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SSCE & UTME
Physics

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PREFACE

The writing of this review book has been necessitated by the high incidence of failure in *Physics* at the Secondary School Certificate Examination (SSCE) and the Joint Matriculation Examinations (JME). The book will be found to be a valuable companion to the candidate during the preparations for these examinations. It is made up of twenty chapters which cover the entire syllabuses of both the WASSCE and the JME, preceded by an introduction on strategies for taking the examinations. Each chapter consists of:

- ***Concise Revision Notes*** highlighting key points, essential definitions, laws and principles, description of physical phenomena and relevant equations.

- ***True or False - Type Questions*** which have been carefully phrased in order to focus the candidate's attention on key and subtle points which students often find confusing.

- ***Detailed Explanations*** to the True or False - type questions.

- ***SSCE/JME - Type Objective Questions***, which are slightly modified versions of the actual past questions of the SSCE and the JME. Nearly every type of question which has appeared in the SSCE (from1988 to date) and the UME (from 1978 to date) will be found under this section.

- ***Answer Key*** to the SSCE/JME - type questions

- ***Detailed Explanations*** of the answers to the SSCE/JME - type questions.

- ***Revision Check-list*** highlighting all the essential points which the candidate needs to learn before attempting the examinations.

Three ***Model Objective Tests*** are included at the end of the book which are closely fashioned after the SSCE and the JME objective papers.

The layout of the book is such that the candidate will find it very helpful even without the aid of a teacher. It is thus a comprehensive self-help study pack which guarantees an excellent performance in the examinations.

The publishers acknowledge with deep appreciation the valuable suggestions offered towards the improvement of this book by Dr. H.O. Oseni, proprietor of Anifa Preparatory School in Lagos. The motivation to see this project to fruition was provided largely by the support, both material and intangible, offered by Engr. Funso Kupolokun and Engr. Abidoye Ayoola, to whom the publishers are highly indebted. This reprinted edition of the book has benefited tremendously by the constructive criticisms by Rev. O. O. Okunola, Senior Physics teacher at the University of Ibadan International School, who painstakingly read through the first edition and offered many useful suggestions.

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May 2001

Introduction

The aim of writing this book is to help you, the candidate, achieve high scores in WASSCE and JME Physics. To derive the maximum benefit from the book, it is important that you devote some time to reading carefully through this introduction which contains strategies for providing appropriate answers to the examination questions.

The main purpose of any examination is to test the candidate's understanding of the subject matter. The first step in preparing for an examination is thus to have a good mastery of the subject. In Physics this is usually acquired through a long period of study and consistent problem-solving. Most of the candidates sitting for the examinations are expected to have undergone several years of formal instruction in a seoondary school. Assimilation of the basic concepts and principles of Physics, like most other subjects, is difficult to acquire overnight.

Except for objective (multiple-choice) examinations, you must be able to communicate effectively with the examiner in order to excel in the examination. This involves the ability to present your answers in a clear, ccncise and readable form. It is helpful to follow the following basic rules of presentation:

- Your hand-writing must be *legible*. This is usually achieved by writing more slowly and clearly.
- Write *short* and *clear* sentences. Each sentence written must convey at least one key point.
- Avoid *circumlocution*, i.e. express yourself in as few words as possible, making sure the idea is effectively communicated.
- Try as much as possible to stay within the context of the question. Information which is not relevant to the question, even if correct, will *not* earn you extra marks. On the other hand, it is a time waster.
- Above all, your answers should be *neatly* presented.

Structure of the Examinations

The WASSCE* *Physics* consists of

Paper 1 - a paper testing the candidate's practical skills, This paper carries a total of 50 marks

Paper 2 - The theory paper consisting of two sections - A and B. Section A is an objective paper comprising 50 multiple-choice questions, for a total of 50 marks. Section B comprises essay-type questions, for a total of 60 marks.

Paper 3 - A test-of-practical examination for private candidates who are not in a position to take Paper 1 due to lack of access to laboratory facilities during the examination. This paper, like Paper 1, attracts 50 marks.

The UME Physics paper is an objective test consisting of 50 multiple-choice questions. Each question carries 2 marks for a total of 100. This paper is similar to the WASSCE paper 2A.

Details of the strategies for the practical examinations (Papers 1 and 3 of WASSCE) are not covered in this book. The following sections present the strategies for taking the objective and the essay-type examinations.

---

* Although the structure of the WASSCE differs slightly from that of the old SSCE, the syllabuses are not appreciably different.

Objective (Multiple-Choice) Examinations

These are often short questions requiring, on average, about one minute to answer each question. Four or five options are provided out of which you are required to pick the correct option. Many of these questions involve simple definitions and statements which are either true or false. These can usually be answered within a few seconds but care must be taken to ensure that you read through the question and the options carefully to avoid being "trapped" by little tricks which are meant to test the depth of understanding of the subject. In working through an objective paper, it will be helpful to observe the following rules :

(1) As the questions are not all of the same level of difficulty, you should first go through the whole paper and answer the easy questions. This would leave you with sufficient time to devote to the more difficult questions. Remember that all questions carry equal marks.

