails meet very far away at a point just at the level of the eye, i.e. on the horizon line. Even the telegraph and telephone wires running along the track at the sides of the track appear to meet at the same point. This point is a vanishing point.

In fig. 19-10, ab is the top view of a line AB lying on the ground plane and inclined at angle θ to the picture plane. When viewed from the station point s, its

on the horizon line. This point on the horizon line is the front-view position of the vanishing point.

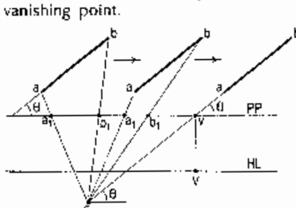


FIG. 19-10

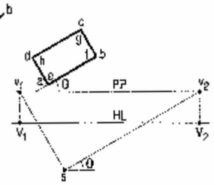


FIG. 19-11

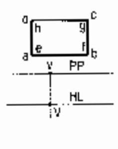


FIG. 19-12

In fig. **19-11**, $abcd$ is the top view of a rectangular block placed on the ground plane so that a vertical face is inclined at angle θ to the picture plane.

The vanishing point for the line ab and for lines cd, ef and gh (which are parallel to ab) is obtained by drawing a line through s, parallel to ab and intersecting PP at a point v_2. Through v_2, a vertical line is drawn to meet **HL** at a point V_2.

Then V_2 is the front-view position of the vanishing point. In perspective view of the block, edges AB, CD, EF and GH will converge to this point V_2.

Similarly, V_1 is the vanishing point to which edges AD, BC, EH and FG will converge.

Thus, perspectives of all horizontal lines, if produced, pass through their respective vanishing points on the horizon line. Perspectives of all horizontal parallel lines converge to a vanishing point on the horizon line.

Vanishing point for lines perpendicular to the picture plane is obtained by drawing a line through the top view of the station point, and perpendicular to the picture plane. It lies on the horizon line and coincides with the centre of vision. It is the front-view position of the station point.

In fig. 19-12, V is the front-view position of the station point and the vanishing point, at which perspectives of lines AD, BC, EH and FG will converge. Thus, perspectives of all lines perpendicular to the picture plane converge to the centre of vision on the horizon line.

Lines which are parallel to the picture plane will have no vanishing points. They vanish at infinity. Therefore, perspectives of vertical lines are vertical; perspectives of horizontal lines which are parallel to the picture plane, remain horizontal; and

Fig. 19-13 shows the perspective view of a hut having its front face in the picture plane. The front face is seen in its true size and shape, while the back parallel face is of the same shape but reduced in size. As the lines *AF, BG, CH, DJ* and *EK* are perpendicular to the picture plane, their perspectives *A' F', B' G'* etc. converge to the centre of vision *c'* on HL. Note that vertical lines *AE, CD* etc. remain vertical in perspective. Similarly, horizontal lines *ED* and *KJ*, and sloping lines *AB, BC, FG* and *GH* (which are all parallel to the picture plane) remain respectively horizontal and sloping in perspective.

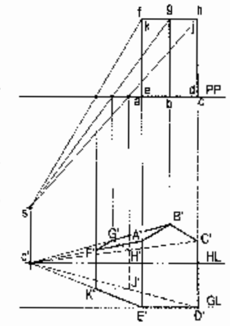
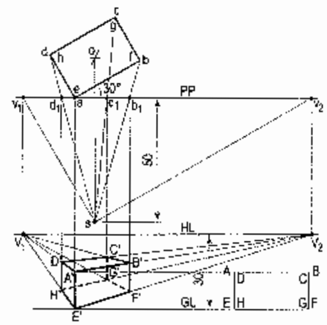


Fig. 19-13

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 47 for the angular or two point perpective.

(2) Angular perspective or two point perpective: When an object has its two faces inclined to the picture plane, its perspective is called *angular perspective* also called *two point perspective* as the edges of the object converge to two vanishing points.



Problem 19-4. (fig. 19-14): *A rectangular block, 30 mm × 20 mm × 15 mm, is lying on the ground plane on one of its largest faces. A vertical edge is in the picture plane and the longer face containing that edge makes an angle of 30° with the picture plane.*

The station point is 50 mm in front of the picture plane, 30 mm above the ground plane and lies in a central plane which passes through the centre of the

(iv) Through s, draw lines parallel to *ad* and *ab* cutting PP at points v_1 and v_2 respectively. Project v_1 to V_1 and v_2 to V_2 on HL. V_1 and V_2 are the vanishing points. Perspectives of edges *AD, EH, BC* and *FG* will converge to V_1 and those of edges *AB, CD, EF* and *GH* will converge to V_2. Perspectives of vertical edges *AE, BF, CG* and *DH* will remain vertical.

(v) As *AE* is in the picture plane, its perspective will be equal to the true length and the end *E* will lie on GL. Therefore, through a, draw a vertical line to a point *E'* on GL and on it, mark *A'* so that *A'E'* = *AE*.

(This length may be measured directly or may be projected from the front view as shown.)

(vi) Draw lines joining *A'* and *E'* with V_1 and V_2. Through b_1, draw a vertical line to intersect $A'V_2$ at *B'* and $E'V_2$ at *F'*. Similarly, draw a vertical through d_1 and obtain points *D'* and *H'*.

(vii) Draw lines joining *B'* and *F'* with V_1 and *D'* and *H'* with V_2, intersecting at points *C'* and *G'* respectively. They must lie on the vertical line through c_1. Note that lines meeting at *G* are all hidden and therefore, shown dotted.

In fig. 19-15, the ground line GL has been so drawn that HL coincides with PP. Hence, V_1 and V_2 coincide with v_1 and v_2 respectively on PP. The perspective view is obtained in the same manner as described above.

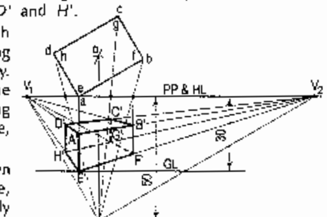
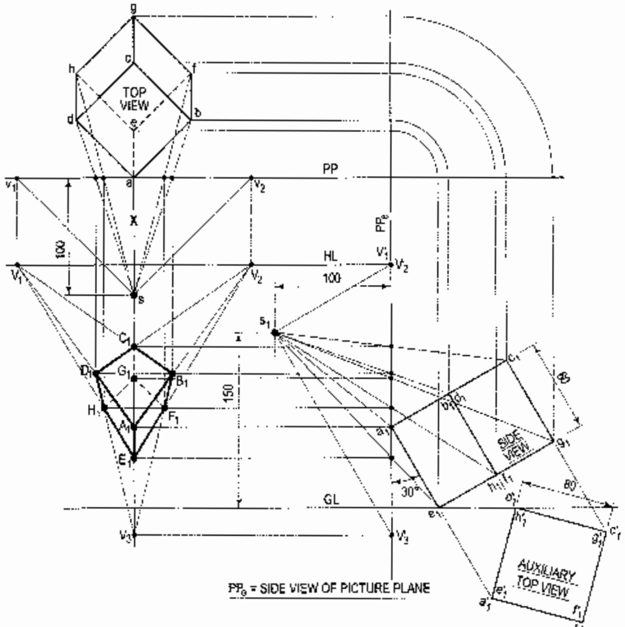


Fig. 19-15

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 48 for the oblique or three point perspective

(3) Oblique perspective or three point perspective: When an object has its three faces inclined to the picture plane, its perspective is called *oblique perspective* also called *three point perspective* as edges of the object converge to three vanishing points, as shown in fig. 19-16.

Problem 19-5: *Draw the perspective view of a cube of 60 mm side having its one corner of the edge on the ground plane and the other corner of the edge resting on the*



Oblique perspective or three point perspective
Fig. 19-16

19-9. DISTANCE POINTS

Vanishing points for all horizontal lines inclined at 45° to the picture plane are

(i) Draw the top view of the cube and of the station point.

(ii) Draw lines GL and HL. Obtain distance points P_1 and P_2 in the same manner as the vanishing points. Or, project s to *c'* on HL and mark points P_1 and P_2 such that $P_1c' = P_2c'$ = sc. Draw the perspective view as described in the previous problem.

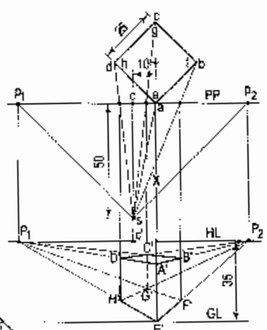
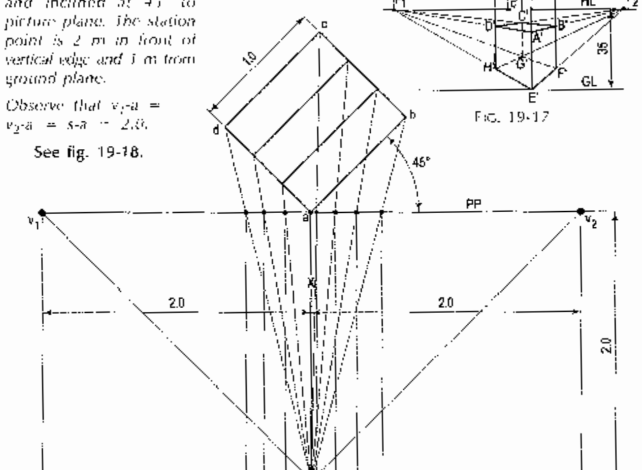


Fig. 19-17

Problem 19-7: *Fig. 19-18 shows the two point perspective of model of steps with the base on ground plane and vertical edge in picture plane and inclined at 45° to picture plane. The station point is 2 m in front of vertical edge and 1 m from ground plane.*

Observe that v_1-*a* = v_2-*a* = *s-a* = *2.0.*

See fig. 19-18.



19-10. MEASURING LINE OR LINE OF HEIGHTS

We have seen that when a line is in the picture plane, it is seen in its true length in perspective. When a line is behind the picture plane, it is foreshortened in its perspective view.

In fig. 19-19, *ab* is the top view of a rectangle *ABCD* whose surface is vertical and inclined to the picture plane, the edge *DC* is on the ground plane and the edge *AD* is in the picture plane.

In its perspective view *A'B'C'D'*, *A'D'* is equal to the true length *AD*, while *B'C'* is shorter. *A'D'* lies on a vertical line drawn through *a*. The length *B'C'* is derived from *A'D'*. Let us now consider the rectangle *EBCF* within the rectangle *ABCD*. *E'B'C'F'* is its perspective view. *E'F'* is shorter than *EF* or *AD*. Its length has been derived from *A'D'*.

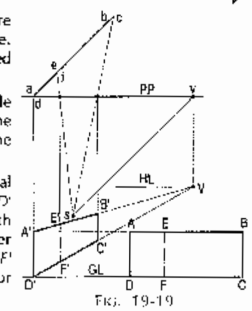


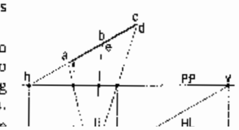
FIG. 19-19

Thus, *aD'* is the measuring line or the line of heights for points *E*, *F*, *B* and *C*. It is obtained by producing *be* to intersect PP at the point *a*; through *a*, a perpendicular is dropped to meet GL at a point *D'*. In other words, if we imagine that the rectangle *EBCF* is moved along the line *eb* to meet the picture plane, its edge *EF* will strike it at the line *A'D'* showing its true length.

Thus, the measuring line or the line of heights is the trace or the line of intersection with the picture plane, of the vertical plane containing the point or points whose heights are to be determined. Heights of points lying in different vertical planes can be measured from their respective lines of heights. Heights on this line may be measured directly with a scale or may be projected from the front view.

Problem 19-8. (fig. 19-20): *Determine the line of heights for points lying in the line ac which is the top view of a regular hexagon ABCDEF (the front view of which is shown on GL) and then, draw its perspective view from the given position of the station point.*

As *ac* is behind the picture plane, all the sides of the hexagon will be foreshortened.



(i) To determine the measuring line, produce *ca* to meet PP at a point *h*; through *h*, draw a vertical to meet GL at a point *H*. Then *hH* is the measuring line for heights of all points in the hexagon.

(ii) To draw the perspective view, determine the

19-11. PERSPECTIVES OF CIRCLES AND SOLIDS

A circle will appear as a circle in its perspective view when it is parallel to the picture plane. In other positions its perspective will be an ellipse (except when it lies in the central plane).

To obtain points for the ellipse, the circle is enclosed or *crated* in a square. The mid-points of the sides of the square are the four points for the ellipse. Points of intersection of the diagonals with the circle are the other four points. Lines are drawn through these points, parallel to the sides of the square. Perspective of the square along with the parallel lines is then drawn, locating the eight points for drawing the ellipse.

Problem 19-9. (fig. 19-21): *Draw the perspective view of a circle of 50 mm diameter, lying on the ground plane and touching the picture plane. The station point is 80 mm in front of the picture plane and 60 mm above the ground plane. The central plane passes through the centre of the circle.*

(i) With o as centre, draw the circle touching **PP**. Enclose it in a square *abcd* with *ab* in PP. Draw the horizontal and vertical diameters and the diagonals of the square. Mark points 1 to 8 as shown. Through the points on the diagonals, draw lines *ef* and *gh* parallel to *ad*.

(ii) Draw lines GL and HL, and mark s, the top view of the station point. Project s to c' on HL. c' is the centre of vision to which the perspectives of lines perpendicular to PP will converge.

(iii) Draw the perspective view of the square. Draw the diagonals, intersecting each other at O'. Through O', draw horizontal and vertical lines, intersecting the sides at points 1', 2', 3' and 4'. Draw perspectives of lines *ef* and *gh*, cutting the diagonals at points 5', 6', 7' and 8'. Draw the ellipse through points 1', 5', 2'....... 8'. The ellipse is the required perspective view of the circle.

(iv) It may be noted that the centre of the ellipse does not coincide with O', the centre of the perspective of the square.

Perspectives of concentric circles are not concentric ellipses as can be seen from fig. 19-22. The circles are on the ground plane. The station point is away

FIG. 19-21

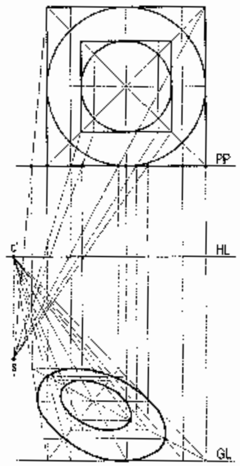
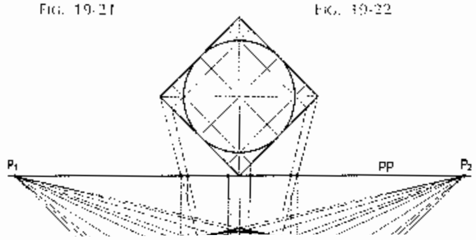


FIG. 19-22



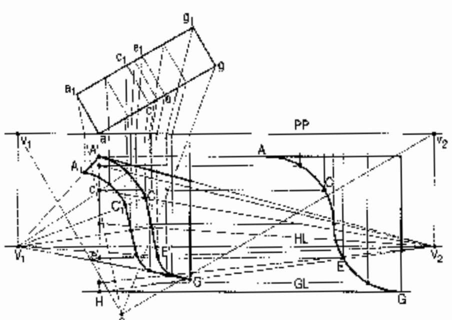


FIG. 19-24

19-12. TYPICAL PROBLEMS OF PERSPECTIVE PROJECTION

Problems 19-10 to 19-15: *Draw perspective views of a straight line AB, 30 mm long, in the given positions. The station point is 40 mm in front of the picture plane (PP), 30 mm above the ground plane (GP) and lies in a central plane (CP) in the given positions.*

Problem 19-10. (fig. 19-23): *AB in GP and inclined at 0 to PP; A in PP; CP, 10 mm to the right of A.*

(1) *Visual-ray method – by means of the top view and the front view* [fig. 19-23(i)]:

(i) Draw the top view *ab* with *a* in PP.

(ii) Draw the front view *a'b'* in GL. Mark *s*, the top view and *s'*, the front view of the station point.

(iii) Join *s* with *a* and *b*, and *s'* with *a'* and *b'*. As *A* is in PP and on GP, its perspective *A'* will coincide with *a'*. *B'* will lie on *s'b'* on a vertical through b_1.

(iv) Join *A* with *B'*. Then *A'B'* is the perspective view of *AB*.

(2) *Visual-ray method – by means of the top view and the side view*

(iii) Draw a vertical through b_1 and obtain B on $A'V$. $A'B'$ is the required perspective view.

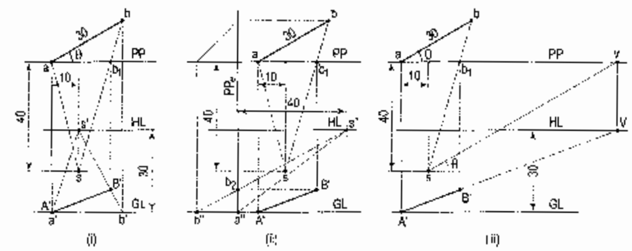


FIG. 19-25

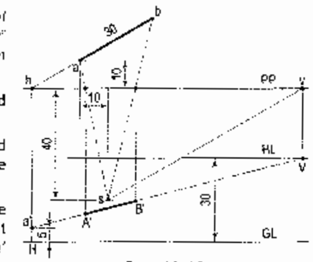


FIG. 19-26

Problem 19-11. (fig. 19-26): *AB parallel to GP and 5 mm above it; inclined at 30° to PP; A, 10 mm behind PP, CP, 10 mm to the right of A.*

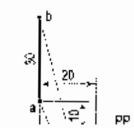
(i) Draw the top view *ab*, mark *s* and obtain the vanishing point *V*.

(ii) Join *s* with **a** and **b**. As *A* is behind PP, the line of heights will be necessary.

(iii) Produce *ba* to *h* on PP. Draw the line of heights *hH*. Mark a point *a'* on *hH*, 5 mm above GL. Join *a'* with *V*. Obtain points *A'* and *B'* on the line *a' V* as shown *A'B'* is the required perspective view.

Problem 19-12. (fig. 19-27): *AB, perpendicular to PP; A, 10 mm behind PP and 5 mm above GP, CP, 20 mm to the right of AB.*

(i) Draw the top view *ab*, and the front view *a'*. Mark *s* and *s'*.



Problem 19-13. (fig. 19-28): *AB, parallel to both PP and GP; 5 mm above GP and 15 mm behind PP; CP, 15 mm to the left of A.*

As the line is parallel to PP, it will have no vanishing point. The perspective view *A'B'* is drawn by means of the top view and the front view (visual-ray method). It is parallel to *a'b'*. (See note at the end of problem 19-15.)

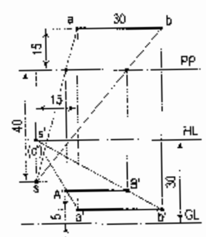


FIG. 19-28

Problem 19-14. (fig. 19-29): *AB, parallel to and 15 mm behind PP; inclined at 30° to GP; A, 5 mm above GP; CP, 15 mm to the left of A.*

As *AB* is parallel to PP, it will have no vanishing point. The perspective *A'B'* is obtained by means of the top view and the front view (visual-ray method). It is parallel to the front view *a'b'*. (See note at the end of problem 19-15.)

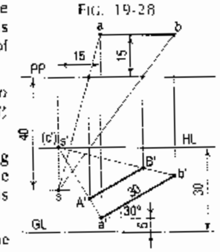


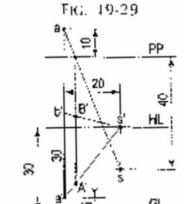
FIG. 19-29

Problem 19-15. (fig. 19-30): *AB, perpendicular to GP and 10 mm behind PP; A, 5 mm above GP; CP, 20 mm to the right of AB.*

As *AB* is parallel to PP, it will have no vanishing point. *a* is the top view and *a'b'* is the front view. The perspective *A'B* is obtained by visual-ray method. It is perpendicular to GL.

Note : Problems 19-13, 19-14 and 19-15 may also be interpreted as solved by vanishing-point method. The ends *A* and *B* of the line may each be assumed to be the ends of two separate lines perpendicular to the PP and which in perspective view would vanish at the centre of vision *c'*, i.e. at *s'*.

These problems may also be termed as cases of parallel perspective. Horizontal, inclined and vertical lines are each parallel to the PP. In their perspective views they remain respectively horizontal, inclined and vertical.



Problem 19-16. (fig. 19-31): *A rectangle ABCD, 30 mm × 20 mm, has its surface parallel to and 10 mm above*

(iv) Draw a line through *H'* and V_1 and on it, obtain points *A'* and *D'* as shown.

(v) Draw lines joining V_2 with *A'* and *D'*, and on them, obtain points *B'* and *C'*.

(vi) Join *B'* with *C'*. Then *A'B'C'D'* is the perspective view of the rectangle. Note that *B'C'*, if produced, will pass through V_1.

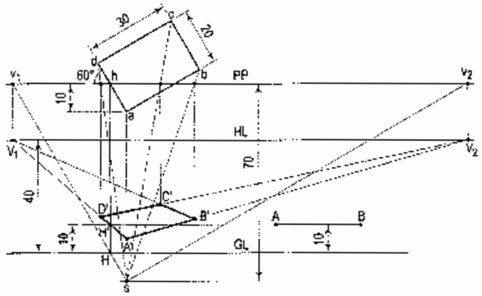


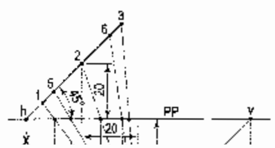
FIG. 19-31

It may also be noted that *H'* can be marked directly 10 mm above *H*. Hence, it is not absolutely essential to draw the front view in this particular case. (A line of heights may also be drawn through the point of intersection of *ab* with PP. In that case, *H* will be joined with V_2 and the point *B'* obtained on *H' V*$_2$.)

Problem 19-17. (fig. 19-32): *Draw the perspective view of a circle of 40 mm diameter, having its surface vertical and inclined at 45° to the picture plane. The centre of the circle is 25 mm above the ground plane. The positions of the station point and the horizon level are as shown in the figure.*

(i) Draw the top view of the circle. Obtain the vanishing point *V*.

(ii) Draw the front view of the circle (on the right-hand side) with its centre 25 mm above GL and mark eight points on it. Mark these points on the top view also.



(v) Draw the ellipse through these points. It is the perspective view of the circle. Note that points 5', 6', 7' and 8' lie on the diagonals of the perspective view of the square in which the circle is enclosed.

Problem 19-18. (fig. 19-33): *Draw the perspective view of a pentagonal prism, lying on the ground plane on one of its rectangular faces, the axis being inclined at 30° to the picture plane, and a corner of the base touching the picture plane. The station point is 65 mm in front of the picture plane, and lies in a central plane which bisects the axis. The horizon is at the level of the top edge of the prism.*

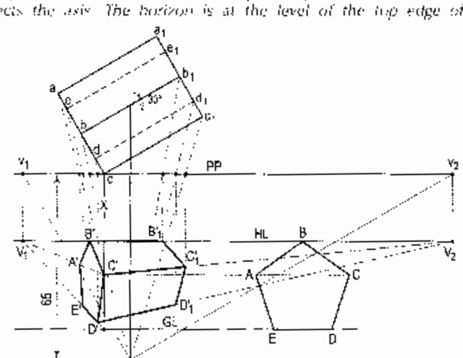


FIG. 19-33

(i) Draw the top view and the front view of the prism. Mark *s* and obtain the two vanishing points V_1 and V_2. Through *c*, draw the line *X* which is the line of heights for points *A*, *B* . . . . *E*. Join *s* with all the points in the top view.

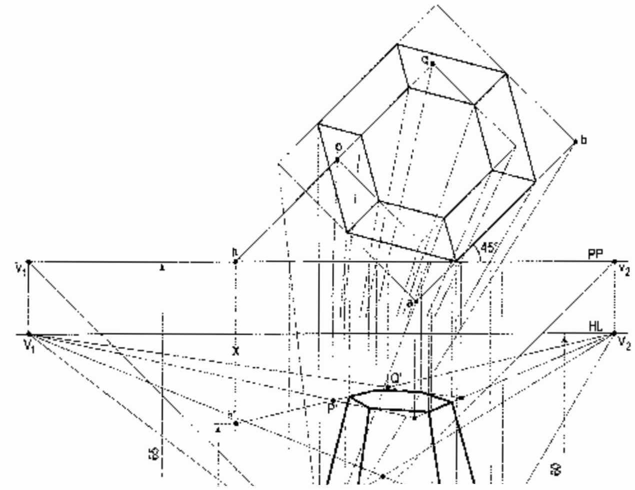
(ii) Project horizontally, all the corners in the front view to points on the line *X* and join these points with V_1. Obtain points *A'*, *B'*, . . . *E'* on these lines. Draw lines joining *B'*, *C'* and *D'* with V_2 and obtain points B'_1, C'_1 and D'_1 on these lines. Complete the perspective view as shown. The vanishing point V_2 is not shown in the figure. Hidden edges of the prism

(iv) Mark the corners of the top of the frustum and complete the perspective view as shown. **Hidden** edges have not been shown.

The data in the problem on perspective view is generally given in the form of a figure showing the top view and the front view of the object together with the position of the station point or the observer.

In the following more advanced problems, the data of each problem along with the solution is given in the same figure. All construction lines are shown to make the solutions self-explanatory. Hints are given only where deemed necessary.

Students are advised to copy only the data of each object, draw its perspective view and then compare with the given solution. Lines of heights are marked with letter X.



Problem 19·20. (fig. 19·35): *Letter P.*

Perspectives of semi-circles are drawn by enclosing the outer semi-circle in a rectangle and then marking points at which the diagonals cut the semi-circles.

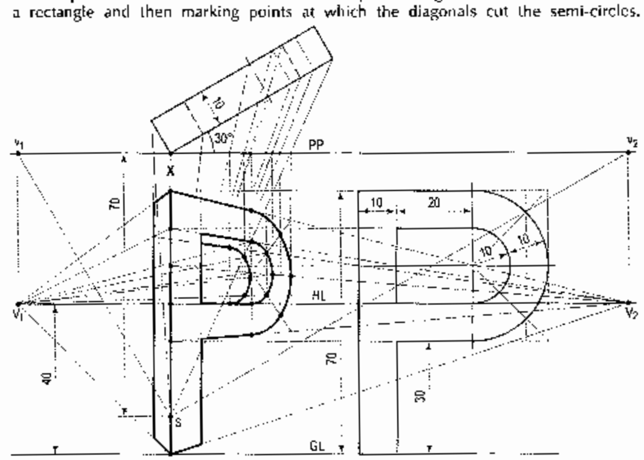
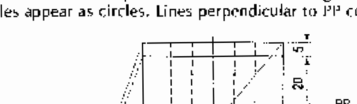


FIG. 19·35

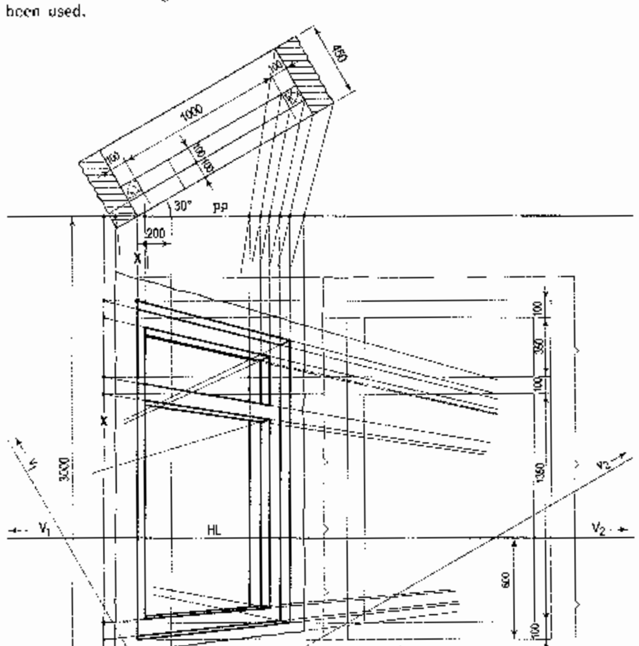
Problem 19·21. (fig. 19·36): *Guide-block.*

This is a problem on **parallel** perspective. The front face is in **PP** and **hence**, it is seen in its true shape and size. It is above the ground plane and therefore above GL. Circles appear as circles. Lines perpendicular to PP converge to the centre of vision c'.



Problem 19·24. (fig. 19·39): *Window-frame placed in a wall.*

Two lines **of heights** – one for the frame and the other for the wall – have been used.



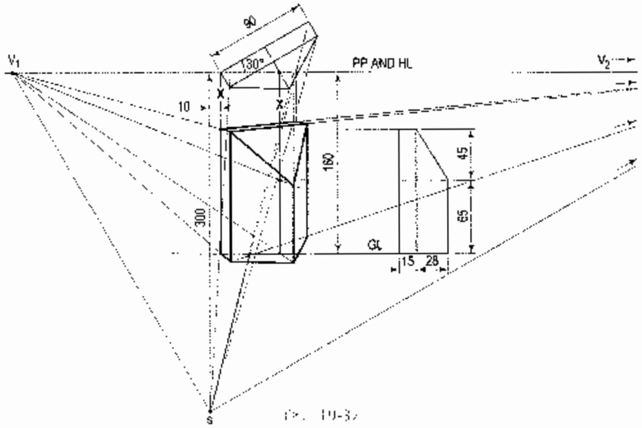


FIG. 19·37

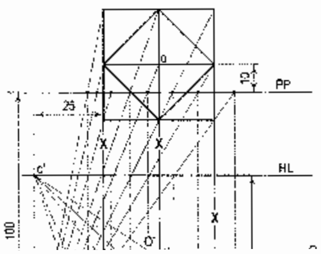
Problem 19·22. [illegible]

PP passes through the stone. Hence, the perspective of the front part will appear bigger. A separate line of heights is needed for the front vertical edge.

The station point and vanishing points are not shown in the figure. HL is shown coinciding with PP.

Problem 19·23. [illegible] *A square prism with a square pyramid placed centrally on its top.*

This is also a case of parallel perspective, but some portions of the solids are in front of PP.



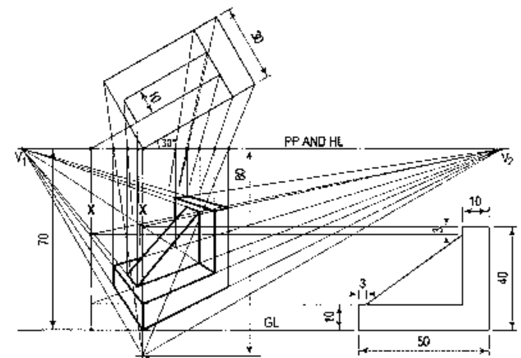
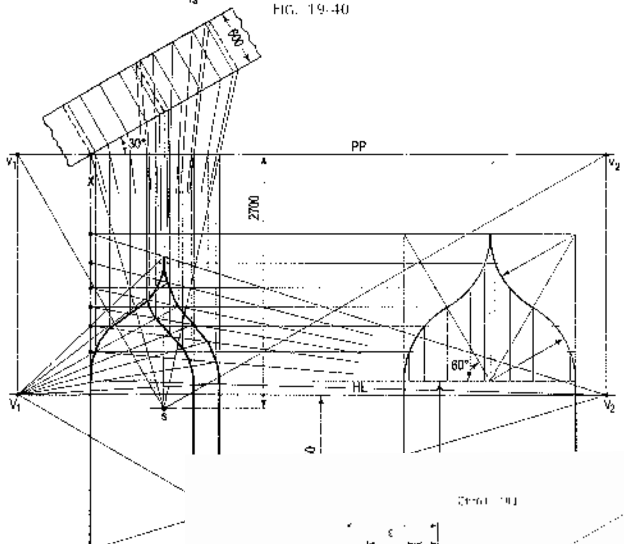
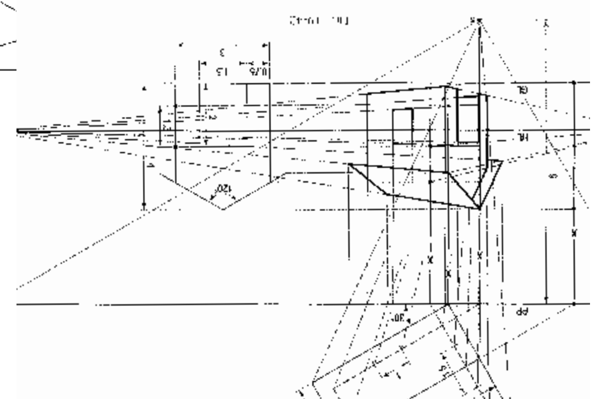
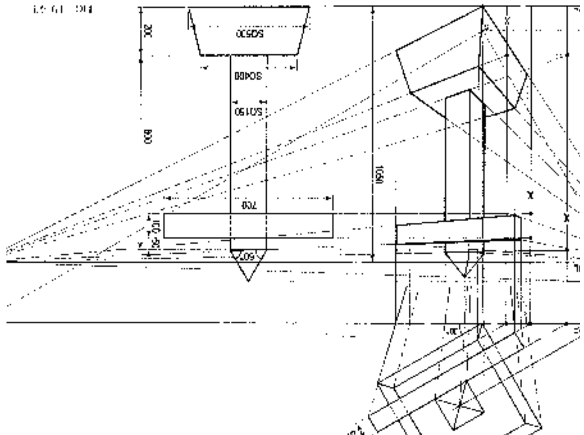


FIG. 19-40





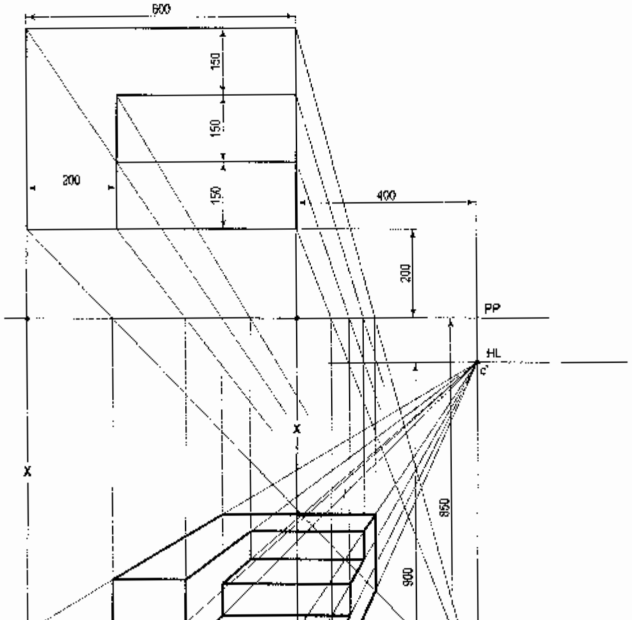
Problem 19-27. (fig. 19-42): H... door and a side window. All dimensio... metres.
Note that a corner of the roof... Four lines of heights are needed.



Problem 19-28. (fig. 19-43): Stone pillar.
Four lines of heights have been used. Vanishing p... not shown in the figure.

Problem 19-29. (fig. 19-44): *Model of steps.*

This is also a problem on parallel perspective, but the front face is behind PP. Hence, that face will be smaller in size.



EXERCISES 19

1. A man stands at a distance of 5 m from a flight of four stone steps having a width of 2 m, tread 0.3 m and rise 0.2 m. The flight makes an angle of 45° with the picture plane and touches the same at a distance of 2 m to the right of the centre of vision. Draw the perspective view of the flight.
2. Draw the perspective view of a square pyramid of base 100 mm side and height of the apex 120 mm. The nearest edge of the base is parallel to and 30 mm behind the picture plane. The station point is situated at a distance of 300 mm from the picture plane, 60 mm above the ground plane and 200 mm to the right of the apex.
3. Draw the perspective view of the model of steps shown in fig. 17-57. The position of the steps relative to the picture plane is shown in fig. 19-47. The station point is 200 mm from the picture plane. Take horizon level to be 100 mm above the ground level.
4. Draw the perspective view of the memorial shown in fig. 19-48. The horizon level is 8 m above the ground plane, while the observer is stationed at a distance of 12 m from the picture plane. (All dimensions are in metres.)

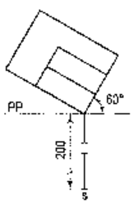


FIG. 19-47

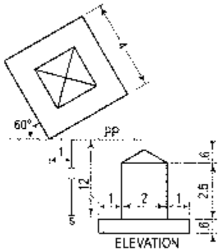


FIG. 19-48

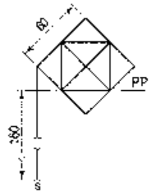
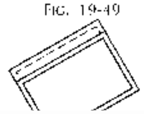


FIG. 19-49

5. Fig. 19-49 shows the top view of a square prism of 40 mm thickness with a square pyramid of 60 mm long axis, placed centrally on it. The station point is 160 mm from the picture plane and 100 mm above the ground



8. Draw the perspective view of the wooden cabinet shown in fig. 19-51. The thickness of wood is 20 mm. The cabinet is placed with one edge touching the picture plane and 1000 mm to the left of the centre of vision. The station point is 2500 mm away from the picture plane and 1500 mm above the ground plane.

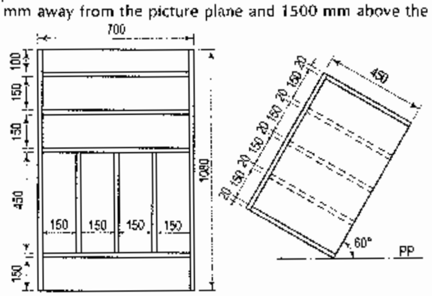


FIG. 19-51

9. Draw the perspective view of the pedestal for a statue (neglecting the sphere) shown in fig. 17-127(5). The edges of the base, as shown in fig. 19-52, are equally inclined to the picture plane. Assume the horizon plane to be 150 mm above the ground plane.
10. The casting shown in fig. 17-127(2) is placed behind the picture plane as shown in fig. 19-53. Draw its perspective view, assuming the horizon plane to be 80 mm above the ground plane.
11. Draw the perspective view of the model of a memorial shown in fig. 19-54. The station point is 200 mm in front of the picture

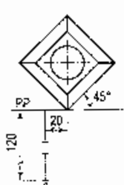


FIG. 19-52

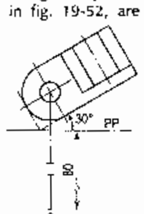
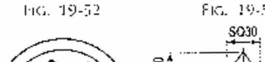
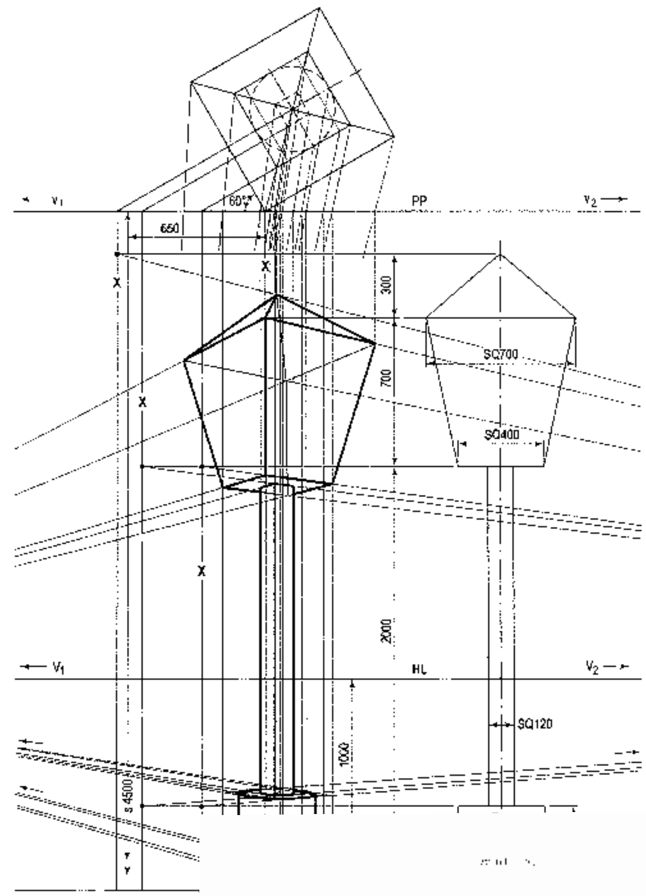
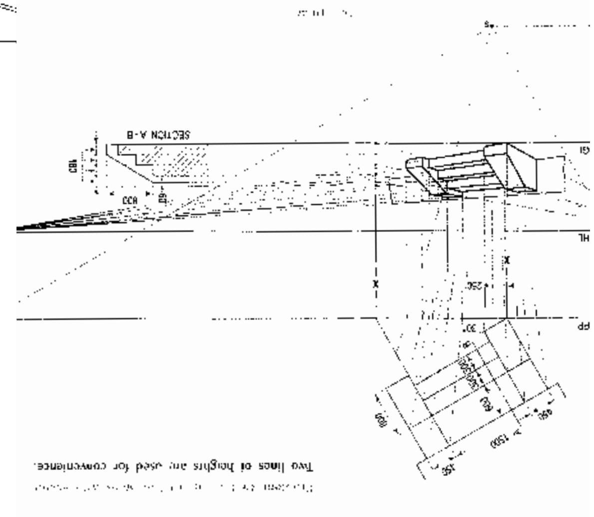
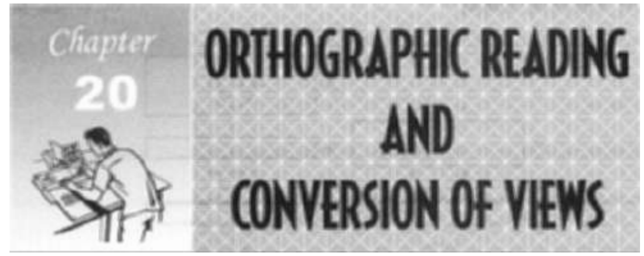


FIG. 19-53









Chapter 20 ORTHOGRAPHIC READING AND CONVERSION OF VIEWS

20-1. INTRODUCTION

Orthographic reading is the ability to visualize the shape of an object from its drawing in orthographic views. Every engineer or technician connected with the work of construction should possess this ability. Without it, it would be difficult for him to execute, independently, any work according to a given drawing.

An engineering drawing is not read aloud. It is read mentally. The whole drawing cannot be read or interpreted at a glance. It should be read systematically and patiently. The easiest way to learn reading such a drawing is to learn how to prepare one.

However, it is not impossible to know how to read it without learning how to draw. In either case, a sound knowledge of the principles of orthographic projection is quite essential for reading the drawing without hesitation.

We studied in chapter 8 that *in orthographic projection, any one view shows only two dimensions of a three dimensioned object. Hence, it is impossible to visualize the shape of the object from a single view. The second view shows the third dimension. Thus, at least two views are necessary to determine its shape.* Sometimes, a third view is also necessary to completely visualize an object.

20-2. READING OF ORTHOGRAPHIC VIEWS (BLUE-PRINT READING)

Every object may be imagined as consisting of a number of components having forms of simple solids such as prisms, cylinders, cones, etc. with some additions or

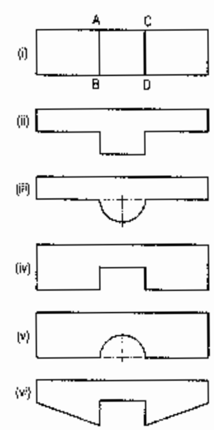


FIG. 20-1

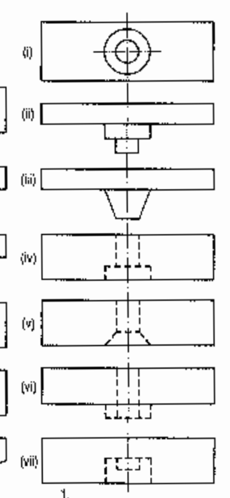


FIG. 20-2

Similarly, the two circles in fig. 20-2(i) may either represent additions [figs. 20-2(ii) and (iii)] or holes [figs. 20-2(iv) and (v)] or both [figs. 20-2(vi) and (vii)]. Thus, *every point and every line in an orthographic view has a meaning. A point may represent a corner or an edge. A line may represent an edge or a surface.* The meaning of each point or line should be interpreted by systematically referring back and forth from one view to the other. Simultaneously, the shape of the object as a whole should be visualized.