(2) It is extremely important to pay close attention to the ***units*** in questions involving numerical problems. Consider the following example :

An object of mass 200 g is lifted through a vertical height of 50 cm. The work done in lifting the object is
A. 0.1 J **B.** 1.0 J **C.** 10 J **D.** 100 J

Since the options are provided in SI units, it is necessary to convert all the given data into this system of units before attempting a solution. Thus vertical distance $h = 50$ cm $= 0.5$ m and mass $m = 200$ g $= 0.2$ kg. At this point, some candidates will, without further contemplation, simply multiply 0.5 m by 0.2 kg and obtain 0.1, leading to the choice of option (A), which is incorrect. With the knowledge that the gravitational force exerted by a mass is equal to mg, its weight, the force in this case is $0.2 \text{ kg} \times 10 \text{ ms}^{-2} = 2.0$ N, and the work done is force x distance $= 2.0 \text{ N} \times 0.5 \text{ m} = 1.0$ J. The correct option is therefore **(B)**. Note that options **(C)** and **(D)** which are both wrong, can also be obtained through different manipulations of the given data.

(3) Read the questions carefully to ascertain exactly what is required. Quite often, examiners include intermediate as well as other seemingly plausible answers in the list of options which may mislead the not-so-careful candidate. Consider the following question:

A candle is placed 20 cm from a concave mirror of focal length 10 cm. The distance between the candle and its image is
A. 40 cm **B.** 20 cm **C.** 10 cm **D.** zero

The image distance is given by

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10} - \frac{1}{20} = \frac{1}{20}$$

or $v = +20$ cm.

A candidate who has not read the question carefully might pick option **(B)**, which corresponds to the calculated value of v. Another candidate might simply add the object distance to the image distance to obtain 40 cm, corresponding to option **(A)**. Both options are, however, wrong. To obtain the correct answer, you should know that the positive value of v indicates that the image is real, i.e. it is located *in front of* the mirror and 20 cm from it. Since this coincides with the position of the candle, the distance between the candle and its image is *zero*, option **(D)**.

(4) Many of the numerical problems can be solved by making approximate estimates, rather than detailed calculations.

(5) Where you are not sure of the correct answer to a question, it is permissible, and indeed desirable, to make an *educated* guess. Generally one or two of the options supplied are not reasonable and can be eliminated right away. If you have to guess between just two or three reasonable options, your chances of guessing correctly are enhanced. Consider the following question:

> A fixed mass of gas which occupies a volume of 500 cm^3 has its pressure reduced to one-quarter of its original value while the temperature remains constant. The new volume of the gas is
> A. 125 cm^3 B. 500 cm^3 C. 1,000 cm^3 D. 2,000 cm^3

This question tests the candidate's understanding of *Boyle's Law* (PV = constant). But even if all you know is that the volume of a given mass of gas should *increase* as the pressure is *reduced* at constant temperature, you can eliminate options (A) and (B). If you now have to guess between options (C) and (D), your chance of guessing correctly is 50 percent, which is better than the chance in a completely random guess (25 percent). The correct option here is (D).

Essay - Type Examination

This paper usually consists of a combination of the following:

(i) Definition of physical quantities, terms and concepts;
(ii) Statement of laws and principles;
(iii) Explanation or description of physical phenomena;
(iv) Description of experiments; and
(v) Numerical problems.

Definitions

A *definition* is a simple statement which expresses the meaning of a physical quantity. It frequently happens in physics that the definitions of two or three physical concepts may appear really identical except for some key words which distinguish one from the other. This often leads to confusion on the part of the candidate and examiners take delight in probing the candidate's understanding of such concepts. As an example, consider the definitions of *heat capacity, specific heat capacity* and the *kilocalorie:*

Heat capacity: the quantity of heat needed to raise the temperature of a **given mass** of a substance by one kelvin (or 1 Celsius degree).

Specific heat capacity: the quantity of heat needed to raise the temperature of **1 kilogram** (or unit mass) of a substance by one kelvin (or 1 Celsius degree).

Kilocalorie: the quantity of heat needed to raise the temperature of **1 kilogram of water** by one kelvin (or 1 Celsius degree).

Note that the difference between *heat capacity* and *specific heat capacity* is that one refers to any given mass, while the other refers to *1 kilogram* of the substance. Also, the main difference between *specific heat capacity* and the *kilocalorie* is that the former refers to *any substance* while the latter refers specifically to *water*. Indeed the *specific heat capacity of water* is the *kilocalorie*. To score full marks in the definitions, you must pay particular attention to these (sometimes) subtle differences.

The list of physical concepts whose definitions are often required in the examination is provided under the check-list section at the end of each chapter. As part of your preparation, you should:

(1) identify all such concepts in each chapter;

(2) practise defining from memory all these terms until you are able to do so correctly; and
(3) note the distinctions between the definitions of concepts which appear similar.

When only a definition is required in the examination, this should be stated as concisely as possible without going into lengthy explanations. Unless specifically required, it is *not* always necessary to write equations to support your definition.

Statement of Laws and Principles

A *law* or *principle* is a statement which describes the behaviour of a certain body under a given set of conditions, or the relationship between two or more physical quantities. When required, a law must be stated clearly and precisely while paying close attention to all key words and phrases, as well as the conditions under which the law is valid. *Charles' law* for instance states that:

> The volume of a *fixed mass* of gas is directly proportional to the *absolute* temperature, provided the *pressure is maintained constant*.