Practice in reading a drawing can be had by either projecting one or more

or missing views. In orthographic views, if a line or lines are not drawn in order to test the understanding of students, such lines are known as *missing lines*. Similarly, if amongst the three views, only two views are given then third view will be known as *missing view*.

Following procedure can be adopted in order to identify missing lines or missing views.

(i) From the given orthographic views, try to visualize an object and prepare a pictorial view.

(ii) From pictorial view, prepare orthographic views and compare with given views. Read carefully each line in each view and find out corresponding projection from another view.

Following conclusion from the projections of lines and planes will be useful for identification of lines and planes in the given views.

(a) When a line is perpendicular to a plane, its projection on that plane is point, while its projection on the other plane is a line equal to its true length.

(b) When a line is inclined to both the planes (H.P. and V.P.), its projections are shorter than the true length in both the plane and inclinations to *xy* line are greater than true inclinations.

(c) When a line is parallel to a plane, its projection on that plane will show its true length and true inclination with the other plane.

(d) When a plane is perpendicular to a reference (principal planes H.P. and V.P.) plane, its projection on that plane is a straight line.

(e) When a plane is parallel to a reference plane, its projection on that plane shows its true shape and size.

(f) When a plane is perpendicular to one of the reference plane and inclined to the other, its inclination is shown by the angle which its projection on the plane to which it is perpendicular, makes with *xy* line. Its projection on the plane to which it is inclined, is smaller than the plane it self.

(iii) Remember that each line in one view, represents a plane in another view depending upon the position of the plane with reference to the plane

Problem 20-2. *In fig. 20-4(i) two views are given. Draw its pictorial view and missing view.*

See fig 20-4(ii).

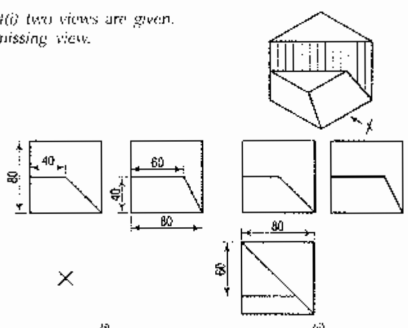


FIG. 20-4

Problem 20-3. *In fig. 20-5(i) two views are given. Draw its missing view and show missing lines alongwith its pictorial view.*

See fig 20-5(ii)

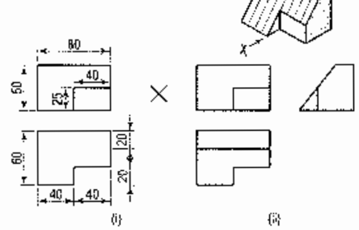


FIG. 20-5

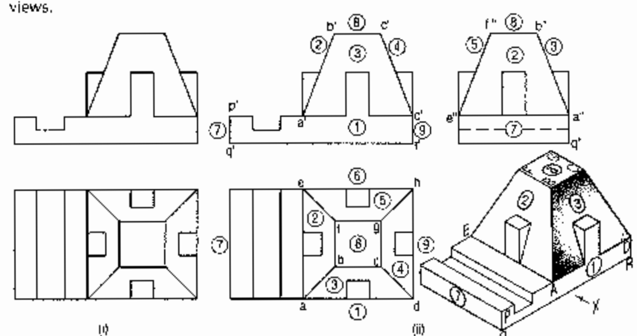
Problem 20-4. *In fig. 20-6(i) two views are given. Draw its pictorial view and missing view.*

See fig 20-6(ii).

20-4. IDENTIFICATION OF PLANES

Problem 20-5. *Two views (front view and top view) are given in fig. 20-7(i). Draw third view (side view) and identify each plane.*

See fig. 20-7(ii) along with pictorial view. Read each line and the plane in different views.



(i) (ii)

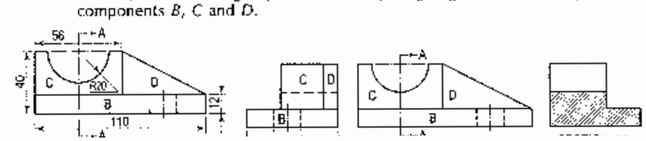
FIG. 20-7

Problem 20-6. *Two views of a casting are shown in fig. 20-8. Using both first angle projection method and third angle projection method, draw the given views and add following views*

(i) *the side view looking from the right and*

(ii) *a sectional side view: section A-A.*

Step 1: The shape of the casting may be visualized by imagining it to be broken up in three components *B*, *C* and *D*.



The component *C* has a semi-circular cavity at its top, while the part *D* is a wedge-shaped piece of uniform thickness. The side view of each part may be imagined separately and then projected from the two views as shown in fig. 20-9.

Step 3: The sectional side view is obtained by imagining the block to be cut in two parts through the line *A-A*. The portion that is cut is shown in section by means of section lines. Note that the curved surface of the cavity behind the cutting-plane line is also shown as a rectangle in the sectional view. Dashed lines for hidden features may not be shown in the sectional view.

Fig. 20-10 shows the four views of the casting drawn according to the third-angle projection method. There is no change in shape or size of the views. Only their positions are changed.

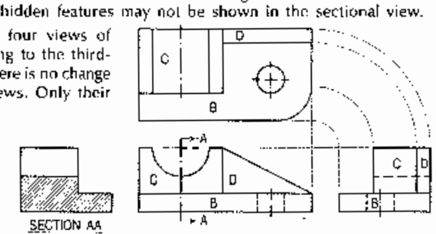


FIG. 20-10

Problem 20-7. *Two views of a shaft support are given in fig. 20-11. Draw: scale full size.*

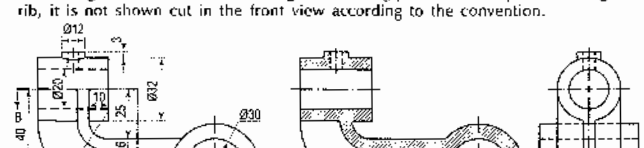
(i) *Sectional front view on A-A.*

(ii) *Sectional top view on B-B.*

(iii) *Side view from the left.*

The object is composed of two cylinders and two ribs. Follow step 1, step 2 and step 3 of problem 20-6.

See fig. 20-12. Note that, although the cutting-plane line *A-A* passes through the rib, it is not shown cut in the front view according to the convention.



20-5. CONVERSION OF PICTORIAL VIEWS INTO ORTHOGRAPHIC VIEWS

Having grasped the principles of orthographic and isometric projection, we proceed to deal with the application of the same to conversion of pictorial views of objects, for preparing the orthographic views.

Conversion of a pictorial view into orthographic views requires sound knowledge of the principles of pictorial projection and some imagination. A pictorial view may have been drawn according to the principles of isometric or oblique projection. In either case, it shows the object as it appears to the eye from one direction only. It does not show the real shapes of its surfaces or the contour. Hidden parts and constructional details are also not clearly shown. All these have to be imagined.

For converting a pictorial view of an object into orthographic views, the direction from which the object is to be viewed for its front view is generally indicated by means of an arrow. When this is not done, the arrow may be assumed to be parallel to a sloping axis. Other views are obtained by looking in directions parallel to each of the other two axes and placed in correct relationship with the front view.

When looking at the object in the direction of any one of the three axes, only two of the three overall dimensions (viz. length, height and depth or thickness) will be visible. Dimensions which are parallel to the direction of vision will not be seen. *Lines which are parallel to the direction of vision will be seen as points, while surfaces which are parallel to it will be seen as lines.*

While studying a pictorial view, it should be remembered that, *unless otherwise specified:*

(i) A hidden part of a symmetrical object should be assumed to be similar to the corresponding visible part. For example, in fig. 20-49, the back rib is assumed to be similar as the front rib.

(ii) All holes, grooves etc. should be assumed to be drilled or cut right through. Refer fig. 20-18 and fig. 20-19.

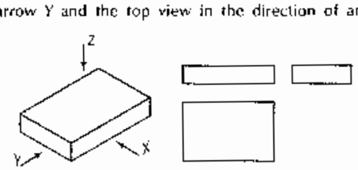
(iii) Suitable radii should be assumed for small curves of fillets etc.

An object in its pictorial view may sometimes be shown with a portion cut and removed, to clarify some internal constructional details. While preparing its orthographic views, such object should be assumed to be whole, and the views should then be drawn as required.

(iii) Measurements of all its details and overall sizes are taken and inserted in the views, along with important notes and instructions.

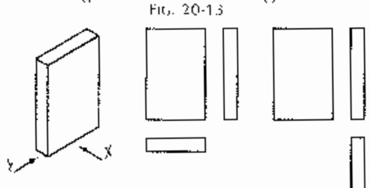
(iv) Finally, a scale-drawing is prepared from these sketches.

A pictorial view of a rectangular plate is given in fig. 20-13(i). Its front view when seen in the direction of the arrow *X*, side view from the left, i.e. in the direction of the arrow Y and the top view in the direction of arrow *Z*, are shown in fig. 20-13(ii).



(i) (ii)

FIG. 20-13



(i) (ii) (iii)

FIG. 20-14

The same plate is shown in fig. 20-14(i) with its longer edges vertical. Its front view looking in the direction of the arrow *X*, side view from the left and the top view are shown in fig. 20-14(ii). These three views are similar in shape and size to the views shown in fig. 20-13(ii). Only their positions and conditions have changed. Even when the front view is drawn looking in the direction of the arrow *Y* [fig. 20-14(iii)], the three views remain similar in shape and size.

The same plate is shown cut in various shapes in fig. 20-15. *The front view and the side view in each case will be the same as in fig. 20-13(ii).* The changed

In case of the triangular groove, three vertical lines are required. Although edges *AB* and *CD* are cut, they are seen as continuous lines *ab* and *cd*. In the top view, shapes of the grooves are seen. The grooves are not visible in the side view and hence, they are shown by a hidden line.

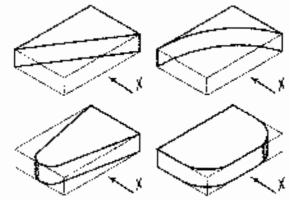


FIG. 20-15

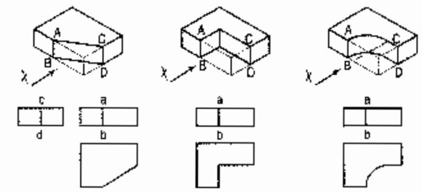
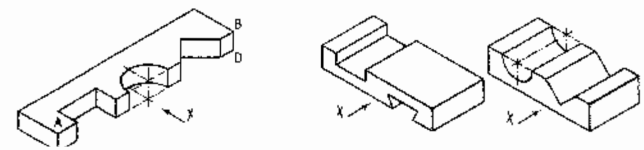


FIG. 20-16



the edges of rectangular as well as semi-circular grooves are drawn. For the triangular grooves, three lines are required. The tapered groove in the bottom surface is assumed to be cut throughout the width of the plate. It is not visible from above and hence, its four edges are shown by four hidden lines in the top view. In their side views, each groove should be shown by a horizontal hidden line. Therefore the side view in this case is not necessary.

A plate having holes of different shapes is shown in fig. 20-19. These shapes are seen in the top view. Holes are assumed to be cut or drilled right through. They are shown by hidden lines in the front and the side views. Here also the right side view is not necessary.

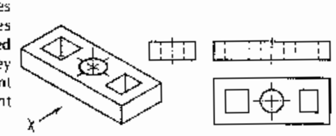


FIG. 20-19

The semi-circular groove in the block shown in fig. 20-20 does not extend upto the opposite surface. *Therefore, although the edge AB is broken, ab is seen as a continuous line in the front view.* The groove is shown by hidden lines in the side view. In the top view it is drawn as a rectangle.

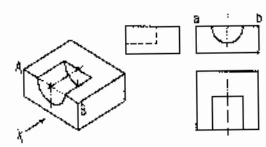
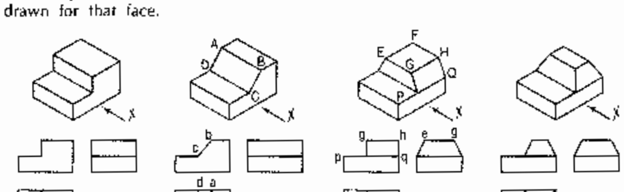


FIG. 20-20

Fig. 20-21 shows a block in the shape of steps, along with its three views. In fig. 20-22, its face *ABCD* is inclined. Hence, in the top view, two lines *ab* and *cd* are drawn for that face.



A casting having a hollow cylinder supported by a vertical rib is shown in fig. 20-25. The width of the rib is equal to the diameter of the cylinder. Hence, in the front view, vertical lines for the rib are tangential to the circle for the cylinder.

In the side view, the line showing the thickness of the rib vanishes just at the centre line. The rib is not visible when seen from top. Hence, it is shown by a hidden line in the top view. Note that the third view (top view) is a 'necessary' view to show the shape of rectangular slot.

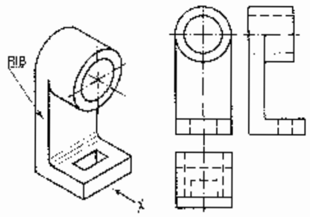


FIG. 20-25

In the bearing block shown in fig. 20-26, the line for the rib is inclined and tangent to the semi-circle in the front view. Vanishing points for the lines for the rib in the side view and the top view are obtained by projecting the tangent-point from the front view.

From the above discussion, the following important points are to be noted:

(i) An object can be observed from six sides such as
   (a) front side
   (b) back side
   (c) left-hand side
   (d) right-hand side
   (e) top side and
   (f) bottom side.

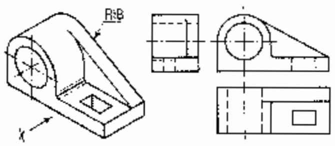
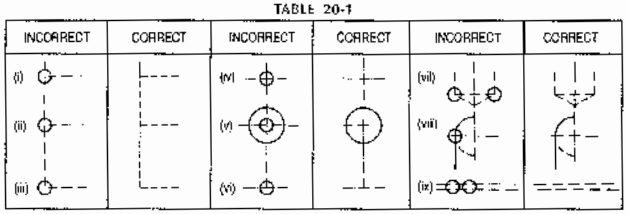


FIG. 20-26

It is not necessary to draw all the possible six views to describe completely the shape of the object. In practice, only those views which are *necessary to describe the shape of the object should be drawn.*

The view should be selected in such a way that minimum dotted lines are necessary to show internal details. The object which has both the

TABLE 20-1



(v) (a) When a visible line coincides with either a dotted line or a centre line, *the visible line is shown* and a centre line is extended beyond the outlines of the view.
   (b) When a section-plane line coincides with a centre line, the *centre line is shown* and the section-plane line is drawn outside the out-lines of the object at the ends of centre line by thick dashes.
   (c) When a dotted line coincides with the centre line, *the dotted line should be shown.*

20-7. PROCEDURE FOR PREPARING A SCALE-DRAWING

A scale-drawing must always be prepared from freehand sketches initially prepared from a pictorial view or a real object. In the initial stages of a drawing, always use a soft pencil viz. HB, and work with a light hand, so that lines are thin, faint and easy to erase, if necessary.

1. Determine overall dimensions of the required views. Select a suitable scale so that the views are conveniently accommodated in the drawing sheet.
2. Prepare the sheet layout as described in illustrative problem 20-8. Draw rectangles for the views, keeping sufficient space between them and from the borders of the sheet.
3. Draw centre lines in all the views. When a cylindrical part or a hole is seen as a rectangle, draw only one centre line for its axis. When it is seen as a circle, draw two centre lines intersecting each other at right angles at its centre.
4. Draw details simultaneously in all the views in the following order:

20-8. ILLUSTRATIVE PROBLEMS

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 49 for the following problem.

Problem 20-8 [fig. 20-27(i)]. *A pictorial view of bearing block is shown in fig. 20-27(i). Draw the front view, left-hand side view and top view according to the First-Angle projection method.*

The procedure of preparing the orthographic views is illustrated in the following steps:

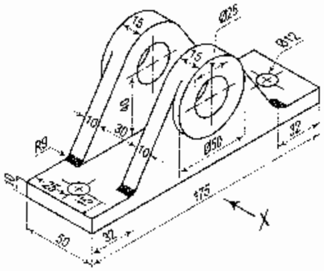


Fig. 20-27(i)

Step 1 [fig. 20-27(ii)]:

(i) Take a half imperial size drawing paper of 560 mm × 380 mm.

(ii) Draw the border lines taking A = 30 mm and B = 10 mm as shown in fig. 20-27(ii).

Now clear space in the drawing paper is 520 mm × 360 mm.

(iii) The scale of drawing is decided from the size of object and number of views required to draw. Let L, W and H be the length, width and height of the object. The spacing between two views can be calculated as under:

(a) ***For four views*** (front view, top view and two side views):	$E = \frac{520 - (L + 2W)}{4}$ mm	$F = \frac{360 - (H + W)}{3}$ mm
(b) ***For three views*** (front view, top view and side view):	$E = \frac{520 - (L + W)}{3}$ mm	$F = \frac{360 - (H + W)}{3}$ mm

If these distances E and F are less than 20 mm, adopt the suitable standard scale. In the above illustrated problem E and F are 95 mm and 75 mm respectively. Select suitable scale approximately and draw required blocks depending

Step 4 [fig. 20-27(v)]:

(i) Clean the drawing paper. Fair first circles. Complete the views by fairing various lines. The thickness of different types of lines should be as suggested in fig. 3-1, table 3-2 and table 3-3. The lines should be clean, dense and uniform.

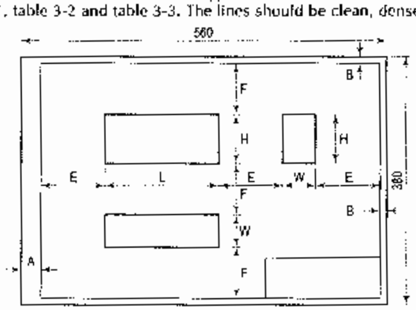


Fig. 20-27(ii)

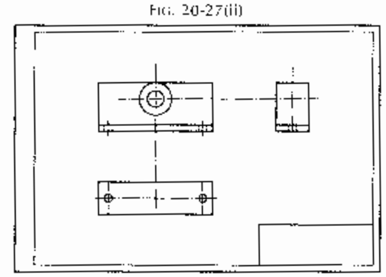
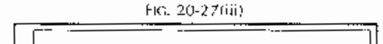


Fig. 20-27(iii)



(ii) Draw extension lines.

(iii) Draw dimension lines. Insert dimensions. Observe that the height of numerals should not be more than 3 mm. It should be written freehand. Aligned method of writing dimensions is recommended. Follow IS:11669 (1986) for dimensioning.

(iv) Complete title block by specifying unit of dimensions, symbol for method of projection and scale adopted.

(v) Fair boundary lines by 2H pencil.

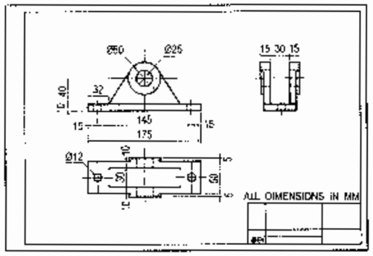


Fig. 20-27(v)

Problem 20-9. *Draw the front view and a side view of the wedge-shaped piece shown in pictorial view in fig. 20-28(i).*

The edge AB is parallel to the isometric axis oz and hence, it will be seen as a horizontal line in the front view [fig. 20-28(ii)]. The edge CD will be seen as an inclined line.

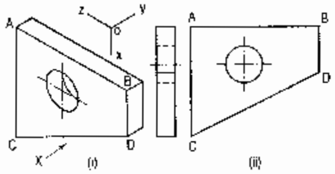


Fig. 20-28

Problem 20-10. *Draw the front view and a side view of the wedge-shaped piece shown pictorially in fig. 20-29(i).*

It can be seen from the shape of the circular hole that the pictorial view is drawn according to *oblique projection*. Hence, the front view [fig. 20-29(ii)] will be similar to the front face shown in the pictorial view.

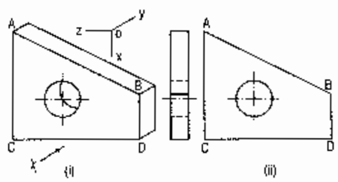


Fig. 20-29

It is interesting to note that the

Note: The three axes are shown along with the pictorial views, only for the purpose of explanation of the above problems No. 20-9, 20-10 and 20-11.

Problem 20-12. *Draw the following views of the object shown pictorially in fig. 20-31(i). (i) Front view. (ii) Top view. (iii) Side view from the right.*

See fig. 20-31(ii).

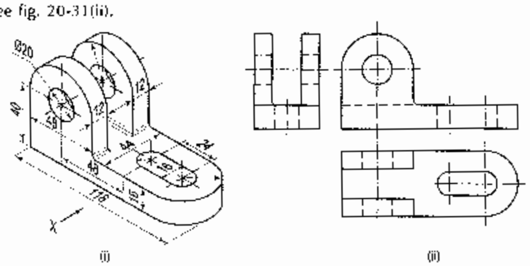
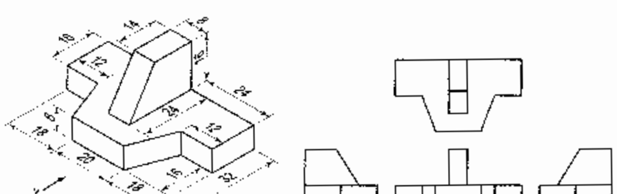


Fig. 20-31

Problem 20-13. *Draw the following views of the block shown pictorially in fig. 20-32(i). Use third-angle projection method. (i) Front view. (ii) Top view. (iii) Both side views.*

See fig. 20-32(ii).



1. Fig. 20-33: (i) Front view. (ii) Side view. (iii) Top view.

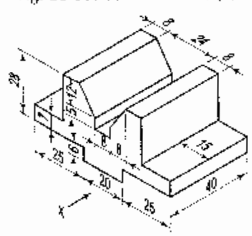


Fig. 20-33

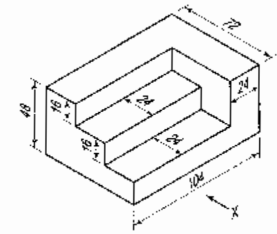


Fig. 20-34

2. Fig. 20-34: (i) Front view. (ii) Side view from the left. (iii) Top view. Use third-angle projection method.
3. Fig. 20-35: (i) Front view. (ii) Side view. (iii) Top view.

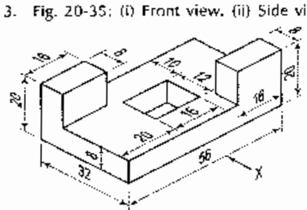


Fig. 20-35

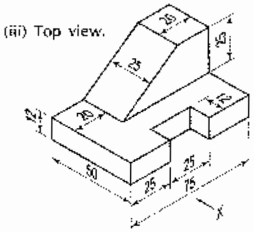
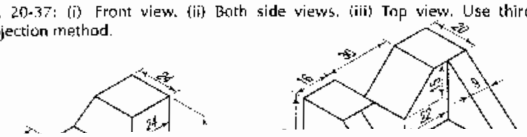


Fig. 20-36

4. Fig. 20-36: (i) Front view. (ii) Side view from the left. (iii) Top view.
5. Fig. 20-37: (i) Front view. (ii) Both side views. (iii) Top view. Use third-angle projection method.



7. Fig. 20-39: (i) Front view. (ii) Side view from the left. (iii) Top view.

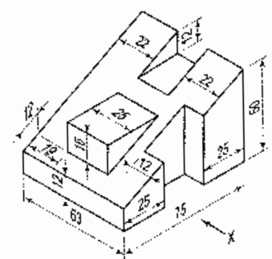


Fig. 20-39

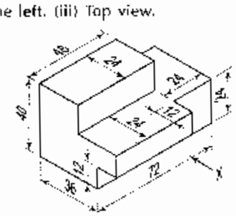


Fig. 20-40

8. Fig. 20-40: (i) Front view. (ii) Both side views. (iii) Top view.
9. Fig. 20-41: (i) Front view. (ii) Both side views. (iii) Top view.
Use third-angle projection method.

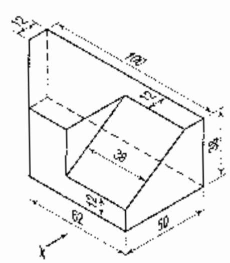


Fig. 20-41

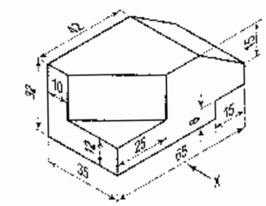


Fig. 20-42

10. Fig. 20-42: (i) Front view. (ii) Both side views. (iii) Top view.
11. Fig. 20-43: (i) Front view. (ii) Both side views. (iii) Top view. Use third-angle projection method.

13. Fig. 20-45:
    (i) Front view.
    (ii) Side view.
    (iii) Top view.
14. Fig. 20-46:
    All the six views.
    Use third-angle projection method.

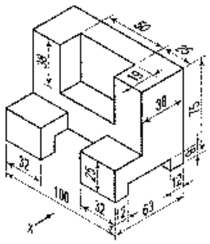


Fig. 20-45

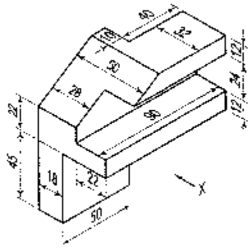


Fig. 20-46

15. Fig. 20-47: (i) Front view. (ii) Side view from the right. (iii) Top view.

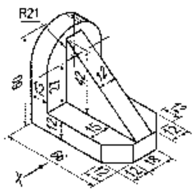


Fig. 20-47

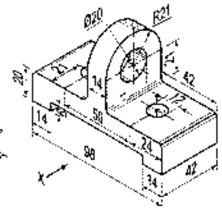


Fig. 20-48

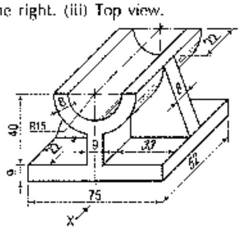
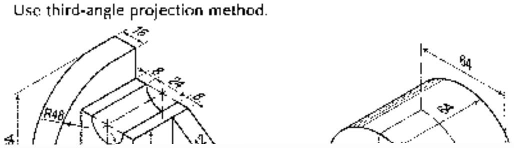


Fig. 20-49

16. Fig. 20-48: (i) Front view. (ii) Side view. (iii) Top view.
17. Fig. 20-49: (i) Front view. (ii) Side view. (iii) Top view.
Use third-angle projection method.



20. Fig. 20-52:
    (i) Front view.
    (ii) Both side views.
    (iii) Top view.
21. Fig. 20-53:
    (i) Front view.
    (ii) Both side views.
    (iii) Top view.

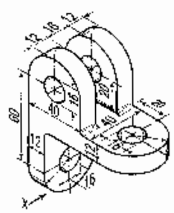


Fig. 20-52

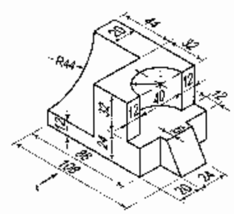


Fig. 20-53

22. Fig. 20-54: (i) Front view. (ii) Both side views. (iii) Top view.

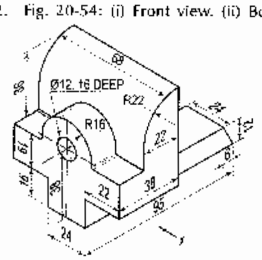


Fig. 20-54

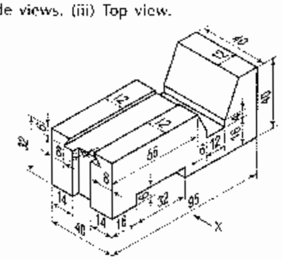


Fig. 20-55

23. Fig. 20-55: (i) Front view. (ii) Side view from the left. (iii) Top view.
Use third-angle projection method.
24. Fig. 20-56: All the six views.

26. Fig. 20-58 (i) Front view. (ii) Side view from the left. (iii) Top view.

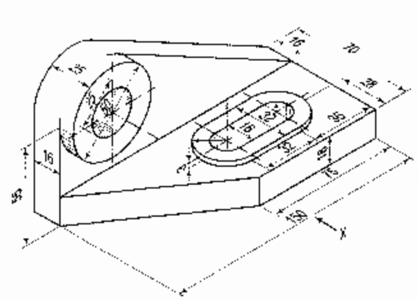


FIG. 20-58

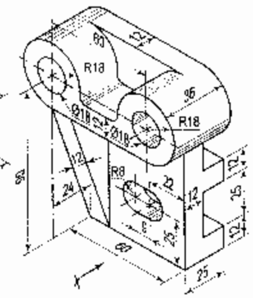


FIG. 20-59

27. Fig. 20-59:

(i) Front view.

(ii) Side view from the right.

(iii) Top view.

Use third-angle projection method.

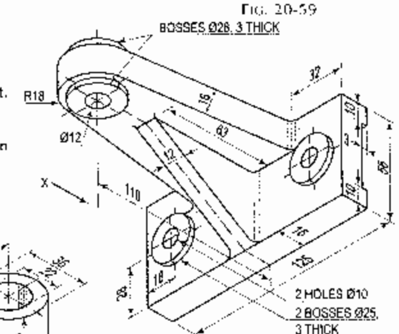
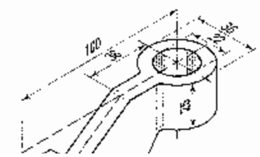


FIG. 20-60



30. Fig. 20-62: (i) Front view. (ii) Side view from the right. (iii) Top view. Use third-angle projection method.

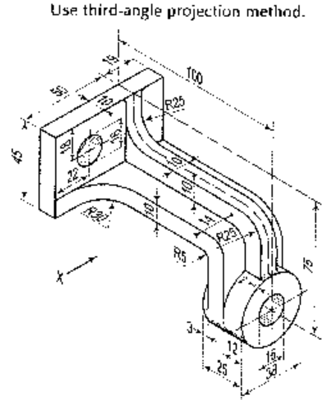


FIG. 20-62

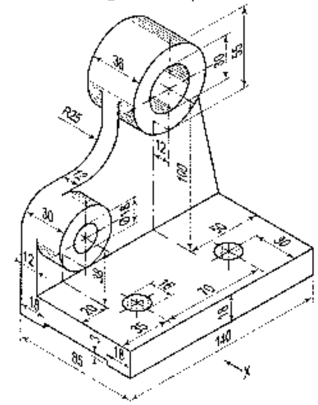
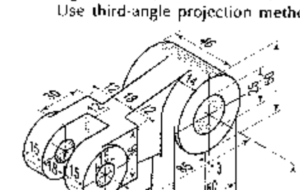
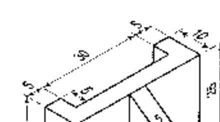


FIG. 20-63

31. Fig. 20-63: (i) Front view. (ii) Side view from the left. (iii) Top view.

32. Fig. 20-64: (i) Front view. (ii) Left-hand side view. (iii) Top view. Use third-angle projection method.





34. Fig. 20-66: (i) Front view. (ii) Right-hand side view. (iii) Top view.

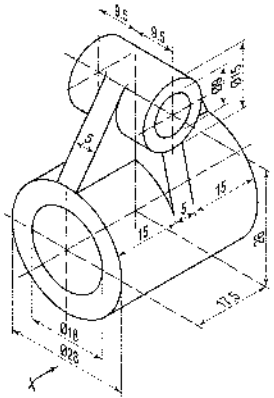


FIG. 20-66

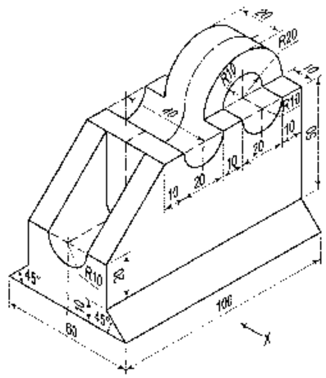
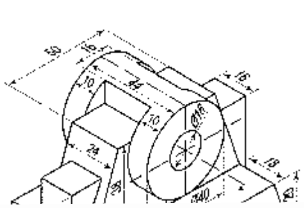
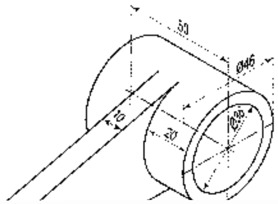


FIG. 20-67

35. Fig. 20-67: (i) Front view. (ii) Left-hand side view. (iii) Top view.

36. Fig. 20-68: (i) Front view. (ii) Side view. (iii) Top view.





38. Fig. 20-70: (i) Front view. (ii) Left-hand side view. (iii) Top view.

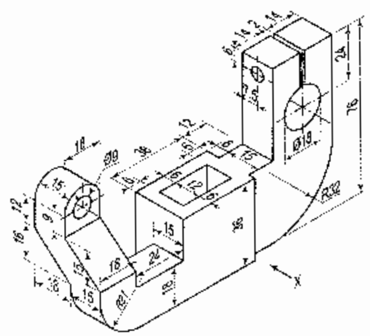
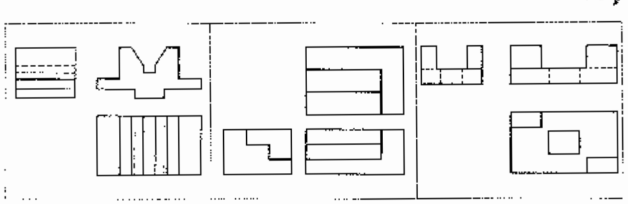
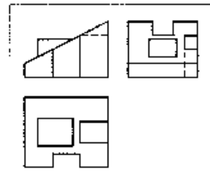


FIG. 20-70

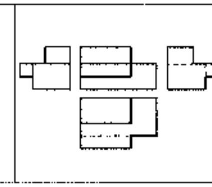
SOLUTIONS TO EXERCISES 20



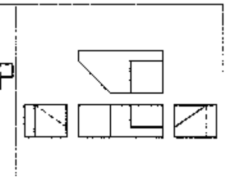
(Ex. 1. FIG. 20-33) (Ex. 2. FIG. 20-34) (Ex. 3. FIG. 20-35)



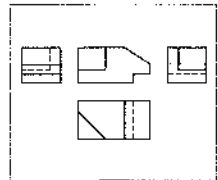
(Ex. 7. Fig. 20-39)
Fig. 20-77



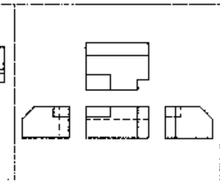
(Ex. 8. Fig. 20-40)
Fig. 20-78



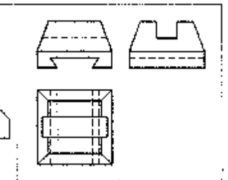
(Ex. 9. Fig. 20-41)
Fig. 20-79



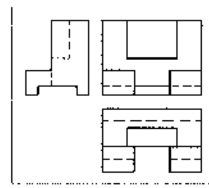
(Ex. 10. Fig. 20-42)
Fig. 20-80



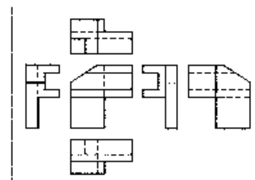
(Ex. 11. Fig. 20-43)
Fig. 20-81



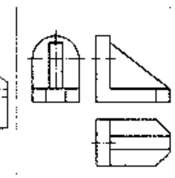
(Ex. 12. Fig. 20-44)
Fig. 20-82



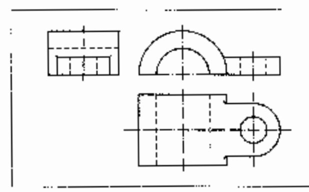
(Ex. 13. Fig. 20-45)
Fig. 20-83



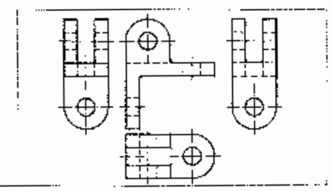
(Ex. 14. Fig. 20-46)
Fig. 20-84



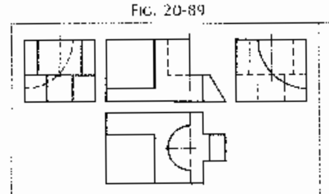
(Ex. 15. Fig. 20-47)
Fig. 20-85



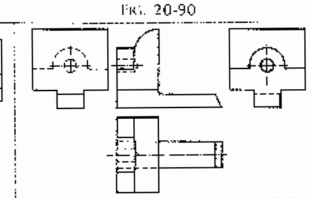
(Ex. 19. Fig. 20-51)
Fig. 20-89



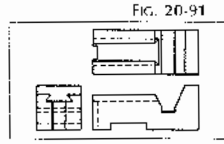
(Ex. 20. Fig. 20-52)
Fig. 20-90



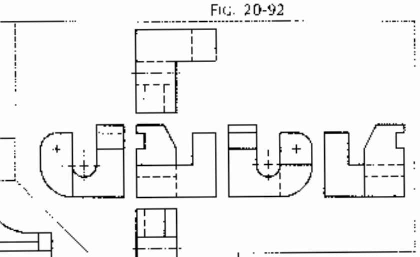
(Ex. 21. Fig. 20-53)
Fig. 20-91

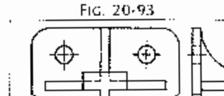


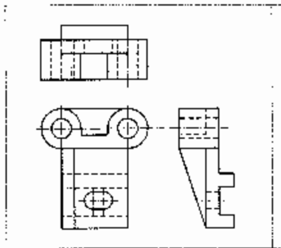
(Ex. 22. Fig. 20-54)
Fig. 20-92



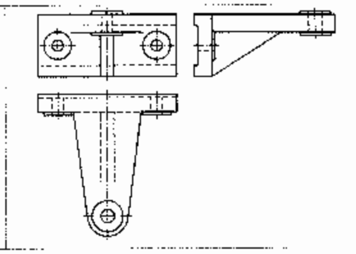
(Ex. 23. Fig. 20-55)
Fig. 20-93



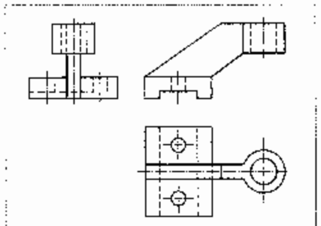




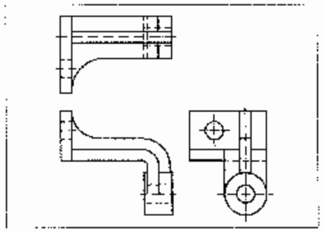
(Ex. 27. Fig. 20-59)
Fig. 20-97



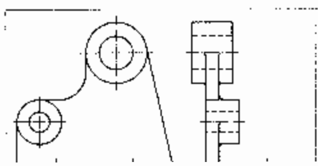
(Ex. 28. Fig. 20-60)
Fig. 20-98

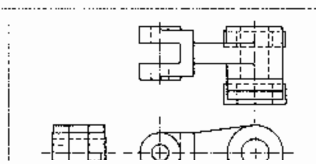


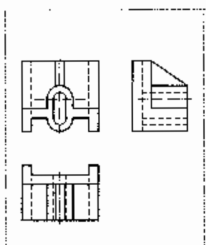
(Ex. 29. Fig. 20-61)
Fig. 20-99



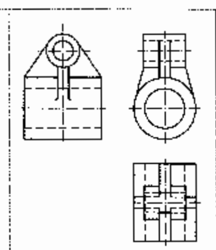
(Ex. 30. Fig. 20-62)
Fig. 20-100



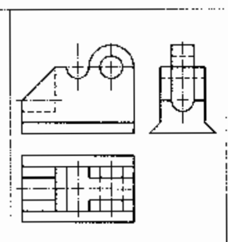




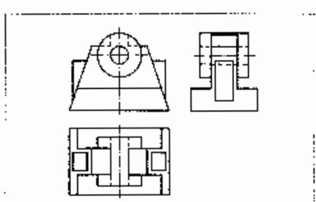
(Ex. 33. Fig. 20-65)
Fig. 20-103



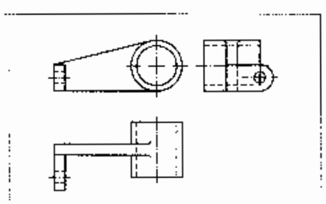
(Ex. 34. Fig. 20-66)
Fig. 20-104



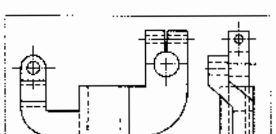
(Ex. 35. Fig. 20-67)
Fig. 20-105



(Ex. 36. Fig. 20-68)
Fig. 20-106



(Ex. 37. Fig. 20-69)
Fig. 20-107



Chapter 21 CENTRES OF GRAVITY AND MOMENTS OF INERTIA OF AREAS

21-0. INTRODUCTION

Centres of gravity and moments of inertia of areas of plane surfaces are frequently used in engineering practice. Therefore, we shall study in this chapter, about these *two* parameters as shown below:

(1) Centre of gravity of symmetrical and unsymmetrical areas

(2) Moment of inertia of plane surfaces.

21-1. CENTRE OF GRAVITY

A body consists of numerous particles on which the pull of the earth, i.e. the forces of gravity act. The resultant of these forces acts through a point. This point is called the *centre of gravity* of the body. It can also be defined as a point about which the weights of all the particles balance. It may not necessarily lie within the body.

In case of an area, the figure is assumed to be a lamina of negligible thickness so that its centre of gravity will be practically on the surface. As the area has no weight this point is also called the *centroid*.

21-1-1. CENTRES OF GRAVITY OF SYMMETRICAL AREAS

When an area is symmetrical about both its axes, the centre of gravity will be at the point of intersection of these axes. Thus, the centre of gravity of a square, rectangle, parallelogram or rhombus will be at the point of intersection of its diagonals. The centre of gravity of a circle will be at the point of intersection of its any two diameters, i.e. at its centre.

(ii) Draw lines joining G_1 with G_2, and G_3 with G_4. G, the point of intersection of lines G_1G_2 and G_3G_4 is the centre of gravity of the quadrilateral *ABCD*.

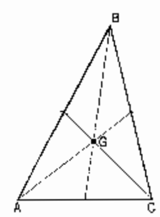


Fig. 21-1

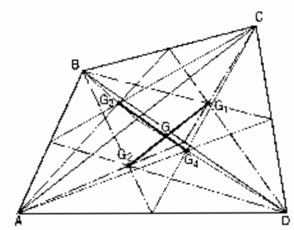


Fig. 21-2

A simple method of finding the centre of gravity of a trapezoid is illustrated in problem 21-2. It can also be located as explained in problem 21-3.

Problem 21-2. *Determine the position of the centre of gravity of the trapezoid ABCD shown in fig. 21-3.*

(i) Draw a line joining the mid-points *P* and *Q* of the parallel sides *AB* and *DC* respectively.

(ii) Produce *AB* to a point *E* so that *BE* = *DC*. Similarly, produce *CD* to a point *F* so that *FD* = *AB*.

(iii) Draw the line *EF* intersecting the line *PQ* at a point *G*. Then *G* is the required centre of gravity.

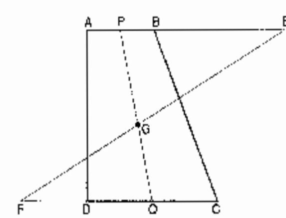


Fig. 21-3

21-1-2. CENTRES OF GRAVITY OF UNSYMMETRICAL AREAS

For locating the position of the centre of gravity of an area of unsymmetrical

21-1-3. ILLUSTRATIVE PROBLEMS ON CENTRE OF GRAVITY

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 50 for the following problem.

Problem 21-3. *Find graphically the centre of gravity of the I-section shown in fig. 21-4.*

As the section is symmetrical about its vertical axis *yy'*, the centre of gravity must lie on that axis.

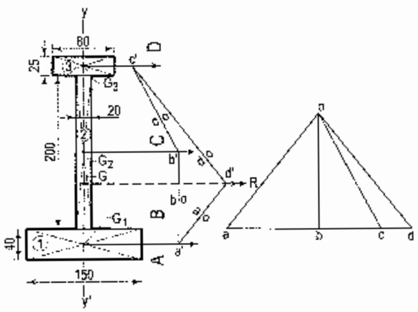


Fig. 21-4

(i) Draw the given section to a convenient scale. Divide it into three rectangles viz. 1, 2 and 3 and locate their centres of gravity G_1, G_2 and G_3 respectively at the points of intersection of their respective diagonals. Through these points, draw parallel lines of action of forces representing the area of each rectangle. These lines may be drawn in any direction except vertical, as the centre of gravity lies in the vertical axis. Name these forces as *AB*, *BC* and *CD* respectively according to Bow's Notation. This figure is called the *space diagram*.

(ii) Calculate the areas of the rectangles 1, 2 and 3. They will be 6000, 4000 and 2000 sq. mm respectively.

the line of action of the force *CD* at a point *c'*. Through *c'*, draw a line parallel to *do* to intersect the line drawn parallel to *ao* at a point *d'*. Through *d'*, draw a line parallel to the lines of action to intersect the axis *yy'* at a point *G*. This line is the line of action of the resultant *R* of the forces and *G* is the centre of gravity of the section. Figure *a'b'c'd'* is called the *funicular polygon or link polygon*.

Problem 21-4. *Find graphically the centre of gravity of the channel section shown in fig. 21-5.*

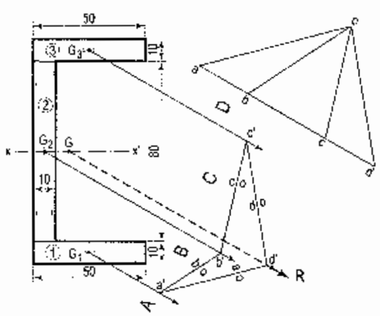


Fig. 21-5

As the section is symmetrical about its horizontal axis *xx'*, the centre of gravity must lie on this axis.

(i) Draw the section to any convenient scale. Divide it into three rectangles 1, 2 and 3 and locate their centres of gravity G_1, G_2 and G_3 respectively. Through these points, draw (in any direction except horizontal) parallel lines of action of forces representing the area of each rectangle.

(ii) Draw the polar diagram and funicular polygon as explained in problem 21-3 and obtain the point *G* where the line of action of the resultant *R* of the forces intersects the axis *xx'*. *G* is the centre of gravity

(ii) Mark the centres of gravity G_1, G_2 and G_3 of these rectangles. Through these centres, draw lines of action of the forces in any one direction, say vertical. Calculate the areas of the three rectangles and draw the polar diagram and funicular polygon as explained in problem 21-3 and obtain the position of the resultant *R*.

Similarly, through points G_1, G_2 and G_3, draw horizontal or inclined parallel lines of action of forces and determine the position of the resultant R_1. The point of intersection *G*, between the lines of action of the resultants *R* and R_1 is the required centre of gravity of the section.

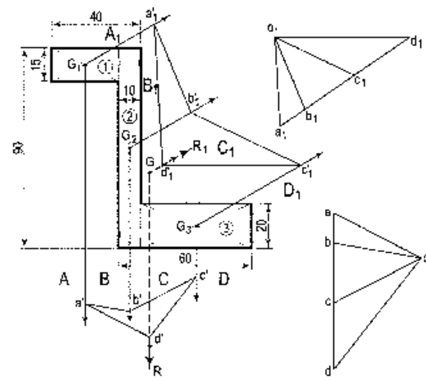


FIG. 21-6

Problem 21-6. *Find graphically the centre of gravity of the plate PQRS of negligible thickness having a circular hole in it as shown in fig. 21-7.*

(i) Draw the plate to a convenient scale. Complete the rectangle *PTRS*.

(ii) Find the centres of gravity of the circle, the rectangle *PTRS* and the triangle *QTR* and name them as G_1, G_2 and G_3 respectively. Through these points, draw vertical lines of action of forces representing

direction of the force *AB*, i.e. upwards. Cut-off a length *bc* = 6 cm in direction of the force *BC*, i.e. downwards. Again mark a length *cd* = 1.2 cm in direction of the force *CD*, i.e. upwards. Mark a suitable point *o* and draw lines *ao*, *bo*, *co* and *do*, thus completing the polar diagram.

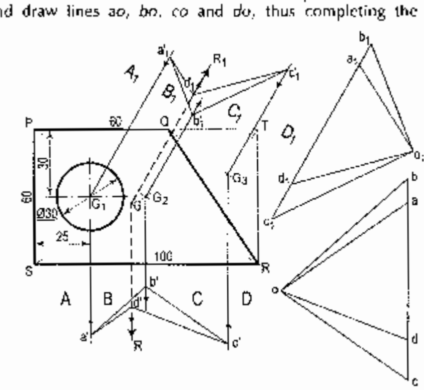


FIG. 21-7

(iv) Mark any point *a'* on the line of action of the force *AB* and through it, draw a line parallel to *ao*. Through the same point, draw another line *a'b'* parallel to *bo* and intersecting the line of action of the force *BC* at a point *b'*. Similarly through *b'*, draw a line *b'c'* parallel to *co* and intersecting the line of action of the force *CD* at a point *c'*. Through *c'*, draw a line parallel to *do* and intersecting the line drawn parallel to *ao* at a point *d'*. Through *d'*, draw a line parallel to the lines of action. This line is the line of action of the resultant *R*.

(v) Similarly, through point G_1, G_2 and G_3, draw inclined (or horizontal) parallel lines of action and determine the position of the line of action of the resultant R_1 as explained above. Note that this line passes through

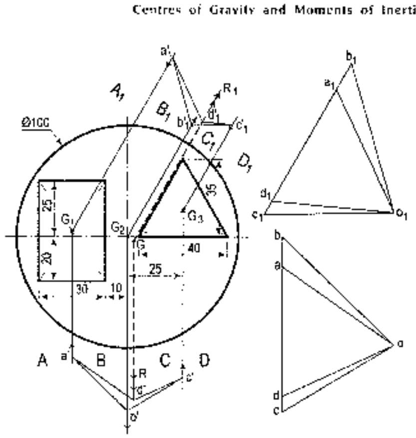
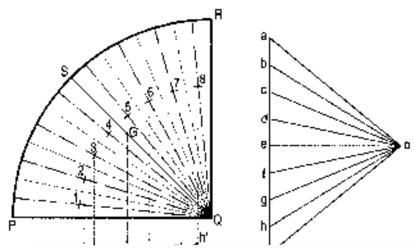


FIG. 21-8

Problem 21-8. *Determine graphically the centre of gravity of the quarter circle PQR shown in fig. 21-9.*



(ii) Assuming the sectors to be isosceles triangles, mark the centre of gravity (the point 1) of any one sector, say the end sector. It will lie on the altitude, at a distance of $\frac{2}{3}$ the altitude from the apex Q.

(iii) With Q as centre and Q1 as radius, draw an arc to cut the other altitudes at the centre of gravity of each sector. Name these points as 2, 3,...8. Through points 1, 2...8, draw vertical lines of action of forces.

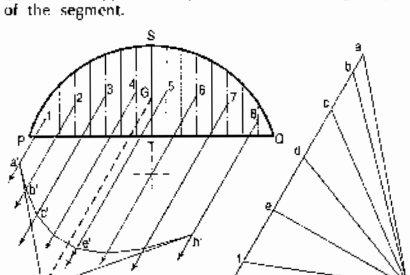
(iv) Draw the polar diagram taking *ab*, *bc* etc. of equal lengths, as all the sectors are of the same area.

(v) Complete the funicular polygon and draw the line of action of the resultant *R* through the point *k'*. *G*, the point of intersection between this line and the line *SQ* is the required centre of gravity.

Problem 21-9. *Find graphically the centre of gravity of the segment of the circle shown in fig. 21-10.*

(i) Divide the chord *PQ* into a number of equal parts and through the division-points, draw lines perpendicular to *PQ*, thus dividing the segment into a number of smaller parts. The centre of gravity of the segment must lie on the line *ST* which bisects the segment.

(ii) Draw the mid-ordinates of each part and find the mid-point of each mid-ordinate. These points will approximately be the centres of gravity of the respective parts of the segment.



(v) Through the point k', draw the line of action of the resultant R. G, the point of intersection between this line and the line ST is the required centre of gravity.

Note: This is an approximate and quick method. More accurate method would be to (i) consider the end parts as triangles and the remaining parts as trapezoids, (ii) determine their centres of gravity, (iii) calculate their areas and then (iv) draw the polar diagram and funicular polygon.

Problem 21-10. *Find graphically the centre of gravity of the section of a retaining wall shown in fig. 21-11.*

Adopt the same method as explained in problem 21-5. The point G is the required centre of gravity. The section has been divided into two triangles and one rectangle. It can also be divided into two trapezoids and one square by drawing horizontal lines.

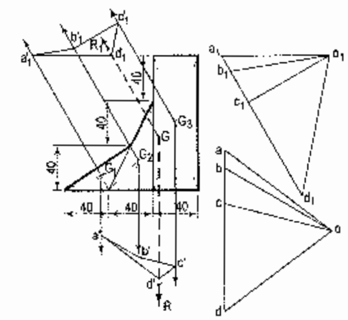


Fig. 21-11

21-2. MOMENTS OF INERTIA OF AREAS

Moment of inertia of an area of a plane figure about an axis in the plane of the area is a frequent requirement in engineering practice. The graphical method of determining the moment of inertia of areas gives fairly accurate results speedily. It is more useful in case of areas of irregular shapes.

(1) **Definition:** The moment of inertia of an area about an axis in the plane

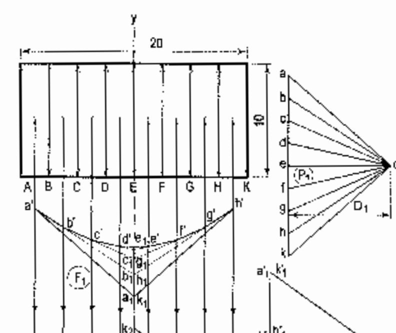
In S.I. Units, the area is calculated in square metres (m^2) and the distances are also measured in metres. Therefore, the unit of moment of inertia (area × distance^2) will be in metres raised to the fourth power, i.e. m^4.

(3) **Graphical method:** The moment of inertia is graphically determined by Culmann's method with the help of space diagrams, force diagrams, polar diagrams and funicular polygons as explained in the following illustrative problems.

21-3. ILLUSTRATIVE PROBLEMS ON MOMENTS OF INERTIA

This book is accompanied by a computer CD, which contains an audiovisual animation presented for better visualization and understanding of the subject. Readers are requested to refer Presentation module 51 for the following problem.

Problem 21-11. *Find graphically the moment of inertia of the rectangular section 20 cm wide × 10 cm deep shown in fig. 21-12, about the axis yy passing through its centre of gravity.*



(i) Draw the given rectangle to a suitable scale, say 1 cm = 2 cm and draw the axis yy' passing through its centre of gravity.

(ii) Divide the rectangle into a number of equal strips, say 8, parallel to the axis.

(iii) Draw lines of action of forces representing the area of each strip, parallel to the axis and passing through the respective centres of gravity of the strips. This is the space diagram.

Calculate the area of each strip. Select a convenient scale, say 1 cm = 20 sq. cm and draw the load line ak as explained in problem 21-3. Lengths ab, bc etc. will each be equal to 1.25 cm each. Mark the pole o at any convenient polar distance D_1, say 5 cm, from the line ak and complete the polar diagram P_1 by joining o with points a, b,.....k.

(iv) Draw the funicular polygon F_1 as explained in problem 21-3. Produce all the sides of the polygon to intersect the axis at points a_1, b_1....k_1. Note that in this problem points a_1, b_1, c_1 and d_1 coincide with points k_1, h_1, g_1 and f_1 respectively.

(v) Measure the intercepts $a_1 b_1$, $b_1 c_1$ etc. Assuming these intercepts to be forces and selecting a convenient scale, say 1 cm = 0.333 cm, draw the second load line. While drawing this line it should be noted that the intercepts for the strips on one side of the axis should be drawn in one direction, while those for the strips on the other side of the axis should be drawn in the opposite direction.

Thus the intercepts from a'_1 to e'_1 coincide with those from k'_1 to e'_1. Note that according to the selected scale, length $a'_1e'_1$ is three times the length a_1e_1. Select a pole o_1 at a suitable distance D_2, say 6 cm, and complete the polar diagram P_2.

(vi) Draw the corresponding funicular polygon F_2. The intercept $a_2\ k_2$ of this polygon on the axis yy' is the moment of inertia of the rectangle about the axis yy' to the *moment scale* which is determined as shown below: If,

(i) the scale of the space diagram is 1 cm = n cm

(ii) the area scale for the first load line is 1 cm = n_1 cm^2

(iii) the intercepts from the funicular polygon F_1 are represented on the second load line to the scale 1 cm = n_2 cm

(iv) the polar distances in polar diagrams P_1 and P_2 are D_1 cm and D_2 cm

Problem 21-12. *Find graphically the moment of inertia of the isosceles triangle, base 9 cm long and altitude 9 cm, shown in fig. 21-13, about the vertical centroidal axis yy'.*

Adopt the same method as explained in problem 21-11. The areas of the strips are unequal. The scales and distances selected are as under:

(i) The scale for the space diagram is 1 cm = 1 cm.

(ii) The scale for the first load line is 1 cm = 4 sq. cm.

(iii) The scale for the second load line is 1 cm = 0.2 cm.

(iv) The polar distances D_1 and D_2 are each 6 cm.

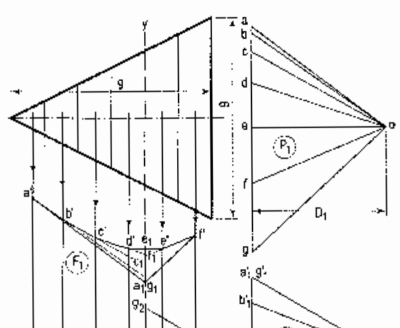
The moment scale $= 1^2 \times 4 \times 0.2 \times 6 \times 6$

$= 28.8$ cm^4.

The length of the intercept $a_2g_2 = 6.3$ cm.

∴ The moment of inertia $= 6.3 \times 28.8$

$= 181.4$ cm^4.



See fig. 21-14. Adopt the same method as explained in problem 21-11 and obtain the intercept $a_2 g_2$. The scales and distances selected are as under:

(i) The scale for the space diagram is 1 cm = 1 cm.

(ii) The scale for the first load line is 1 cm = 5 sq. cm.

(iii) The scale for the second load line is 1 cm = 0.2 cm.

(iv) The polar distances D_1 and D_2 are each 6 cm.

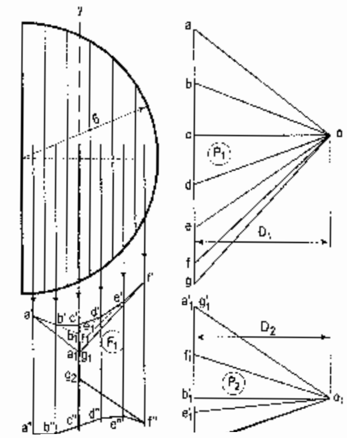
The moment scale $= 1^2 \times 5 \times 0.2 \times 6 \times 6$

$= 36 \text{ cm}^4.$

The length of the intercept $a_2 g_2$ is equal to 3.9 cm.

∴ The moment of inertia $= 3.9 \times 36$

$= 140.4 \text{ cm}^4.$



(ii) Draw the axis yy' at a distance of 15 cm from G.

(iii) Obtain the intercepts a_1b_1, b_1c_1 etc. by producing the lines $a'g'$, $a'b'$ etc. to intersect yy' at points a_1b_1, etc.

(iv) Draw the polar diagram P_2 and the funicular polygon F_2 as explained in problem 21-11 and obtain the intercept a_2g_2 on yy'. Measure its length and calculate the moment of inertia as shown below:

The scales and distances selected in the figure are as under:

(i) The scale for the space diagram is 1 cm = 2 cm.

(ii) The scale for the first load line is 1 cm = 4 sq. cm.

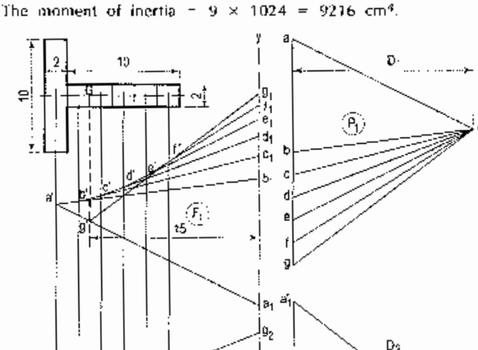
(iii) The scale for the second load line is 1 cm = 1 cm.

(iv) The distances D_1 and D_2 are each 8 cm.

The moment scale $= 2^2 \times 4 \times 1 \times 8 \times 8 = 1024 \text{ cm}^4.$

The length of the intercept a_2g_2 is 9 cm.

∴ The moment of inertia $= 9 \times 1024 = 9216 \text{ cm}^4.$



EXERCISES 21

1 to 12. Determine graphically the position of the centre of gravity of each area shown in fig. 21-16 to fig. 21-27. All dimensions are in millimetres.

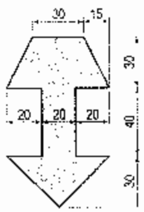


FIG. 21-16

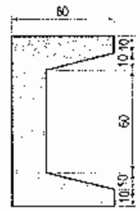


FIG. 21-17

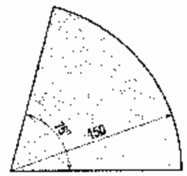


FIG. 21-18

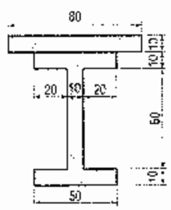


FIG. 21-19

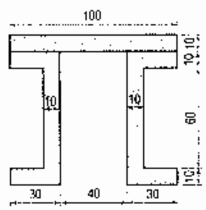


FIG. 21-20

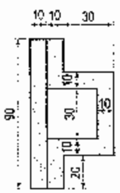
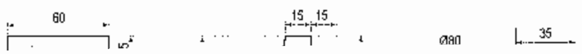


FIG. 21-21



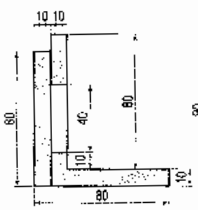


FIG. 21-25

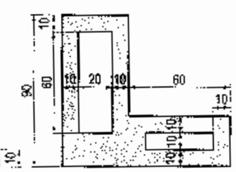


FIG. 21-26

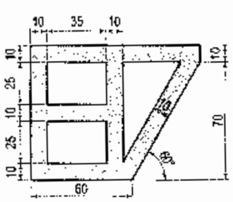


FIG. 21-27

13 to 20. Find graphically the moments of inertia of areas shown in fig. 21-28 to fig. 21-33, fig. 21-17 and fig. 21-19, as stated below:

Fig. 21-28, fig. 21-29 and fig. 21-30: About the vertical centroidal axis of each area.

Fig. 21-31 and fig. 21-32: About the horizontal centroidal axis of each area.

Fig. 21-33: About the base AB.

Fig. 21-17: About the horizontal axis situated at a distance of 100 mm below the centroid of the area.

Fig. 21-19: About the horizontal axis situated at a distance of 60 mm above the centre of gravity of the area.

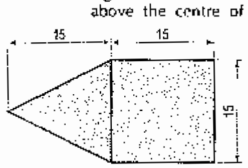


FIG. 21-28

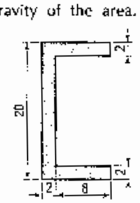


FIG. 21-29

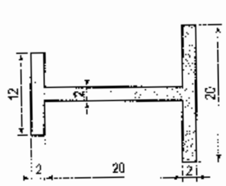
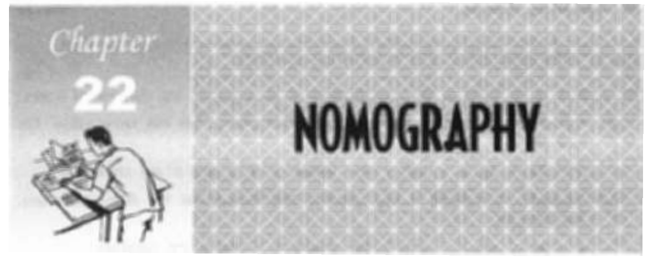


FIG. 21-30



22-0. INTRODUCTION

The *term nomography* is derived from the Greek words nomos (law) and graphein (to write) which refers to the graphical representation of mathematical laws or relationships. The law or relationship so represented is always in the form of a mathematical equation.

The *nomographs* which provide quick graphical answers where numerical data are substituted into formulae and *empirical equations* which are the mathematical expressions of data plotted in the form of curves.

A working knowledge of nomographs is useful not only to engineers but also to physicists, doctors and other scientific and professional groups. Applications of nomographs may be found in many phases of industry, such as production, management, sales, research and development. The nomographs are most advantageous when only an approximate answer, say within a few per cent is needed and the same equation is repeatedly required for several sets of values of the variables.

In this chapter, we shall learn about nomographs as shown below:

(1) Types of nomographs
(2) Definitions of various terms
(3) Principle of construction of nomographs of three variables
(4) Layout of nomographs
(5) Z-type nomographs.

22-1. TYPES OF NOMOGRAPHS

22-2. DEFINITIONS OF VARIOUS TERMS

The various terms used in the construction of nomographs are defined as under:

(i) *Constant:* A constant is any quantity that always has the same value. For example

$z = 3x + 4y,\ z = ax^2 + by^2$ where 3, 4, a and b are constants.

(ii) *Variable:* A variable is any quantity that always has the different values. For example

$z = 3x + 4y,\ z = ax^2 + by^2$ where x, y and z are variables.

(iii) *Scales:* A graphical representation of physical quantity on a straight or a curve line of a selected length. The scales are further classified as follows:

(a) *Uniform scales* or *linear scales* or *natural scales* are scales on which the spaces between division marks are constant.

(b) *Logarithmic scales* or *non-linear scales* are scales in which the spaces between division marks are not uniform but vary according to the logarithms of the numbers that are represented on the scales.

(iv) *Function:* This is a mathematical equation which expresses the relationship of a group of variables and constants. For example $y = x^2 + \frac{3}{x^3}$. The variable x and constant term 3 are related with y. In short form, we can write as $y = f(x)$.

(v) *Functional modulus:* This is defined as the length of the scale for a unit value of the functional variable. Mathematically, we can write as

$$m = \frac{L}{f(x_{max}) - f(x_{min})} \quad \text{.............. (22-1)}$$

where m is the functional modulus

L = scale length.

x_{max} and x_{min} represent the values of the variable x corresponding to the maximum and minimum values of the function respectively.

22-3. PRINCIPLE OF CONSTRUCTION OF NOMOGRAPHS OF THREE VARIABLES

In chapter 4, we have discussed how equation involving two variables can be represented in a graphical form by a chart of two scales side by side, one for each variable. Such a chart of two scales is also known as comparative scales or conversion scales. (Refer to chapter 4.)

For equations containing three or more variables, a graphical solution must have three or more scales, one for each variable. These scales are properly matched and spaced. Such charts are known as *Nomographs* or *Alignment charts*. The construction of nomographs for the equation with three variables, involving the sum, difference or multiplication of two variables, is based on the following geometrical derivation.

Consider the general equation of three variables

(i) $f(z) = f(x) \pm f(y)$ .... [22-2(a)]

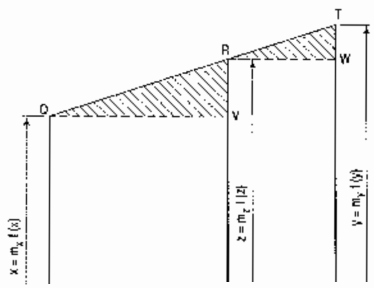
(ii) $f(z) = f(x) \times f(y)$ .... [22-2(b)]

Equation of type (ii) is required to transform into type (i) by taking logarithms of the functions.

i.e. $f(z) = f(x) \times f(y)$

$\therefore$ $\log f(z) = \log f(x) + \log f(y)$.

The ranges of values are given for the variables x and y.



From similar triangles QVR and RWT

$$\frac{VR}{QV} = \frac{WT}{RW}$$

i.e. $$\frac{SR - SV}{a} = \frac{UT - UW}{b}.$$

i.e. $$\frac{SR - PQ}{a} = \frac{UT - SR}{b}. \quad (\text{as } SV = PQ \text{ and } UW = SR)$$

Substituting values of PQ, SR and UT from fig. 22-1

$$\frac{m_z f(z) - m_x f(x)}{a} = \frac{m_y f(y) - m_z f(z)}{b}$$

where m_x, m_y and m_z are functional moduli.

$\therefore$ $b\, m_z f(z) - b\, m_x f(x) = a\, m_y f(y) - a\, m_z f(z)$

$\therefore$ $b\, m_z f(z) + a\, m_z f(z) = a\, m_y f(y) + b\, m_x f(x)$

Divide both sides by b

$\therefore$ $m_z f(z) + \frac{a}{b} m_z f(z) = \frac{a}{b} m_y f(y) + m_x f(x)$

$\therefore$ $m_z \left(1 + \frac{a}{b}\right) f(z) = m_x f(x) + \frac{a}{b} m_y f(y)$ .... (22-3)

But $f(x) + f(y) = f(z)$ only if the coefficients of the three terms in eq. (22-3) are equal.

i.e. $m_z \left(1 + \frac{a}{b}\right) = m_x = \frac{a}{b} m_y$ .... (22-4)

From equation (22-4), we have

$m_x = \frac{a}{b} m_y$ i.e. $\frac{a}{b} = \frac{m_x}{m_y}$ .... (22-4a)

and $m_x = \left(1 + \frac{a}{b}\right) m_z$ .... (22-4b)

Substituting eq. (22-4a) in eq. (22-4b), we have

$m_x = \left(1 + \frac{m_x}{m_y}\right) m_z$ i.e. $m_x = \left(\frac{m_x + m_y}{m_y}\right) \cdot m_z$

$\therefore$ $m_z = \frac{m_x \times m_y}{(m_x + m_y)}$ .... (22-5)

22-4. METHOD OF CONSTRUCTING PARALLEL SCALE NOMOGRAPHS

For illustrations, following *three* types of equations are considered here:

(1) Addition of two functional values, say $z = x + y$, where x and y vary from 0 to 10.

(2) Subtraction of two functional values, say $z = x - y$, where both x and y variables vary from 0 to 10.

(3) Multiplication of two functional values, say $z = x \times y$, where both x and y variables vary from 0 to 10.

The problems of type-1 and type-2 are in the required standard form for three parallel scales. In such cases linear or natural scale can be used.

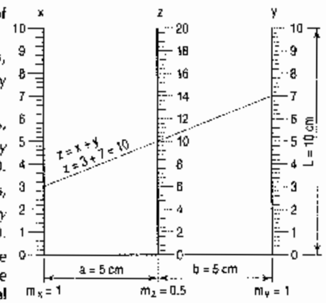


FIG. 22-2 (Refer table 22-1)

While the equation $z = x \times y$ of problem 22-3 is not in the required form of parallel scales. Therefore, it is necessary to transform in the required form by taking logarithms of the functions. That is $z = x \times y$, is transformed to $\log z = \log x + \log y$. Instead of, the natural scale, the logarithmic scale is used. The steps of construction of nomographs for above three types of problems are described in table 22-1, table 22-2, table 22-3 and corresponding fig. 22-2, fig. 22-3, fig. 22-4 respectively.

In plotting parallel scales nomographs following important points must be noted.

(i) When positive values *of variable* are laid out in one direction (upward), *negative values must be laid out in* the opposite *direction*.

(ii) Note that a function with a negative sign has an inverted *scale* and the *origins are in alignment.*

TABLE 22-1 (fig. 22-2)

(i)	Write down values of variables x and y	x	0	1	2	3	4	5	6	7	8	9	10
		y	0	1	2	3	4	5	6	7	8	9	10
(ii)	Calculate the values of function z by substituting values of step (i)	$z = x + y$	0	2	4	6	8	10	12	14	16	18	20
(iii)	To construct nomograph, select a suitable length of scale to fit on A4 size paper. Also compute m_x, m_y and m_z	For x-scale, we select the length of scale, L as 10 cm. Using equation (22-1), $m_x = \frac{L}{f\left(x_{max}\right) - f\left(x_{min}\right)} = \frac{10}{10 - 0} = 1.$ The scale modulus M_x can be determined by multiplying m_x by constant coefficient of function x. $M_x = 1 \times m_x = 1 \times 1 = 1$. Similarly, we can determine the fonctional modulus m_y and scale modulus for the variable y, by selecting same scale length (10 cm). $\therefore$ $m_y = 1$, $M_y = 1$. Functional modulus m_z for the middle z-scale for variable z is determined by equation (22-5). $m_z = \frac{m_x \times m_y}{\left(m_x + m_y\right)} = \frac{1 \times 1}{1 + 1} = \frac{1}{2}$ $\therefore$ The scale length for variable z $= m_z [f(z_{max}) - f(z_{min})]$ $= \frac{1}{2}[20 - 0] = 10$ cm.											
(iv)	Compute the horizontal distance of x-scale and y-scale from the middle z-scale. Draw three vertical parallel lines of 5 cm apart from each other, denoting x-scale, z-scale and y-scale.	Let a and b be the distances of x-scale and y-scale from z-scale. Using equation (22-6), $a = \frac{m_x(a + b)}{(m_x + m_y)}$, assume $(a + b) = 10$ cm on the basis of available width of the paper (21 cm). $\frac{1 \times 10}{}$ ...											

TABLE 22-2 (fig. 22-3)

(i)	Write down values of variables x and y	x	0	1	2	3	4	5	6	7	8	9	10
		y	0	1	2	3	4	5	6	7	8	9	10
(ii)	Compute the values of function z by substituting values of step (i) in $z = x - y$	$y = 0$, $x = 0$ to 10	0	1	2	3	4	5	6	7	8	9	10
		$y = 10$, $x = 0$ to 10	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1	0
(iii)	Same as table 22-1, except the functional modulus of variable z will be different.	For x-scale and y-scale, select the length of scales 10 cm. Therefore functional moduli for x-scale and y-scale are: $m_x = 1$, $m_y = 1$. The funcional modulus m_z for the middle z-scale is equal to $m_z = \frac{m_x \times m_y}{\left(m_x + m_y\right)}$ $\therefore m_z = \frac{1 \times 1}{1 + 1} = \frac{1}{2}$. The scale length for variable z is $L = m_z [f(z_{max}) - f(z_{min})]$ $L = \frac{1}{2}[10 - (-10)]$ $= \frac{20}{2} = 10$ cm.											
(iv)	Compute the horizontal distances of x-scale and y-scale from the centre z-scale.	Same as table 22-1.											
(v)	Multiply functional moduli m_x, m_y and m_z by the functional values. These are measuring lengths for the graduations on the scale for the values of function.	$m_x = 1$, $m_y = 1$ and $m_z = \frac{1}{2}$											
		$m_x x = 1.x$	0	1	2	3	4	5	6	7	8	9	10
		$m_y y = 1.y$	0	1	2	3	4	5	6	7	8	9	10
		$m_z z = \frac{1}{2}.z$	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
			−5	−4.5	−4	−3.5	−3	−2.5	−2	−1.5	−1	−0.5	0
(vi)	Lay-off the distance obtained in step (v) on the x-scale, y-scale and z-scale. Note that y-scale is the inverted scale as it is starting from top.												

TABLE 22-3 (Fig. 22-4)

Step	Description	Computation										
(i)	Write down values of variables x and y. Compute values of variable z.	x	1	2	3	4	5	6	7	8	9	10
		y	1	2	3	4	5	6	7	8	9	10
		$z = x.y$	1	4	9	16	25	36	49	64	81	100
(ii)	Now convert eq. $z = x.y$ in the standard form by taking logarithms on both the sides i.e., $\log z = \log x + \log y$ and compute $\log x$, $\log y$ and $\log z$ of variables x, y and z	$\log x$	0	0.301	0.477	0.602	0.698	0.778	0.845	0.903	0.954	1
		$\log y$	0	0.301	0.477	0.602	0.698	0.778	0.845	0.903	0.954	1
		$\log z$	0	0.602	0.954	1.204	1.398	1.556	1.690	1.806	1.908	2
(iii)	Select suitable length for the x-scale, y-scale and z-scale. Determine the functional moduli m_x, m_y and m_z.	For x-scale and y-scale, we select the length of the scale as 10 cm. Hence the functional modulus $m_x = \frac{L}{f\left(x_{max}\right) - f\left(x_{min}\right)} = \frac{10}{\log 10 - \log 0} = \frac{10}{1 - 0} = 10$. Similarly, we can have the functional modulus m_y for the y-scale $m_y = \frac{L}{f\left(y_{max}\right) - f\left(y_{min}\right)} = \frac{10}{\log 10 - \log 0} = \frac{10}{1 - 0} = 10$. The functional modulus for the z-scale is determined by $m_z = \frac{m_x \times m_y}{\left(m_x + m_y\right)} = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5$.										
(iv)	Same as table 22-1.	$a = \frac{m_x(a + b)}{(m_x + m_y)}$, assume $(a + b) = 10$ $\therefore a = \frac{1 \times 10}{1 + 1} = 5$ cm. $\therefore b = 5$ cm. The length of z-scale is calculated as follows: $L = m_z [f(z_{max}) - f(z_{min})]$ $= 5 (\log 100 - \log 1) = 5 (2 - 0) = 10$ cm.										
(v)	Draw three vertical parallel lines of length of 10 cm and 5 cm apart, representing x-scale, z-scale and y-scale.	$m_x = 10$, $m_y = 10$ and $m_z = 5$										
		$m_x \log x$ cm	0	3.01	4.77	6.02	6.98	7.78	8.45	9.03	9.54	10

22-3. LAYOUT OF NOMOGRAPHS

Following illustrations of different types of nomographs reveal the application of principle of construction and layout of the nomographs.

Problem 22-1. *Construct the nomograph to find the velocity of free-falling body for which the equation of motion is*

$$V_f = V_o + gt$$

where
V_f = *velocity of free-falling body*
V_o = *initial velocity (0 to 10 m/sec)*
g = *acceleration due to gravity (9.81 m/sec²)*
t = *time taken to attain V_f (0 to 10 sec).*

(i) Equation $V_f = V_o + gt$ can be expressed in the standard form

$$f(V_f) = f(V_o) + gf(t).$$

(ii) Choose convenient lengths for parallel scales for both the variables V_o and t, say 20 cm.

(iii) Determine the functional moduli and scale moduli, m_x, m_y, M_x and M_y for V_o and t scales. Use equation (22-1).

(a) $m_x = \dfrac{L}{f(V_o)_{max} - f(V_o)_{min}}$

$= \dfrac{20}{[10-0]} = 2$

$M_x = 1 \times m_x$

$= 1 \times 2 = 2.$

(b) $m_y = \dfrac{L}{g\,[f(t)_{max} - f(t)_{min}]}$

$= \dfrac{20}{9.81\,[10-0]}$

$= 0.2038.$

$M_y = 9.81 \times m_y$

$= 9.81 \times 0.2038 \simeq 2$

(c) Equation (22-5) can be used to determine the functional modulus m_z for the variable V_f.

$m_z = \dfrac{m_x \times m_y}{m_x + m_y} = \dfrac{2 \times 0.2038}{2 + 0.2038} = 0.185.$

(iv) Distance of V_o-scale and t-scale from the centre scale (V_f-scale) is determined by equation (22-6). Assuming $(a + b) = 10.81$ cm.

(d) The maximum range of V_f is determined by substituting maximum values of variables V_o and t in the equation

$V_f = V_o + gt = 10 + (9.81 \times 10) = 108.1$ m/sec.

$a = \dfrac{2 \times 10.81}{(2 + 0.2038)} = 9.81.$

$\therefore\ a = 9.81$ cm and $b = 1$ cm;

(v) Prepare table 22-4 as shown below:

TABLE 22-4

$V_f = V_o + gt$	V_o	$f(V_o)$	0 to 10 m/sec	2	2	20	$a = 9.81$	$x = m_x f(V_o)$
	t	$g.f(t)$	0 to 10 sec	0.2038	2	20	$b = 1$	$y = m_y \cdot gf(t)$
	V_f	$f(V_f)$	0 to 108.1 m/sec	0.185	0.185	20		$z = m_z f(V_f)$

(vi) Calculate plotting length for each variable taking suitable values within given ranges of the variables as shown in table 22-5:

TABLE 22-5

1	2	3	4	5	6
V_o m/sec	Plotting equation $x = 2f(V_o)$ cm	t sec	Plotting equation $y = 0.2038 \times 9.81 \times f(t)$ cm	V_f m/sec	Plotting equation $z = 0.185\,f(V_f)$ cm
0	0	0	0	0	0
1	2	1	2	10	1.85
2	4	2	4	20	3.70
3	6	3	6	30	5.55
4	8	4	8	40	7.40
5	10	5	10	50	9.25
6	12	6	12	60	11.10

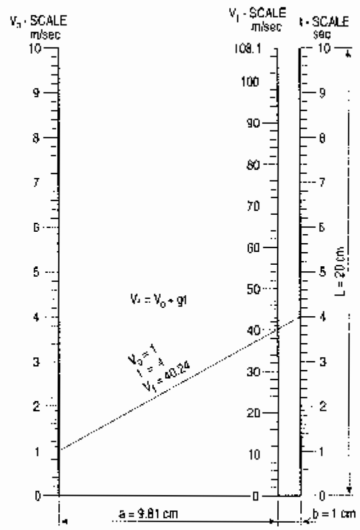


FIG. 22-5

Problem 22-2. *Prepare a nomograph for finding moment of inertia of rectangular cross-section for which the equation is*

$$I = \frac{bd^3}{12} \quad \ldots\ldots\ldots \text{(i)}$$

where I = *moment of inertia of rectangular cross-section, cm⁴*
b = *breadth of the cross-section which varies from 1 cm to 30 cm*
d = *width of the cross-section which varies from 1 cm to 30 cm.*

Above equation (i) contains the product of two functions rather than the sum of two functions. In this form, it does not fit the parallel scales nomographs. However, ...

$I_{(min)} = \dfrac{1}{12}\,bd^3 = \dfrac{1}{12}\,(1)\,(1)^3 = 0.0833$ cm⁴.

$I_{(max)} = \dfrac{1}{12}\,bd^3 = \dfrac{1}{12}\,(30)\,(30)^3 = 67500$ cm⁴.

(iii) Determine the functional moduli and scale moduli for b and d.

(a) $m_x = \dfrac{L}{[f(b)_{max} - f(b)_{min}]} = \dfrac{15}{\log 30 - \log 1} = \dfrac{15}{[1.4771 - 0]}$

$= 10.155$

$M_x = 1 \times m_x = 1 \times 10.155 = 10.155.$

(b) Similarly,

$m_y = \dfrac{L}{[f(d)_{max} - f(d)_{min}]} = \dfrac{15}{3\log 30 - 3\log 1} = \dfrac{15}{4.4313 - 0}$

$= 3.385$

$M_y = 3 \times m_y = 3 \times 3.385 = 10.155.$

(c) The functional modulus for the functional variable $f(I)$ is determined as under:

$m_z = \dfrac{m_x \times m_y}{(m_x + m_y)} = \dfrac{(10.155 \times 3.385)}{(10.155 + 3.385)} = 2.5387$

$\boxed{\text{OR}}$

$m_z = \dfrac{L}{\log f(I)_{max} - \log f(I)_{min}} = \dfrac{15}{\log 67500 - \log 0.0833} = 2.5387$

$M_z = 1 \times m_z = 1 \times 2.5387 = 2.5387.$

(iv) To compute the horizontal distances of b-scale and d-scale from the center I-scale.

Let a be the distance between b-scale and I-scale

Let b be the distance between d-scale and I-scale

and assume $(a + b) = 15$ cm

$\therefore\ a = \dfrac{m_x\,(a+b)}{(m_x + m_y)}$ .... (using eqation 22-6)

$= \dfrac{10.155 \times 15}{10.155 + 3.385} = 11.25$ cm.

(i) Select suitable length for variables M and σ_b, say 18 cm. The functional moduli for variables M and σ_b are determined by using the following equations:

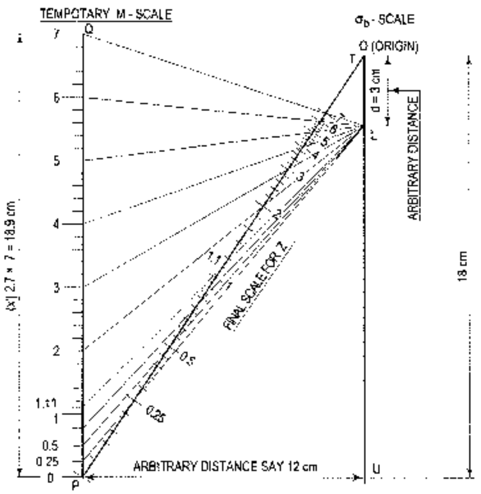
(a) $m_x = \dfrac{L}{[f(M)_{max} - f(M)_{min}]} = \dfrac{18}{[2 \times 10^6 - 0]} = 9 \times 10^{-6}$

(b) $m_y = \dfrac{L}{[f(\sigma_b)_{max} - f(\sigma_b)_{min}]} = \dfrac{18}{[18 \times 10^5 - 0]} = 1 \times 10^{-5}$

(c) $Z_{min} = \dfrac{M}{\sigma_b} = 0.$

$Z_{max} = \dfrac{M}{\sigma_b} = \dfrac{2 \times 10^6}{1.8 \times 10^6} = 1.11\ m^2.$

(ii) Before plotting final nomograph, it is necessary to prepare temporary scale to obtain diagonal scale. The method of constructing temporary scale is described as follows.



Construction of the temporary scale
FIG. 22-7

(a) The plotting equation for temporary M-scale is
(b) Draw two parallel lines PQ of 18.9 cm long and UT of 18 cm long for temporary M-scale and σ_b-scale with arbitrary distance say 12 cm between them. Join them by diagonal line PT to generate final scale for Z as shown in fig. 22-7. where d = Distance from the origin of σ_b-scale (3 cm selected here)

(c) Mark divisions on line of temporary M-scale. One unit will measure 2.7 cm. Join the division points to the L-point as shown in fig. 22-7. Intersections of these lines with the diagonal PT gives the required final scale for the variable Z.

(iii) Prepare table 22-8 and table 22-9 as shown below.

(iv) Redraw two parallel lines of 18 cm long for M-scale and σ_b-scale, 12 cm apart. Mark divisions on M-scale and σ_b-scale by taking distances from column 3 and 5 of table 22-9.

(v) Redraw diagonal scale for z from fig. 22-7.

(vi) Complete the nomograph as shown in fig. 22-8.

TABLE 22-8

$Z = M/\sigma_b$	M	$f(M)$	0 to 2.0×10^6	9×10^{-6}	9×10^{-6}	18
	σ_b	$f(\sigma_b)$	0 to 1.8×10^6	1×10^{-6}	1×10^{-5}	18
	Z	$f(Z)$	0 to 1.11			

TABLE 22-9

1	2	3	4	5	6
Sl. NO.	M (Nm)	Plotting equation $x = m_x \cdot M$ cm	σ_b (N/m²)	Plotting equation $y = m_y \cdot \sigma_b$ cm	$Z = M/\sigma_b$

(vi) Calculate plotting length for each variable taking suitable values within given range, as shown in table 22-7.

(vii) Draw three parallel lines of 15 cm representing b-scale, I-scale and d-scale separated at a distance of a = 11.25 and b = 3.75 cm from I-scale as shown in fig. 22-6.

(viii) Draw a horizontal base line through the initial marks 1, 0.0833 and 1 of b-scale, I-scale and d-scale respectively as shown in fig. 22-6.

(ix) Mark division on b-scale, I-scale and d-scale from initial marks by taking distances from columns 3, 5 and 7 of table 22-7, than write values as given in columns 2, 4 and 6 of table 22-7 against the each division mark respectively. Note that the scale generated is logarithmic scale in which the spaces between division marks are not uniform.

(x) Using above steps complete the nomograph as shown in fig. 22-6.