Candidates often lose marks in this type of question because of

(1) the omission of the key phrase "fixed mass", or the key word "absolute" qualifying the temperature, and
(2) the omission of the condition of *constant pressure* under which the law is valid.

The laws with which candidate are expected to be familiar are given under the check-list section at the end of each chapter. Make sure you can recite each of these laws correctly before the examination. Again, the writing of an equation is not necessary unless the question specifically calls for it. The statement of Charles' law above will attract full marks without further elaboration.

Explanation or Description of Physical Phenomena

When a certain question calls for the explanation or description of a physical phenomenon, candidates often make the mistake of writing everything they know about the subject, thus wasting valuable time. Examiners are looking for certain key points, the listing of which will earn the candidate full marks. Further elaboration beyond this is unnecessary and time wasting. A typical question is

"Explain the phenomenon of *photoelectric emission*", to which an appropriate (and adequate) answer will be

> When *high frequency radiation* falls on the *surface of a metal, electrons are ejected*. The frequency of incident radiation must be higher than a certain minimum value, called the *threshold frequency*.

Note the highlighted key phrases in the statements above. Since it is not specified in the question, it is unnecessary to describe a *photocell*, or to write Einstein's photoelectric equation, as these will not attract additional marks.

In response to certain questions, however, an example may serve to elucidate your explanation. Consider for instance, the question "Explain what is meant by *surface tension*." An appropriate answer to this question would be:

(1) The molecules on the surface of a liquid exert *cohesive (attractive) forces* on their neighbours.
(2) This causes the surface of the liquid to act like a *stretched elastic skin*, offering some resistance to the penetration of a light object placed on the surface.
(3) Hence a steel razor blade, for example, can be made to float on water surface, even though steel is denser than water.

Note that statement (3), though not specifically demanded in the question, nonetheless conveys to the examiner, a clear understanding of the phenomenon of surface tension. The ability to identify situations in which this type of example is necessary comes with experience and also after repeated interaction with your teacher through question and answer sessions.

Description of Experiments

The answer to the description of an experiment should include the following:

(1) a list of the apparatus required;
(2) a clear, large and labelled diagram;
(3) a write-up in the *present tense* mentioning only the essential points in the experiment;
(4) how the parameters measured from the experiment are displayed (e.g. as tables);
(5) the procedure for data analysis, and
(6) the conclusion(s).

Example: Describe an experiment to determine the acceleration due to gravity using a simple pendulum.

Answer

(1) *Apparatus required*: A simple pendulum consisting of about one metre length of string attached to a small lead ball, a stand, a clamp, a metre rule and a stop watch.
(2) *Diagram*: (Consult your textbook)
(3) *Write - up*: The essential points are that
 (a) the apparatus is set up as shown in the diagram;
 (b) the length of the pendulum from the clamp to the centre of the bob is measured with a metre rule and recorded as L;
 (c) the pendulum is made to oscillate and the time, T^*, to make 50 complete oscillations is recorded.
 (d) the average time (T) to make one complete oscillation is calculated as $T = T^*/50$.
 (e) the length of the pendulum is reduced in regular steps of about 0.1m and steps (b) to (d) are repeated for each length.
(4) A table is made showing the parameters L, T^*, T and T^2
(5) The equation for the simple pendulum is $T = 2\pi\sqrt{L/g}$ where g is the acceleration due to gravity. Squaring both sides gives $T^2 = (4\pi^2/g)L$. A graph of T^2 (ordinate) is plotted against L (abscissa). The graph is a straight line passing through the origin and with a slope $m = 4\pi^2/g$.
(6) The value of g is determined as $g = 4\pi^2/m$.

Precautions

These are the steps which need to be taken in order to improve on the accuracy of the result. It is *not* necessary to state the precautions unless it is so specified in the question. In the example above, the important precautions are:

(i) The amplitude of the oscillations must be kept small.
(ii) The size of the bob must be quite small.
(iii) Before starting the oscillations, the pendulum is allowed to rest in the equilibrium (vertical) position and a mark is made (e.g. with chalk) on the side of the work-bench which is later used as a reference for counting the oscillations.
(iv) Steps (c) and (d) are repeated twice to obtain a total of three readings for T^* and for T, from which an average reading is calculated.

A list of the experiments which candidates are expected to learn for the WASSCE examination is provided under the check-list section in each chapter of this book. Make sure you can repeat the above procedure for each of the listed experiments.

Numerical Problems

In approaching a numerical problem in the examination, it is often helpful to

(1) read the question carefully to ascertain what exactly is required. Quite often, many candidates provide answers which bear little relevance to the question being asked;

(2) list the given data using appropriate symbols;

(3) write down the relevant equation(s) and define all symbols;

(4) sketch a diagram where necessary;

(5) ensure that all the data to be substituted into the equation are in the correct system of units (SI)

(6) rearrange the equation so that the required parameter becomes the subject; and

(7) write carefully to avoid computational errors.

Suggested Study Procedure

To get the best out of this book, you are advised to adopt the following study procedure:

(1) Study the revision notes thoroughly. Where necessary, refer to your textbooks for further clarification.

(2) Attempt all the true or false - type questions before looking up the answers.

(3) Attempt all the SSCE/JME - type objective questions. Allow yourself approximately one minute to each question, on average. Use the answer key provided at the end of the problem set to score yourself. If you are unable to complete the whole problem set within the appropriate time, continue all the way to the end and note how much extra time you have consumed. This is an indication of how much faster you should try to work under real examination conditions.