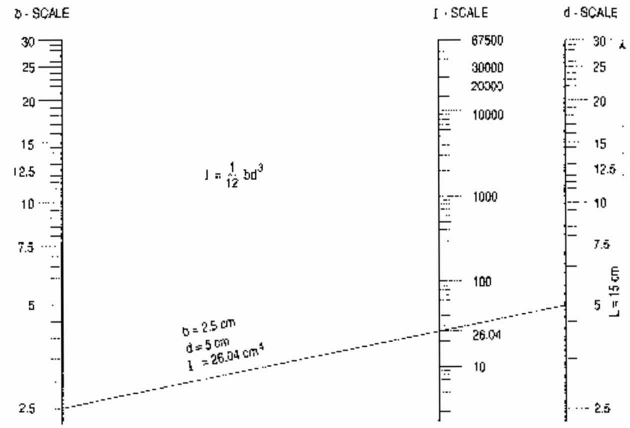


TABLE 22-7

1	1.0	0.00	1.0	0.00	0.083	0.00
2	2.5	4.04	2.5	4.04	10	5.28
3	5.0	7.10	5.0	7.10	100	7.82
4	7.5	8.89	7.5	8.89	1000	10.36
5	10.0	10.15	10.0	10.15	10000	12.89
6	12.5	11.14	12.5	11.14	20000	13.66
7	15.0	11.94	15.0	11.94	30000	14.11
8	20.0	13.21	20.0	13.21	40000	14.42
9	25.0	14.20	25.0	14.20	50000	14.67
10	30.0	15.00	30.0	15.00	67500	15.00

22-6. Z-TYPE NOMOGRAPHS

Certain nomographs for three variables can be plotted on non-parallel scales. For the equation of the type

$f(z) = \dfrac{f(x)}{f(y)}$ or $f(x) = f(y) \times f(z)$, in which Z is the dependent variable, a nomograph in the shape of Z can be prepared by using non-logarithmic scales.

The equation $f(x) = f(y) \times f(z)$ can be transformed into a form similar to equation (22-2) by taking logarithms. A method of constructing nomograph for such equations is illustrated as follows.

Problem 22-3. Construct a nomograph to read a section modulus of beam for which the equation is

Chapter 23

SCREW THREADS

23-0. INTRODUCTION

If a cylindrical rod is rotated at a constant speed, and simultaneously, if a pointed tool, just touching the rod is moved parallel to the axis of the rod at a constant speed, the cut made by the tool on the rod will be continuous and of a helical form. A screw thread is formed by cutting a helical groove on a cylindrical surface. *The threaded rod is called a screw.* It engages in a corresponding threaded hole inside a nut or a machine part. The screws are used for joining two parts temporary. Therefore such a joint is known as the detachable joint or temporary joint.

Threads are generally cut on a machine called a *lathe*. On a small-size screw, thread is often cut by means of a tool called a *die*. A small-size hole is threaded by means of a tool called a *tap*. Such a hole is called a *tapped hole*.

23-1. DEFINITIONS

Various parts of a screw thread are shown in fig. 23-1 and defined below.

(1) Crest: The crest is the outer-most part of a thread.

(2) Root: The root is the inner-most portion of a thread.

(3) Flank: The surface between the crest and the root is called the flank of the thread.

(4) Angle: It is the angle between the flanks, measured on an axial plane.

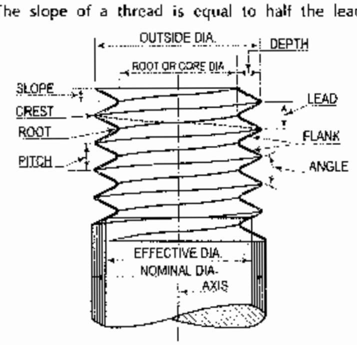
(5) Depth: The depth is the distance between the crest and the root, measured

(9) Effective diameter: It is equal to the length of the line, perpendicular to and passing through the axis, and measured between the points where it cuts the flanks of the thread.

(10) Pitch: It is the distance measured parallel to the axis, between a point on one thread form and a corresponding point on the adjacent thread form, i.e. from crest to crest or root to root. It may also be described as the reciprocal of the number of thread forms per unit length, i.e. $p = \frac{1}{n}$.

(11) Lead: It is the distance measured parallel to the axis from a point on a thread to a corresponding point on the same thread after one complete revolution. It can also be described as the distance moved by a nut in the axial direction in one complete revolution. The lead is equal to the pitch in case of single-start threads. See table 23-5.

(12) Slope: The slope of a thread is equal to half the lead.



Screw thread
FIG. 23-1

23-2. FORMS OF SCREW THREADS

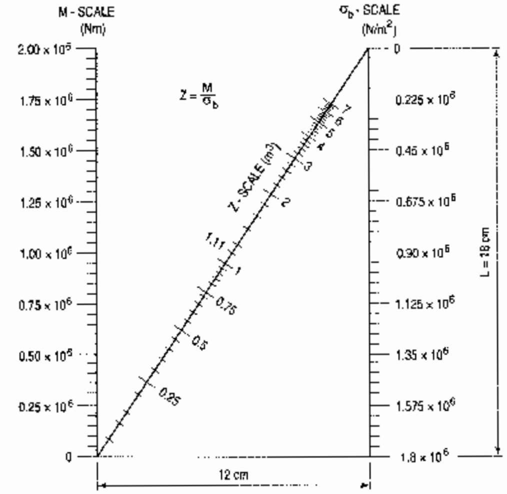


FIG. 22-8

EXERCISES 22

1. Construct a nomograph to read the velocity of free-falling body for which the equation is

$$V_f^2 = 2gs$$

where V_f = final velocity, m/sec

V_0 = initial velocity (3 to 15 m/sec)

3. Prepare parallel scales nomograph to determine voltage through transmission line

$$V = I R$$

where V = Potential (volts)

I = Electric current (0.1 to 10 amperes)

R = Resistance, 1 to 100 ohms.

4. A railway wagon runs at a speed of v m/sec. Its kinetic energy can be expressed as

$$\text{K.E.} = \frac{1}{2} M \cdot v^2$$

where M = Mass of wagon

v = Speed of wagon.

Prepare alignment chart to read kinetic energy when mass of the wagon and the speed vary from 1000 kg to 50000 kg and 6 m/sec to 12 m/sec respectively.

5. Construct alignment chart (Z-type) to read coefficient of friction for which the equation is

$$\mu = \frac{F}{N}$$

where F = Frictional force, N

μ = Coefficient of friction (0.15 to 0.6)

N = Normal force (25 N to 750 N).

6. Kinetic energy of rotating disk is given by

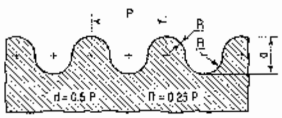
$$\text{K.E.} = \frac{1}{2} I \cdot \omega^2$$

where I = mass moment of inertia (kg-m²)

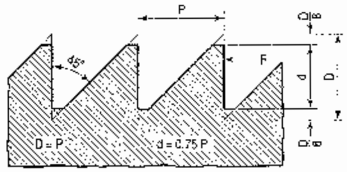
ω = angular velocity, rad/sec.

I and ω vary from 10 to 80 kg-m² and 5 rad/sec to 30 rad/sec respectively. Construct alignment chart.

7. Frequency of compound pendulum is given by expression



Knuckle thread
Fig. 23-9



Buttress thread
Fig. 23-10

23-3. CONVENTIONAL REPRESENTATION OF THREADS SP: 46-2003

The true form of a screw thread is helical and it would take considerable time and labour to draw the same. In actual practice, threads are usually shown by conventional methods.

Method I:

This conventional method is recommended for use by the Bureau of Indian Standards for Metric screw threads and square threads for which Standards have been published.

(1) External threads: These threads in outside view [fig. 23-11(i)] are shown by *means of two continuous thin lines drawn parallel to the axis, thus indicating the minor or root diameter of the threads.* The limit of the length of the thread is shown by a continuous thick line drawn perpendicular to the axis and upto the major or outside diameter of the threads. The runout of the thread is shown by lines drawn at an angle of 30° or 45° to the axis. The runout may not be shown if there is no likelihood of any misunderstanding.

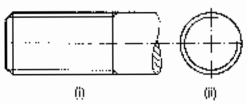


Fig. 23-11

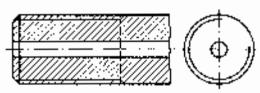


Fig. 23-12

External thread in section (fig. 23-12) is shown in the same manner, except that the limit of the length of the thread is shown by a medium dashed line. The section

In the side view of the external thread [fig. 23-11 and fig. 23-12] the minor or root diameter is represented by a part of a continuous thin-line circle about three quarters of the circumference; while in the side view of the internal thread (fig. 23-13) the major or outside diameter is shown in the similar manner.

In sectional views where threaded parts are assembled together, externally threaded parts are always shown covering the internally threaded parts as shown in fig. 23-14.

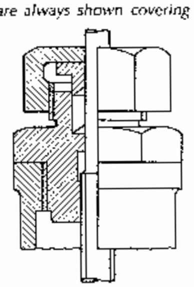


Fig. 23-14

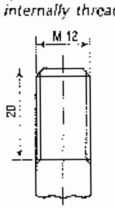


Fig. 23-15

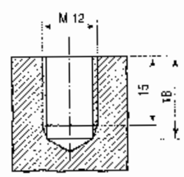


Fig. 23-16

The method of designating and dimensioning Metric screw threads is shown in fig. 23-15 and fig. 23-16. In case of square thread (fig. 23-17), the type, size and pitch are clearly indicated.

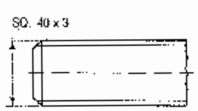


Fig. 23-17

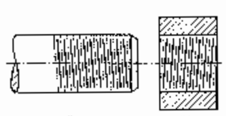


Fig. 23-18

Method II:

(1) External V thread: This thread in its outside view is shown by sloping straight lines alternately thin and thick, and spaced one-half the pitch apart [fig. 23-18(i)]. The slope is kept equal to half the lead. The thick lines are drawn shorter than the thin lines by a distance equal to one-half the pitch on each side, thus indicating

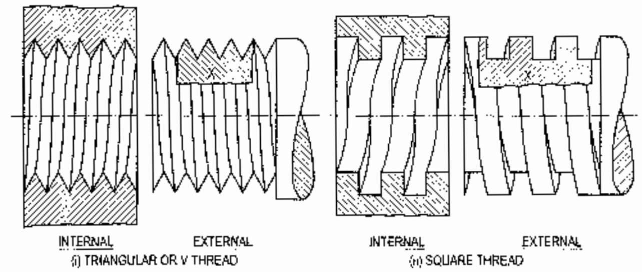
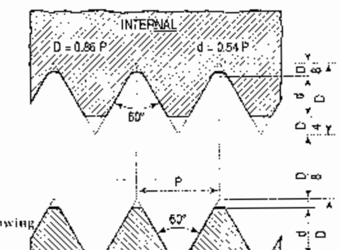


Fig. 23-2

The figures accompanying the description of the various forms of screw threads are shown in section and on an enlarged scale, e.g. fig. 23-4 and fig. 23-7 show, on an enlarged scale, the sectional portions (marked X in fig. 23-2) of the V thread and the square thread respectively.

23-2-1. TRIANGULAR OR V THREADS

(1) Unified thread (fig. 23-3): In 1947, the International Organization for Standardization (I.S.O.) of which India, U.S.A., United Kingdom, Canada and a number of other countries are members, came into being. It decided to adopt the Unified screw thread profile as the I.S.O. basic profile. It also decided to recognize two separate I.S.O. series based on inch and metric systems of measurement, with this common basic profile for threads.



Unified thread
Fig. 23-3

In this form of thread, the external thread (on a screw) varies slightly in shape from the internal thread (inside a nut) as can be seen from fig. 23-3. The angle of the thread is 60°. Roots of both external and internal threads are rounded, while the crests are cut parallel to the axis of the screw. The root of the internal thread is rounded *within* the depth of $\frac{D}{8}$ as shown in the figure. See table 23-1.

TABLE 23-1

Types of thread	Thread angle	Theoretical depth *D*	Actual depth *d*
External thread	60°	0.866 *P*	0.61 *P*
Internal thread	60°	0.866 *P*	0.54 *P*

The maximum depth of engagement between the external and the internal threads is $\frac{5}{8}$ D.

Table 23-2 gives useful data of Unified screw thread based on inch system:

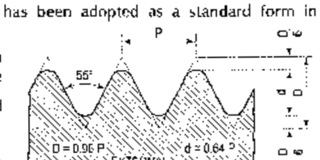
(2) **Metric thread** (fig. 23-3): The Bureau of Indian Standards has recommended the adoption of the Unified screw thread profile based on metric system as a standard form for use in India, and has designated it as Metric screw thread with I.S.O. profile. In this system, the pitch of the thread (instead of the number of threads per unit length) is fixed.

Metric thread is designated by the letter M followed by the nominal diameter, e.g. M 20, where 20 is the nominal diameter of the screw in millimetres. Refer to IS: 4218:1976 and IS: 11698:1986.

Table 23-3 gives the values of pitch and core diameters for screws of 6 mm to 39 mm diameters:

(3) **Whitworth thread** (fig. 23-4): This form of thread is also known as British Standard Whitworth (B.S.W.) thread and has been adopted as a standard form in the United Kingdom.

The angle is 55°. The theoretical depth $D = 0.96P$, where P is the pitch of the thread. $\frac{1}{6}$ of the theoretical depth is rounded off at the top and at the bottom.



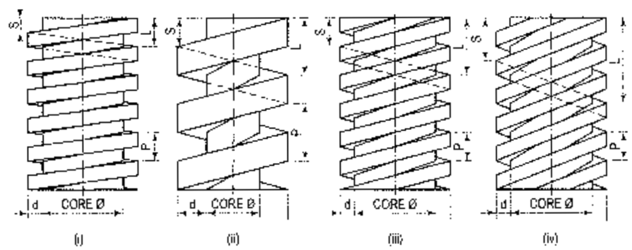
Therefore, the actual depth $d = 0.64P$.

(4) **Internal square thread:** In its outside view, this thread also is shown as described in method I. In its sectional view [fig. 23-19(ii)] it is shown by parallel lines sloping in opposite direction. The depth of the thread is shown at right angles to the axis.

The present practice is to follow B.I.S. recommendations. Students must show threads in their drawings by method I only.

23-4. MULTIPLE-START THREADS

In a single-start thread, the pitch is equal to the lead [fig. 23-20(i)]. Since the depth of the thread is dependent on the pitch, greater the lead, greater will be the depth of the thread and smaller will be the core diameter. When a nut is required to move a considerably long axial distance in one revolution (i.e. when the lead is large), the core diameter of the screw, in a single-start thread, will be so much reduced as to make the screw too weak [fig. 23-20(ii)]. This is avoided by cutting what are known as multiple-start threads, in which two or more threads having the same pitch as in a single-start thread, but with increased lead, run parallel to one another.



Single-start and multiple-start threads
FIG. 23-20

The pitch being the same, the depth of the thread remains the same as in a single-start thread and the core diameter also remains unaffected. The depth of the thread in each case remains the same, i.e. $D = \frac{1}{2}P$, while the slope S is equal to one-half the corresponding lead L. The relationship between lead and pitch is shown in table 23-5.

23-5. RIGHT-HAND AND LEFT-HAND THREADS

If a nut, when turned in clockwise ↻ direction screws on a bolt, the thread is a right-hand thread; but if it screws off the bolt when turned in the same direction, the thread is said to be a left-hand thread. Both these types of threads are shown in **fig. 23-22**. Note that when the axis of the screw is vertical, the lines slope downwards from right to left in case of the right-hand thread. They slope in the reverse direction, i.e. from left to right downwards when it is a left-hand thread. For indicating a left-hand thread, an abbreviation L.H. is used. Unless otherwise stated, a thread should always be assumed to be a right-hand one.

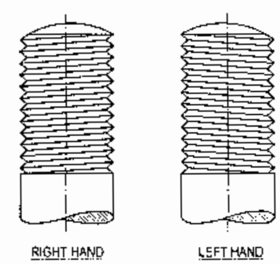


FIG. 23-22

Conventional method of designating and dimensioning a left-hand thread is shown in fig. 23-23.

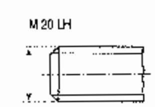


FIG. 23-23

Practical application of these threads is made in a coupler-nut or turn-buckle shown in fig. 23-24. The length of a tie-bar can be adjusted by this nut. Looking from the right, if the nut is turned in clockwise ↻ direction, the ends of the rods will move closer to each other. They will move further apart when the nut

EXERCISES 23

1. Define the following terms used in connection with a screw thread:

   Core diameter; outside diameter; crest; flank; depth; pitch. Show each on a sketch of the threaded end of a screw.
2. Sketch neatly, any three types of profiles of triangular threads. State the angle of the thread in each case and dimension the depth, assuming a pitch of 10 mm.
3. Give dimensioned sketches of the following forms of screw threads:

   Acme, Buttress; Unified; Whitworth.
4. Show by means of neat and dimensioned sketches, the difference in profiles of internal and external Unified threads.
5. State the difference between a right-hand and a left-hand thread. Illustrate by means of a sketch, the use of both on the same piece.
6. What is the lead in a screw thread? How does it differ from pitch in a double-start thread? Illustrate your answer by means of a sketch of a square-threaded screw.
7. Show by means of neat sketches, the following threads conventionally:
   - (a) External V thread.
   - (b) External V thread in section.
   - (c) Internal V thread in section.
8. Show by means of sketches, conventional methods of showing the following screw threads:
   - (a) Metric thread, nominal diameter 12 mm.
   - (b) Square thread, nominal diameter 20 mm and pitch 3 mm.
   - (c) Left-hand square thread, nominal diameter 20 mm and pitch 3 mm.
   - (d) Double-start square thread, nominal diameter 40 mm and pitch 3 mm.
9. Prepare a neat sketch of a coupler-nut connecting a tie-bar of 25 mm diameter.
10. Fill-up the blanks in the following sentences with appropriate words selected from the list of words given below:
    - (a) A screw thread is formed by cutting a ________ groove on a cylindrical

- (g) The slope of the thread is equal to one-half its ________.
- (h) In a double-start thread the lead is equal to ________ the pitch.
- (i) The angle between the flanks of Whitworth thread is ________, while that in case of Unified thread is ________.
- (j) The ________ of Unified threads are rounded while its ________ are cut parallel to the axis of the screw.
- (k) The square thread is used for ________ transmission. Its flanks make ________ angles with the axis.
- (l) ________ thread is used in the lead screw of the lathe.
- (m) Knuckle thread is a modified form of ________ thread.
- (n) The combination of square and V threads is made in ________ thread which is used in the screw of ________.

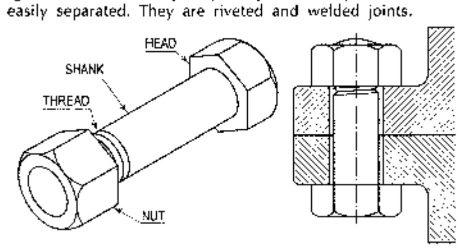
List of words for Exercise 10:

Acme; Bench-vice; Buttress; Conical; Crests; Die; Drill; Effective, External; Flanks; Half; Helical; Internal; Lathe; Lead; Major; Minor; Nominal; Pitch; Power; Roots; Sellers; Slope; Square; Tap; Twice; Unified; V; 29°; 47.5°; 55°; 60°; 90°.

Chapter 24 SCREWED FASTENINGS

24-0. INTRODUCTION

A machine is an assembly of different parts arranged in definite order and is used to transform energy for doing some useful work. The connection between two parts can be either temporary or permanent. The temporary joints are (i) Screwed joints, (ii) Keys, cotter and pin joints, (iii) Pipe joints. As the parts thus connected can be easily separated by screwing off the nut or removing the cotter or the pin, the fastening is said to be temporary. In permanent joints, the connected parts cannot be easily separated. They are riveted and welded joints.



Screw pair
FIG. 24-1

A *nut and a screw* or a *bolt* comprise what is known as a screw pair (fig. 24-1).

octagonal nut would require only $\frac{1}{8}$ turn, but there would be greater tendency for the spanner to slip. Hence, this shape is seldom used. Nuts of forms other than the above two are usually provided with special facilities for screwing them on or off the bolts.

24-1-1. HEXAGONAL NUT (FIG. 24-2)

The upper corners of this nut are rounded-off or chamfered. The chamfering is generally conical. The angle of chamfer is 30° to 45° with the base of the nut. Due to chamfering, an arc is formed on each vertical face, and a circle is formed on the top surface of the nut.

The dimensions of the hexagonal nut cannot be expressed exactly in terms of the nominal diameter of the bolt.

The standard proportions for nuts and bolt-heads may be obtained from the standard tables published by B.I.S. For elementary work, the following approximately standard dimensions may be adopted (fig. 24-2(i)]. See table 24-1.

Let D = the nominal diameter of the bolt.

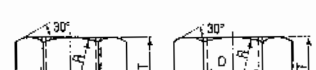
TABLE 24-1
APPROXIMATE STANDARD DIMENSIONS

1.	Height or thickness of the nut, T	$T = D$
2.	Width across flats, W	$W = 1.5D + 3$ mm
3.	Angle of chamfer	30°
4.	Radius of chamfer arc, R	$R = 1.4D$ (approx.)

TABLE 24-2
ROUGH RULE DIMENSIONS

1.	Height or thickness of the nut, T	$T = D$
2.	Distance across diagonally opposite corners	$2D$
3.	Angle of chamfer	30°
4.	Radius of chamfer arc, R	$R = 1.5D$ (approx.)

Very often, and especially when a nut is shown in one view only, the rough-rule dimensions are used [fig. 24.2(ii)]. See table 24-2.



Problem 24-1. *To draw three views of a hexagonal nut for a bolt diameter D, by approximately standard dimensions (table 24-1) (fig. 24-3).*

Step 1: Begin with the top view. Draw a circle of diameter W equal to $1.5D + 3$ mm. Circumscribe a regular hexagon about this circle with two sides horizontal. Project the front view of the hexagonal prism, taking T equal to D. Project the circle to points A-A on the upper face. Through points A-A, draw lines AB inclined at 30° to the upper face. Draw the line BB cutting the edges of the central face at points C-C.

Step 2: Draw the central arc passing through points C-C and touching the line AA, as shown by construction lines. Its radius R will be approximately equal to $1.4D$. Similarly, draw arcs passing through points B and C and touching the line AA. The radius R_1 and the centre for these arcs may be found by trial.

Step 3: Project the side view. Only two faces of the nut will be seen. The distance between the outer edges will be equal to W. Project the line BB and obtain points E-E on the vertical edges. Draw arcs in each face passing through points E-E as shown.

Step 4: Finalise the three views by adding two circles in the top view and dashed lines for the screwed hole in the front and side views. The diameter of the inner circle will be equal to the core diameter. The outer circle is kept thinner and partly cut, approximately 75% according to convention.

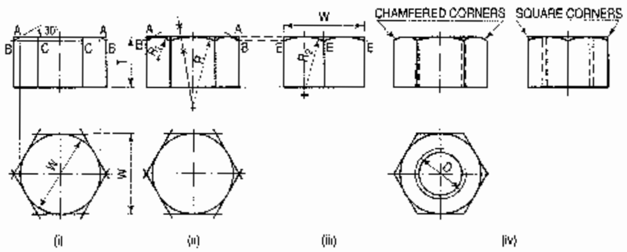


FIG. 24-3

Note carefully that in the front view where three faces of the nut are seen, the upper outer corners should be shown chamfered. When only two faces are visible, as in the side view, the corners must be shown square. The remaining vertical

Step 1: Draw a circle of diameter equal to $2D$ and inscribe a regular hexagon in it, with two sides horizontal. Inscribe the chamfer circle inside the hexagon. Its diameter, and the width W, across the flat sides will be equal to $\sqrt{3} \times D$. Project the front view and draw arcs as described in problem 24-1. The radius R will be approximately equal to $1.5D$.

Step 2: Complete the three views as shown in the figure.

Alternative method (assuming $R = 1.5D$):

As the distance across corners is equal to $2D$, the width of the central face in the front view will be equal to D.

Beginning can therefore be made with the front view taking the distance between the outer lines to be equal to $2D$ and that between the inner lines to be equal to D. Draw the central arc with radius R equal to $1.5D$ and then complete the front view as explained in the alternative method of problem 24-1. Draw the top view and the side view as shown in fig. 24-4(ii).

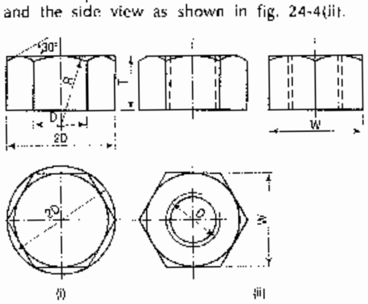


FIG. 24-4

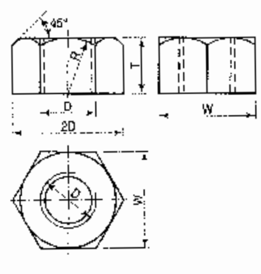
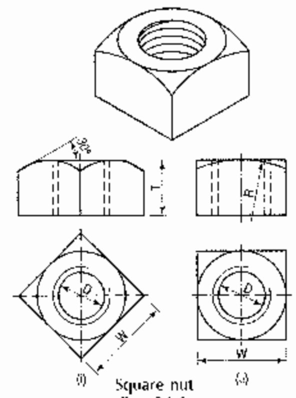


FIG. 24-5

Fig. 24-5 shows three views of the nut having 45° chamfer and drawn according to the alternative method. Note that the radius R for the arc in the central face is equal to D.



Square nut
FIG. 24-6

Step 1: When its two faces are equally seen in the front view [fig. 24-6(i)].

Draw a square in the top view with a side equal to W, i.e. $1.5D + 3$ mm, and all sides equally inclined to the horizontal. Complete the top view by drawing the chamfer circle and circles for the screwed hole.

Project the two faces in the front view and complete the view as explained in case of the hexagonal nut.

Step 2: When only one face of the nut is seen in the front view [fig. 24-6(ii)].

The top view is the same except that two sides of the square are horizontal.

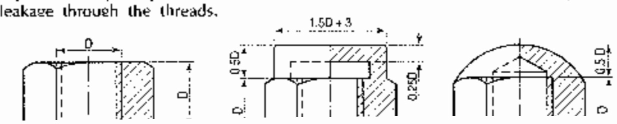
Project the rectangle in the front view and draw the chamfer arc with radius R equal to $2D$.

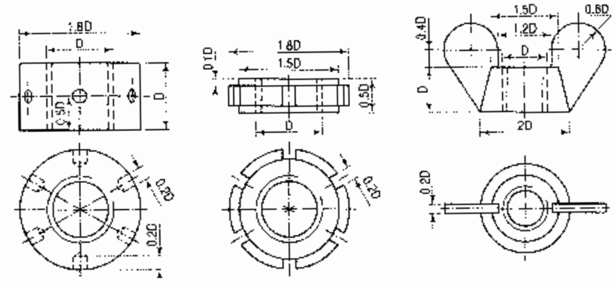
24-2. TYPES OF NUTS FOR SPECIAL PURPOSE

The following different types of nuts are used for special purpose:

(1) Flanged nut (fig. 24-7): This is a hexagonal nut with a washer, i.e. a flat circular disc attached to it. It is thus provided with a larger bearing surface. A bolt can be used in a comparatively large-size hole with the help of this nut. It is widely used in automobiles.

(2) Cap nut (fig. 24-8): It is also a hexagonal nut provided with a cylindrical cap at the top to protect the end of the bolt from corrosion. It also prevents leakage through the threads.





Capstan nut
FIG. 24-10

Ring nut
FIG. 24-11

Wing nut
FIG. 24-12

(5) Ring nut (fig. 24-11): It is in the form of a ring provided with slots in the curved surface for a special C-spanner. These nuts are generally used in pairs, one nut acting as a lock-nut for the other.

(6) Wing nut (fig. 24-12): This nut can be easily operated by the thumb and a finger and is used where it is required to be adjusted frequently. It is used in a hacksaw.

24-3. WASHERS (FIG. 24-13)

A washer is a cylindrical piece of metal placed below the nut to provide smooth bearing surface for the nut to turn on. It spreads the pressure of the nut over a greater area. It also prevents the nut from cutting into the metal and thus, allows the nut to be screwed-on more tightly. It is sometimes chamfered on the top flat surface.

Let D = the nominal diameter of the bolt.

Fig. 24-13(i) shows two views of a plain washer. A chamfered washer is shown in fig. 24-13(ii). See table 24-4.

Washers can also be applied as locking arrangements for nuts. Fig. 24-63 to ... 0.12D

24-4. BOLTS (FIG. 24-5)

A bolt comprises of two parts — a shank and a head. The shank is cylindrical and is threaded at the tail end for a sufficient length so as to effectively engage with a nut. The shape of the head depends upon the purpose for which the bolt is required. While considering the length of the bolt, the thickness of the head is not taken into account.

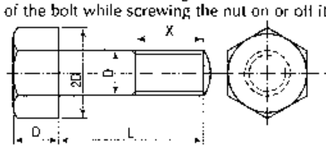
Methods of preventing rotation of a bolt while screwing a nut on or off it: When it is not possible to hold a bolt-head by means of a spanner, the bolt is prevented from rotating by the provision of one of the following, below the bolt-head:

(i) a square neck (ii) a pin (iii) a snug.

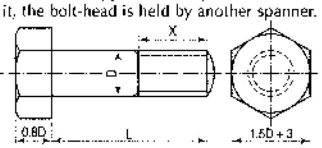
These are shown and described below while dealing with various forms of bolts.

24-5. FORMS OF BOLTS

(1) Hexagonal-headed bolt (fig. 24-14 and fig. 24-15): This is the most common form of a bolt. The hexagonal head is chamfered at its upper end. To prevent rotation of the bolt while screwing the nut on or off it, the bolt-head is held by another spanner.



Hexagonal-headed bolt
– rough-rule dimensions
FIG. 24-14



Hexagonal-headed bolt
– approximately standard dimensions
FIG. 24-15

The dimensions of the bolt-head are the same as those of the hexagonal nut, except for the thickness. For elementary work, the thickness is taken as $0.8D$ to D. Fig. 24-14 and fig. 24-15 show two views each of a hexagonal-headed bolt drawn according to *rough-rule dimensions* and *approximately standard dimensions* respectively. Note that the length of the face of the bolt-head is equal to D in fig. 24-14, while it is less than D in fig. 24-15 and X is the length of thread.

Problem 24-4. *To draw three views of a hexagonal-headed bolt, 24 mm diameter and 100 mm long, with a hexagonal nut and a washer.*

Step 1: Draw the horizontal centre line and around it construct a rectangle 100 mm × 24 mm for the shank.

Step 2: Add the view of the bolt-head and the nut showing three faces. The distance between the outer edges will be 48 mm.

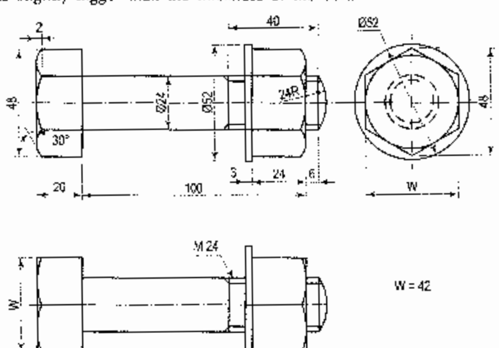
Step 3: Draw the chamfer arcs etc. as explained in problem 24-2.

Step 4: Draw the rectangle for the washer, 52 mm × 3 mm, attached to the nut.

Step 5: The end of the bolt is usually rounded. It is drawn by a radius equal to the diameter of the bolt.

Step 6: Project the side view and the top view. The width W across the flats will be equal to $\sqrt{3} \times 24$ mm.

(iii) When drawing the views according to approximately standard dimensions, beginning must be made with the hexagon in the side view and the other views must then be projected from it. The distance W between the flat sides of the hexagon should be equal to $1.5D + 3$ mm. Note that the diameter of the hole is slightly bigger than the thickness of the bolt.

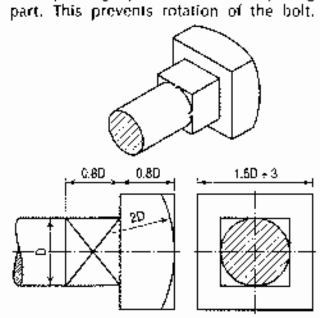


W=42

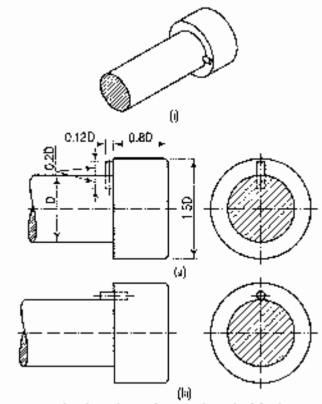
Thickness of bolt-head = 0.8D to D

Width across flats = 1.5D + 3 mm.

When a square-headed bolt is to be used with its head projecting outside, it is provided with a neck of square cross-section (fig. 24-18), which fits into a corresponding square hole in the adjoining part. This prevents rotation of the bolt.



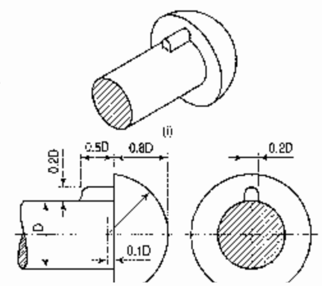
Square-headed bolt (with square neck)
FIG. 24-18

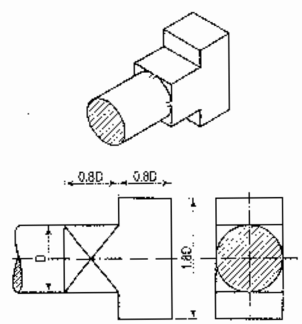


Cylindrical or cheese-headed bolt
FIG. 24-19

(3) **Cylindrical or cheese-headed bolt** (fig. 24-19): This bolt is used when the space for accommodating the bolt-head is comparatively limited, or where the use of a spanner for holding it is to be avoided. It is commonly used in big ends of connecting rods, eccentrics etc.

The rotation of the bolt is prevented by means of a pin inserted into the shank just below the head [fig. 24-19(ii)]. The projecting part of this pin fits into a



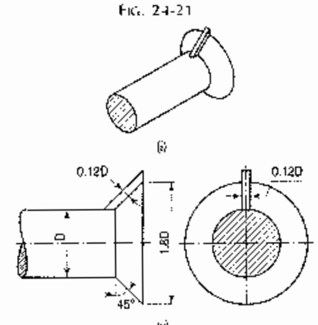


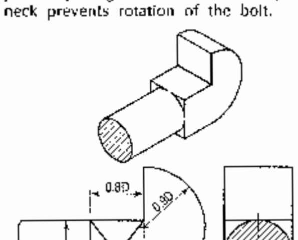
T-headed bolt
FIG. 24-21

(5) **T-headed bolt** (fig. 24-21): It is used in machine-tool tables in which T-slots are cut to accommodate the T-heads. The neck of this bolt also is usually square in section. The T-headed bolt is often made use of in gland and stuffing box arrangement in boiler mountings such as stop valve, feed-check valve etc. In that case, the square neck becomes unnecessary and hence, it is not provided.

(6) **Countersunk-headed bolt** (fig. 24-22): Where the head of a bolt must not project above the surface of the connected piece, this form of bolt is used. It may be provided with a snug [fig. 24-22(ii)] or a neck of square cross-section [fig. 24-22(iii)].

(7) **Hook bolt** (fig. 24-23): This bolt passes through a hole in one piece only, while the other piece is gripped by the hook-shaped bolt-head. It is used when it is not possible to drill a hole in the piece adjoining the bolt-head. The square neck prevents rotation of the bolt.

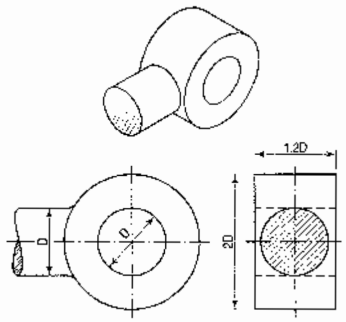




(9) **Eye-bolt** (fig. 24-25): This bolt has a circular ring of rectangular cross-section as its head, which can be conveniently held to prevent its rotation.

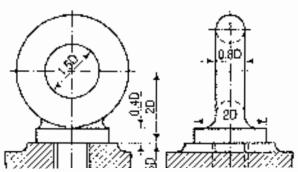
(10) **Lifting eye-bolt** (fig. 24-26): It is used as an appliance for lifting heavy machines. It is screwed inside a threaded hole on the top of the machine, directly above its centre of gravity.

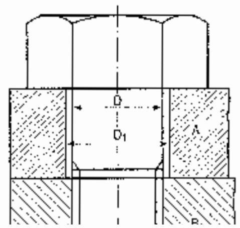
(11) **Tap-bolt or cap-screw** (fig. 24-27): It is a bolt used as a screw, i.e. screwed into a threaded hole in a casting instead of a nut. It is used when it is not possible to accommodate the nut. It passes loosely through a clear hole in the piece A, adjoining the bolt-head, and is screwed into a threaded hole in the casting B.



Eye-bolt
FIG. 24-25

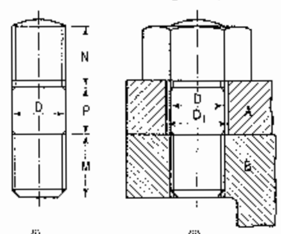
Frequent insertion or removal of the tap-bolt is likely to damage the threads in the casting. Owing to this disadvantage, this method of fastening is employed only when parts are not to be disconnected very often. Tap-bolts have various forms of heads, similar to those of set-screws as shown in fig. 24-34 to 24-42. They are used for connecting a cylinder-head with a cylinder of an internal combustion engine.





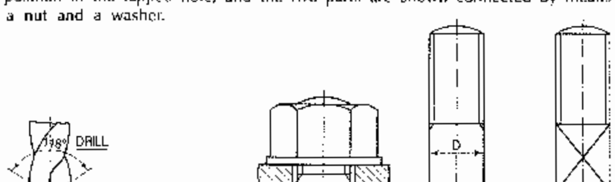
of the plain part P, between the two ends, depends upon the thickness of the piece adjoining the nut. The stud is used in place of a bolt, when there is insufficient space to accommodate the bolt-head or to avoid use of an unnecessarily long bolt. Studs are commonly used to connect cylinder-covers to engine cylinders.

The metal-end M is screwed into the threaded hole in the casting B [fig. 24-28(ii)] by means of a stud-driver which consists of a thick hexagonal nut having a partly threaded hole. The upper piece A has a clear hole (of diameter D_1 = 1.1D) through which the stud passes. The two pieces are fastened together by a nut screwed on the nut-end. In this case, it is not necessary to withdraw the stud when disconnecting the two pieces and hence, the threaded hole does not get damaged. The disadvantage of the tap-bolt is thus overcome by using a stud.



Stud-bolt
FIG. 24-28

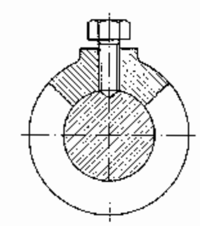
When a stud is used for connecting a piece to a very thick block, the hole is drilled in that block and then tapped. Fig. 24-29 shows the drilled hole in section. The diameter d of the drill is equal to the core diameter of the stud. The end of the hole is conical on account of the pointed end of the drill. The depth of the hole is kept at least equal to 1.5D (where D is the diameter of the stud). The threaded hole in section is shown in fig. 24-30. In fig. 24-31 the stud is shown in position in the tapped hole, and the two parts are shown connected by means of a nut and a washer.



24-6. SET-SCREWS

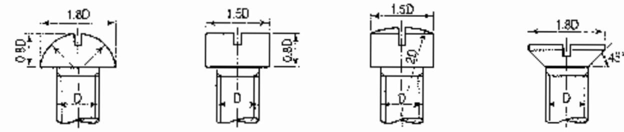
A set-screw is similar to a tap-bolt, but is threaded practically throughout its length.

It is used to prevent relative movement between two pieces. It is screwed into a tapped hole (fig. 24-33) in the piece adjoining the screw-head, while its end presses on the other piece, thus preventing relative rotation or sliding. Heads of set-screws except those which can be operated by spanners or wrenches are provided with screw-driver slots.

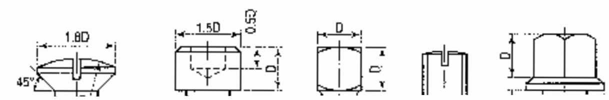


Set-screw
Fig. 24-33

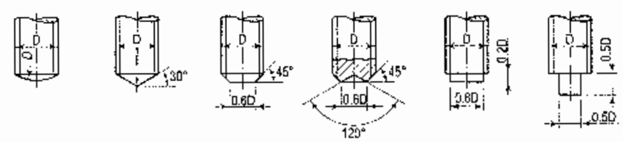
Set-screws have heads of various forms. Hexagonal and square heads are similar to bolt-heads. The other forms of heads as shown in fig. 24-34 round or cup, fig. 24-35 cylindrical or cheese, fig. 24-36 fillister, fig. 24-37 countersunk, fig. 24-38 rounded countersunk (called instrument screw) and fig. 24-39 socket. The square head is sometimes made of smaller size as shown in fig. 24-40. The grub screw (fig. 24-41) has no head. Fig. 24-42 shows a collar screw with a square head. Width of the slot for the screw driver, in each case, is equal to $0.2D + 0.1$ mm, while its depth is equal to $0.25D$ and $0.4D$ in case of flat top and rounded top respectively.



Round or cup — Fig. 24-34
Cylindrical or cheese — Fig. 24-35
Fillister — Fig. 24-36
Countersunk — Fig. 24-37



Ends of set-screws, particularly the grub screws are made in one of the following shapes shown in fig. 24-43 oval, fig. 24-44 conical, fig. 24-45 flat, fig. 24-46 cup, fig. 24-47 half dog and fig. 24-48 full dog.

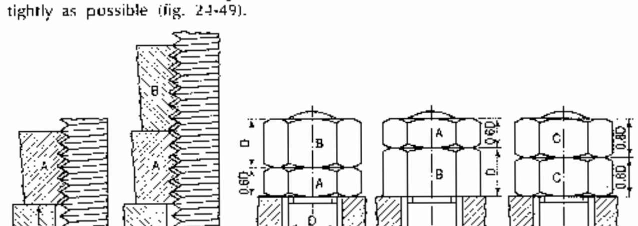


Oval — Fig. 24-43
Conical — Fig. 24-44
Flat — Fig. 24-45
Cup — Fig. 24-46
Half dog — Fig. 24-47
Full dog — Fig. 24-48

24-7. LOCKING ARRANGEMENTS FOR NUTS

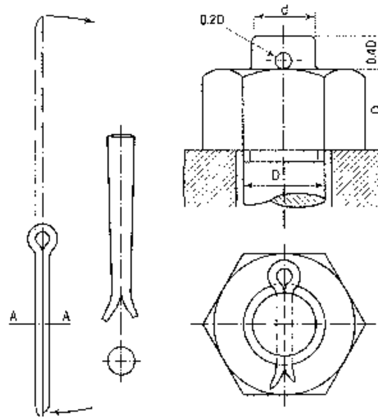
Owing to vibrations in moving parts of machines, there is always a tendency for the nuts to get slack and to screw off the bolts slightly. The connected parts might get loose, and lead to serious breakdown. It is, therefore, desirable to secure the nut in some way so as to prevent it from getting loose. Methods employed to do so are called locking arrangements for nuts, a few of which are described below.

(1) **Lock-nut or check-nut:** This nut is used along with an ordinary nut. It is chamfered on both the hexagonal faces. The nut *A* is first screwed on the bolt as tightly as possible (fig. 24-49).

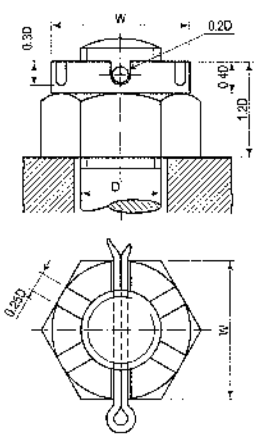


axial load on the bolt. It should therefore be of the standard size. The nut *A* which is called a lock-nut, may be thinner. Its thickness is kept equal to 0.6 times the diameter of the bolt (fig. 24-51). To turn the lock-nut backward, a thin spanner would be necessary. As thin spanners are not always readily available, the lock-nut is often placed above the standard nut (fig. 24-52). A compromise is sometimes made by using two nuts of uniform thickness equal to 0.8 times the diameter of the bolt (fig. 24-53).

(2) **Split-pin:** It is made from a steel wire of semi-circular cross-section, bent as shown in fig. 24-54(i). It is inserted in a hole drilled in the bolt so that it bears on the top face of the nut, thus preventing it from turning. The diameter of the hole is kept equal to approximately $0.2D$. The pin is then split open at its tail-end as shown in fig. 24-54(iii). The projecting portion of the bolt is usually turned down to the core diameter. The split-pin is also used in conjunction with special nuts designed for the purpose. A round tapered pin split at its thinner end is also sometimes used [fig. 24-54(ii)].



(4) **Castle nut** (fig. 24-56): Slots are cut in a cylindrical collar provided on the top of the nut, thus overcoming the disadvantage of the slotted nut. These nuts are widely used in automobile and locomotive engines where they are subjected to sudden shocks and vibrations. It is used in a steam engine.

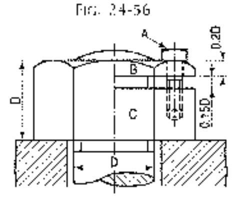


Castle nut
Fig. 24-56

(5) **Sawn nut or Wiles nut** (fig. 24-57): This is a hexagonal nut with a slot cut half way across it. A cap-screw *A* is passed through a clear hole in the upper part *B* and screwed into a tapped hole in the lower part *C*. On tightening the screw, the friction between the thread in part *B* and that in the bolt increases and prevents slackening of the nut.

(6) **Simmond's lock-nut** (fig. 24-58): A collar is provided at the upper end of the hexagonal nut and a fibre ring *R* is fitted inside it. The internal diameter of the ring is less than the core diameter of the bolt. The end of the bolt, on reaching the ring, cuts its own thread in the ring when the nut is screwed on. This thread gives a greater grip over the bolt-thread thus preventing the slackening of the nut.

(7) **Penn, ring or grooved nut** (fig. 24-59): This nut has a cylindrical grooved collar at its lower end. This collar fits into a corresponding recess in the adjoining piece. A set-screw is inserted through the nearest face of the piece. The dog-end of the set-screw enters the groove and prevents slackening of the nut. The width *W* of the groove is kept equal to the diameter of the dog-end of the screw. This arrangement is feasible only when the bolt is placed reasonably



Sawn nut

When the bolt is considerably away from the edge, this nut is used in conjunction with a separate cylindrical collar (fig. 24-60). A pin, screwed into the adjoining piece keeps the collar in fixed position.

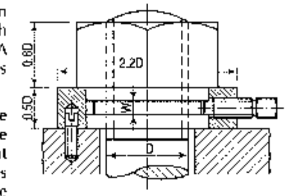


FIG. 24-60

A small pin (fig. 24-61), screwed in the piece adjoining the nut so that it touches one of the faces of the hexagonal nut, is sufficient to prevent its getting loose. But it becomes an obstruction if the nut is required to be tightened further through a small angle.

(8) **Stop-plate or locking-plate** (fig. 24-62): it is a plate grooved in such a way that it fits hexagonal nut in any position at intervals of $\frac{1}{12}$th of a revolution, i.e. at 30° intervals. It is fixed around the nut by means of a tap-bolt, thus preventing its rotation.

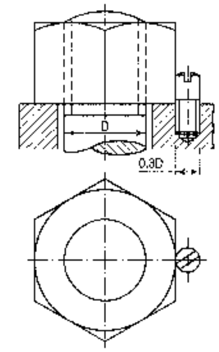
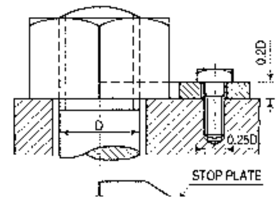
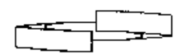
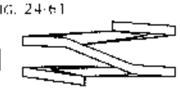


FIG. 24-61

(9) **Spring-washer**: A single-coiled spring (fig. 24-63) or a double-coiled spring (fig. 24-64) placed under the nut as a washer, offers stiff resistance when compressed by tightening of the nut and keeps the thread in the nut gripped with the thread on the bolt. Fig. 24-65 shows a single-coiled spring washer placed under a nut.




Single-coiled spring washer
FIG. 24-63

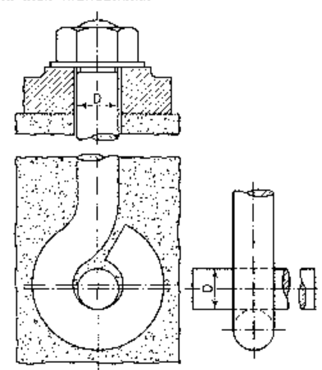

Double-coiled spring washer
FIG. 24-64

24-8. FOUNDATION BOLTS

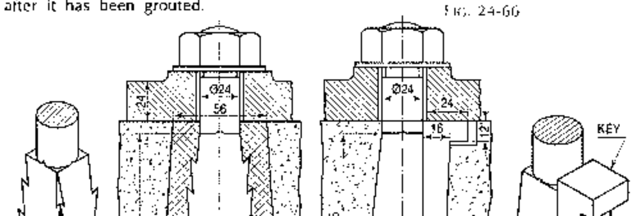
These bolts are used for fixing machines to their foundations.

(1) **Eye or Hoop bolt** (fig. 24-66): Simple forms of these bolts can be quickly forged from a mild-steel or wrought-iron bar. These bolts are suspended in the hole and cement grout is then poured to fill up the space around them. Fig. 24-66 shows two views of an eye-bolt forged from a bar. It has a piece of mild-steel bar passing through the eye and at right angles to it. The stationary engines and lathe machines are fixed on the foundation by these bolts.

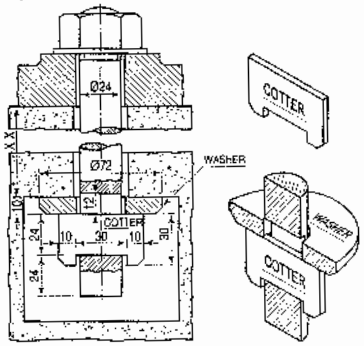
(2) **Rag bolt** (fig. 24-67): It has its lower part rectangular in cross-section and increasing in width only. Its edges are indented or grooved. The bolt is freely suspended in its position in concrete or stone foundation and the annular space around it is filled with molten lead or sulphur. This bolt cannot be easily dislodged after it has been grouted.



Eye bolt
FIG. 24-66

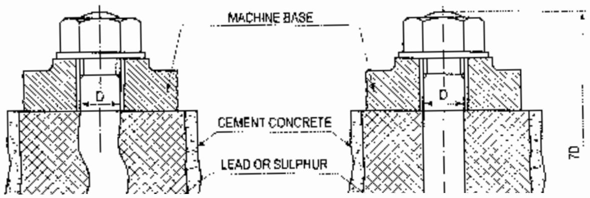


(4) **Cotter bolt** (fig. 24-69): It is used for fixing heavy machines. It has a rectangular slot to receive a cotter, which is inserted through a hand-hole, previously kept in the foundation for this purpose. A cast-iron washer provides bearing surface for the cotter. Heavy machine-tools are fixed on the foundation by these bolts.



Cotter bolt
FIG. 24-69

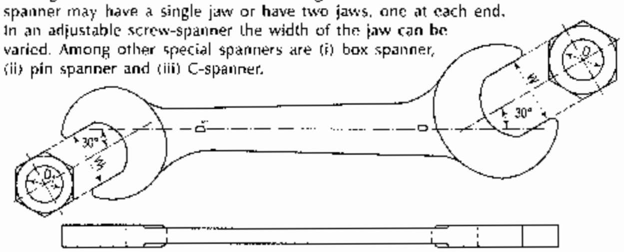
(5) **Curved or bent bolt** (fig. 24-70): The shank of this bolt is forged in curved or bent form, set first in lead or sulphur around it and then set in cement concrete, so as not to dislodged. The end is forged approximately twice the shank diameter.



(6) **Squar-headed bolt** (fig. 24-71): As name says, this type of bolt is having simple square head and square neck which is carrying a square plate. Both square head and neck locks the rotation as well as movement of the bolt where as the square plate sets firmly in sulphur which resist the bolt from movement automatically.

24-9. SPANNER

A spanner is made of steel or malleable cast-iron. It is used for turning a nut or for holding a bolt-head while the nut is being screwed on or off the bolt. An ordinary spanner may have a single jaw or have two jaws, one at each end.
In an adjustable screw-spanner the width of the jaw can be varied. Among other special spanners are (i) box spanner, (ii) pin spanner and (iii) C-spanner.

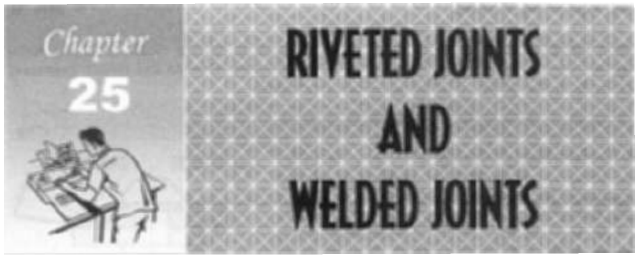


Spanner
FIG. 24-72

Fig. 24-72 shows an ordinary spanner with two jaws. The width of each jaw is slightly more than the width across the flats of the corresponding nuts. *A spanner is specified by the nominal diameter of the bolt* (for the nut of which, it is used). This diameter is usually stamped near the jaw. Jaws are usually made thicker than the body of the spanner.

24-10. LONGITUDINAL OR BAR STAY

Stays are used to prevent flat ends of boiler-shells from bulging out due to high steam pressure. They are generally made of wrought-iron.



25-1. INTRODUCTION

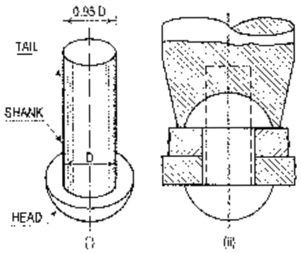
Rivets are used to fasten permanently two or more plates or pieces of metal. Joints made with rivets are called riveted joints. They are commonly used in ship-building and for the construction of steel buildings, bridges, boilers, tanks etc. Plates joined together by means of a riveted joint cannot be disconnected without chipping-off rivet-heads from one side of the joint.

Rivets are usually made of C-30. In its initial form (fig. 25-1(i)). A rivet comprises of following:

(i) a head,

(ii) cylindrical body of shank and

(iii) a slightly tapered tail.



Rivet and riveting
FIG. 25-1

A rivet is specified by the diameter of its shank. The length of the tail, out of which another head is formed, is kept about 1.25 times the diameter of the rivet.

25-2. RIVETING

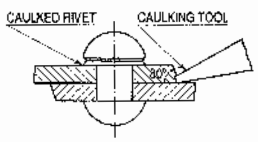
The process of forming another rivet-head, after the rivet is placed in the hole previously drilled or punched through the plates, is called riveting. The diameter of

done speedily or on a large scale. The rivet-head is formed under a steady force applied by means of hydraulic or pneumatic pressure. Due to the steady pressure, the hole in the plates is filled up more completely.

25-2-1. CAULKING AND FULLERING

To prevent leakage through the joint, the plates are firmly forced together by caulking or fullering processes. The edges of the plates are hammered and driven-in by a caulking tool (fig. 25-2) or a fullering tool (fig. 25-3). The caulking tool is in the shape of a blunt chisel. The thickness of the fullering tool is about the same as that of the plates. To facilitate these operations the edges of the plates are usually machined to an angle of about 80° before joining them together. This angle is increased to about 85° after the fullering process.

Leakage through the hole is prevented by the caulking operation on the edge of the rivet-head (fig. 25-2). Both these processes are generally performed with the aid of pneumatic power.



Caulking
FIG. 25-2

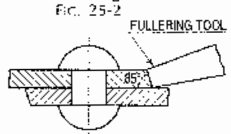
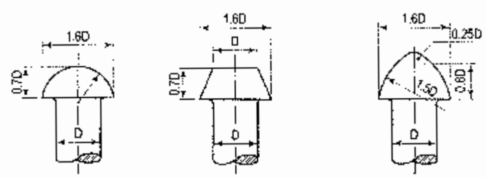
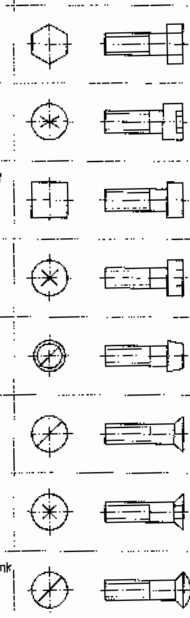
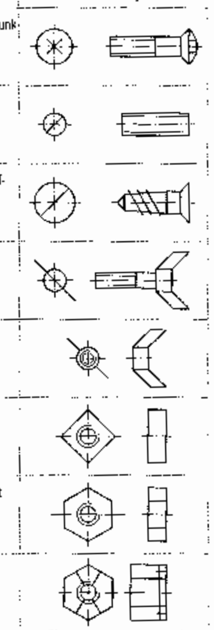


FIG. 25-3

25-3. FORMS AND PROPORTIONS OF RIVET-HEADS



24-11. CONVENTIONAL SYMBOLS FOR NUTS AND BOLTS

No	Type	Conventional symbol	No	Type	Conventional symbol
1	Hexagonal headed bolt		9	Oval countersunk headed screw cross slot	
2	Hexagonal socket bolt		10	Set screw slot	
3	Square headed bolt		11	Wood and self-tapping screw slot	
4	Cylinder screw cross slot		12	Wing screw	
5	Cylinder screw pan head type slot		13	Wing nut	
6	Countersunk headed screw slot		14	Square nut	
7	Countersunk headed screw cross slot		15	Hexagonal nut	
9	Oval countersunk headed screw slot		16	Crown nut	

FIG. 24-74

4. Draw neat and dimensioned sketches of any five forms of bolts showing clearly the method used for preventing rotation in each case.
5. Explain by means of sketches, any three methods of preventing a bolt from rotating while screwing the nut on or off it.
6. Illustrate by means of sketches, difference between a tap-bolt and a stud-bolt.
7. Draw two views of a 24 mm diameter stud, 100 mm long, with a castle nut and a split-pin.
8. Draw the sectional front view and the top view of two 20 mm thick plates fastened together by means of 20 mm diameter stud, a hexagonal nut and a washer. Insert important dimensions.
9. Show by means of neat sketches, sectional views of (a) the drilled hole and (b) the tapped hole for 24 mm dia. stud, in a block 75 mm thick. Take the length of the metal-end of the stud to be 30 mm.
10. Give neat sketches (a) to show the difference between, and (b) to illustrate the uses of, a set-screw and a cap-screw.
11. Show clearly with the help of neat sketches the difference between (i) bolt and nut fastening, (ii) stud-bolt and nut fastening and (iii) tap-bolt fastening.
12. Sketch, giving dimensions, any four forms of set-screws and name them. Show a different type of end in each case and name it. Assume the diameter to be 12 mm and length 50 mm.
13. Show by means of neat sketches, any three methods employed for preventing nuts from getting loose on account of vibrations.
14. Sketch neatly two types of bolts used to secure a machine to its foundation showing clearly how each is fixed.
15. Give by means of neat sketches, an example of each of the following methods of locking a nut:

    (i) By a split-pin (iii) By a washer

    (ii) By a set-screw (iv) By a fibre-ring.

16. Sketch neatly, giving important dimensions:

    (i) Any two forms of studs

    (ii) Any three methods of locking a nut

The snap or cup head is the most common form in use. The countersunk head is used when the surface of the plate is required to be free from projecting heads. Conical and ellipsoid heads are generally used in boiler work.

25-4. FAILURE OF RIVETED JOINTS

A riveted joint may fail in any one of the following ways (fig. 25-5):

(i) Tearing of the plate between the holes if they are very near each other [fig. 25-5(i)].

(ii) Tearing of the plate between the edges of the plate and the rivet-hole, if the hole is too near the edge [fig. 25-5(ii)].

(iii) Shearing of the rivet if the diameter of the rivet is smaller than necessary [fig. 25-5(iii)].

(iv) Crushing of the plate or the rivet [fig. 25-5(iv)].

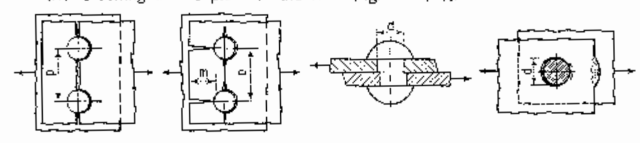


FIG. 25-5

25-5. DIMENSIONS OF A RIVETED JOINT

To prevent failure, the joint should be carefully designed. For elementary work, suitable values of the rivet diameter, positions of holes etc. for a given thickness of the plates, may be obtained by using the following empirical formulae:

(i) $d = 6\sqrt{t}$

(ii) $p = d$

(iii) $m = d$

where t = thickness of plates in mm

d = diameter of rivets

p = pitch, i.e. the distance between centres of adjoining rivets in the same row (parallel to the edge of the plate)

25-6. TYPES OF RIVETED JOINTS

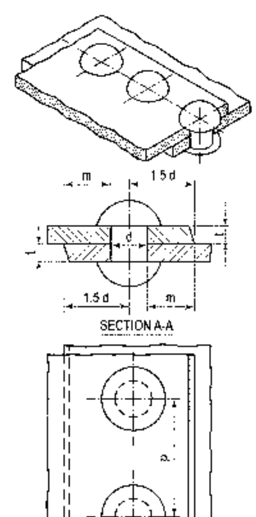
There are two types of riveted joints:

(1) Lap joint

(2) Butt joint.

Each of the above riveted joints will now briefly described.

25-6-1. LAP JOINT



In a lap joint, the plates to be connected overlap each other. When the joint is made with only one row of rivets, it is called a *single-riveted lap joint*.

Fig. 25-6 shows the sectional front view and top view of a single-riveted lap joint along with its pictorial view. The width of overlap L is equal to $3d$.

A joint is said to be *double-riveted*, *triple-riveted* etc. according to the number of rows of rivets in it.

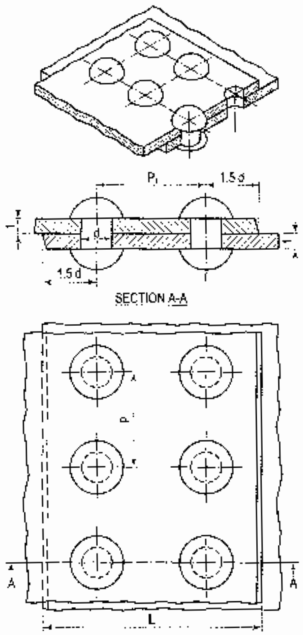
When two or more rows of rivets are required, rivets may be arranged in one of the following formations:

(i) *chain* formation or

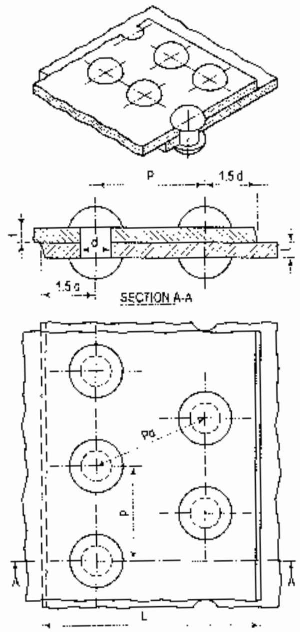
(ii) *zigzag* formation.

In chain arrangement shown in the double-riveted lap joint in fig. 25-7, rivets in the adjoining rows are placed directly opposite each other.

In zigzag formation they are staggered as shown in fig. 25-8. The distance between the rows of rivets, called the row pitch p_r, should not be less than 0.6p for zigzag riveting, and 0.8p for chain riveting.

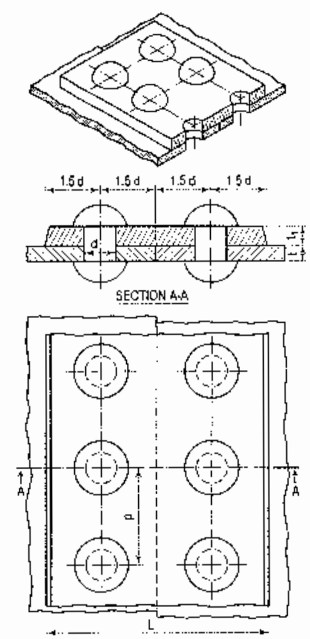


Double-riveted (chain) lap joint
FIG. 25-7

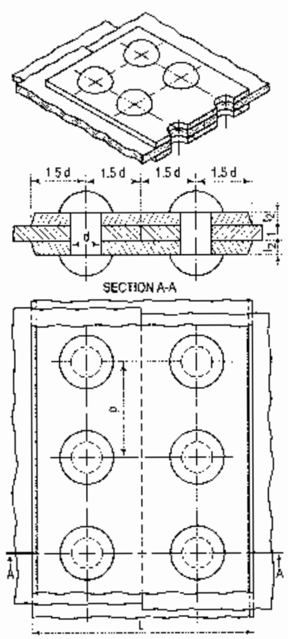


Double-riveted (zigzag) lap joint
FIG. 25-8

25-6-2. BUTT JOINT

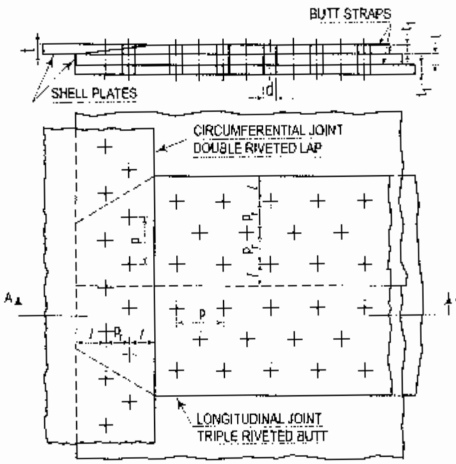


Single-riveted (single strap) butt joint
FIG. 25-9



Single-riveted (double straps) butt joint
FIG. 25-10

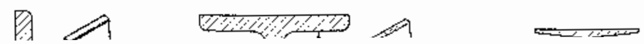
Two rings of a steam-boiler shell are connected as shown in fig. 25-12. The circumferential joint is a double-riveted lap joint. A triple-riveted or treble-riveted butt joint with two cover-straps is used for the longitudinal joint.



Boiler-shell plate joints
FIG. 25-12

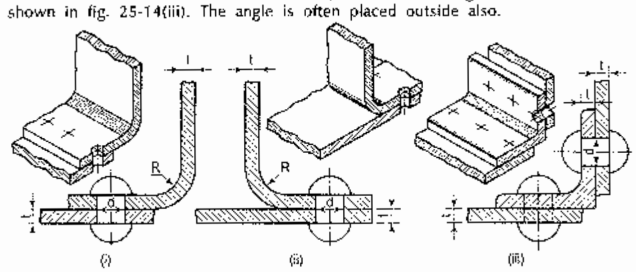
25-7. ROLLED-STEEL SECTIONS (FIG. 25-13)

These are largely used in steel structures. The common shapes are: (i) angle, (ii) tee, (iii) channel and (iv) H or joist.

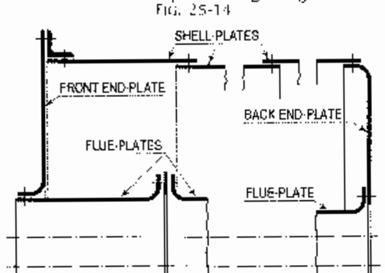


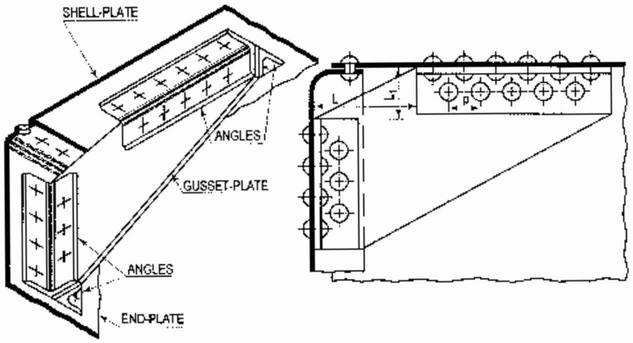
25-7-1. CONNECTION OF PLATES AT RIGHT ANGLES

Plates may be connected at right angles by flanging one of the plates. Fig. 25-14(i) shows a plate bent inside. The plate may also be bent outside as shown in fig. 25-14(ii). The radius *R* of the inside curve of the bent plate should not be less than twice its thickness. Another method, in which an angle-section is used, is shown in fig. 25-14(iii). The angle is often placed outside also.



Connection of plates at right angles
FIG. 25-14





Gusset stay
FIG. 25-16

25-8. WELDED JOINTS

25-8-1. WELDING

Welding is a technique of making permanent joint. It is the process of joining two parts of metal by fusing them together. Until recently riveted joints were the main type of permanent joint extensively used in the construction of boilers, ships, bridges, steel structures, etc. During the last decade, however, the rapid development of welding methods has replaced the riveted joints. Since welding is used so widely, and for a large variety of purposes, it is essential to have an accurate method of showing on the working drawing of machines or structures, the types, sizes, and locations of weld desired by the machine designer.

25-8-2. TYPES OF WELDING PROCESS

The welding processes can be classified into the following *three* groups:

(1) Pressure welding or forge welding

In case of arc fusion welding, the welding puddle is created by the effect of an arc. The arc produce between the electrode and the work-piece. The entrance of atmospheric gases into the arc and the welding puddle is prevented by the inert gases or slags produced by the electrode in case of consumable coated electrode.

(3) Fusion and pressure welding: In this welding heavy current (50,000A) is passed through the joint which gets melt. The welding is completely under external pressure. Spot welding, seam welding, flash butt welding and pressure butt are the examples of the pressure resistance welding.

25-8-3. TYPES OF WELDED AND WELDS JOINTS

(1) Types of welded joints: There are four important types of welded joints classified according to the positions of the workpiece being joined as shown in fig. 25-17.

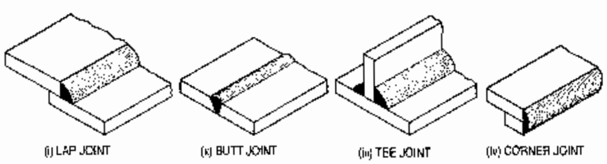


FIG. 25-17

(2) Types of welds: There are four types of basic welds of arc and gas welds as shown in fig. 25-18.

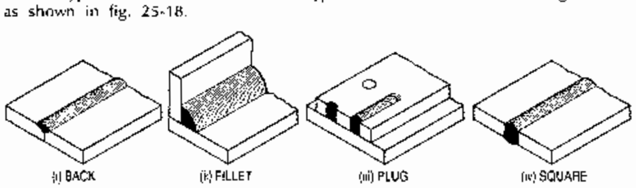


FIG. 25-18

Similarly, the resistance welds are also of four types.

25-8-4. REPRESENTATION OF WELDED JOINTS

A welded joint is shown on a drawing by means of (i) a symbol which specifies the form of weld and (ii) a bent arrow and a reference line indicating the location of the weld as shown in fig. 25-20.

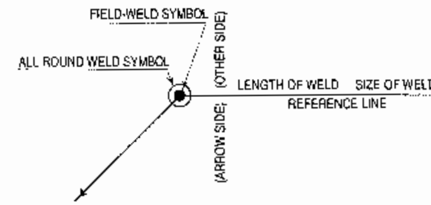


Fig. 25-20

Table 25-2 shows symbols for various forms of welded joints as recommended by the Bureau of Indian Standards.

TABLE 25-2

No.	FORM OF WELD	ILLUSTRATION	SYMBOL	No.	FORM OF WELD	ILLUSTRATION	SYMBOL
(i)	FILLET			(viii)	SINGLE-BEVEL BUTT		
(ii)	SQUARE BUTT			(ix)	SINGLE-BEVEL BUTT WELD WITH BROAD ROOT FACE		
(iii)	SINGLE-V BUTT			(x)	DOUBLE-BEVEL BUTT		
(iv)	DOUBLE-V BUTT			(xi)	DOUBLE-BEVEL BUTT WELD WITH BROAD ROOT FACE		
(v)	SINGLE-U BUTT			[illegible]	[illegible]		

The symbol should be shown only in one of the views. When a weld is to be on the arrow side, the symbol should be inverted and placed below the reference line as shown in fig. 25-21(i). When a weld is to be on the other side, the symbol should be placed in its correct position, but over the reference line. For welds on both the sides, a symbol is placed above as well as below the reference line. See fig. 25-21(ii). Note that in each case, the vertical portion of the symbol is always kept on the left-hand side of the symbol. The size of weld is indicated on the left-side of the weld symbol.

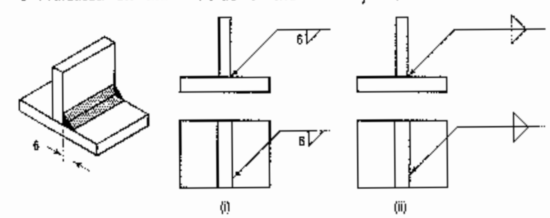


Fig. 25-21

The depth of a partially penetrated U-butt or V-butt weld is indicated by means of a dimension placed to the left of the symbol. Fig. 25-22(i) shows a V-butt weld partially penetrated on the top surface, while the dimensions of the same weld, partially penetrated on both the sides are shown in fig. 25-22(ii).

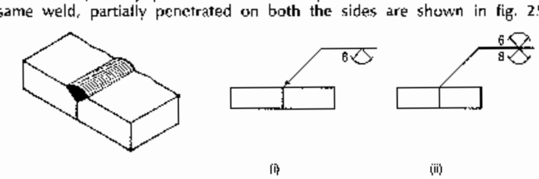


Fig. 25-22

Sometimes the welding is required to carry out at the site or in the field. This can be indicated on a drawing by placing a filled circle drawn around the point of intersection between the arrow and reference lines as shown in fig. 25-25.

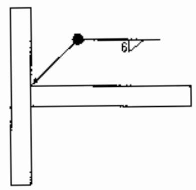


Fig. 25-25

EXERCISES 25

1. Show by means of neat, dimensioned sketches the shapes of the following rivets:

   Cup head; pan head; conical head; countersunk head.
2. Explain with the aid of sketches the processes of (i) caulking and (ii) fullering, used in riveted joints.
3. Describe the ways in which a riveted joint may fail. What steps are taken to prevent failures? Illustrate your answer with necessary sketches.
4. Draw the sectional front view, the top view and a side view of a single riveted lap joint for 12 mm thick plates. Show the pitch, margin and width of overlap.
5. Show by means of sketches, the difference between chain riveting and zigzag riveting. What is the advantage of one over the other arrangement?
6. Sketch neatly, two views of a double-riveted lap joint using rivets in zigzag arrangement. State why this arrangement is used. Thickness of plates = 10 mm. Diameter of rivets = 20 mm. Give all other dimensions.
7. Draw three views of the triple-riveted lap joint shown in fig. 25-26, taking t = 12 mm, d = 20 mm, p = 60 mm and p_t = 40 mm.

9. Draw two views of the double-riveted butt joint shown in fig. 25-11. Take t = 10 mm and d = 20 mm. Insert all dimensions on your drawing.
10. Draw neat sketches to show the circumferential and longitudinal joints between two rings of shell plates in a boiler.
11. Show with the aid of sketches, three different ways in which two plates may be connected at right angles to each other by means of rivets.
12. Sketch neatly, two views to show how two plates, each 12 mm thick can be joined at right angles by using an angle-iron and rivets.
13. Draw neat sketches to show how the end-plates of a Cornish boiler are joined to (i) the shell-plates and (ii) the flue-plates.
14. Draw two views of the Gusset stay shown in fig. 25-16. Take t = 16 mm, d = 24 mm, L = 200 mm, L_1 = 100 mm, p = 60 mm.
15. Draw three dimensioned views of the riveted joint for a tie-bar shown in fig. 25-27. Take the thickness of the bar as 12 mm.

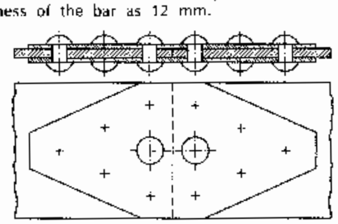
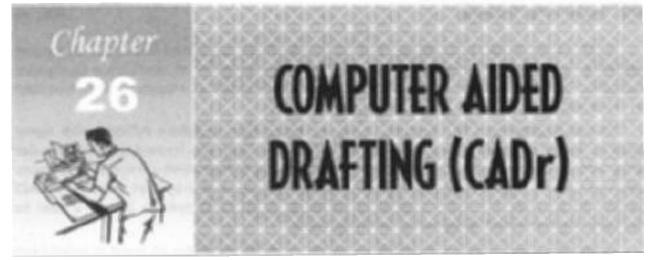


Fig. 25-27

16. Discuss in brief various methods of welding.
17. Why welding is more popular than riveted joints?
18. Show by means of sketches the method of showing location, symbol, size and depth of the following forms of weld:

    (i) Single V-butt weld



26-1. INTRODUCTION

Manufacturing of a product is the main activity in engineering profession. The design of a product may start with trial designs in the form of sketches on paper. As the design improves and undergoes changes, the final form of design must be the scaled manufacturing drawings with finer details included. These drawings are two-dimensional representations of three-dimensional objects designed.

During the process of design, the designer may have to carry out a large amount of computations so that an optimum design is obtained. A computer with good graphic capabilities helps the designer to

(i) realize his ideas.

(ii) carry out complex computations.

(iii) present the results of computations in a useful form for decision making and possible improvement.

(iv) present the improved model for evaluation.

Interactive Computer Graphics (ICG) is the tool of the designer.

26-2. COMPUTER AIDED DRAFTING

A part to be manufactured is defined first in terms of its geometry which also includes dimensions, tolerances, surface finish, and in some cases the type of fit between two mating parts. The two-dimensional representation of a part, called an engineering

CAD is the product of computer era. Its development originated from early computer graphics systems. CAD can find its roots to the development of Interactive Computer Graphics (ICG). A system called *Sketchpad* was developed at Massachusetts Institute of Technology, U.S.A., in 1963 by Ivan Sutherland.

In the beginning, CAD systems were no more than graphics editors with some built-in design symbols. The geometry available to the user was limited to lines, circular arcs, and a combination of the two. The development of free-form curves and surfaces such as Coon's patch, Ferguson's patch, Bezier's curve, and B-splines enabled a CAD system to be used for more sophisticated work. A 3D CAD system allows a user to do very sophisticated design and analysis work.

Computer aided drawing and drafting system uses the computer to assist in generation of blueprint data. CAD systems are essential in design and a large number of computer based systems are commercially available. 2D drawing systems correspond directly to traditional engineering drawings, and they are developed to substitute manual drafting.

The advantages offered by computerized drafting systems can be summarized as:

(a) It increases the accuracy and productivity of designer.

(b) It allows design alterations to be made easily.

(c) It offers better drawing visualization through colours.

(d) It improves the quality of drawings produced.

(e) Drawings are easier to store and retrieve.

(f) Storage space required is less.

(g) Transfer of drawings is faster and cheaper.

(h) It permits the use of library of standard symbols for more productive CAD work (refer to art. 26-6).

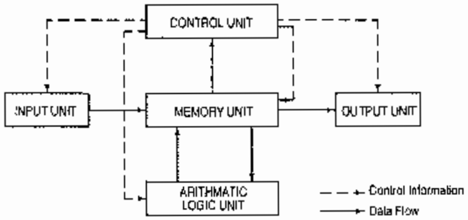
Although the capital investment required in setting up a computer aided drafting system is high, the greater capabilities offered by computers and software are making the systems more affordable.

26-3. COMPUTER (Fig. 26-1)

A computer system consists of

(a) Central Processing Unit (CPU), also known as processor

(b) Main memory



Organisation of a computer
Fig. 26-1

It must be remembered that the main memory is directly connected to the CPU. The main memory stores the program instructions and all the data being used for processing until the data are released as output under the instructions from the CPU. A control unit inside the CPU directs and coordinates all the operations of the system that are called for by the program. It involves control of the input and output devices, the storage and retrieval of information from memory, and the transfer of data between memory and ALU.

A CAD system consists of Hardware and Software. The system usually has the following major hardware elements:

26-3-1. PROCESSOR (CPU) (Fig. 26-2(vii))

Every CAD system must have a CPU to process and store a very large amount of graphics data. The speed and processing power of a computer is mainly decided by the CPU speed and the amount of main memory (RAM) installed.

26-3-2. DISPLAY (Fig. 26-2(iv))

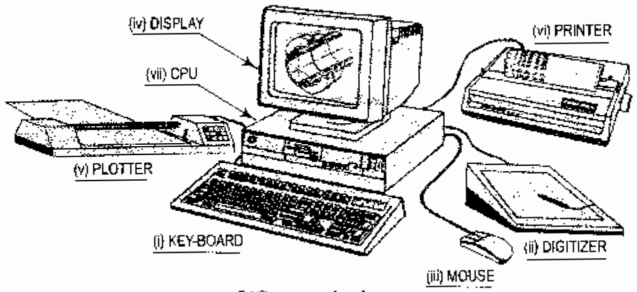
The most common type of display device for CAD systems is a Cathode Ray Tube (CRT). The display device must be capable of displaying both graphical and alphanumeric data. Although the display looks like television monitors, they have special electronics

26-3-3. INPUT DEVICES (Fig. 26-2)

(1) Keyboard [fig. 26-2(i)]: This is the most common input device. It is preferred for entering commands, text or value such as coordinates of a point or radius of a circle. The 101-key keyboards have special function keys to support special graphic functions. Whenever a key is pressed, the key character is identified by the computer and a character is displayed on the screen. If function keys are pressed or a combination of keys is pressed, the software takes the appropriate action.

(2) Mouse [fig. 26-2(iii)]: The mouse is a pointing device which is moved across a flat surface (usually on a mouse pad) by hand to indicate *X-Y* movement. The rotation of rubber ball underneath the device is translated and the corresponding cursor movement on the screen provides a visual feedback. The mouse is used as a pointing and pick-up device.

Either two-button or three-button mice are available in the market. The mouse has become very popular with microcomputers in recent years, and it is an indispensable pointing device. It is inexpensive, small, and convenient to use. However, fine and very precise sketching is very difficult to obtain with the mouse.



CAD system hardware

26-3-4. GRAPHIC OUTPUT DEVICES

A hard copy i.e. copy on paper of what is displayed on a graphics terminal can be obtained by a variety of graphics printers and plotters. The computer graphic output device may be thought of as paper and a pen or a pencil.

(1) Dot Matrix Printers (DMP) and Laser Printers: Dot Matrix Printer is the most commonly used printer for text printing. The characters are formed by printing dots in a specific manner. The dot matrix printer [fig. 26-2(vi)] can also be used for printing of drawings, but the quality of output is poor.

(2) Pen Plotters [fig. 26-2(v)]: Pen plotters are the simplest output devices for CAD. A pen plotter consists of a device to hold the paper. Usually two orthogonal motorized carriages hold a pen and move it under computer control. There are *three* inputs to the pen plotter: (i) an *X* coordinate, (ii) a *Y* coordinate and (iii) a pen variable. The pen variable can specify the pen colour by pen number, the pen to be *up* (non-drawing position) or *down* (in contact with paper in drawing position).

The two varieties of plotters are flat-bed and drum plotters. The flat-bed plotter is limited by the paper size it can handle. The drum plotter utilizes a continuous roll of paper which rolls over the top of the drum. The capacity and capabilities of a plotter are evaluated by the size of paper it can handle, resolution, speed of plotting, number of pens it can handle, etc.

(3) Ink-Jet printers/plotters: These are dot matrix printers. The drawing which is made up of lines, arcs, characters and symbols is converted into dot form. Then the rows of dots are printed across the width of the paper by impelling a tiny jet of ink on the surface of paper. The jets are switched on and off at high frequency to create multicolour plots.

Typically, the resolution is 600 to 900 dots per inch, and each dot is arranged to overlap the adjacent ones. This provides a high quality photo-realistic picture. These plotters are quiet during operation. These plotters are used for colour plots of drawings, shaded images, contour plots and artistic work.

(4) Laser printers: A laser printer rapidly produces high quality text and graphics on plain paper. The fastest colour laser printers can print over 100 pages per minute. It can write with much greater speed than an ink jet and can draw more precisely, without spilling any excess ink. The toner powder of laser printer is cheap and lasts a long time compared to expensive ink cartridges.

26-4. CAD SOFTWARE

The major functions to be performed by a computer aided drafting system are:

(a) Basic set-up of a drawing
(b) Drawing the objects
(c) Changing the object properties
(d) Translating the objects
(e) Scaling the objects
(f) Clipping the objects to fit the image to the screen
(g) Creating symbol libraries for frequently used objects
(h) Text insertion
(i) Dimensioning
(j) Creates various layers (Transparent sheets)
(k) Allows zoom-in and zoom-out of any components of drawing or complete drawing
(l) Creates different numbers of print/plot layouts.

Some of the features of CAD systems are:

(1) Modelling and Drafting: The majority of systems provide 2D and 3D modelling capabilities. Some low cost CAD systems are dedicated to 2D drafting only.

(2) Ease of use: The users find CAD systems very easy to learn and use.

(3) Flexibility: Popular CAD systems provide greater flexibility when configuring the available hardware. Hundreds of computers, display devices, expansion boards, input and output devices are compatible and configurable with popular softwares.

(4) Modularity: Standard input and output devices are attached to standard connectors thereby making the system modular in nature.

(5) Low maintenance cost: Little maintenance is needed to keep the system functional.

Capabilities and versatilities of the drafting system vary depending on the system on which they are implemented. AutoCAD, VersaCAD, CADKey, DesignCAD, ZWCAD, etc. are few popular commercially available drafting systems in use. These systems provide a variety of features required for producing engineering drawings.

The basic drawing entities are lines, polylines [refer to art. 26-5-4] of any width, circles, arcs, ellipses and solids. There are many ways of defining a drawing entity, and the software always prompts the user for all options. Each drawing entity has an associated line-type, colour, layer [refer to art. 26-5-5(2)] and thickness. The thickness is a property associated with 3D entities.

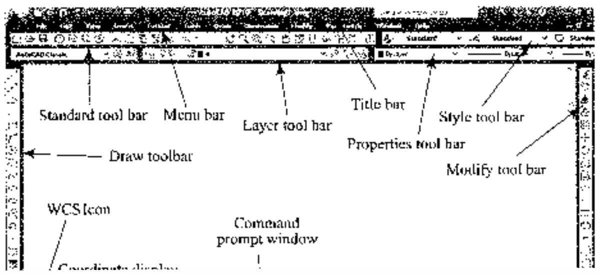
Before any drawing is started, the AutoCAD environment must be prepared for proper units of measurement, line-type, drawing size, layer, etc. In AutoCAD the drawings are always prepared at full scale, and the drawing size can be changed at any instant of time by using LIMITS command.

26-5-1. HARDWARE REQUIRED FOR AUTOCAD 2009/2010

(1) P IV Intel processor and motherboard
(2) 160/320 GB Hard disk
(3) 1 GB/2 GB RAM
(4) Microsoft Window XP Operating system software.

26-5-2. CLASSIC SCREEN LAYOUT OF AUTOCAD 2010

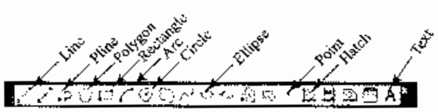
The default AutoCAD 2010 drawing screen can be divided into four areas such as drawing area, command area, menu bar area and tool bar area. The various component of Graphical User Interface (GUI) of AutoCAD 2010 is shown in fig. 26-3.



26-5-3. FUNCTION KEYS

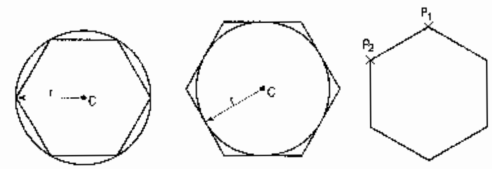
F1	Online Help		
F2	Toggles between Drawing screen to text screen		
F3	Toggles between OSNAP	–	On and Off
F4	Toggles between Tablet	–	On and Off
F5	Switches among Isoplanes Top, Right and Left		
F6	Toggles between Coordinates	–	On and Off
F7	Toggles between Grid	–	On and Off
F8	Toggles between Ortho Mode	–	On and Off
F9	Toggles between Snap Mode	–	On and Off
F10	Toggles between Polar Tracking	–	On and Off
F11	Toggles between Objects Snap Tracking	–	On and Off

26-5-4. DRAWING ENTITIES (DRAW COMMANDS)



(1) Line (Refer module 26-1): A line is specified by giving its two endpoints. The LINE command can be used to draw a single line or a series of lines with the end-point of one being the start-point of the next. When a series of such lines is created, each line is treated as a separate entity. To create a closed polygon, the user has to type in C (close option) for the *To point:* prompt. This causes the last and the first points to be joined by a line and thus cerating a closed boundary.