(4) Go over the solutions carefully and note your areas of weakness. If the explanation is not clear, you may need to re-visit the revision note, and even your textbook in order to gain a better understanding of the subject. Consultation with your teacher will also be helpful.

(5) You should take the model objective tests after completing the whole book, and as close to the examination as possible. Your average score on these should give you an indication of your expected performance in the actual examination.

(6) GOOD LUCK !

1 Measurement; Scalars and Vectors

1.1 Fundamental Concepts

- The quantities ***length***, ***mass*** and ***time*** which occur frequently in mechanics are referred to as ***fundamental quantities.***
- Other fundamental quantities are ***electric current*** and ***temperature.***
- The units in which these quantities are measured are called ***fundamental units***.
- In the international system (SI), the units are:

Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A

- The prefixes *mega, kilo, centi, milli*, etc. are used to indicate multiples and sub-multiples of these units. e.g. the kilometre is 1,000 metre and 1 centimetre is 10^{-2} metre.

Prefix	Factor	Example
mega (M)	10^6	1Ms = 10^6 s
kilo (k)	10^3	1 km = 10^3 m
deca (da)	10^1	1 dam = 10 m
deci (d)	10^{-1}	1 dm = 10^{-1} m
centi (c)	10^{-2}	1 cm = 10^{-2} m
milli (m)	10^{-3}	1 mg = 10^{-3} g
micro (μ)	10^{-6}	1 μs = 10^{-6} s
nano (n)	10^{-9}	1 ns = 10^{-9} s
pico (p)	10^{-12}	1 ps = 10^{-12} s

1.2 Derived Concepts

- Quantities such as area, volume, speed, density, etc. which can be derived from the fundamental quantities are called ***derived quantities***
- Their units are referred to as ***derived units***. Examples are provided below.

Quantity	Derived Unit	Symbol
Area	square metre	m^2
Density	kilogram per cubic metre	$kg\ m^{-3}$
Speed	metre per second	ms^{-1}
Force	newton	$N = kg.m.s^{-2}$
Energy	joule	$J = N.m = kg\ m^2s^{-2}$

1.3 Measurement of Length

- Lengths are measured using a graduated scale e.g a ***meter rule*** in measuring the length of a table.
- The precision of a measurement depends on the graduation of the instrument being used. One can estimate the length to a fraction of the *least* graduation on the scale.

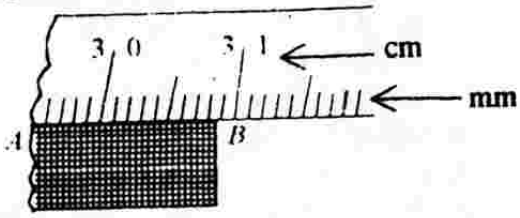


Fig. 1.1

- The scale division for the ruler in Fig. 1.1 is in millimetres. Length *AB* is measured as 30.85 cm.
- The last digit has to be estimated. Conventionally, the uncertainty (or error) in the measurement is taken to be *half the smallest scale division*. In Fig. 1.1, the uncertainty is 0.5 mm or 0.05 cm
- To measure small distances, ***vernier callipers*** can be used e.g. measuring the diameter of a rod or the inside diameter of a tube.
- The first decimal place in the measurement is the *major scale mark located just before the zero mark* of the division on the vernier scale. The second decimal place is given by the *number on the vernier scale which coincides with a major scale mark.*
- The vernier reading shown in Fig. 1.2 is 3.26 cm.

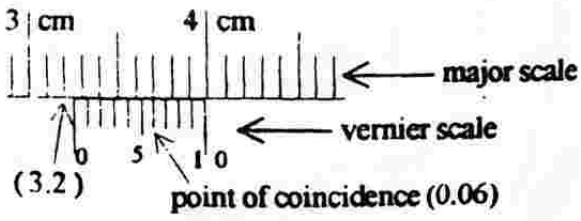


Fig. 1.2

- For even smaller lengths, e.g. the diameter of a wire, a ***micrometer screw gauge*** is used.
- The last visible division on the main scale is recorded (e.g. 5.0 in Fig. 1.3).
- The division on the circular scale which coincides with the central horizontal line on the main scale (e.g. 0.17 in Fig. 1.3) is also recorded in decimals (0.17).
- The micrometer screw gauge reading is given as the sum of these two numbers (i.e. 5.0 + 0.17, or 5.17 mm).

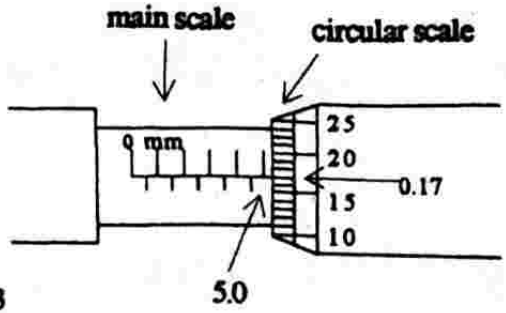


Fig 1.3

1.4 Position and Direction

- The *position* of an object is usually specified relative to some fixed reference position, e.g. the origin (O) of the x - y coordinate axes (for a plane which is two dimensional) or x-y-z coordinate axes (for three-dimensional space).
- In Fig. 1.4 the position of an object P is written as (x_p, y_p) where x_p is the perpendicular distance from P to OY and y_p is the perpendicular distance from P to OX.
- The *direction* of P relative to O is described by the angle θ which OP makes with a reference line such as OX. In terms of the four cardinal points (*north, south, east and west*), the direction is specified relative to the cardinal points, e.g. direction OA (Fig. 1.5) is 30°N of E or N60° E while direction OB is 15° W of S or S 15° W.

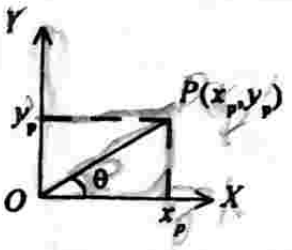


Fig 1.4

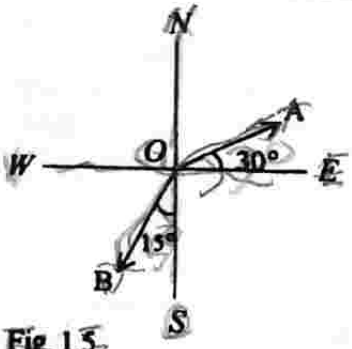


Fig 1.5

1.5 Scalars and Vectors

- ***Scalars*** are physical quantities which have *magnitude but no direction* associated with them. Examples include *length, mass, time and speed.*
- ***Vectors*** are physical quantities which have *both magnitude and direction*. Examples include *displacement, velocity, acceleration and force.*
- A vector quantity is represented by a line with an arrow on it. The length of the line represents the magnitude while the arrow indicates the direction of the vector.

1.6 Addition of Vectors

- The addition of two vectors $\underline{A}$ and $\underline{B}$ gives a third vector $\underline{R}$ which is also known as the resultant of the two vectors.
- ***Parallelogram of Vectors:*** If two vectors are represented by two adjacent sides of a parallelogram the resultant is represented in magnitude and direction by the diagonal of the parallelogram drawn from the point of intersection of the two sides. In Fig. 1.6 the resultant of $\underline{A}$ and $\underline{B}$ is written as

$$\underline{R} = \underline{A} + \underline{B} \qquad (1.1)$$

- The vector $-\underline{B}$ is equal in magnitude to $\underline{B}$ but in opposite direction. Thus $\underline{A} - \underline{B} = \underline{A} + (-\underline{B})$ = resultant of $\underline{A}$ and $-\underline{B}$ (Fig. 1.7).

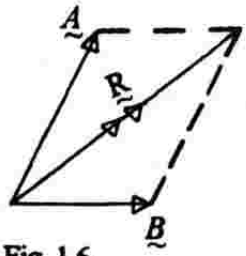


Fig. 1.6

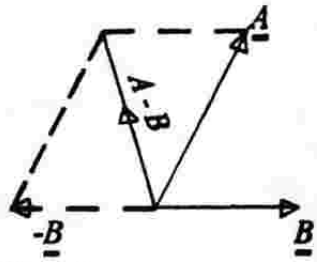


Fig. 1.7

- In solving problems on parallelogram of vectors, the following trigonometric relationships are often found to be useful:
  - (i) The *cosine formula*, for a triangle with sides a, b, c, where b makes angle θ with a (Fig. 1.8)

$$c^2 = a^2 + b^2 - 2ab\cos\theta \qquad (1.2)$$

  - (ii) *Pythagoras Theorem*: for a right-angled triangle (Fig. 1.9)

$$c^2 = a^2 + b^2 \qquad (1.3)$$

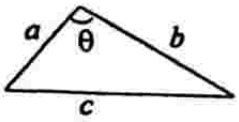


Fig. 1.8

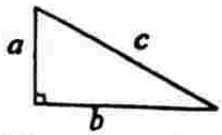


Fig. 1.9

1.7 Resolution of Vectors

- A single vector can be replaced by two components acting along two perpendicular directions. These are the *resolved components* along the two directions.
- The magnitude of the resolved component of a vector along a specified direction is the product of the vector and the cosine of the angle which the vector makes with the direction. For a vector $\underline{A}$ lying in an x-y plane and which makes an angle θ with the x-axis (Fig. 1.10) the resolved components are $A_x = A\cos\theta$ along the x-direction,

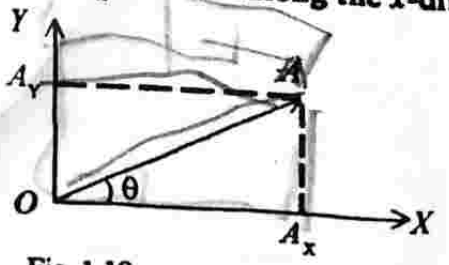


Fig. 1.10

and $A_y = A\cos(90-\theta) = A\sin\theta$ along the y-direction. The relationship between A and the resolved component is found by Pythagoras theorem

$$A^2 = A_x^2 + A_y^2 \text{ or}$$
$$A = \sqrt{A_x^2 + A_y^2} \qquad (1.4)$$
$$\text{and the angle } \theta = \tan^{-1}\left[\frac{A_y}{A_x}\right]$$

True or False-Type Questions

1. Answer True(T) or False (F) to the following questions.
   a. Both a spring balance and a chemical balance are used to measure the mass of an object.
   b. Either may be used to measure the weight.
   c. Hooke's law forms the basis of operation of the spring balance.
   d. The chemical balance works on the principle of moments.
   e. If the acceleration due to gravity changes, the reading of a spring balance will change but that of a chemical balance will not.
   f. A micrometer screw gauge can be used to measure the internal diameter of a tube.
   g. For a ruler graduated *only* in centimetres, measurements can be made accurately to the nearest millimetre.