(2) Pline (refer module 26-9, 26-25): Polylines are interesting



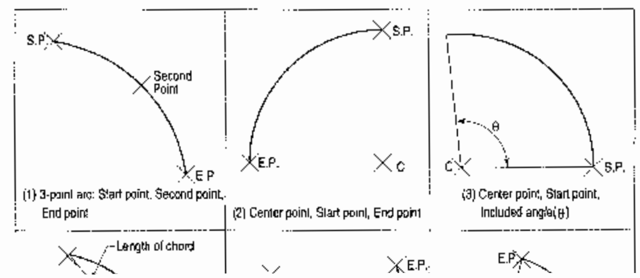
Polygon
FIG. 26-4

(5) Arc (fig. 26-5) (Refer module 26-8, 26-26, 26-27): This command is used to draw an arc accurately. Usually there are *three* parameters required for drawing an arc. Different ways of drawing circular arcs are:

(i) ***3 point arc:*** The arc is drawn by specifying three points on the chord of arc. The first and third points define the start and end-points of an arc respectively.

(ii) ***Start, Center:*** This option needs start point and center point of an arc. The third parameter may either be an end-point, included angle, or length of chord.

(iii) ***Start, End:*** This option asks the user to enter the start and end-points of an arc. The arc is completed by either specifying radius or included angle or center point.

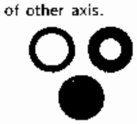


(6) Circle (Refer module 26-5, 26-11, 26-13): There are many ways of drawing a circle, the default being the centre point of circle and radius. Either on typing the command CIRCLE or selecting it from a menu bar with the help of mouse, all circle drawing options are displayed. The options available are:

(a) Center point and Radius
(b) Center point and Diameter
(c) 3P: This specifies 3 points on the circumference of a circle. There is a unique circle passing through three given non-collinear points.
(d) 2P: This specifies the end-points of diameter of a circle.
(e) TTR (Tangent Tangent Radius): This command draws a circle of specified radius that is tangent to two lines, circles or arcs.
(f) TTT (Tangent Tangent Tangent): This command draws a circle tangent to three entities.

(7) Ellipse (Refer module 26-11): An ellipse can be constructed by specifying the center point, radial length of major and minor axes. An ellipse can also be constructed by specifying end-points of one of its axis and the radial length of other axis.

(8) Donut (fig. 26-6) (Refer module 26-10): The DONUT is a special type of polyline which is made up of arc segments. A DONUT has two properties: it has width, and it is closed. The width of DONUT is set by specifying inside and outside diameters. The inside diameter may be zero thereby making it a filled circle.



Donut examples
FIG. 26-6

(9) Hatch patterns (Refer module 26-12): The HATCH command is used to fill up the area using a suitable pattern. The type of pattern and pattern variables can be chosen from a library of patterns available. The hatching will be carried out inside a closed defined area.

(10) Text (Refer module 26-6): Words, messages and numbers can be inserted as required on an engineering drawing. The alphanumeric keyboard is used extensively for non-graphical input such as text. The text style, height, text angle, aspect ratio, colour, etc. are some of the attributes associated with text. These attributes can be changed as per requirements.

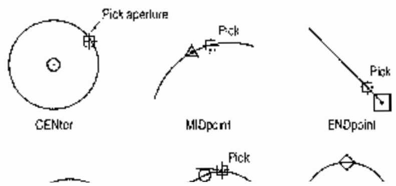
(11) Rectangle (Refer module 26-6, 26-10): Rectangles are drawn by three methods
(i) By specifying the co-ordinates at the 'specify first corner point" prompt and at the "specify other corner point" prompt.
(ii) By entering area of rectangle in current units and specifying length or

(2) Layer (Refer module 26-6, 26-13): A layer can be thought of as a transparent sheet on which drawings can be prepared. Drawings can be logically divided into different layers, and layers can be selectively displayed either individually or in any combination. Each layer is identified by a name. If the drawing becomes too dense or complicated, some layers can be turned off so that they do not interfere with the work. The drawing can be edited on any one layer at a time, called *current layer*. The colour, linetype and line weight are the properties associated with a layer. This controls an entity's colour, linetype and line weight drawn on that layer.

(3) Dimensioning (Refer module 26-7): The manufacturing drawing must be dimensioned for size and tolerances so that the right information can be conveyed. The appearance and size of dimension arrows, size and style of dimension text with or without tolerances, and the layer on which dimensions are placed can be controlled by setting dimension variables.

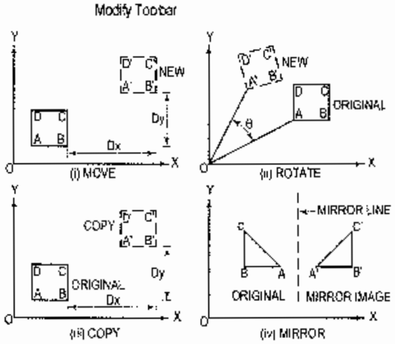
(4) Object snap (fig. 26-7) (Refer module 26-4): A very useful drawing aid, the OSNAP identifies the points on drawing entities that are visible on the screen. For example, the start point of an arc can be the endpoint of an existing line. This option allows the user to pick-up the points very accurately with respect to drawing displayed. Some of the OSNAP modes are:

⌛ NEArest	:	Closest point on an entity.
○ CENter	:	Center of a circle or an arc.
△ MIDpoint	:	Midpoint of a line or an arc.
□ ENDpoint	:	Closest endpoint of a line or an arc.
× INTersection	:	Intersection of two lines, two arcs, or a line with an arc or a circle.
◯ TANgent	:	Tangent to an arc or circle.
◇ Quadrant	:	Quadrant points will be located for circle and ellipses.



26-5-6. EDITING OF A DRAWING (MODIFY COMMANDS)

Modify Toolbar



Common drawing editing commands
FIG. 26-8

The fundamental commands to edit a drawing are:

(1) Move [fig. 26-8(i)]: Moves selected objects to another location about a base point.

(2) Rotate [fig. 26-8(ii)] (Refer module 26-12): Rotates selected objects through a specified angle about a base point.

(3) Copy [fig. 26-8(iii)] (Refer module 26-6): Creates one or more copies of selected

(9) Fillet (Refer module 26-5, 26-13): This command is used to create a round corner between two lines. The lines are shortened or extended to fit a tangent arc of specified radius. FILLET works on any combination of two lines, arcs, circles, non-parallel lines, or a single polyline.

(10) Chamfer (Refer module 26-8): This command works on two lines or a single polyline to create a bevelled edge.

(11) Extend (Refer module 26-11): This command extends the lines, polylines and arcs to a boundary edge which can be a line, polyline, arc or circle. A closed polygon cannot be extended. When you invoke this command, you will be prompted to select the boundary edges. These edges can be lines, polylines, circles, arcs,, ellipse, xllines, rays,splines etc. After the boundary edges are selected, you must select each object to be extended. An object can be both a boundary edge and an object to be extended.

(12) Offset (Refer module 26-5): This command creates a parallel single copy of line, arc, circle, rectangle, polygon, or 2D polyline at a given offset distance. Each offset creates a new entity with the same linetype, color and layer settings.

(13) Stretch (Refer module 26-12): The STRETCH command can either lengthen entities or shorten them, and thus alter their shapes. The centre points of arcs or polyline arcs are adjusted accordingly.

(14) Trim (Refer module 26-5, 26-13): This command trims the objects that extend beyond a required point of intersection. When you invoke this command, you will be prompted to select the cutting edges. These edges can be lines, polylines, circles, arcs, ellipse, xlines, rays, splines, text, blocks or even viewports. After the cutting edges are selected, you must select each object to be trimmed. An object can be both a cutting edge and an object to be trimmed.

(15) Scale (Refer module 26-12): The SCALE command allows to shrink or enlarge the already existing drawing objects about a base point by specifying a scale factor.

(16) Pedit: A polyline is a single entity which is made up of a continuous series of line and arc segments. The PEDIT command is exclusively used for editing of polyline properties. The selected line, arc and polyline can be added to an existing polyline by a JOIN option. A smooth curve passing through all vertices of a polyline can be created by using FIT option. Similarly, a spline can also be constructed by using SPLINE option.

(17) Explode (Refer module 26-6): This command breaks a polyline into its individual segments. These segments can then individually be edited, and rejoined again to form an edited polyline.

(18) U (Refer module 26-8): The U command reverses the effects of a series of previously used commands and hence allows back-stepping. The REDO command wipes out the effect of U command.

The *advanced features* of AutoCAD are:

(1) Built in programming language AutoLISP provides programming environment

26-6. SYMBOL LIBRARY (BLOCK, WBLOCK AND INSERT)

A complete drawing or a part of a drawing can be given a specific name and then stored as a block. A collection of such blocks form a library which is very useful for drawing purpose. The blocks, also referred to as symbols, can be scaled, rotated or mirrored if necessary and inserted into the drawing at the appropriate location e.g. bolt heads to be used at different locations in a drawing. Many suppliers of CAD add-on products offer symbol libraries of standard mechanical components, electronic components, architectural symbols, piping symbols, etc. The **block** and **wbluck** command groups a number of selected entities together and treats them as a single object i.e. single block. Block commands saves the group of selected entities with block name and is inserted in the file in which it is created, but wblock command saves the group of selected entities as a drawing file and can be inserted in any drawing file. The blocks and wblocks can be scaled, rotated, stretched or mirrored. The explode command separates the entities of block and wblock.

INSERT (Refer module 26-14): INSERT command is used to insert blocks and wblocks in current drawing. Blocks will be inserted only in the drawing file in which they created and wblocks will be inserted in any drawing files.

26-7. TWO DIMENSIONAL DRAWINGS

The following modules (26-1 to 26-14) are self interactive and self learning practice modules to generate two dimentional drawings covering all possible 2-D commands. The configuration of computer will be as mentioned in art. 26-5-1.

(1) Absolute coordinate method: In the absolute coordinate method, the points are located with respect to the origin (0, 0). The syntax is **X, Y.**

Module 26-1. *Draw a line diagram as shown in fig. 26-9. Use Absolute Coordinate Method.*

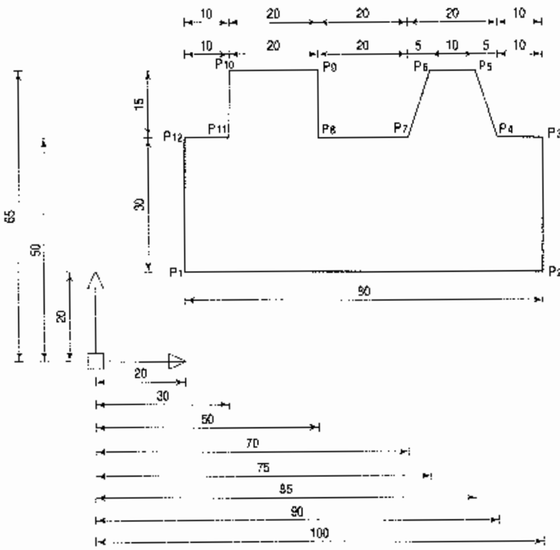
To draw a line diargram using Absolute Coordinate Method, follow the steps mentioned below.

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)
(2) Command: **ZOOM** (↵)

Specify next point or [Close/Undo]: **30,65** (↵)
Specify next point or [Close/Undo]: **30,50** (↵)
Specify next point or [Close/Undo]: **20,50** (↵)
Specify next point or [Close/Undo]: **C** (↵)
(4) Save This File As **Module 26-1.DWG**

Output of Module 26-1 (fig. 26-9):

MODULE 26-1: ABSOLUTE COORDINATE METHOD

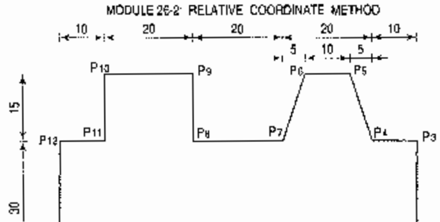


ABSOLUTE COORDINATES OF POINTS P_1 TO P_{12}

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)
(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)
Regenerating model.
(3) Command: **LINE** (↵)
Specify first point: **20,20** (↵)
Specify next point or [Undo]: **@80,0** (↵)
Specify next point or [Undo]: **@0,30** (↵)
Specify next point or [Close/Undo]: **@–10,0** (↵)
Specify next point or [Close/Undo]: **@–5,15** (↵)
Specify next point or [Close/Undo]: **@–10,0** (↵)
Specify next point or [Close/Undo]: **@–5,–15** (↵)
Specify next point or [Close/Undo]: **@–20,0** (↵)
Specify next point or [Close/Undo]: **@0,15** (↵)
Specify next point or [Close/Undo]: **@–20,0** (↵)
Specify next point or [Close/Undo]: **@0,–15** (↵)
Specify next point or [Close/Undo]: **@–10,0** (↵)
Specify next point or [Close/Undo]: **C** (↵)
(4) Save This File As **Module 26-2.DWG**

Output of Module 26-2 (fig. 26-10):

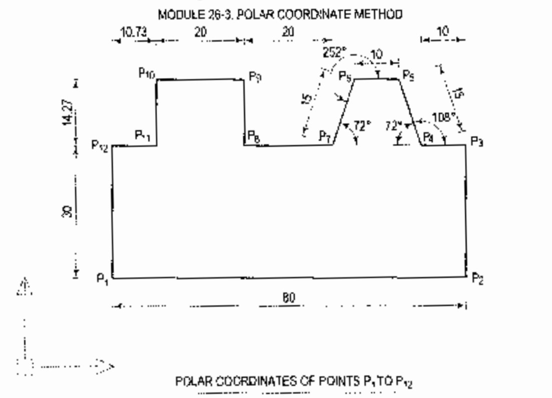
MODULE 26-2: RELATIVE COORDINATE METHOD



(3) **Relative polar coordinate method:** In the relative polar coordinate method a point is located by defining the direct distance of the point from current point and the angle that the direct distance makes with the positive X-axis in counter clockwise direction. It's syntax is **@direct distance < angle.**

Module 26-3. *Draw a line diagram as shown in fig. 26-11. Use Relative Polar Coordinate Method.*

Output of Module 26-3 (fig. 26-11):



POLAR COORDINATES OF POINTS P_1 TO P_{12}

P_1 = 20, 20	P_4 = @10 < 180	P_7 = @15 < 252	P_{10} = @20 < 180
P_2 = @80 < 0	P_5 = @15 < 108	P_8 = @20 < 180	P_{11} = @14.27 < 270
P_3 = @30 < 90	P_6 = @10 < 180	P_9 = @14.27 < 90	P_{12} = @10.73 < 180

FIG. 26-11

To draw a line diagram using Polar Coordinate Method, follow the steps mentioned below.

(1) Command: **LIMITS** (↵)
Reset Model space limits:

Specify next point or [Close/Undo]: **@10<180** (↵)
Specify next point or [Close/Undo]: **@15<252** (↵)
Specify next point or [Close/Undo]: **@20<180** (↵)
Specify next point or [Close/Undo]: **@14.27<90** (↵)
Specify next point or [Close/Undo]: **@20<180** (↵)
Specify next point or [Close/Undo]: **@14.27<270** (↵)
Specify next point or [Close/Undo]: **@10.73<180** (↵)
Specify next point or [Close/Undo]: **C** (↵)

(4) Save This File As **Module 26-3.DWG**

Module 26-4. *Draw a line diagram as shown in fig. 26-12. Use Object-Snap (Osnap) Method.*

To draw a line diargram using Object-Snap (Osnap) Method, follow the steps mentioned below.

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)
Regenerating model.

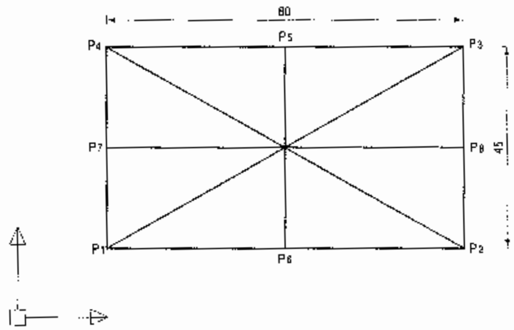
(3) Command: **LINE** (↵)
Specify first point: **20,20** (↵)
Specify next point or [Undo]: **@80<0** (↵)
Specify next point or [Undo]: **@45<90** (↵)
Specify next point or [Close/Undo]: **@80<180** (↵)
Specify next point or [Close/Undo]: **C** (↵)

(4) Press **F3 key** to Switch ON 'OSNAP' if it is OFF

(5) Command: **LINE** (↵)
Specify first point: (Get Mouse Near To **P5** and CLICK When MIDPOINT magnet gets ON)
Specify next point or [Undo]: (Get Mouse Near To **P6** and CLICK When MIDPOINT magnet gets ON)
Specify next point or [Undo]: (↵)

(6) Command: **LINE** (↵)
Specify first point: (Get Mouse Near To **P7** and CLICK When MIDPOINT magnet gets ON)
Specify next point or [Undo]: (Get Mouse Near To **P8** and CLICK When MIDPOINT magnet gets ON)

Output of Module 26-4 (fig. 26-12):



USE ABSOLUTE, RELATIVE OR POLAR METHOD TO GET COORDINATES OF P_1 TO P_4
REST OF THE POINTS SELECT BY OSNAP MAGNETS

P_1 = 20, 20	P_5 = (Select Using MIDPOINT magnet)	P_1 = (Select Using ENDPOINT magnet)
P_2 = @80 < 0	P_6 = (Select Using MIDPOINT magnet)	P_3 = (Select Using ENDPOINT magnet)
P_3 = @45 < 90	P_7 = (Select Using MIDPOINT magnet)	P_2 = (Select Using ENDPOINT magnet)
P_4 = @80 < 180	P_8 = (Select Using MIDPOINT magnet)	P_4 = (Select Using ENDPOINT magnet)

FIG. 26-12

Module 26-5. *Draw a line diagram as shown in fig. 26-13. Use Circle, Offset, Trim and Fillet commands.*

To draw a line diargram using circle, offset, trim and fillet commands, follow the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-13(i) to fig. 26-13(x).

(1) {Switch ON POLAR switch by Mouse Click or press **F10** key}

(2) Command: **LIMITS** (↵)
Reset Model space limits:

Specify next point or [Close/Undo]: **90** (↵) (When **180°** POLAR is ON)
Specify next point or [Close/Undo]: **C** (↵)

(5) Command: **OFFSET** (↵)
Specify offset distance or [Through] <Through>: **35** (↵)
Select object to offset or <exit>: (Select Line **L1**)
Specify point on side to offset: (Click Mouse Above Line L1)
Select object to offset or <exit>: (↵)

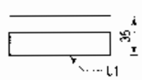


FIG. 26-13(i)

(6) Command: **CIRCLE** (↵)
Specify center **point** for circle or [3P/2P/Ttr (tan tan radius)]: (Select MIDPOINT magnet of **L3**)
Specify radius of circle or [Diameter]: **D** (↵)
Specify diameter of circle: **40** (↵)

(7) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: (Select MIDPOINT magnet of **L3**)
Specify radius of circle or [Diameter] <20.0000>: **D** (↵)
Specify **diameter** of circle <40.0000>: **20** (↵)

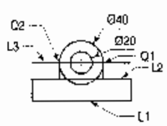


FIG. 26-13(iii)

(8) Command: **LINE** (↵)
Specify first **point**:(Select **0°** QUADRANT magnet **Q1** of **Ø40** Circle)
Specify next point or [Undo]:(Select PERPENDICULAR magnet on Line **L2**)
Specify next point or [Undo]: (↵)

(9) Command: **LINE** (↵)
Specify first point:(Select **180°** QUADRANT magnet **Q2** of **Ø40** Circle)
Specify next point or [Undo]:(Select PERPENDICULAR magnet on Line **L2**)
Specify next point or [Undo]: (↵)

(10) Command: **OFFSET** (↵)
Specify offset distance or [Through] <35.0000>: **8** (↵)
Select object to offset or <exit>: (Select Line **L1**)
Specify point on side to offset: (Click Mouse Above Line **L1**)
Select object to offset or <exit>: (↵)

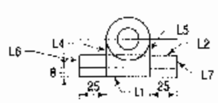


FIG. 26-13(iv)

(11) Command: **OFFSET** (↵)
Specify offset distance or [Through] <8.0000>: **25** (↵)
Select object to offset or <exit>: (Select Line **L6**)
Specify point on side to offset: (Click Mouse on Right Side of Line **L6**)

(13) Command: **TRIM** (↵)

Current settings: Projection- UCS, Edge: None

Select cutting edges ...

Select objects: (Select Line **L9**)

Select objects: (Select Line **L10**)

Select objects: (↵)

Select object to trim or shift-select to extend or [Project/Edge/Undo]: (Select Line **L1** from Arrow Head)

Select object to trim or shift-select to extend or [Project/Edge/Undo]: (↵)

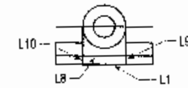


FIG. 26-13(vi)

(14) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 0.0000

Select first object or [Polyline/Radius/Trim]: **R** (↵)

Specify fillet radius <0.0000>: **2.5** (↵)

Select first object or [Polyline/Radius/Trim]: (Select Line **L8** from Arrow Head)

Select second object: (Select Line **L10** from Arrow Head)

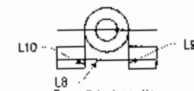


FIG. 26-13(vii)

(15) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 2.5000

Select first object or [Polyline/Radius/Trim]: (Select line **L8** from Arrow Head)

Select second object: (Select Line **L9** from Arrow Head)

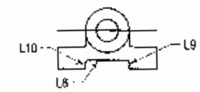


FIG. 26-13(viii)

(16) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 2.5000

Select first object or [Polyline/Radius/Trim]: **R** (↵)

Specify fillet radius <2.5000>: **5** (↵)

Select first object or [Polyline/Radius/Trim]: (Select line **L4** from Arrow Head)

Select second object: (Select Line **L11** from Arrow Head)

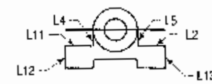


FIG. 26-13(ix)

(17) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 5.0000

Select first object or [Polyline/Radius/Trim]: (Select Line **L5** from Arrow Head)

Select second object: (Select Line **L2** from Arrow Head)

(18) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 5.0000

MODULE 26-5. USE OF CIRCLE, OFFSET, TRIM, AND FILLET COMMANDS

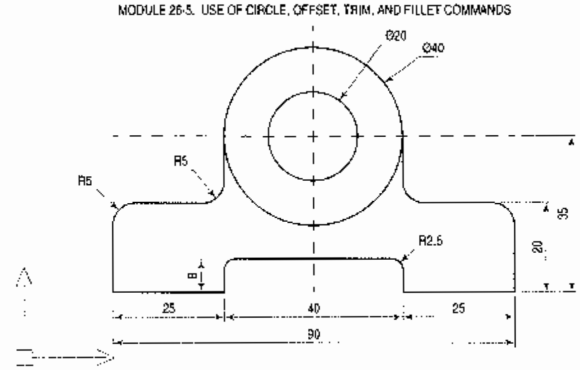


FIG. 26-13

Module 26-6. *Draw a title block as shown in fig. 26-14. Use Layer, Rectangle, Explode, Text and Copy commands.*

To draw a line diagram using Circle, Offset, Trim and Fillet commands, follow the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-14(i) to fig. 26-14(vii).

(1) Command: **LIMITS** (↵)

Reset Model space limits:

Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)

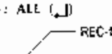
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **ZOOM** (↵)

Specify corner of window, enter a scale factor (nX or nXP), or [All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)

Regenerating model.

(3) Command: **–LAYER** (↵)



New color [Truecolor/COlorbook] : **MAGENTA** (↵)

Enter name list of layer(s) for color 6 (magenta) <0>: **TXT** (↵)

Enter an option

[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight/...]: (↵)

(4) Command: **RECTANGLE** (↵)

Specify first corner point or [Chamfer/Elevation/Fillet/Thickness/Width]: **20,20** (↵)

Specify other corner point or [Dimensions]: **@100,45** (↵)

(5) Command: **EXPLODE** (↵)

Select objects: (Select Rectangle **REC-1**)

Select objects: (↵)

(6) Use OFFSET and TRIM Command to complete the Drawing as shown on Right Side

(7) Command: **–LAYER** (↵)

Current layer: "0"

Enter an option

[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight...]: **SET** (↵)

Enter layer name to make current <0>: **GRID** (↵)

Enter an option

[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight...]: (↵)

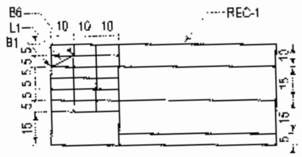


FIG. 26-14(ii)

(8) Command: **LINE** (↵)

Specify first point: (Select **B1** by ENDPOINT Osnap)

Specify next point or [Undo]: (Select **B6** by Osnap)

Specify next point or [Undo]: (↵)

(9) Command: **COPY** (↵)

Select objects: (Select Line **L1**)

Select objects: (↵)

Specify base point or disp... : (Select **B1** by Osnap)

Specify second point of dis.. : (Select **B2** by Osnap)

Specify second point of dis.. : (Select **B3** by Osnap)

Specify second point of dis.. : (Select **B4** by Osnap)

Specify second point of dis.. : (Select **B5** by Osnap)

Specify second point of dis.. : (Select **B6** by Osnap)

Specify second point of dis.. : (Select **B7** by Osnap)

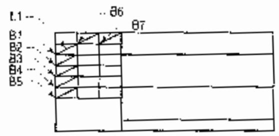


FIG. 26-14(iii)

(12) Command: **LINE** (↵)

Specify first point: (Select **B12** by Osnap)

Specify next point or [Undo]: **@70,7.5** (↵) (Point **B13**)

Specify next point or [Undo]: (Select **B9** by Osnap)

Specify next point or [Close/Undo]: (↵)

(13) Command: **LINE** (↵)

Specify first point: (Select **B15** by Osnap)

Specify next point or [Undo]: **@30,7.5** (↵) (Point **B16**)

Specify next point or [Undo]: (Select **B14** by Osnap)

Specify next point or [Close/Undo]: (↵)

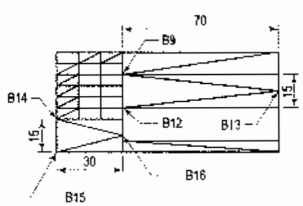


FIG. 26-14(v)

(14) Command: **–LAYER** (↵)

Current layer: "0"

Enter an option

[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight...]: **SET** (↵)

Enter layer name to make current <0>: **TXT** (↵)

Enter an option

[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight...]: (↵)

(15) Command: **DTEXT** (↵)

Current text style: "Standard" Text height: 0.2000

Specify start point of text or [Justify/Style]: **J** (↵)

Enter an option [Align/Fit/Center/Middle/Right/TL/TC/TR/ML/MC/...]: **MC** (↵)

Specify middle point of text: (Select **M1** by Osnap)

Specify height <0.2000>: **2** (↵)

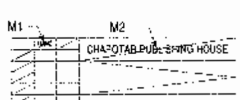
Specify rotation angle of text <0>: **0** (↵)

Enter text: **NAME** (↵)

Enter text: (↵)

(16) Command: **DTEXT** (↵)

Current text style: "Standard" Text height: 2.0000



Enter an option [Align/Fit/Center/Middle/Right/TL/TC/TR/ML/MC/...]: **MC** (↵)
Specify middle point of text: (Select **M3** by Osnap)
Specify height <3.5000>: **3** (↵)
Specify rotation angle of text <0>: **0** (↵)
Enter text: **SCALE** (↵)
Enter text: (↵)

(18) Complete The Text Writing by DTEXT Command

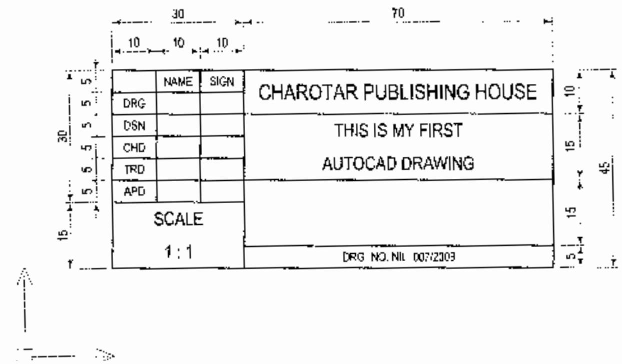
(19) Command: **–LAYER** (↵)
Current layer: "0"
Enter an option
[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight/...]: **OFF** (↵)
Enter name list of layer(s) to turn off or <select objects>: **GRID** (↵)
Enter an option
[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight/...]: (↵)


FIG. 26-14(vii)

(20) Save This File As **Module 26-6.DWG**

Output of Module 26-6 (fig. 26-14):

MODULE 26-6: USE OF LAYER, RECTANGLE, EXPLODE, TEXT AND COPY COMMANDS



(3) Command: **DIMDEC** (↵)
Enter new value for DIMDEC <4>: **0** (↵)

(4) Command: **DIMEXO** (↵)
Enter new value for DIMEXO <0.0625>: **0.2** (↵)

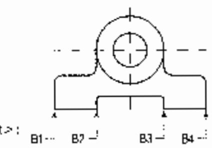


FIG. 26-15(i)

(5) Command: **DIMLINEAR** (↵)
Specify first extension line origin or <select object>: (Select **B1** by OSNAP)
Specify second extension line origin: (Select **B2** by OSNAP)
Specify dimension line location or
[Mtext/Text/Angle/Horizontal/Vertical/Rotated]: (Select Point Below **B1** or **B2**)
Dimension text = **25**

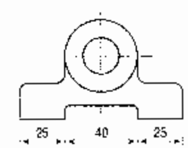
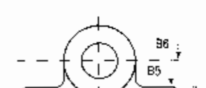


FIG. 26-15(ii)

(6) Command: **DIMCONTINUE** (↵)
Specify a second extension line origin or [Undo/Select] <Select>: (Select **B3** by OSNAP)
Dimension text = **40**
Specify a second extension line origin or [Undo/Select] <Select>: (Select **B4** by OSNAP)
Dimension text = **25**
Specify a second extension line origin or [Undo/Select] <Select>: (↵)
Select continued dimension: (↵)

(7) Command: **DIMLINEAR** (↵)
Specify first extension line origin or <select object>: (Select **B4** by OSNAP)
Specify second extension line origin: (Select **B5** by OSNAP)
Specify dimension line location or
[Mtext/Text/Angle/Horizontal/Vertical/Rotated]: (Click on Right of **B4**)
Dimension text = **20**

(8) Command: **DIMBASELINE** (↵)
Specify a second extension line origin or [Undo/Select] <Select>: (Select **B6** by OSNAP)
Dimension text = **35**



(11) Command: **DIMRADIUS** (↵)
Select arc or circle: (Select Arc **A1**)
Dimension text = **5**
Specify dimension line location or [Mtext/Text/Angle]: (Click Outside **A1**)

(12) Similarly complete the other dimensions.

(13) Save This File As **Module 26-7.DWG**

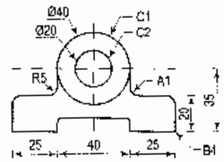


FIG. 26-15(iv)

Output of Module 26-7 (fig. 26-15):

MODULE 26-7: USE OF DIMENSIONS

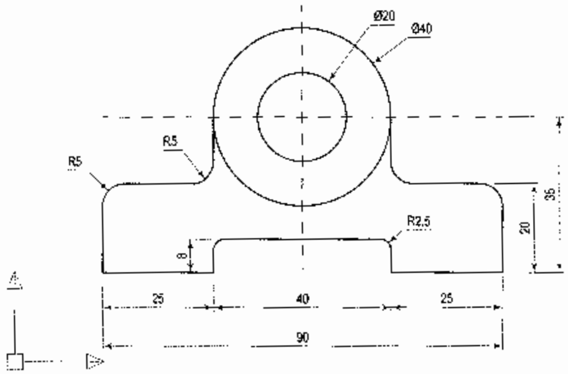


FIG. 26-15

Module 26-8. *Draw a line diagram as shown in fig. 26-16. Use Polygon, Chamfer, Arc and Mirror commands.*

To draw a line diagram using Polygon, Chamfer, Arc and Mirror commands, follow the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-16(i) to fig. 26-16(v).

(1) Command: **LIMITS** (↵)

Specify next point or [Undo]: **10** (↵) (When **270°** POLAR is ON)
Specify next point or [Close/Undo]: **20** (↵) (When **0°** POLAR is ON)
Specify next point or [Close/Undo]: **10** (↵) (When **90°** POLAR is ON)
Specify next point or [Close/Undo]: **20** (↵) (When **0°** POLAR is ON)
Specify next point or [Close/Undo]: (↵)

(4) Command: **ARC** (↵)
Specify start point of arc or [Center]: (Click Point **P1** When ENDPOINT magnet gets ON)
Specify second point of arc or [Center/End]: **E** (↵)
Specify end point of arc: **@0,–40** (↵) (Point **P2**)
Specify center point of arc or [Angle/Direction/Radius]: **A** (↵)
Specify included angle: **180** (↵)

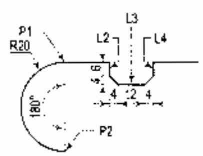


FIG. 26-16(ii)

(5) Command: **CHAMFER** (↵)
(TRIM mode) Current chamfer Dist1 = 0.5000, Dist2 = 0.5000
Select first line or [Polyline/Distance/Angle/Trim/Method]: **D** (↵)
Specify first chamfer distance <0.5000>: 4 (↵)
Specify second chamfer distance <4.0000>: **4** (↵)
Select first line or [Polyline/Distance/Angle/Trim/Method]: (Select Line **L2**)
Select second line: (Select Line **L3**)

(6) Command: **CHAMFER** (↵)
(TRIM mode) Current chamfer Dist1 = 4.0000, Dist2 = 4.0000
Select first line or [Polyline/Distance/Angle/Trim/Method]: (Select Line **L3**)
Select second line: (Select Line **L4**)

(7) Command: **MIRROR** (↵)
Select objects: (Select Arc **A1**)
Select objects: (↵)
Specify first point of mirror line: (Click MIDPOINT magnet of Line **L3**)
Specify second point of mirror line: (Click When **270°** POLAR is ON)
Delete source objects? [Yes/No] <N>: **N** (↵)

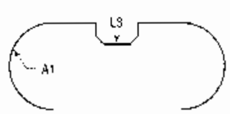
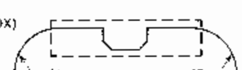


FIG. 26-16(iii)

(8) Command: **MIRROR** (↵)
Select objects: (Select All Objects in Dotted BOX)
Select objects: (↵)
Specify first point of mirror line: (Click MIDPOINT



Specify first point of mirror line: (Click MIDPOINT of L3)
Specify second point of mirror line: (Click When **270°** POLAR is ON)
Delete source objects? [Yes/No] <N>: **N** (↵)

(11) Command: **ERASE** (↵)
Select objects: **ALL** (↵)
Select objects: (↵)

(12) Command: **U** (↵)

(13) Save This File As **Module 26-8.DWG**

Output of Module 26-8 (fig. 26-16):

MODULE 26-8: USE OF POLYGON, CHAMFER, ARC AND MIRROR COMMANDS

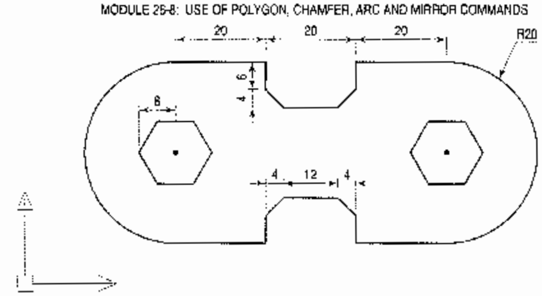


FIG. 26-16

Module 26-9. *Draw a line diagram as shown in fig. 26-17. Use Polyline command.*

To draw a line diagram using Polyline command, follow the steps mentioned below.

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)
Regeneration model

Specify next point or [Arc/Close/Halfwidth/...]: **50** (↵) (When **0°** POLAR is ON)
Specify next point or [Arc/Close/Halfwidth/Length/Undo/Width]: **ARC** (↵)
Specify endpoint of arc or
[Angle/CEnter/CLose/Direction/Halfwidth/...]: **40** (↵) (When **90°** POLAR is ON)
Specify endpoint of arc or
[Angle/CEnter/CLose/Direction/Halfwidth/Line/Radius/...]: **LINE** (↵)
Specify next point or [Arc/Close/Halfwidth/...]: **50** (↵) (When **180°** POLAR is ON)
Specify next point or [Arc/Close/Halfwidth/Length/Undo/Width]: **WIDTH** (↵)
Specify starting width <2.5000>: **10** (↵)
Specify ending width <10.0000>: **0** (↵)
Specify next point or [Arc/Close/Halfwidth/...]: **30** (↵) (When **180°** POLAR is ON)
Specify next point or [Arc/Close/Halfwidth/Length/Undo/Width]: (↵)

(4) Save this File As **Module 26-9.DWG**

Output of Module 26-9 (fig. 26-17):

MODULE 26-9: USE OF POLYLINE COMMAND

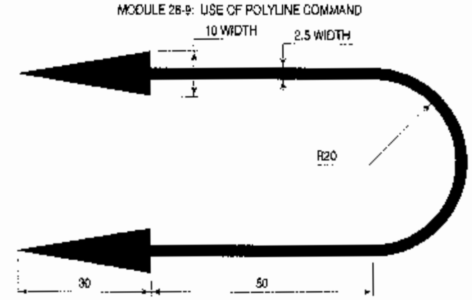


FIG. 26-17

Module 26-10. *Draw a line diagram as shown in fig. 26-18. Use Donut and Rectangular Array commands.*

To draw a line diagram using Donut and Rectangular Array commands, follow the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-18(i) to fig. 26-18(iii).

(4) Command: **DONUT** (↵)
Specify inside diameter of donut <0.5000>: **4** (↵)
Specify outside diameter of donut <1.0000>: **6** (↵)
Specify center of donut or <exit>: **FROM** (↵)
Base point: (Select **R1** Point by ENDPOINT magnet) <Offset>: **@10,10** (↵)
Specify center of donut or <exit>: (↵)

(5) Command: **ARRAY** (↵)
Select objects: (Select Donut **D1**)
Select objects: (↵)

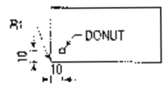


FIG. 26-18(ii)

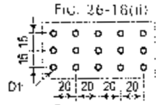


FIG. 26-18(iii)

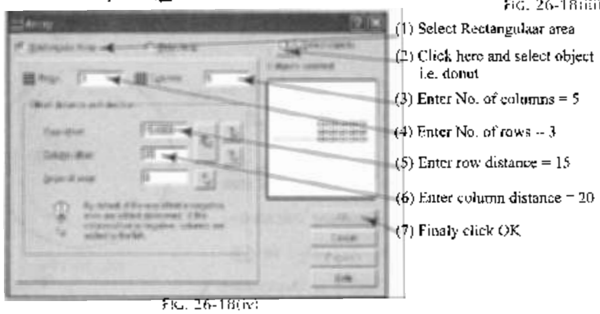


FIG. 26-18(iv)

(6) Save this File As **Module 26-10.DWG**

Output of Module 26-10 (fig. 26-18):

MODULE 26-10: USE OF DONUT AND RECTANGULAR ARRAY COMMANDS

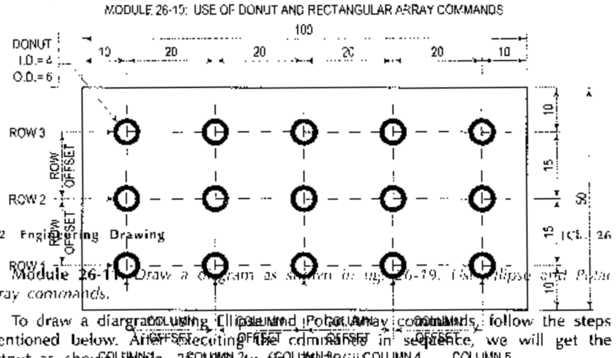


FIG. 26-18

Module 26-11. *Draw a diagram as shown in fig. 26-19. Use Ellipse and Polar Array commands.*

To draw a diagram using Ellipse and Polar Array commands, follow the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-19(i) to fig. 26-19(iii).

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)
Regenerating model.

(3) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **60,45** (↵)
Specify radius of circle or [Diameter]: **D** (↵)
Specify diameter of circle: **80** (↵)

(4) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: (Select CENTER magnet **C1** of **Ø80** Circle)
Specify radius of circle or [Diameter] <40.0000>: **D** (↵)
Specify diameter of circle <80.0000>: **60** (↵)

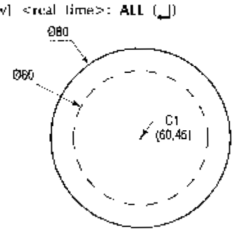


FIG. 26-19(i)

(5) Command: **ELLIPSE** (↵)
Specify axis endpoint of ellipse or [Arc/Center]: **C** (↵)
Specify center of ellipse: (Select **90°** QUADRANT **Q1** magnet of **Ø60** Circle)
Specify endpoint of axis: 6 (↵) (when **90°** POLAR is ON)
Specify distance to other axis or [Rotation]: 3 (↵)

(6) Command: **ARRAY** (↵)
Specify center point of array: (Select CENTER magnet **C1**)
Select objects: (Select Ellipse **E1**)
Select objects: (↵)

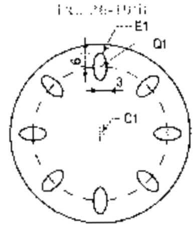


FIG. 26-19(ii)

(7) Command: **DIMSCALE** (↵)
Enter new value for DIMSCALE <1.0000>: **10** (↵)

(8) Command: **DIMCENTER** (↵)
Select arc or circle:(Select Circle **CR1**)

(9) Command: **EXTEND**
Current settings: Projection UCS, Edge=None
Select boundary edges ...
Select objects or <select all>: (Select Circle **CR1**)
Select objects: (↵)
Select object to extend or shift-select to trim or [Fence/Crossing/Project/Edge/Undo]:(Click Right End of Line **L1**)
Select object to extend or shift-select to trim or [Fence/Crossing/Project/Edge/Undo]: (Click Left End of Line **L1**)
Select object to extend or shift-select to trim or [Fence/Crossing/Project/Edge/Undo]: (Click Topt End of Line **L2**)
Select object to extend or shift-select to trim or [Fence/Crossing/Project/Edge/Undo]: (Click Bottom End of Line L2)
Select object to extend or shift-select to trim or [Fence/Crossing/Project/Edge/Undo]: (↵)

(10) Save This File As **Module 26-11.DWG**

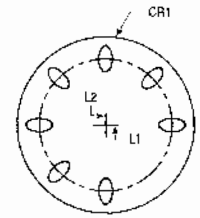


FIG. 26-19(iv)

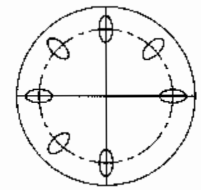


FIG. 26-19(v)

Output of Module 26-11 (fig. 26-19):

MODULE 26-11: USE OF ELLIPSE AND POLAR ARRAY COMMANDS

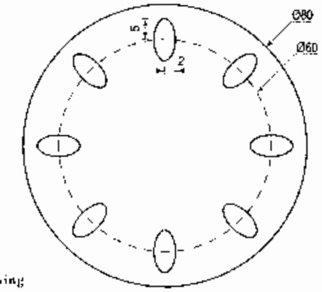


FIG. 26-19

Module 26-12. Draw a line diagram as shown in fig. 26-20. Use of Hatch, Rotate, Stretch and Scale commands.

To draw a line diagram using Hatch, Rotate, Stretch and Scale commands, follow the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-20(i) to fig. 26-20(vi).

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or [All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)

(3) Command: **POLYGON** (↵)
Enter number of sides <4>: **5** (↵)
Specify center of polygon or [Edge]: **E** (↵)
Specify first endpoint of edge: **45,40** (↵)
Specify second endpoint of edge: **30** (↵) (When **0°** POLAR is ON)

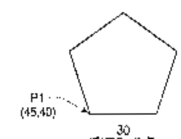


FIG. 26-20(i)

(4) Command: **BHATCH** (↵)

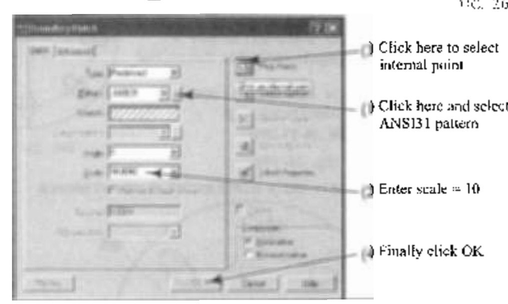


FIG. 26-20(ii)

Select internal point: (Click Inside Pentagon)
Selecting everything visible...

(6) Command: **STRETCH** (↵)
Select objects to stretch by crossing-window or crossing-polygon...
Select objects: (Click near to **S1** and then click near to **S2**)
Select objects: (↵)
Specify base point or displacement: (Select ENDPOINT magnet **B2**)
Specify second point of displacement or <...>: **40** (↵) (When **0°** POLAR is ON)

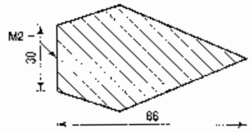


FIG. 26-20(v)

(7) Command: **SCALE** (↵)
Select objects: (Select Pentagon)
Select objects: (Select Hatch Pattern)
Select objects: (↵)
Specify base point: (Select MIDPOINT magnet **M2**)
Specify scale factor or [Reference]: **0.5** (↵)

(8) Save This File As **Module 26-12.DWG**

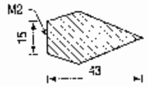


FIG. 26-20(vi)

Output of Module 26-12 (fig. 26-20):

MODULE 26-12: USE OF HATCH, ROTATE, STRETCH AND SCALE COMMANDS

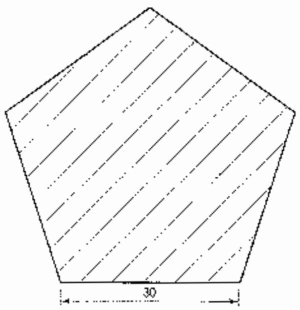


FIG. 26-20

(3) Command: **LTSCALE** (↵)
Enter new linetype scale factor <1.0000>: **15** (↵)

(4) Command: **–LAYER** (↵)
Enter an option
[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight/Plot/Freeze/...]: **NEW** (↵)
Enter name list for new layer(s): **CENLIN** (↵)
Enter an option
[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight/Plot/Freeze/...]: **COLOR** (↵)
New color [Truecolor/COlorbook] : **41** (↵)
Enter name list of layer(s) for color 41 <0>: **CENLIN** (↵)
Enter an option
[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight/Plot/Freeze/...]: **LTYPE** (↵)
Enter loaded linetype name or [?] <Continuous>: **DASHDOT** (↵)
Enter name list of layer(s) for linetype "DASHDOT" <0>: **CENLIN** (↵)
Enter an option
[?/Make/Set/New/ON/OFF/Color/Ltype/LWeight/Plot/Freeze/...]: (↵)

(5) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **90,100** (↵)
Specify radius of circle or [Diameter]: **d** (↵)
Specify diameter of circle: **68** (↵)

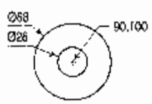
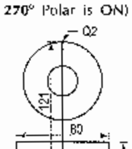


FIG. 26-21(i)

(6) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **90,100** (↵)
Specify radius of circle or [Diameter] <3.4000>: **d** (↵)
Specify diameter of circle <6.8000>: **26** (↵)

(7) Command: **LINE** (↵)
Specify first point: (Select QUADRANT Magnet **Q2** of Circle **Ø68**)
Specify next point or [Undo]: (Type **121** and press enter when **270°** Polar is ON)
Specify next point or [Undo]: (Type **40** and press enter when **0°** Polar is ON)
Specify next point or [Close/Undo]: (Type **34** and press enter when **90°** Polar is ON)
Specify next point or [Close/Undo]: (Type **80** and press enter when **180°** Polar is ON)
Specify next point or [Close/Undo]: (Type **34** and press enter when **270°** Polar is ON)



Specify radius of circle or [Diameter] <1.7000>: **d** (↵)
Specify diameter of circle <3.4000>: **16** (↵)

(11) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/...]: (Select MIDpoint Magnet **M2** of Line **14**)
Specify radius of circle or [Diameter] <1.7000>: **d** (↵)
Specify diameter of circle <3.4000>: **16** (↵)

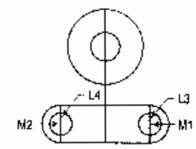


FIG. 26-21(iv)

(12) Command: **LINE** (↵)
Specify first point: (Select MIDpoint Magnet **M3** of Arc **A1**)
Specify next point or [Undo]: (Type **34** and press enter when **180°** Polar is ON)
Specify next point or [Undo]: (↵)

(13) Command: **LINE** (↵)
Specify first point: (Select MIDpoint Magnet **M4** of Arc **A2**)
Specify next point or [Undo]: (Type **34** and press enter when **0°** Polar is ON)
Specify next point or [Undo]: (↵)

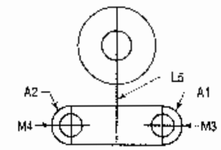


FIG. 26-21(v)

(14) Command: **OFFSET** (↵)
Specify offset distance or [Through/Erase/Layer] <Through>: **15** (↵)
Select object to offset or [Exit/Undo] <Exit>: (Select Line **L5**)
Specify point on side to offset or [Exit/..] <Exit>: (Click on Right Side of Line **L5**)
Select object to offset or [Exit/Undo] <Exit>: (Select Line **L5**)
Specify point on side to offset or [Exit/..] <Exit>: (Click on Left Side of Line **L5**)
Select object to offset or [Exit/Undo] <Exit>: (↵)

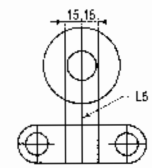


FIG. 26-21(vi)

(15) Command: **FILLET** (↵)
Select first object or [Undo/Polyline/Radius/Trim/Multiple]: **r** (↵)
Specify fillet radius <0.0000>: **10** (↵)
Select first object or [Undo/Polyline/Radius/...] : (Select Line **L6**)
Select second object or shift-select to apply corner: (select Circle **CR1**)

(16) Command: **FILLET** (↵)

Select object to trim or shift-select to extend or [Fence/......../Undo]: (Select **Line L6** from below Line **L1**)
Select object to trim or shift-select to extend or [Fence/......../Undo]: (Select Line **L7** from below Line **L1**)
Select object to trim or shift-select to extend or [Fence/Crossing/Project/Edge/eRase/Undo]: (↵)

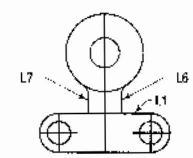


FIG. 26-21(viii)

(18) Command: **TRIM** (↵)
Current settings: Projection=UCS, Edge Extend
Select cutting edges ...
Select objects or <select all>: (Select Line **L6**)
Select objects: (Select Line **L7**)
Select objects: (↵)
Select object to trim or shift-select to extend or [Fence/..]: (Select Line **L1** from between Line **L6** and **L7**)
Select object to trim or shift-select to extend or [Fence/Crossing/Project/Edge/eRase/Undo]: (↵)

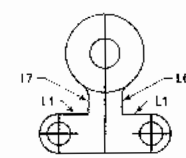


FIG. 26-21(ix)

(19) Command: **LINE** (↵)
Specify first point: (Select QUADRANT Magnet **Q1** of Circle **Ø68**)
Specify next point or [Undo]: (Select QUADRANT Magnet **Q3** of Circle **Ø68**)
Specify next point or [Undo]: (↵)

(20) Select Line L3,L4,L5,L8, L9 and L10 by Mouse and Click in Layer tool box and select CENLIN Layer and Press Esc key.

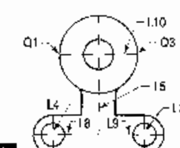
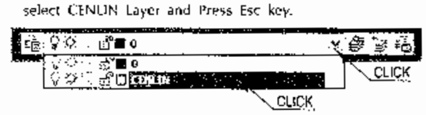


FIG. 26-21(x)



(21) Save This File As **Module 26-13.DWG**

Output of Module 26-13 (fig. 26-21):

Module 26-14. *Draw 2D diagram as shown in fig. 26-22(i) and fig. 26-22(ii). Using BLOCK and INSERT command create assembly as shown in*

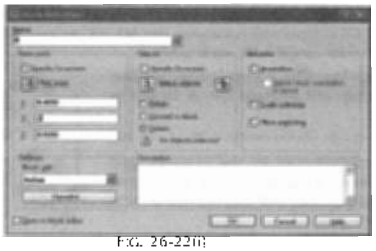


FIG. 26-22(ii)

(2) Select objects: (Select All Objects of PIN Fig 26-22(iii))
Select objects: (↵)
(3) Finaly click **OK** button.

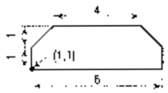


FIG. 26-22(ii)

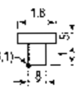


FIG. 26-22(iii)

(3) Command: **OOPS** (↵)
(4) Command: **INSERT** (↵)
(1) The Dialog Box Of INSERT will Open as shown below in fig. 26-22(iv).
(2) Select 'B' block from **NAME** box. Enter **1** in **X** box. Enter **0** in **Rotation** box. Finaly click **OK** button.

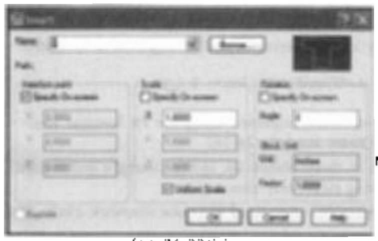


FIG. 26-22(iv)

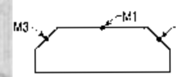
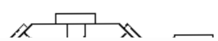


FIG. 26-22(v)

FIG. 26-22(vi)

(3) Specify insertion point or [Basepoint/Scale/Rotate]: (Select MIDpoint **M1**)



(iii) As shown in fig. 26-23, the three principal axes are AB (30° inclined with horizontal), AC (30° inclined with horizontal) and AD (90° inclined with horizontal). They also make 120° angle with each other.

(iv) Isometric drawings have three principal planes, isoplane right, isoplane top and isoplane left as shown in fig. 26-23.

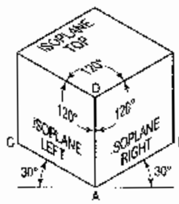


FIG. 26-23

(1) To set isometric mode (Refer module 26-15, 26-16)

(i) Use the snap command to set the isometric grid and snap. The isometric grid lines are displayed at 30° of the horizontal axis and also set the vertical spacing between grid.

(ii) The command sequence is as below:
Command: **-GRID** (↵)
Specify grid spacing or [ON/OFF/...] <1.0000>: **1** (↵)
Command: **-GRID** (↵)
Specify grid spacing or [ON/OFF/...] <1.00000>: **ON** (↵)
Command: **-SNAP** (↵)
Specify snap spacing or [ON/OFF/.../style...] <0.5000>: **5** (↵)
Enter snap grid style [Standard/Isometric] <S>: **I** (↵)
Specify vertical spacing <0.5000>: **1** (↵)

(iii) The cross hair now will be displayed at an isometric angle.

(2) To set Isoplane (Refer module 26-15, 26-16)

(i) There are three orientation of crosshairs, isotop, isoright and isoleft.

(ii) These orientation are set by isoplane command, the sequence is as below:
Command: **ISOPLANE** (↵)
Enter isometric plane setting [Left/Top/Right] <Top>: **T** (↵)
Current Isoplane: **Top**

(iii) We can also toggle among different isoplanes using the **F5** function key.

(3) Drawing isometric circles (Refer module 26-16)

(i) Isometric circles are drawn in three planes i.e. isotop, isoright and isoleft.

(ii) So first set the isoplane using ISOPLANE command.

(iii) Now use isocircle option of ELLIPSE command to create isometric circle. The sequence is as below:
Command: **ELLIPSE** (↵)

(iv) For this use STYLE command to create two text styles (iso 30 and iso 330) having 30° and 330° oblique angle as shown in module 26-18.

(v) Set the isoplane and use DT (Dynamic Text) command to write text in respective plane.

(5) Isometric dimension (Refer module 26-17)

(i) Dimension the distance using DIMALIGNED command.

(ii) Change the oblique angle of dimension by using oblique option of DIMEDIT command. Note: The oblique angle is determined by the angle the extension line of the isometric dimension makes with the positive X-axis.

Module 26-15. *Draw a isometric line diagram as shown in fig. 26-24(ii), use Grid, Snap and Isoplane commands.*

(1) Command: **GRID** (↵)
Specify grid spacing(X) or [ON/OFF/Snap/Major/aDaptive/...] <0.5000>: 1 (↵)
(2) Command: **GRID** (↵)
Specify grid spacing(X) or [ON/OFF/Snap/Major/aDaptive/...] <1.0000>: **ON** (↵)
(3) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Aspect/Style/Type] <0.5000>: **STYLE** (↵)
Enter snap grid style [Standard/Isometric] <S>: **ISOMETRIC** (↵)
Specify vertical spacing <0.5000>: (↵)
(4) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Style/Type] <0.5000>: **OFF** (↵)
(5) Command: **ISOPLANE** (↵)
Current isoplane: **Right**
Enter isometric plane setting [Left/Top/Right] <Left>: **RIGHT** (↵)
Current isoplane: **Right**
(6) Command: **LINE** (↵)
Specify first point: **6,1** (↵)
Specify next point or [Undo]: **4** (↵) (When **30°** POLAR is ON)
Specify next point or [Undo]: **4** (↵) (When **90°** POLAR is ON)
Specify next point or [Close/Undo]: 4 (↵) (When **210°** POLAR is ON)
Specify next point or [Close/Undo]: **C** (↵)

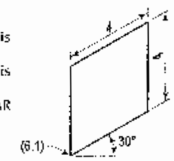
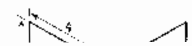


FIG. 26-24(ii)

(7) Command: **ISOPLANE** (↵)
Current isoplane: **Right**
Enter isometric plane setting [Left/Top/Right] <Left>: **LEFT** (↵)
Current isoplane: **Left**
(8) Command: **LINE** (↵)



(10) Command: **LINE** (↵)
Specify first point: (Select ENDPOINT magnet **E1**)
Specify next point or [Undo]: **4** (↵) (When **150°** POLAR is ON)
Specify next point or [Undo]: **4** (↵) (When **210°** POLAR is ON)
Specify next point or [Close/Undo]: (↵)
(11) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Aspect/Style/Type] <0.5000>: **STYLE** (↵)
Enter snap grid style [Standard/Isometric] <S>: **STANDARD** (↵)
Specify vertical spacing <0.5000>: (↵)

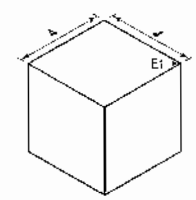
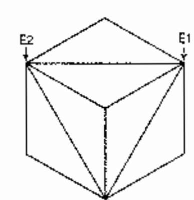


FIG. 26-24(iii)

(12) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Style/Type] <0.5000>: **OFF** (↵)
(13) Save this File As **Module 26-15.DWG**

Module 26-16. *Open the file Module 26-15.DWG and create Isocircles in each isoplane using Ellipse command.*

(1) Open The File **Module 26-15.DWG**
(2) Command: **GRID** (↵)
Specify grid spacing(X) or [ON/OFF/Snap/Major/aDaptive/...] <0.5000>: **1** (↵)
(3) Command: **GRID** (↵)
Specify grid spacing(X) or [ON/OFF/Snap/Major/aDaptive/...] <1.0000>: **ON** (↵)
(4) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Aspect/Style/Type] <0.5000>: **STYLE** (↵)
Enter snap grid style [Standard/Isometric] <S>: **ISOMETRIC** (↵)
Specify vertical spacing <0.5000>: (↵)
(5) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Style/Type] <0.5000>: **OFF** (↵)
(6) Command: **LINE** (↵)
Specify first point: (Select ENDPOINT magnet **E1**)
Specify next point or [Close/Undo]: (Select ENDPOINT magnet **E2**)
Specify next point or [Close/Undo]: (Select ENDPOINT magnet **E3**)
Specify next point or [Close/Undo]: (↵)



(7) Command: **ISOPLANE** (↵)
Current isoplane: **Left**

(10) Command: **ELLIPSE** (↵)
Specify axis endpoint of ellipse or [Arc/Center/ Isocircle]: **I** (↵)
Specify center of isocircle: (Select MIDPOINT magnet **M2** by mouse)
Specify radius of isocircle or [Diameter]: **1.25** (↵)
(11) Command: **ISOPLANE** (↵)
Current isoplane: **Right**
Enter isometric plane setting [Left/Top/Right] <Left>: **LEFT** (↵)
Current isoplane: **Left**
(12) Command: **ELLIPSE** (↵)
Specify axis endpoint of ellipse or [Arc/Center/ Isocircle]: **I** (↵)
Specify center of isocircle: (Select MIDPOINT magnet **M3** by mouse)
Specify radius of isocircle or [Diameter]: **1.25** (↵)
(13) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Aspect/Style/Type] <0.5000>: **STYLE** (↵)
Enter snap grid style [Standard/ Isometric] <S>: **STANDARD** (↵)
Specify vertical spacing <0.5000>: (↵)
(14) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Style/Type] <0.5000>: **OFF** (↵)
(15) Save this File As **Module 26-16.DWG**

Module 26-17. *Open the file Module 26-15.DWG and create Aligned dimensions.*

(1) Open the file **Module 26-15.DWG**
(2) Command: **DIMDEC** (↵)
Enter new value for DIMDEC <4>: **1** (↵)
(3) Command: **DIMALIGNED** (↵)
Specify first extension line origin or <select object>: (Select ENDpoint **E1**)
Specify second extension line origin: (Select ENDpoint **E2**)
Specify dimension line location or
[Mtext/Text/Angle]: (Click below line **L1**)
Dimension text = 4.0000

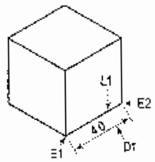
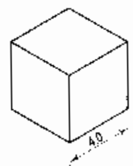


FIG. 26-26(i)

(4) Command: **DIMEDIT** (↵)
Enter type of dimension editing [Home/New/Rotate/Oblique] <Home>: **O** (↵)
Select objects: (Select dimension **D1**)
Select objects: (↵)
Enter obliquing angle (press ENTER for none): **90** (↵)
(5) Command: **DIMALIGNED** (↵)
Specify first extension line origin or <select object>: (Select ENDpoint **E3**)
Specify second extension line origin: (Select ENDpoint **E4**)



Specify dimension line location or
[Mtext/Text/Angle]: (Click Left of line **L3**)
Dimension text = 4.0000
(8) Enter type of dimension editing [Home/New/Rotate/Oblique] <Home>: **O** (↵)
Select objects: (Select dimension **D3**)
Select objects: (↵)
Enter obliquing angle (press ENTER for none): **150** (↵)
(9) Save this File As **Module 26-17.DWG**

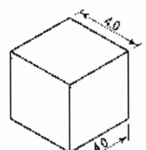


FIG. 26-26(iv)

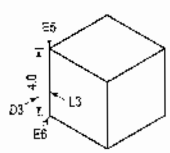


FIG. 26-26(v)

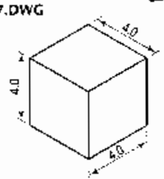


FIG. 26-26(vi)

Module 26-18. *Open the file Module 26-15.DWG and create Isotext in each plane as shown in fig. 26-27(iii).*

(1) Open the File **Module 26-15.DWG**
(2) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Style/Type] <0.5000>: **S** (↵)
Enter snap grid style [Standard/Isometric] <I>: **I** (↵)
Specify vertical spacing <0.5000>: (↵)
(3) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Style/Type] <0.5000>: **OFF** (↵)
(4) Command: **ISOPLANE** (↵)
Current isoplane: **Left**
Enter isometric plane setting [Left/Top/Right] <Top>: **TOP** (↵)
Current isoplane: **Top**
(5) Command: **-STYLE** (↵)
Enter name of text style or [?] <ISO330>: **ISO30** (↵)
Specify full font name or font filename (TTF or SHX) <ROMANS.shx>: **ROMANTIC** (↵)
Specify height of text or [Annotative] <0.2000>: **0.18** (↵)
Specify width factor <1.0000>: (↵)

(7) Command: **ISOPLANE** (↵)
Current isoplane: **Top**
Enter isometric plane setting [Left/Top/Right] <Right>: **RIGHT** (↵)
Current isoplane: **Right**

(8) Command: **DT** (↵)
Current text style: "ISO30" Text height: 0.1800 Annotative: No
Specify start point of text or [Justify/Style]: **J** (↵)
Enter an option [Align/Fit/Center/Middle/Right/TL/TC/TR/ML/MC/MR/BL/BC/BR]: **BC** (↵)
Specify bottom-center point of text: (Select MIDpoint **M2**)
Specify rotation angle of text <330>: **30** (↵)
Enter text: **HOUSE** (↵)
Enter text: (↵)

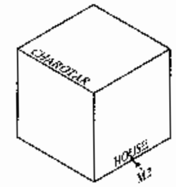


Fig. 26-27(ii)

(9) Command: **ISOPLANE** (↵)
Current isoplane: **Right**
Enter isometric plane setting [Left/Top/Right] <Top>: **FRONT** (↵)
Current isoplane: **Front**

(10) Command: **-STYLE** (↵)
Enter name of text style or [?] <ISO30>: **ISO330** (↵)
Specify full font name or font filename (TTF or SHX) <ROMANS.shx>: **ROMANTIC** (↵)
Specify height of text or [Annotative] <0.2000>: **0.18** (↵)
Specify width factor <1.0000>: (↵)
Specify obliquing angle <30>: **330** (↵)
Display text backwards? [Yes/No] <No>: (↵)
Display text upside-down? [Yes/No] <No>: (↵)
Vertical? [Yes/No] <No>: (↵)
"ISO330" is now the current text style.

(11) Command: **DT** (↵)
Current text style: "ISO330" Text height: 0.1800 Annotative: No
Specify start point of text or [Justify/Style]: **J** (↵)
Enter an option [Align/Fit/Center/Middle/Right/TL/TC/TR/ML/MC/MR/BL/BC/BR]: **BC** (↵)
Specify bottom-center point of text: (Select MIDpoint **M3**)
Specify rotation angle of text <30>: **330** (↵)
Enter text: **PUBLISHING** (↵)
Enter text: (↵)

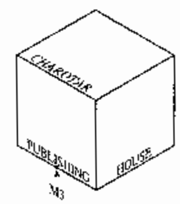


Fig. 26-27(iii)

(12) Command: **SNAP** (↵)
Specify snap spacing or [ON/OFF/Style/Type] <0.5000>: **5** (↵)

26-9-1. 3D WIREFRAME MODELLING

It represents a model by it's edge only. Nothing is between the edges and so cannot hide objects that are behind them. Fig. 26-28 shows a simple 3D Wireframe model. It is made of 18 lines with four circles represnting the edges of a round hole. It gives the look of 3D but it is not real 3D. You cannot apply Boolean operations on them and cannot calculate the mass properties. It can be used as skeleton for surface and solid modeling.

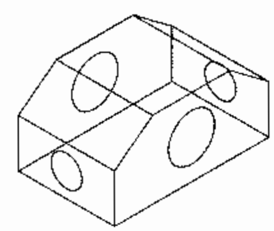


Fig. 26-28

Commonly used 3D command to generate 3D wire frame model are discussed below:

(1) VPOINT command: The VPOINT command is used to set the viewpoint in 3D space for viewing the 3D models. There are basic 4 isometric views to set view point. They are given below with their coordinates value to set. Enter any of this coordinate value against the command prompt.

(i) South West Isometric view −1, −1, 1
(ii) South East Isometric view 1, −1, 1
(iii) North East Isometric view 1, 1, 1
(iv) North West Isometric view −1, 1, 1

The command sequence is given below.

Command : **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1, −1, 1** (↵)
Regenerating model.

(2) UCS Command: The UCS command is used to set a new coordinate system by shifting the working *XY* plane to the desired location. "New" option will create new UCS by "3point" or "Zaxis" method and "Move" option will shift the UCS at desired location by entering coordinates *(X, Y, Z)* or using Osnap magnet. The command sequence is given below.

Command: **UCS** (↵)

(3) 3D Cylindrical Coordinate Method (fig. 26-29) (Refer module 26-20): **The** points for some 3D models such as helix and spirals are entered by using this method.

Format: $D < A, Z$

where D = Point's distance in *XY* plane from fixed origin
A = Point's angle on the *XY* plane from *X* axis
Z = Point's distance from *XY* plane

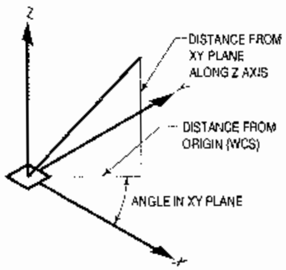


Fig. 26-29

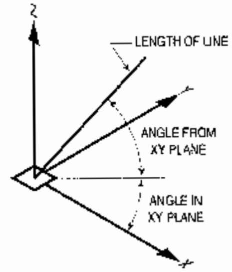


Fig. 26-30

(4) 3D Spherical Coordinate Method (fig. 26-30) (Refer module 26-20): It uses a distance and two angles to specify points in space.

Format: $D < HA < VA$

where D = Point's straight line distance from fixed origin
HA = Point's **angle** on *XY* plane from *X* axis
VA = Point's vertical angle from *XY* plane.

Methods (1) to (4) are explained below vide self interactive module 26-19 and module 26-20.

Module 26-19. *To generate 3D Wireframe model as shown in fig. 26-31 using 3D Absolute Coordinate Method and 3D Rectangular Coordinate Method.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000

Specify next point or [Close/Undo]: **0,8,0** (↵)
Specify next point or [Close/Undo]: **C** (↵)

(4) Command: **LINE** (↵)
Specify first point: **5,0,0** (↵)
Specify next point or [Undo]: **@0,0,4** (↵)
Specify next point or [Undo]: **@0,2,0** (↵)
Specify next point or [Close/Undo]: **@0,2,−1.5** (↵)
Specify next point or [Close/Undo]: **@0,2,1.5** (↵)
Specify next point or [Close/Undo]: **@0,2,0** (↵)
Specify next point or [Close/Undo]: **@0,0,−4** (↵)
Specify next point or [Close/Undo]: (↵)

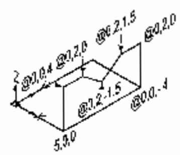


Fig. 26-31(i)

(5) Command: **LINE** (↵)
Specify first point: **0,0,0** (↵)
Specify next point or [Undo]: **@0,0,4** (↵)
Specify next point or [Undo]: **@0,2,0** (↵)
Specify next point or [Close/Undo]: **@0,2,−1.5** (↵)
Specify next point or [Close/Undo]: **@0,2,1.5** (↵)
Specify next point or [Close/Undo]: **@0,2,0** (↵)
Specify next point or [Close/Undo]: **@0,0,−4** (↵)
Specify next point or [Close/Undo]: (↵)

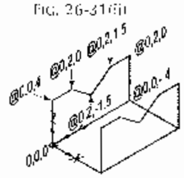


Fig. 26-31(ii)

(6) Similarly using LINE Command and Osnap Magnet create remaining Lines and complete the diagram.

(7) Save This File As **3D-WF-1.DWG**

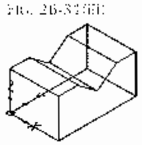
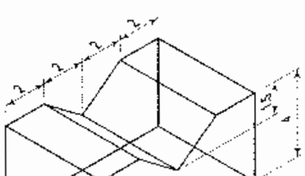


Fig. 26-31(iv)

Output of Module 26-19 (fig. 26-31)



Specify next point or [Undo]: **6<90,3.461** (↵)
Specify next point or [Close/Undo]: **2<90,3.4641** (↵)
Specify next point or [Close/Undo]: **C** (↵)

FIG. 26-32(ii)

(2) Command: **UCS** (↵)
Current ucs name: ***TOP***
Enter an option [New/Move/orthoGraphic/Prev/...] <World>: **M** (↵)
Specify new origin point or [Zdepth]<0,0,0>: **5,0,0** (↵)

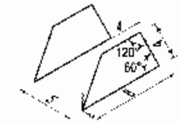


FIG. 26-32(i)

(3) Command: **LINE** (↵)
Specify first point: **0,0,0** (↵)
Specify next point or [Undo]: **8<90<0** (↵)
Specify next point or [Undo]: **@4<90<120** (↵)
Specify next point or [Close/Undo]: **@4<90<180** (↵)
Specify next point or [Close/Undo]: **C** (↵)
(4) Using Line command and Osnap magnet complete the diagram as shown in fig. 26-32
(5) Save This File As **3D-WF-2.DWG**

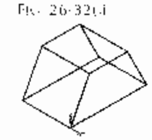


FIG. 26-32

26-9-2. 3D SURFACE MODELLING

In this modeling the objects are created by use of surfaces attached to 3D Wireframe models. The attached surfaces have zero thickness so cannot calculate the mass properties. It can hide objects that are behind them. These models are just empty shells. The surfaces are flat, with curved and rounded surfaces approximated by small rectangular or triangular faces.

Commands used to create 3D Surface Models:

(1) Vpoint: Refer detail on page no. 666

(2) UCS: Refer detail on page no. 666

(3) SHADEMODE command: The SHADEMODE command generates a simple shaded picture of the solids and surface models displayed in the current viewport. It will hide all back portion by "Hide" option. "Realistic" and 'Conceptual' option will

Module 26-21. *To generate 3D Surface using ELEV command model as shown in fig. 26-33.*

(1) Command: **VPOINT** (↵)
Current view direction. VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass.. >: **1,-1,1** (↵)
Regenerating model.
(2) Command: **ELEV** (↵)
Specify new default elevation <0.0000>: (↵)
Specify new default thickness <0.0000>: **4** (↵)
(3) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **0,0** (↵)
Specify radius of circle or [Diameter]: 4 (↵)


FIG. 26-33(i)

(4) Command: **ELEV** (↵)
Specify new default elevation <0.0000>: **4** (↵)
Specify new default thickness <4.0000>: (↵)
(5) Command: **POLYGON** (↵)
Enter number of sides <4>: **6** (↵)
Specify center of polygon or [Edge]: **0,0** (↵)
Enter an option [Inscribed in circle/Circumscribed about circle] <I>: (↵)
Specify radius of circle: 2 (↵)

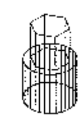


FIG. 26-33(ii)

(6) Command: **ELEV** (↵)
Specify new default elevation <4.0000>: **8** (↵)
Specify new default thickness <4.0000>: (↵)
(7) Command: **POINT** (↵)
Current point modes: PDMODE=0 PDSIZE=0.0000
Specify a point: **0,0** (↵)
(8) Save This File As **3D-SURFACE-ELEV-1.DWG**

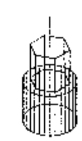


FIG. 26-33

(5) 3DFACE command: It is used for making planar unmeshed surfaces that have three or four sides. They can hide objects, and can be coloured during rendering and shading. The command sequence is explained below vide self interactive module 26-22.

Specify second point or [Invisible]: (Select Point **P2** by Osnap magnet)
Specify third point or [Invisible] <exit>: (Select Point **P3** by Osnap magnet)
Specify fourth point or [Invisible] <create...>: (Select Point **P4** by Osnap magnet)
Specify third point or [Invisible] <exit>: (Select Point **P5** by Osnap magnet)
Specify fourth point or [Invisible] <create...>: (Select Point **P4** by Osnap magnet)
Specify third point or [Invisible] <exit>: (↵)
(4) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **R** (↵)
(5) Save This File As **3DFACE-1.DWG**

(6) PFACE command: It creates planar surfaces on more than 3 vertices of 3D wireframe model. The faces made are tied together as a single object and edges between the faces are invisible. The surfaces generated are polyline variation called a polyline mesh. The command sequence is explained below vide self interactive module 26-23.

Module 26-23. *To generate surface using PFACE command on 3D wireframe model as shown in fig. 26-35.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass...>: **1,-1,1** (↵)
Regenerating model.
(2) Create 3D Wireframe as shown in fig. 26-35
(3) Command: **PFACE** (↵)
Specify location for vertex 1: (Select **P1** by Osnap magnet)
Specify location for vertex 2 or <define faces>: (Select **P2** by Osnap magnet)
Specify location for vertex 3 or <define faces>: (Select **P3** by Osnap magnet)
Specify location for vertex 4 or <define faces>: (Select P4 by Osnap magnet)
Specify location for vertex 5 or <define faces>: (Select **P5** by Osnap magnet)
Specify location for vertex 6 or <define faces>: (↵)
Face 1, vertex **1**:
Enter a vertex number or [Color/Layer]: **1** (↵)
Face 1, vertex 2:
Enter a vertex number or [Color/Layer] <next face>: **2** (↵)
Face 1, vertex 3:
Enter a vertex number or [Color/Layer] <next face>: **3** (↵)
Face 1, vertex 4:
Enter a vertex number or [Color/Layer] <next face>: **4** (↵)

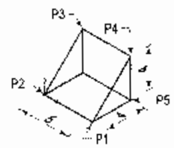


FIG. 26-35

(4) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/.../Conceptual/Other] <Conceptual>: **C** (↵)
(5) Save This File As **PFACE-1.DWG**

(7) Revolve surface command: REVSURF command creates a polygon mesh surface by revolving 2D profile object about an axis. The profile can be open or closed and axis will be a line, an open 2D polyline or an open 3D polyline. The command sequence is explained below vide self interactive module 26-24. The surfaces are generated by the matrix of number of surfaces in longitudinal and latitudunal direction. Their default values are 6 × 6 and are controlled by the command **Surftab1** and **Surftab2**.

Module 26-24. *Create revolved surface using REVSURF command as per fig. 26-36.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)
Regenerating model.
(2) Command: **UCS** (↵)
Current ucs name: ***WORLD***
Enter an option [New/Move/orthoGraphic/Prev/Restore/Save/...]<World>: **G** (↵)
Enter an option [Top/Bottom/Front/BAck/Left/Right]<Top>: **FRONT** (↵)
(3) Command: **PLINE** (↵)
Specify start point. **4,0** (↵)
Current line-width is 0.0000
Specify next point or [Arc/Halfwidth/Length/Undo/Width]: **@-2,4** (↵)
Specify next point or [Arc/Close/Halfwidth/Length/Undo/Width]: **@0,2** (↵)
Specify next point or [Arc/Close/Halfwidth/Length/Undo/Width]: **@-2,0** (↵)
Specify next point or [Arc/Close/Halfwidth/Length/Undo/Width]: (↵)

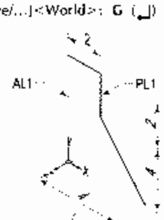
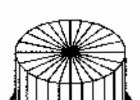


FIG. 26-36(i)

(4) Command: **LINE** (↵)
Specify first point: **0,0** (↵)
Specify next point or [Undo]: **0,6** (↵)
Specify next point or [Undo]: (↵)
(5) Command: **SURFTAB1** (↵)
Enter new value for SURFTAB1 <6>: **24** (↵)



(8) **Tabulated surfaces:** TABSURF command creates a polygon mesh surface by extruding a defining curve in a direction specified by an existing object. The first object to be selected is a path curve (open or closed) and second to be selected is a direction vector, must be a line, an open polyline or an open3D polyline. The path curve can be a line, circle, arc, 2Dpolyline, 3Dpolyline, ellipse or spline. It uses SURFTAB1 command to generate number of surfaces. The command sequence is explained below vide self interactive module 26-25.

Module 26-25. *To generate Surface using TABSURF command as per fig. 26-37.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Command: **PLINE** (↵)
Specify start point: **0,0** (↵)
Current line-width is 0.0000
Specify next point or [Arc/Halfwidth/Length...]: **ARC** (↵)
Specify endpoint of arc or
[Angle/CEnter/Direction/Halfwidth/Line/Radius/...]: **0,4** (↵)
Specify endpoint of arc or
[Angle/CEnter/CLose/Direction/Halfwidth/Line/Radius/...]: **@0,4** (↵)
Specify endpoint of arc or
[Angle/CEnter/CLose/Direction/Halfwidth/Line/Radius/...]: (↵)

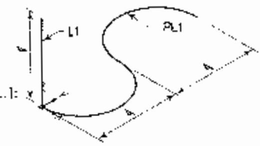
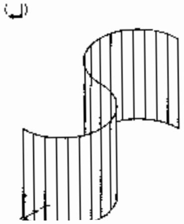


Fig. 26-37(i)

(3) Command: **LINE** (↵)
Specify first point: **0,0** (↵)
Specify next point or [Undo]: **@0,0,4** (↵)
Specify next point or [Undo]: (↵)

(4) Command: **SURFTAB1** (↵)
Enter new value for SURFTAB1 <6>: **24** (↵)

(5) Command: **TABSURF** (↵)
Current wire frame density: SURFTAB1=24
Select object for path curve: (Select Polyline **PL1**)



Module 26-26. *To generate Surface using RULESURF command as per fig. 26-38.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Command: **LINE** (↵)
Specify first point: **0,0** (↵)
Specify next point or [Undo]: **0,4** (↵)
Specify next point or [Undo]: (↵)

(3) Command: **ARC** (↵)
Specify start point of arc or [Center]: **0,0,4** (↵)
Specify second point of arc or [Center/End]: **E** (↵)
Specify end point of arc: **@0,4** (↵)
Specify center point of arc or [Angle/Direction/Radius]: **A** (↵)
Specify included angle: **–180** (↵)

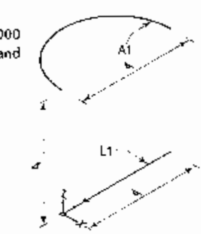


Fig. 26-38(i)

(4) Command: **SURFTAB1** (↵)
Enter new value for SURFTAB1 <6>: **24** (↵)

(5) Command: **RULESURF** (↵)
Current wire frame density: SURFTAB1=24
Select first defining curve: (Select Line **L1**)
Select second defining curve: (Select Arc **A1**)

(6) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(7) Save This File As **RULEDSURFACE-1.DWG**

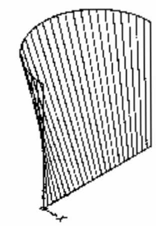


Fig. 26-38

(10) **Edge surfaces:** EDGESURF command creates a polygon mesh surface between four boundary 2D curves. The curves can be a lines, arcs, open 2D or 3D polylines or splines. Their ends must touch. It uses SURFTAB1 and SURFTAB2 commands to generate number of surfaces. The command sequence is explained below vide self interactive module 26-27 and fig. 26-39.

Module 26-27. *To generate Surface using EDGESURF command as per fig. 26-39.*

(1) Command: **VPOINT** (↵)

Specify second point of arc or [Center/End]: **E** (↵)
Specify end point of arc: **0,0** (↵)
Specify center point of arc or [Angle/Direction/Radius]: **A** (↵)
Specify included angle: **180** (↵)

(5) Command: **ARC** (↵)
Specify start point of arc or [Center]: **4,0** (↵)
Specify second point of arc or [Center/End]: **E** (↵)
Specify end point of arc: **4,4** (↵)
Specify center point of arc or [Angle/Direction/Radius]: **A** (↵)
Specify included angle: **180** (↵)

(6) Command: **SURFTAB1** (↵)
Enter new value for SURFTAB1 <6>: **24** (↵)

(7) Command: **SURFTAB2** (↵)
Enter new value for SURFTAB1 <6>: **24** (↵)

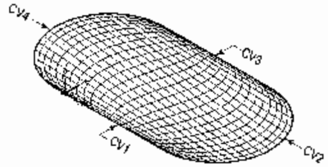


Fig. 26-39

(8) Command: **EDGESURF** (↵)
Current wire frame density: SURFTAB1=24 SURFTAB2=24
Select object 1 for surface edge: (Select curve **CV1**)
Select object 2 for surface edge: (Select curve **CV2**)
Select object 3 for surface edge: (Select curve **CV3**)
Select object 4 for surface edge: (Select curve **CV4**)

(9) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(10) Save This File As **EDGESURFACE-1.DWG**

(11) 3DMESH: 3DMESH command creates a polygon mesh surface of *M* and *N* direction. If we consider *M* as number of vertices in *X* direction then *N* becomes number of vertices in *Y* direction. The command sequence is explained below vide self interactive module 26-28.

Module 26-28. *To generate Surface using 3DMESH command as per fig. 26-40.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR 0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Create 2D wireframe as shown fig. 26-40(i)

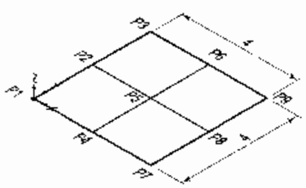


Fig. 26-40(i)

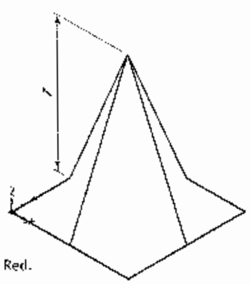


Fig. 26-40

(4) 1. Select any line
2. Select middle blue box so it will become Red.
3. Type @0,0,7 and press Enter key.
4. Press Esc key.

(5) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(6) Save This File As **3DMESH-1.DWG**

(12) 3D Standard shaped surface: Eight numbers of standard shapes are available in CAD to create 3D basic shaped surfaces. They are Box, Pyramid, Wedge, Dome, Dish, Sphere, Cone and Torus. The command sequence for each shape is explained below vide self interactive examples. (module 26-29 to module 26-36 and fig. 26-41 to fig. 26-48.

Module 26-29. *To generate Surface using BOX option of 3D command as per fig. 26-41.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Command: **3D** (↵)

Module 26-30. *To generate Surface using PYRAMID option of 3D command as per fig. 26-42.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)
Regenerating model.

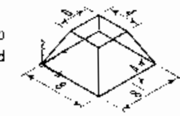


FIG. 26-42

(2) Command: **3D** (↵)
Initializing... 3D Objects loaded.
Enter an option
[Box/Cone/DIsh/DOme/Mesh/Pyramid/Sphere/Torus/Wedge]: **PYRAMID** (↵)
Specify first corner point for base of pyramid: **0,0** (↵)
Specify second corner point for base of pyramid: **8,0** (↵)
Specify third corner point for base of pyramid: **8,8** (↵)
Specify fourth corner point for base of pyramid or [Tetrahedron]: **0,8** (↵)
Specify apex point of pyramid or [Ridge/Top]: **TOP** (↵)
Specify first corner point for top of pyramid: **@2,2,4** (↵)
Specify second corner point for top of pyramid: **@-2,2,4** (↵)
Specify third corner point for top of pyramid: **@-2,-2,4** (↵)
Specify fourth corner point for top of pyramid: **@2,-2,4** (↵)

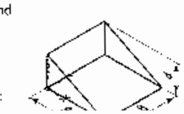
(3) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(4) Save This File As **3DPYRAMIDSURFACE-1.DWG**

Module 26-31. *To generate Surface using WEDGE option of 3D command as per fig. 26-43.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)
Regenerating model.

(2) Command: **3D** (↵)
[Box/Cone/DIsh/DOme/Mesh/Pyramid/Sphere/Torus/Wedge]:



Module 26-32. *To generate Surface using SPHERE option of 3D command as per fig. 26-44.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)
Regenerating model.

(2) Command: **3D** (↵)
Initializing... 3D Objects loaded.
Enter an option
[Box/Cone/DIsh/DOme/Mesh/Pyramid/Sphere/Torus/Wedge]: **SPHERE** (↵)

FIG. 26-44

Specify center point of sphere: **0,0** (↵)
Specify radius of sphere or [Diameter]: **8** (↵)
Enter number of longitudinal segments for surface of sphere <16>: (↵)
Enter number of latitudinal segments for surface of sphere <16>: (↵)

(3) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(4) Save This File As **3DSPHERESURFACE-1.DWG**

Module 26-33. *To generate Surface using CONE option of 3D command as per fig. 26-45.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)
Regenerating model.