2. Each of the quantities in the following list is indicated as a scalar or a vector quantity. Answer *True*(T) if the classification is correct and *False* (F) if incorrect.
   a. Pressure [vector]
   b. Electric potential [scalar]
   c. Impulse [vector]
   d. Heat capacity [scalar]
   e. Altitude [vector]
   f. Momentum [vector]
   g. Electric potential difference [vector]
   h. Magnetic induction [scalar]
   i. Acceleration due to gravity [vector]
   j. Power [scalar]
   k. Electric field [scalar]
   l. Electric current [vector]

3. In the following list the unit of each quantity is indicated in brackets. Answer *True* (T) if the indicated unit is correct and *False* (F) if incorrect.
   a. Work [kgm^2s^{-2}]
   b. Power [Js]
   c. Gravitational potential [Jkg^{-1}]
   d. Pressure [$kgm^{-1}s^{-2}$]
   e. Specific latent heat [$Jkg^{-1}K^{-1}$]
   f. Density [kgm^{-3}]
   g. Elastic modulus [Nm^{-1}]
   h. Electric field [NC^{-1}]
   i. Potential difference [JC^{-1}]
   j. Resistivity [Ωm^{-1}]

Answers to True or False-Type Questions

1. a (F) The chemical balance is used to measure *mass*; the spring balance to measure *weight*.
   b (F) See (a) above.
   c (T) The extension of the spring is directly proportional to the weight of the body.
   d (T) This involes two bodies and a lever.
   e (T) Weight, but *not* mass, depends on gravity.
   f (F) This is best done with a vernier callipers.
   g (F) The precision is limited to one - half of the smallest division on the ruler, or 0.5cm (5 millimetres).

2. a (F)
   b (T)
   c (T)
   d (T)
   e (F)
   f (T)
   g (F)
   h (F)
   i (T)
   j (T)
   k (F)
   l (F)

3. a (T) Work = [Force x distance]
   = [mass x acceleration x distance]
   = [kg x ms^{-2} x m] or [kgm^2s^{-2}]
   b (F) Power = [work/time] = [Js^{-1}]
   c (T)
   d (T) Pressure = [force/area] = [$kgms^{-2}/m^2$]
   = [$kgm^{-1}s^{-2}$]
   e (F) Specific latent heat = [Jkg^{-1}]. Note that the specified unit is that of *specific heat capacity*.
   f (T)
   g (F) Elastic modulus = [Nm^{-2}]. The unit indicated is that of *elastic constant*.
   h (T)
   i (T) Note that [JC^{-1}] is also the volt [V].
   j (F) Resistivity = [Ωm].

SSCE/JME - Type Objective Questions

1. Which of the following are derived units?
I. Metre II. Coulomb III. Kilogram IV. Ampere V. Joule
A. I and III only **B.** II and V only
C. II, IV and V only **D.** All of them.

2. Which of the following are derived quantities?
I. Thrust II. Temperature III. Area IV. Pressure
A. I and IV only **B.** II, III and IV only
C. I, III and IV only **D.** I, II, III and IV

3. The derived dimension $[ML^2T^{-2}]$ is a dimension of
I. acceleration II. torque III. energy
A. I only **B.** III only
C. I and II only **D.** II and III only

4. Which of the following are not fundamental units?
I. Kelvin II. Newton III. Second IV. Radian
A. I and III only **B.** II and IV only
C. I and II only **D.** I, II and IV only.

5. The unit of momentum is
A. Js^{-1} **B.** Ns **C.** Ns^{-1} **D.** Nms

6. The dimension of power is
A. ML^2T^{-3} **B.** MLT^{-2} **C.** ML^2T^{-2} **D.** $ML^{-2}T^3$

7. In which of the following physical quantities are the units correctly indicated?
I. Weight [N] II. Energy [N m]
III. Momentum [$kgms^{-1}$] IV. Acceleration [Nkg^{-1}]
A. I and II only **B.** III and IV only
C. I, II and III only **D.** I, II, III and IV

8. The watt is equivalent to
A. Nms^{-1} **B.** Js **C.** kgm^2s^{-2} **D.** Ns

9. Which of the following quantities has the same unit as the *kilowatt - hour*?
A. Force x acceleration **B.** Force x velocity
C. Force x distance **D.** Force x time.