(2) Command: **3D** (↵)
Initializing... 3D Objects loaded.
Enter an option
[Box/Cone/DIsh/DOme/Mesh/Pyramid/Sphere/Torus/Wedge]: **CONE** (↵)
Specify center point for base of cone: **0,0** (↵)
Specify radius for base of cone or [Diameter]: **4** (↵)
Specify radius for top of cone or [Diameter] <0>: (↵)

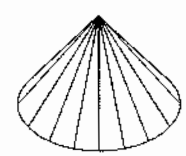


FIG. 26-45

(2) Command: **3D** (↵)
Initializing... 3D Objects loaded.
Enter an option
[Box/Cone/DIsh/DOme/Mesh/Pyramid/Sphere/Torus/Wedge]: **DOME or DISH** (↵)
Specify center point of sphere: **0,0** (↵)
Specify radius of sphere or [Diameter]: **8** (↵)
Enter number of longitudinal segments for surface of sphere <16>: (↵)
Enter number of latitudinal segments for surface of sphere <16>: (↵)

3D DOME

3D DISH

FIG. 26-46

(3) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(4) Save This File As **3DDOMESURFACE-1.DWG**

Module 26-35. *To generate Surface using TORUS option of 3D command as per fig. 26-47.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)
Regenerating model.

(2) Command: **3D** (↵)
Initializing... 3D Objects loaded.
Enter an option
[Box/Cone/DIsh/DOme/Mesh/Pyramid/Sphere/Torus/Wedge]: **TORUS** (↵)
Specify center point of torus: **0,0** (↵)
Specify radius of torus or [Diameter]: **8** (↵)
Specify radius of tube or [Diameter]: **2** (↵)
Enter number of segments around tube circumference <16>: (↵)
Enter number of segments around torus circumference <16>: (↵)

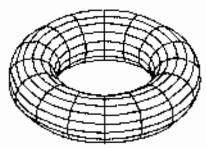


FIG. 26-47

(3) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

Specify first corner point of mesh: **0,0** (↵)
Specify second corner point of mesh: **8,0** (↵)
Specify third corner point of mesh: **8,8** (↵)
Specify fourth corner point of mesh: **0,8** (↵)
Enter mesh size in the M direction: 4 (↵)
Enter mesh size in the N direction: **8** (↵)

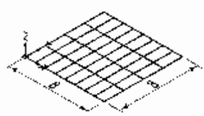


FIG. 26-48

(3) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **C** (↵)

(4) Save This File As **MESHSURFACE-1.DWG**

26-9-3. 3D SOLID MODELLING

Solid modeling is the process of building objects that have all the attributes of an actual solid object. It has mass, weight, volume, center of gravity, moment of inertia etc. in addition to surfaces and edges. We can cut, join and create holes and cavities. It is a single object and are used as a part to create assemblies and interference check. It eliminates the need for building expensive prototypes and makes the product development cycle shorter. The solid model created on the cad software are based on a program called the ACIS Geometrical Modeler. So they are also called ACIS solids. There are two methods to create solids.

Method I: Standard 3D shapes based solids:

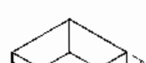
In this method six types of standard shapes available in cad are used to generate solids of different shapes. These shapes are Box, Wedge, Cylinder, Cone, Sphere and Torus. They are also called primitives. The command sequence for each shape is explained below vide self interactive examples (Module 26-37 to Module 26-42 and fig. 26-49 to fig. 26-54.

Module 26-37. *To generate 3D Solid box using BOX command as per fig. 26-42(i).*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)
Regenerating model.

(2) Command: **ISOLINES** (↵)
Enter new value for ISOLINES <4>: **16** (↵)

(3) Command: **BOX** (↵)



(2) Command: **ISOLINES** (↵)
Enter new value for ISOLINES <4>: **16** (↵)

(3) Command: **WEDGE** (↵)
Specify first corner or [CEnter]: **0,0,0** (↵)
Specify other corner or [Cube/Length]: **L** (↵)
Specify length: **8** (↵)
Specify width: **8** (↵)
Specify height or [2Point]: **4** (↵)

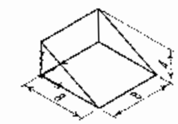


FIG. 26-50

(4) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(5) Save This File As **3DWEDGESOLID-1.DWG**

Module 26-39. *To generate 3D Solid cylinder using CYLINDER command as per fig. 26-51.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Command: **ISOLINES** (↵)
Enter new value for ISOLINES <4>: **16** (↵)

(3) Command: **CYLINDER** (↵)
Specify center point of base or [3P/2P/Ttr/Elliptical]: **0,0,0** (↵)
Specify base radius or [Diameter]: **4** (↵)
Specify height or [2Point/Axis endpoint]: **8** (↵)

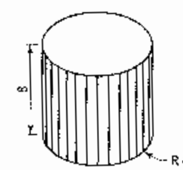


FIG. 26-51

(4) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(5) Save This File As **3DCYLINDERSOLID-1.DWG**

Module 26-40. *To generate 3D Solid cone using CONE command as per fig. 26-52.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Command: **ISOLINES** (↵)

Module 26-41. *To generate 3D Solid sphere using SPHERE command as per fig. 26-53.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Command: **ISOLINES** (↵)
Enter new value for ISOLINES <4>: **16** (↵)

(3) Command: **SPHERE** (↵)
Specify center point or [3P/2P/Ttr]: **3** (↵)
Specify radius or [Diameter]: **4** (↵)

FIG. 26-53

(4) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(5) Save This File As **3DSPHERESOLID-1.DWG**

Module 26-42. *To generate 3D Solid torus using TORUS command as per fig. 26-54.*

(1) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.

(2) Command: **ISOLINES** (↵)
Enter new value for ISOLINES <4>: **16** (↵)

(3) Command: **TORUS** (↵)
Specify center point or [3P/2P/Ttr]: **0,0,0** (↵)
Specify radius or [Diameter] <1.5000>: **8** (↵)
Specify tube radius or [2Point/Diameter] <2.0000>: **2** (↵)

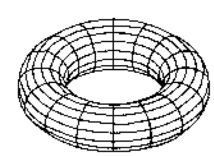


FIG. 26-54

(4) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

(5) Save This File As **3DTORUSSOLID-1.DWG**

Method II: Profile based solids:

In this method the following steps are performed.

(1) Create 2D closed profile in *XY* plane using 2D commands.

(2) Generate surface on this profile by using REGION command.

(3) Use EXTRUDE command to provide height to this profile in *Z* direction OR use

(4) REGION command: Creates regions from the selected 2D closed objects. They are the 2D objects with properties of 3D solids. All 3D commands are used on regions to generate 3D solids. The command sequence is given below.

Command: **REGION** (↵)
Select objects: (Select 2D closed objects)
Select objects: (↵)
1 loops extracted.
1 Region created.

(5) EXTRUDE command: The EXTRUDE command creates solids by extruding 2D closed single object or region in *Z* direction of UCS or about a specified path. The command sequence is given below.

Command : **EXTRUDE** (↵)
Current wire frame density: ISOLINES=4
Select objects to extrude:
Select objects to extrude: (↵)
Specify height of extrusion or [Direction/Path/Taper angle]: (Enter height value) (↵)

(6) REVOLVE command: The REVOLVE command creates solids by revolving 2D closed single object or region about an object or *X* or *Y* axis of UCS. It can revolve only one object at a time. The command sequence is given below.

Command: **REVOLVE** (↵)
Current wire frame density: ISOLINES=4
Select objects to revolve:
Select objects to revolve: (↵)
Specify axis start point or define axis by [Object/X/Y/Z] <Object>: (Select any option) (↵)
Specify angle of revolution or [STart angle] <360>: 360 (↵)

(7) BOOLEAN OPERATIONS:

(i) *UNION:* The UNION command combines selected regions or solids by addition. The command sequence is given below.

Command: **UNION** (↵)
Select objects: (Select more than one solid)
Select objects: (↵)

(iii) *INTERSECT:* The INTERSECT command creates composite solids or regions from the intersection of two or more solids or regions and removes the areas outside of the intersection. The command sequence is given below.

Command: **INTERSECT** (↵)
Select objects: (Select more than one solid)
Select objects: (↵)

(8) 3DARRAY command: 3DARRAY can create a Rectangular array or a Polar array of objects in 3D. In Rectangular array we have to specify number of columns (*X* direction), number of rows (*Y* direction), and number of levels (*Z* direction). And in Polar array we have to select solids and axis about which solids will be arranged. The command sequence is given below.

(i) ***Command sequence for 3D Rectangular Array***

Command: **3DARRAY** (↵)
Initializing... 3DARRAY loaded.
Select objects: (Select solids)
Select objects: (↵)
Enter the type of array [Rectangular/Polar] <R>: **R** (↵)
Enter the number of rows (---) <1>: (Enter Integer value)
Enter the number of columns (|||) <1>: (Enter Integer value)
Enter the number of levels (...) <1>: (Enter Integer value)
Specify the distance between rows (---): (Enter Integer or Real value)
Specify the distance between columns (|||): (Enter Integer or Real value)
Specify the distance between levels (...): (Enter Integer or Real value)

(ii) ***Command sequence for 3D Polar Array***

Command: **3DARRAY** (↵)
Initializing... 3DARRAY loaded.
Select objects: (Select solids)
Select objects: (↵)
Enter the type of array [Rectangular/Polar] <R>: **P** (↵)
Enter the number of items in the array: (Enter Integer value)
Specify the angle to fill (+=ccw, –=cw) <360>: (↵)
Rotate arrayed objects? [Yes/No] <Y>: (↵)

(10) CHAMFER on 3D solids: CHAMFER command is used to create beveled edges on edges of solids. This command is used both in 2D and 3D. In 3D first we have to select edge of solid to get options of 3D. The command sequence is given below.

Command: **CHAMFER** (↵)
(TRIM mode) Current chamfer Dist 1 = 0.0000, Dist 2 = 0.0000
Select first line or [Undo/Polyline/Distance/Angle/Trim/...]: (Select edge of solid)
Base surface selection...
Enter surface selection option [Next/OK (current)] <OK>: (↵)
Specify base surface chamfer distance: (Enter distance value from base surface)
Specify other surface chamfer distance <2.0000>: (Enter distance value from other surface)
Select an edge or [Loop]: (Select edges on base surface)
Select an edge or [Loop]: (↵)

(11) ROTATE3D command: The ROTATE3D command is used to rotate the solids about *X*, *Y* or *Z* axis of UCS or about an Object to required angle. Positive angle will rotate in counter clock wise direction. The command sequence is given below.

Command: **ROTATE3D** (↵)
Current positive angle: ANGDIR: counterclockwise ANGBASE=0
Select objects: (Select solids)
Select objects: (↵)
Specify first point on axis or define axis by
[Object/Last/View/Xaxis/Yaxis/Zaxis/2points]: (Select required option for axis say Z)
Specify a point on the Z axis <0,0,0>: (Specify base point)
Specify rotation angle or [Reference]: (Enter angle value)

(12) MIRROR3D command: The MIRROR3D command is used to mirror the solids about a specified plane in the space. The plane can be the 2D object or three planes of UCS i.e. *XY*, *YZ*, or *ZX*. The command sequence is given below.

Command: **MIRROR3D** (↵)
Select objects: (Select solids)
Select objects: (↵)
Specify first point of mirror plane (3 points) or
[Object/Last/Zaxis/View/XY/YZ/ZX/3points] <3points>: (Select required option as mirror plane say ZX)
Specify point on ZX plane <0,0,0>: (Select base point)
Delete source objects? [Yes/No] <N>: (↵)

26-10. THREE DIMENSIONAL DRAWINGS

Module 26-43. *Draw a three dimensional diagram as shown in fig. 26-55. Use 3D commands such as Region, Extrude and Subtract.*

To draw a three dimensional diargram using the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-55(i) to fig. 26-55(vii).

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/........] <real time>: **ALL** (↵)

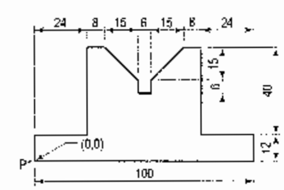


Fig. 26-55(i)

(3) Create 2D diagram (fig. 26-55(i)) Using **Pline** command, take Coordinate of **P1** as **0,0**

(4) Command: **VPOINT** (↵)
Current view direction: VIEWDIR = 0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,-1,1** (↵)

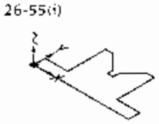


Fig. 26-55(ii)

(5) Command: **REGION** (↵)
Select objects: (Select any Line)
Select objects: (↵)
1 loop extracted.
1 Region created.

(6) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/Conceptual/Other] <Conceptual>: **H** (↵)

Specify a point on the X axis <0,0,0>: (↵)
Specify rotation angle or [Reference]: **90** (↵)

(9) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/........] <real time>: **ALL** (↵)

(10) Command: **UCS** (↵)
Current ucs name: *TOP*
Enter an option [New/Move/orthoGraphic/...] <World>: **M** (↵)
Specify new origin point or [Zdepth]<0,0,0>: (Select Point **SD1**)

(11) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **12,20** (↵)
Specify radius of circle or [Diameter]: **D** (↵)
Specify diameter of circle: **13** (↵)

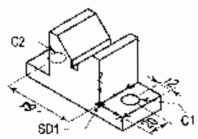


Fig. 26-55(v)

(12) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **-64,20** (↵)
Specify radius of circle or [Diameter] <0.6500>: **D** (↵)
Specify diameter of circle: **13** (↵)

(13) Command: **EXTRUDE** (↵)
Current wire frame density: ISOLINES=4
Select objects: (Select Circle **C1**)
Select objects: (Select Circle **C2**)
Select objects: (↵)
Specify height of extrusion or [Path]: **-40** (↵)

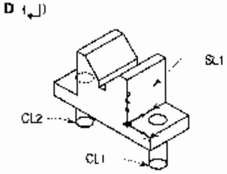


Fig. 26-55(vi)

(14) Command: **SUBTRACT** (↵)
Select solids and regions to subtract from ..
Select objects: (Select Solid **SL1**)
Select objects: (↵)

MODULE 26-43: USE OF 3D COMMANDS REGION, EXTRUDE AND SUBTRACT

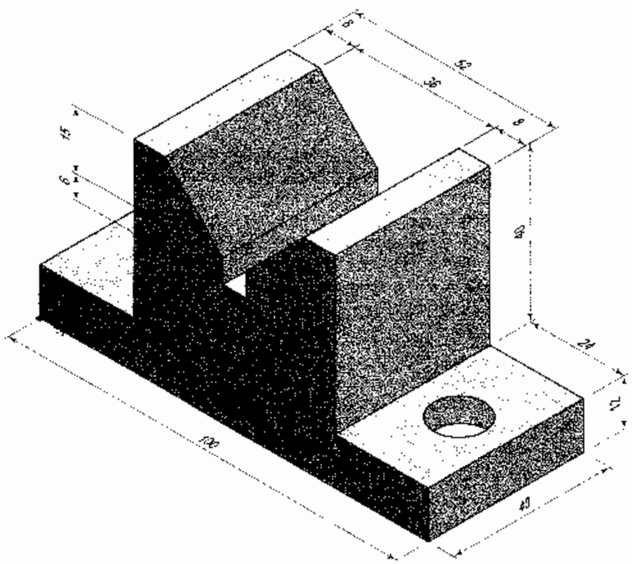


Fig. 26-55

Module 26-44. *Draw a three dimensional diagram as shown in fig. 26-56. Use 3D commands such as Region, Revolve and Fillet.*

(3) Using **PLINE** Command Create 2D diagram (fig. 26-56(i)), take co-ordinate of **P1 0,0**

Fig. 26-56(i)

(4) Command: **VPOINT** (↵)

Current view direction: VIEWDIR = 0.0000,0.0000,1.0000

Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)

Regenerating model.

(5) Command: **REGION** (↵)

Select objects: (Select any Line)

Select objects: (↵)

1 loop extracted.

1 Region created.

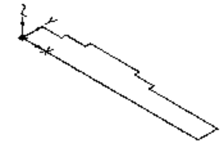


Fig. 26-56(ii)

(6) Command: **SHADEMODE** (↵)

Enter an option [2dwireframe/3dwireframe/3dHidden/Realistic/...] <Conceptual>: H (↵)

(7) Command: **REVOLVE** (↵)

Current wire frame density: ISOLINES=4

Select objects to revolve: (Select any Line)

Select objects to revolve: (↵)

Specify axis start point or define axis by [Object/X/Y/Z] <Object>: **X** (↵)

Specify angle of revolution or [STart angle] <360>: **360** (↵)

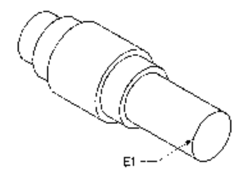


Fig. 26-56(iii)

(8) Command: **ZOOM** (↵)

Specify corner of window, enter a scale factor (nX or nXP), or

[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)

(9) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 0.0000

Select first object or [Polyline/Radius/Trim]: (Select

MODULE 26-44: USE OF 3D COMMANDS REGION, REVOLVE AND FILLET

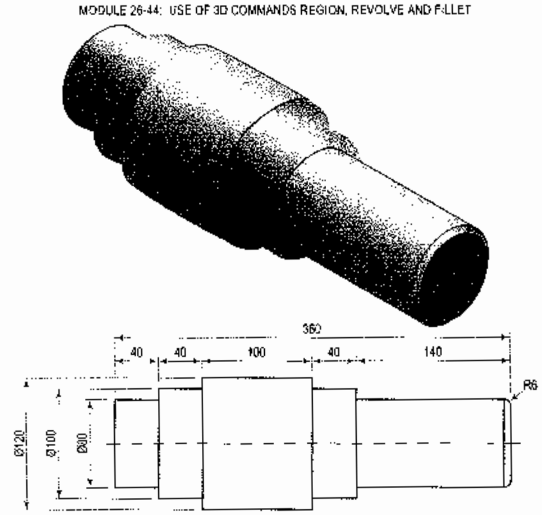


Fig. 26-56

Module 26-45. *Draw a three dimensional diagram as shown in fig. 26-57. Use 3D commands such as Region, Extrude and Union.*

To draw a three dimensional diargram using the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-57(i) to fig. 26-57(ix).

(1) Command: **LIMITS** (↵)

(4) Command: **VPOINT** (↵)

Current view direction: VIEWDIR=0.0000,0.0000,1.0000

Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)

Regenerating model.

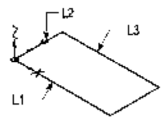


Fig. 26-57(ii)

(5) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 0.0000

Select first object or [Polyline/Radius/Trim]: **R** (↵)

Specify fillet radius <0.0000>: **25** (↵)

Select first object or [Polyline/Radius/Trim]: (Select **L1**)

Select second object: (Select **L2**)


Fig. 26-57(iii)

(6) Command: **FILLET** (↵)

Current settings: Mode = TRIM, Radius = 25.0000

Select first object or [Polyline/Radius/Trim]: (Select **L2**)

Select second object: (Select **L3**)

(7) Command: **CIRCLE** (↵)

Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: (Select CENTER magnet **C1**)

Specify radius of circle or [Diameter]: **D** (↵)

Specify diameter of circle: **24** (↵)

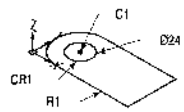


Fig. 26-57(iv)

(8) Command: **EXTRUDE** (↵)

Current wire frame density: ISOLINES=4

Select objects to extrude: (Select Rectangle **R1**)

Select objects to extrude: (↵)

Specify height of extrusion or [Direction/Path/Taper angle] <40.0000>: **40** (↵)

(9) Command: **EXTRUDE** (↵)

Current wire frame density: ISOLINES=4

Select objects to extrude: (Select Circle **CR1**)

Select objects to extrude: (↵)

Specify height of extrusion or [Direction/Path/Taper angle] <40.0000>: **70** (↵)

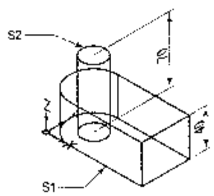


Fig. 26-57(v)

(10) Command: **ZOOM** (↵)

Specify corner of window, enter a scale factor (nX or nXP), or

(12) Command: **UCS** (↵)

Current ucs name: *WORLD*

Enter an option [New/Move/orthoGraphic/Prev/.../World]<World> : **G** (↵)

Enter an option [Top/Bottom/Front/BAck/Left/Right]<Top>: **RIGHT** (↵)

(13) Command: **UCS** (↵)

Current ucs name: *RIGHT*

Enter an option [New/Move/orthoGraphic/Prev/.../World] <World>: **M** (↵)

Specify new origin point or [Zdepth]<0,0,0>: (Select ENDPOINT magnet **E1**)

(14) Command: **CIRCLE** (↵)

Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **2P** (↵)

Specify first end point of circle's diameter: (Select MIDPOINT magnet **M2**)

Specify second end point of circle's diameter: (Select MIDPOINT magnet **M3**)

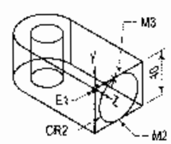


Fig. 26-57(vii)

(15) Command: **EXTRUDE** (↵)

Current wire frame density: ISOLINES=4

Select objects to extrude: (Select Circle **CR2**)

Select objects to extrude: (↵)

Specify height of extrusion or [Direction/Path/Taper angle]<40.0000>: **150** (↵)

(16) Command: **ZOOM** (↵)

Specify corner of window, enter a scale factor (nX or nXP), or

[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL** (↵)

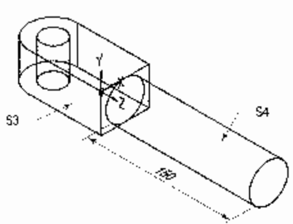
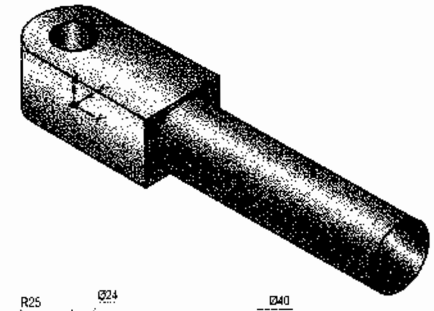


Fig. 26-57(viii)

MODULE 26-45: USE OF 3D COMMANDS REGION, EXTRUDE, SUBTRACT AND UNION



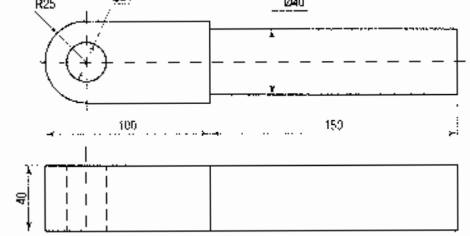


FIG. 26-57

Module 26-46. *Draw a three dimensional diagram as shown in fig. 26-58. Use 3D Polar Array.*

To draw a three dimensional diargram using the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-58(i) to fig. 26-58(vi).

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL**

(3) Command: **VPOINT** (↵)
Current view direction: VIEWDIR 0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: 1,-1,1
Regenerating model.

(4) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/Previous/Scale/Window] <real time>: **ALL**
Regenerating model.

(5) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **0,0** (↵)
Specify radius of circle or [Diameter]: **D** (↵)
Specify diameter of circle: **100** (↵)

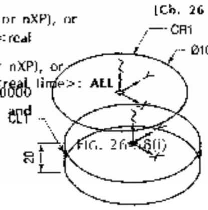


FIG. 26-58(ii)

(6) Command: **EXTRUDE** (↵)
Current wire frame density: ISOLINES=4
Select objects to extrude: (Select Circle **CR1**)
Select objects to extrude: (↵)
Specify height of extrusion or [Direction/Path/Taper angle]<40.0000>: **-20** (↵)

(7) Command: **CIRCLE** (↵)
Specify center point for circle or [3P/2P/Ttr (tan tan radius)]: **0,0** (↵)
Specify radius of circle or [Diameter] <50.0000>: **D** (↵)
Specify diameter of circle <100.0000>: **70** (↵)

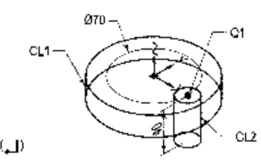


FIG. 26-58(iii)

(8) Command: **CYLINDER** (↵)
Specify center point of base or [3P/2P/Ttr/Elliptical]: (Select QUADRANT **Q1** of **Ø70** circle)
Specify base radius or [Diameter]: **D** (↵)
Specify diameter: **20** (↵)
Specify height or [2Point/Axis endpoint] <-20.0000>: **-40** (↵)

(9) Command: **3DARRAY** (↵)
Initializing... 3DARRAY loaded.
Select objects: (Select Cylinder **CL2**)
Select objects: (↵)
Enter the type of array [Rectangular/Polar] <R>: **P** (↵)
Enter the number of items in the array: **4** (↵)
Specify the angle to fill (+=ccw, -=cw) <360>: (↵)
Rotate arrayed objects? [Yes/No] <Y>: (↵)
Specify center point of array: **0,0,0** (↵)

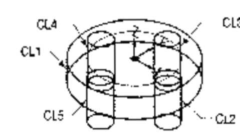
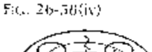


FIG. 26-58(iv)



(12) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/.../Conceptual/...] <Conceptual>: **C** (↵)

(13) Save this File As **Module 26-46.DWG**

Output of Module 26-46 (fig. 26-58):

MODULE 26-46: USE OF 3D POLAR ARRAY

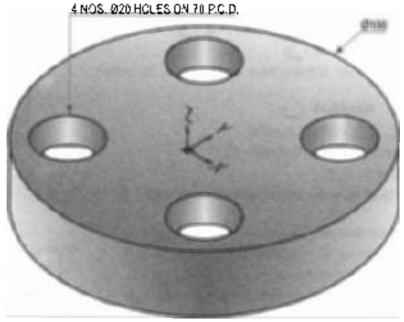


FIG. 26-58

Module 26-47. *Draw a three dimensional diagram as shown in fig. 26-59. Use 3D Rectangular Array.*

To draw a three dimensional diargram using the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-59(i) to fig. 26-59(vi).

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)

(2) Command: **VPOINT** (↵)

(5) Command: **EXTRUDE** (↵)
Current wire frame density: ISOLINES=4
Select objects to extrude: (Select rectangle **R1**)
Select objects to extrude: (↵)
Specify height of extrusion or [Direction/Path/Taper angle]<40.0000>: **-10** (↵)

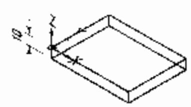


FIG. 26-59(ii)

(6) Command: **CYLINDER** (↵)
Specify center point of base or [3P/2P/Ttr/Elliptical]: **15,15** (↵)
Specify base radius or [Diameter]: **d** (↵)
Specify diameter: **10** (↵)
Specify height or [2Point/Axis endpoint]<-20.0000>: **-30** (↵)

(7) Command: **3DARRAY** (↵)
Initializing... 3DARRAY loaded.
Select objects: (Select Cylinder **CL1**)
Select objects: (↵)
Enter the type of array [Rectangular/Polar] <R>: **R** (↵)
Enter the number of rows (---) <1>: **2** (↵)
Enter the number of columns (|||) <1>: **3** (↵)
Enter the number of levels (...) <1>: **1** (↵)
Specify the distance between rows (---): **30** (↵)
Specify the distance between columns (|||): **25** (↵)

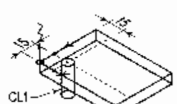


FIG. 26-59(iii)

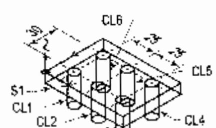


FIG. 26-59(iv)

(8) Command: **SUBTRACT** (↵)
Select solids, surfaces and regions to subtract from ..
Select objects: (Select solid **S1**)
Select objects: (↵)
Select solids, surfaces and regions to subtract ..
Select objects: (Select Cylinder **CL1**)
Select objects: (Select Cylinder **CL2**)
Select objects: (Select Cylinder **CL3**)

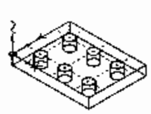


FIG. 26-59(v)

MODULE 26-47: USE OF 3D RECTANGULAR ARRAY

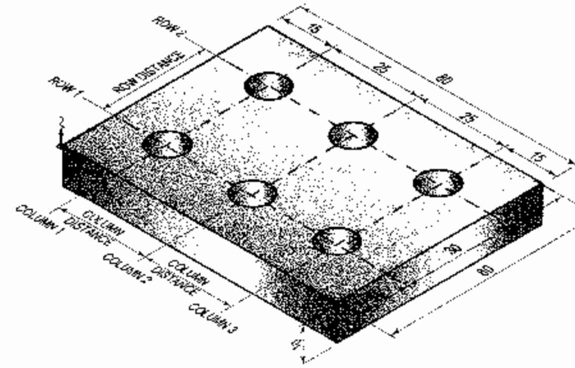


FIG. 26-59

Module 26-48. *Draw a three dimensional diagram as shown in fig. 26-60. Use 3D Slice command.*

To draw a three dimensional diargram using the steps mentioned below. After executing the commands in sequence, we will get the output as shown in fig. 26-60(i) to fig. 26-60(iii).

(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)
(2) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1 0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.
(3) Command: **ZOOM** (↵)

(5) Command: **SLICE** (↵)
Select objects to slice: (Select Cone **CN1**)
Select objects to slice: (↵)
Specify start point of slicing plane or [planar Object/ Surface/Zaxis/View/XY/YZ/ZX/3points] <3points>: **YZ** (↵)
Specify a point on the YZ-plane <0,0,0>: (↵)
Specify a point on desired side or [keep Both sides] <Both>: **B** (↵)
(6) Command: **ERASE** (↵)
Select objects: (Select Half Cone **CN2**)
Select objects: (↵)
(7) Command: **SHADEMODE** (↵)
Enter an option [2dwireframe/3dwireframe/3dHidden/ Realistic/Conceptual/Other] <Conceptual>: **C** (↵)
(8) Save This File As **Module 26-48.DWG**

Output of Module 26-48 (fig. 26-60):

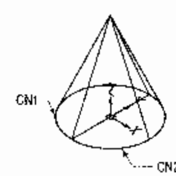
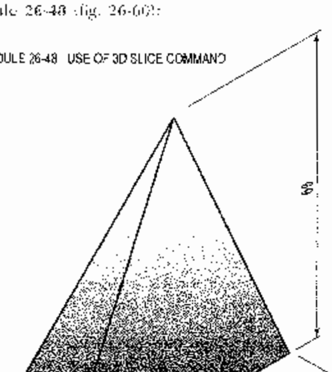


FIG. 26-60(ii)

FIG. 26-60(iii)

MODULE 26-48 USE OF 3D SLICE COMMAND



(1) Command: **LIMITS** (↵)
Reset Model space limits:
Specify lower left corner or [ON/OFF] <0.0000,0.0000>: (↵)
Specify upper right corner <12.0000,9.0000>: **120,90** (↵)
(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Center/Dynamic/Extents/Previous/Scale/...] <real time>: **ALL** (↵)
Regenerating model.
(3) Command: **VPOINT** (↵)
Current view direction: VIEWDIR=0.0000,0.0000,1.0000
Specify a view point or [Rotate] <display compass and tripod>: **1,–1,1** (↵)
Regenerating model.
(4) Command: **BOX** (↵)
Specify first corner or [Center]: **0,0,0** (↵)
Specify other corner or [Cube/Length]: **L** (↵)
Specify length: **50** (↵) (When 0° polar is ON)
Specify width: **40** (↵) (When 90° polar is ON)
Specify height or [2Point]: **30** (↵)

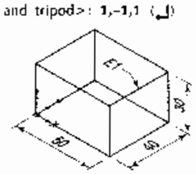


FIG. 26-61(i)

(5) Command: **CHAMFER** (↵)
(TRIM mode) Current chamfer Dist1 = 0.0000, Dist2 = 0.0000
Select first line or [Undo/Polyline/Distance/Angle/ Trim/mEthod/Multiple]: (Select Edge **E1**)
Base surface selection...
Enter surface selection option [Next/OK (current)] <OK>: (↵)
Specify base surface chamfer distance: **20** (↵)
Specify other surface chamfer distance <20.0000>: **40** (↵)
Select an edge or [Loop]: (Select Edge **E1**)
Select an edge or [Loop]: (↵)

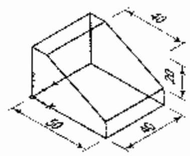


FIG. 26-61(ii)

(6) Command: **MIRROR3D** (↵)
Select objects: (Select solid)
Select objects: (↵)
Specify first point of mirror plane (3 points) or

MODULE 26-49: USE OF MIRROR3D AND CHAMFER COMMANDS

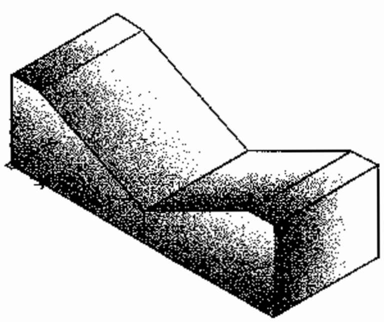


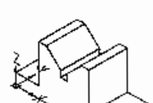
FIG. 26-61

26-11. PERSPECTIVE VIEW IN AUTOCAD

Refer module 26-50
(i) Create 3D solid model or open file.
(ii) Set the isometric view using VPOINT command.
(iii) To set perspective view, use DVIEW command and select DISTANCE option.
(iv) To turnoff perspective view. Use OFF option of DVIEW command.

Module 26-50. *Open file Module 26-43.DWG and set perspective view.*

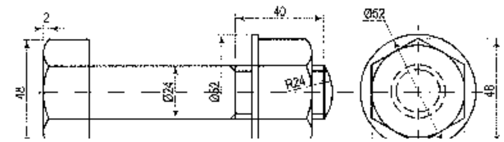
(1) Open File **Module 26-43.DWG**
(2) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Extents/Window/Previous/Object] <real time>: **ALL** (↵)



(5) Command: **ZOOM** (↵)
Specify corner of window, enter a scale factor (nX or nXP), or
[All/Extents/Window/Previous/Object] <real time>: **ALL** (↵)
(6) Click Save from File menu

EXERCISES 26

1. Prepare a report on the computer hardware, peripherals and CAD software available in your laboratory.
2. What are the reasons for implementing a CAD system? What are the disadvantages?
3. List the main functions of a CAD system.
4. Explain the following 2D drawing entities with the help of sketch:
Line, Arc, Polyline, Ellipse, Donut, Polygon.
5. With suitable examples explain the following transformations:
(i) Moving an object (iv) Copying an object
(ii) Scaling an object (v) Mirroring an object.
(iii) Rotation of an object
6. What is the difference between COPY and MOVE?
7. Make sketches of 3D solid modelling primitives and name them.
8. Explain in brief:
(i) Wireframe modelling; (ii) Surface modelling; (iii) Solid modelling.
9. With the help of suitable examples, explain the boolean operations that can be performed on solid primitives.
10. Using the CAD software available in your laboratory, create the drawings of fig. 2-13 to fig. 2-26 shown on pages 31 and 32.
11. Study modules 26-1 to 26-14 carefully. Draw Hexagonal-headed bolt with hexagonal nut and washer as shown in fig. 26-63.



12. Draw fig 26-64 using line, circle, rectangle, fillet, rectangular array, polar array, dimension, hatch, layer, hidden line, center line etc., commands.

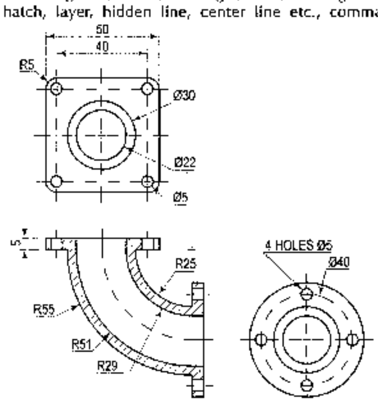


Fig. 26-64

13. Name four UCS options that only rotates the UCS about the origin but do not move the origin.
14. Write differences between Array and 3DArray.
15. How does the TABSURF command differ from the RULESURF command?
16. What are the use of Surftab1 and Surftab2 command?
17. Explain the use of Elev command.
18. How does shademode's flat shading option differs from 3D wireframe option.
19. List basic differences between surface models and solid models.
20. What are the requirements for profile objects of extruded and removed solids.
21. Write the name and sequence of command to create hole in solid.

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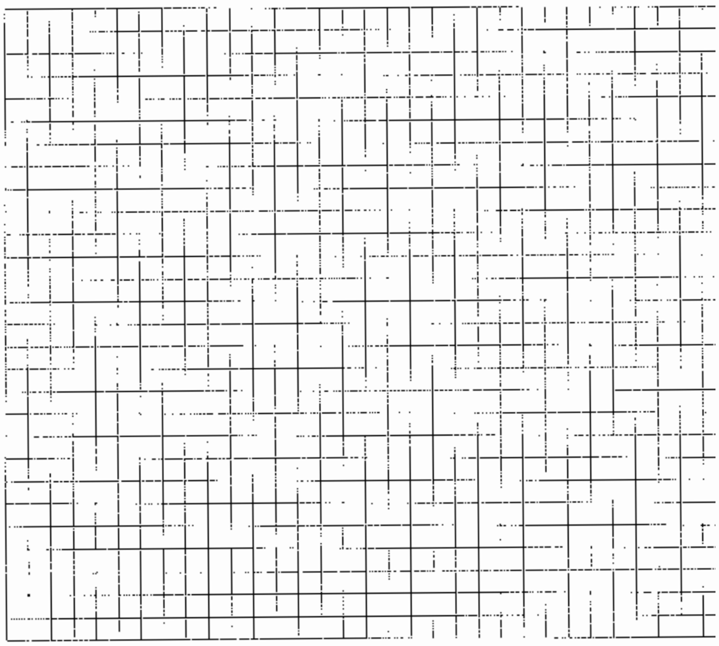

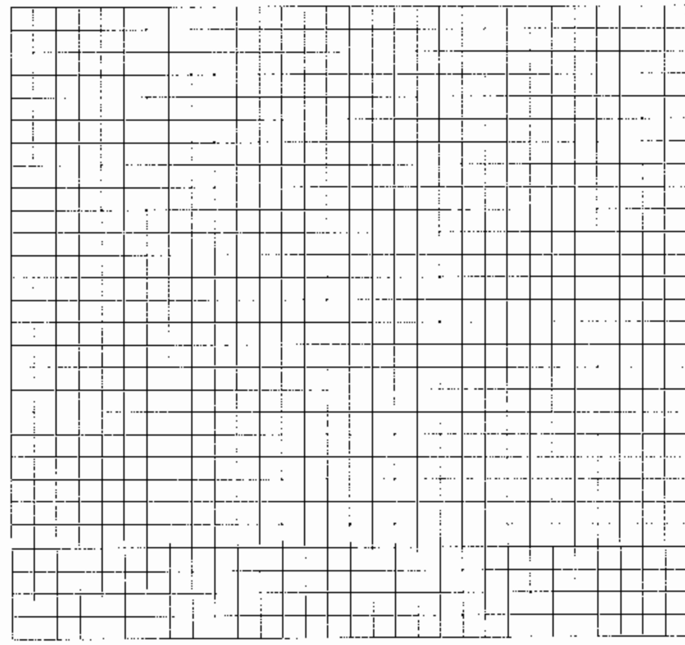

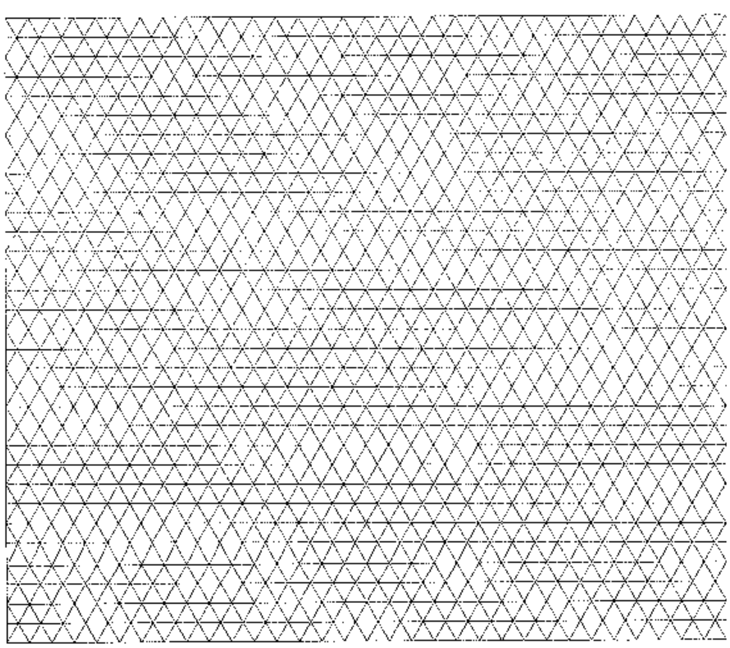

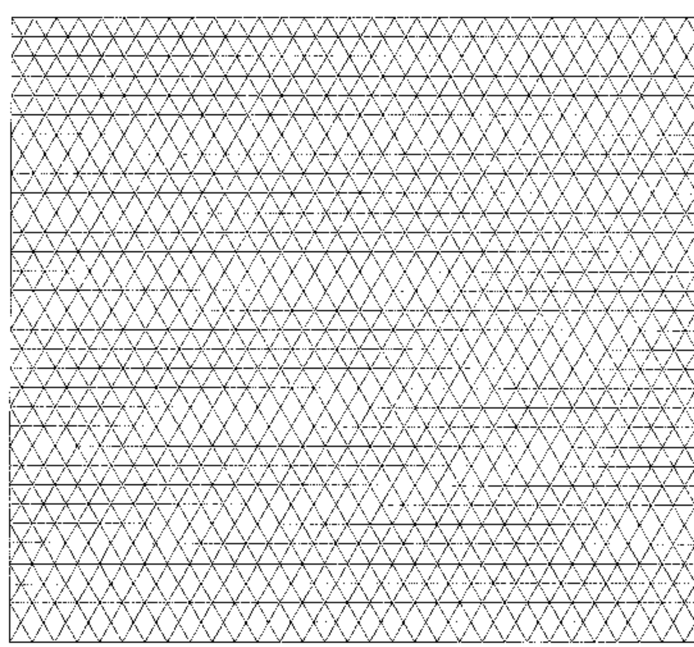

APPLIED MECHANICS
INCLUDING VECTOR APPROACH

DR. H. J. SHAH
S. B. JUNNARKAR

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EXPERIMENTS IN MECHANICS OF SOLIDS
B. M. RAVAL

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MECHANICS OF SOLIDS
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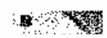

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MECHANICS OF STRUCTURES VOL. I
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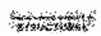

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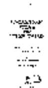

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N. D. BHATT

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DR. ANURAG KANDYA

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S. C. RANGWALA

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ENGINEERING MATERIALS

MATERIAL SCIENCE

S. C. RANGWALA

ISBN : 978-93-80358-15-0
SIZE : 130 mm × 240 mm
PAGES : 444 + 20

1 : PROPERTIES OF ENGINEERING MATERIALS
2 : STONES
3 : CLAY PRODUCTS AND REFRACTORIES
4 : BRICKS
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BUILDING CONSTRUCTION

S. C. RANGWALA

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15 : DAMP-PROOFING, WATER-PROOFING AND TERMITE-PROOFING
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ESTIMATING COSTING AND VALUATION
PROFESSIONAL PRACTICE AND QUANTITY SURVEYING
S. C. RANGWALA

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VALUATION OF REAL PROPERTIES
S. C. RANGWALA

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S. C. RANGWALA

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S. C. RANGWALA

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3 : CONSTRUCTION OF DAMS
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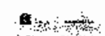

WATER SUPPLY AND SANITARY ENGINEERING
ENVIRONMENTAL ENGINEERING
S. C. RANGWALA

ISBN : 978-93-80358-12-5
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S. C. RANGWALA

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FLUID POWER TRANSMISSION AND CONTROL

APPLIED HYDRAULICS AND PNEUMATICS

A. ALAVUDEEN, KHALID HUSSAIN SYED, N. SHANMUGAM

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FLUID MECHANICS AND MACHINERY LABORATORY MANUAL

DR. N. KUMARA SWAMY

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2 : PRACTICAL APPLICATION OF FLUID MECHANICS IN VARIOUS FIELDS
8 : VIVA QUESTIONS ON FLUID MECHANICS
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PROGRAMMING IN C

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V. J. PATEL

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