10. Which of the following are vector quantities?
I. Work II. Displacement III. Acceleration
IV. Electric field intensity V. Magnetic induction
A. I, II and III only **B.** II, III and IV only
C. III, IV and V only **D.** II, III, IV and V only

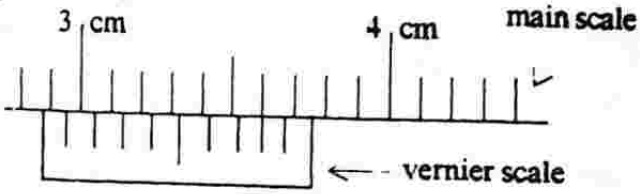
11. Which of the following are scalar quantities?
I. Torque II. Electric potential III. Kinetic energy
IV. Momentum
A. I and IV only **B.** II and III only
C. I, II and III only **D.** II, III and IV only

12. Which of the following is a set of vectors?
A. Weight, displacement and moment
B. Velocity, volume and upthrust
C. Density, capacitance and distance
D. Mass, force and impulse

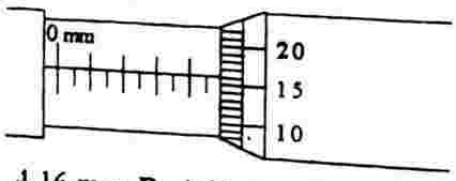
13. Which of the quantities in question 12 is a set of scalars?

14. Which of the following readings gives the correct precision of the length of a rod using vernier callipers?
A. 4.1 cm **B.** 4.13 cm **C.** 4.120 cm **D.** 4.125 cm

15. Which of the following readings gives the correct precision of the length of a rod using a metre rule?
A. 75 mm **B.** 75.0 mm **C.** 75.00 mm **D.** 75.01 mm

16.


The reading of the vernier callipers shown above is
A. 2.38 cm **B.** 2.80 cm **C.** 2.88 cm **D.** 3.60 cm

17. The reading on the micrometer screw gauge shown below is


A. 4.16 mm **B.** 4.60 mm **C.** 4.66 mm **D.** 4.70 mm

18. Which of the following instruments is most suitable for measuring the outside diameter of a narrow pipe a few millimetres in diameter ?
A. Pair of callipers **B.** Metre rule
C. Micrometre screw gauge **D.** Tape rule.

19. A student measures the internal and external diameters of a cylindrical vessel as 100 ($\pm$ 1) mm and 104 ($\pm$ 1) mm respectively. The possible error in the determination of the thickness of the vessel is
A. $\pm$2 mm **B.** $\pm$ 1 mm **C.** $\pm$ 0.5 mm **D.** 0

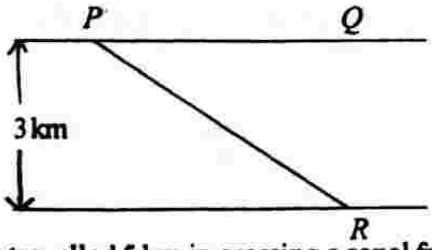
20. The least possible error in using a scale graduated in millimeters is
A. 0.1 mm **B.** 0.5 mm **C.** 1.0 mm **D.** 2.0 mm

21. A boy walks 10 m due west and then 10 m due south. His displacement is
A. 10 m, $S30°W$ **B.** 10 m, $S60°W$
C. $10\sqrt{2}$ m, $S45°W$ **D.** $10\sqrt{2}$ m, $S60°W$

22. A girl walks 12 m northwards, 5 m eastwards and 7 m southwards. Her total displacement is
A. 5 m, north **B.** 5 m, east
C. 7.07 m, $S45°W$ **D.** 7.07 m, $N45°E$

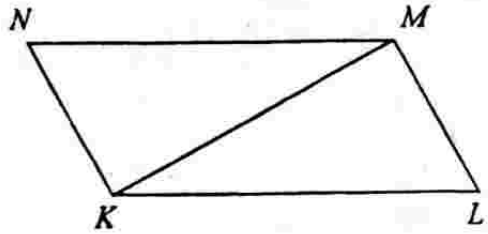
23. A man walks 5 km south and then 3 km in the direction 60° west of south. His distance from the starting point is
A. 7.00 km **B.** 7.50 km **C.** 8.00 km **D.** 10.72 km

24.



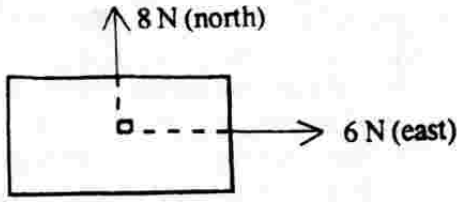
A boat travelled 5 km in crossing a canal from point P to point R (see figure above). The effective displacement of the boat along the edge PQ is
A. 3 km **B.** 4 km **C.** 5 km **D.** 8 km

25.



In the diagram shown above, KM represents the magnitude and direction of a force which is the resultant of forces represented in magnitude and direction by
A. NK and KL **B.** NK and LK
C. KN and KL **D.** KN and LK

26.



A body is acted upon by the two forces 6 N and 8 N as shown in the diagram above. The resultant of the forces is
A. 10 N in the direction $N37°E$
B. 10 N in the direction $N53°E$
C. 10 N in the direction $N37°W$
D. 10 N in the direction $N53°W$

27. Two perpendicular forces have a resultant of 13 N. If one of the forces is 5 N, the other force is
A. 8 N **B.** 9 N **C.** 12 N **D.** 18 N

28. Two forces, 12 N and 16 N inclined at an angle θ to each other, have a resultant which is parallel to the 16 N force. The value of $\cos\theta$ is
A. 1.0 **B.** 3/4 **C.** 1/2 **D.** 0

29. A body of mass M rests on a plane inclined at an angle α to the horizontal. The component of the weight of the body along the normal to the plane is
A. $Mg\sin\alpha$ **B.** $Mg\cos\alpha$
C. $Mg\tan\alpha$ **D.** $Mg/\sin\alpha$

30. A body pulls a box along a horizontal table with a rope inclined to the horizontal at angle 60°. If the tension in the rope 40 N, what is the effective horizontal force?
[$\sin 60° = \sqrt{3}/2$, $\cos 60° = 1/2$, $\tan 60° = \sqrt{3}$, $\cot 60° = 1/\sqrt{3}$]
A. 20 N **B.** $20\sqrt{3}$ N **C.** $40\sqrt{3}$ N **D.** $40/\sqrt{3}$ N

Answer Key

1. B	6. A	11. B	16. C	21. C	26. A
2. C	7. D	12. A	17. C	22. D	27. C
3. D	8. A	13. C	18. C	23. A	28. A
4. B	9. C	14. B	19. A	24. B	29. B
5. B	10. D	15. B	20. B	25. C	30. A

Solutions to Objective Questions

1. **(B)** The *five* frequently occurring fundamental units in physics are the *metre, kilogram, second, kelvin* and *ampere*. All others are derived from a combination of these five. The *coulomb* is [As] while the joule is [N.m] or [$Kgm^2 s^{-2}$]. [Note: The *mole* and the *candella* are also fundamental units, which, however, do not occur as frequently as the five listed above].

2. **(C)** The fundamental quantities are *length, mass, time, temperature* and *electric current*. All others are derived from these. *Thrust* is force which has the unit [N] or [$kgms^{-2}$], Area has unit [m^2] and *pressure* is force/area, with unit [Nm^{-2}].

3. **(D)** M, L, T, stand for mass, length and time respectively. Hence $[ML^2T^{-2}] = [M][LT^{-2}][L]$ = [mass] [acceleration][distance] = [force][distance] = unit of *torque or work* (energy).

4. **(B)** See (1) above.

5. **(B)** Momentum = mass x velocity = [$kgms^{-1}$]
= [$kgms^{-2}$][s] = [Ns].

6. **(A)** Power = energy/time. From (3) above, energy = $[ML^2T^{-2}]$, hence power = $[ML^2T^{-2}/T]$, or $[ML^2T^{-3}]$.

7. **(D)** Weight has unit of force = [N]
Energy has unit of force x distance = [Nm]
Momentum has unit of mass x velocity = [$kgms^{-1}$]
Acceleration has unit of force/mass = [Nkg^{-1}]

8. **(A)** Watt = [Js^{-1}] = [Nms^{-1}]

9. **(C)** Kilowatt-hour = [power x tin e] = [energy]
= [force x distance]

10. **(D)** All except *work*, are vector quantities.

11. **(B)** Electric potential and energy are scalars.

12. **(A)** In groups *B* to *D*, *volume, density, capacitance, distance* and *mass* are scalars.

13. **(C)** See (12) above.

14. **(B)** With the vernier callipers, measurements can be made to the nearest 0.01cm.

15. **(B)** The smallest division on the meter rule is 1mm. Precise measurements can be made to the nearest 0.5 mm.

16. **(C)** The main scale reading (left edge of vernier scale) is 2.80. The *eighth* division on the vernier scale coincides with a division on the main scale. Hence the reading is 2.80 + 0.08, or 2.88 cm.

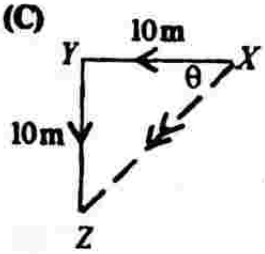
17. **(C)** The reading on the main scale is 4.50 mm. The 16th division on the circular scale coincides with the horizontal line on the main scale. Hence the reading is 4.50 + 0.16, or 4.66 mm.

18. **(C)** The micrometer screw gauge is the most suitable when the diameter is of the order of a few millimetres.

19. **(A)** The internal diameter could range from 99 mm to 101mm and the external diameter from 103 mm to 105 mm. The thickness could therefore range from 103 - 101, or 2 mm to 105 - 99, or 6 mm, i.e. thickness will be measured as 4 mm $\pm$ 2 mm.

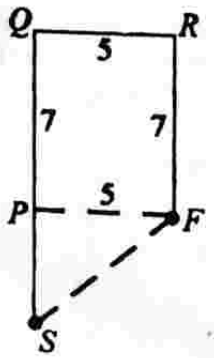
20. **(B)** The scale can be read to the nearest 0.5 mm.

21. **(C)**



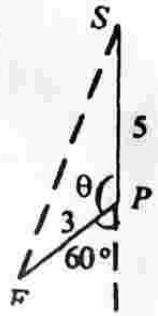
Taking X as the starting point and Z as the end point, (see diagram), the displacement is $XZ = 10\sqrt{2}$ m since XYZ is an isosceles triangle and $\theta = 45°$. The bearing of Z from X is $S45°W$.

22. **(D)**



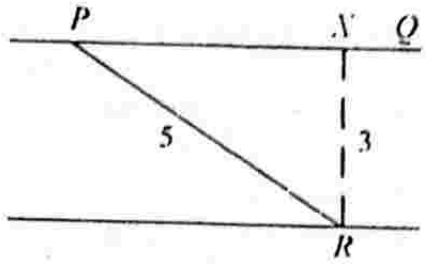
The girl starts from S and ends at F (see diagram). $FP = SP = 5$ m, hence $SF = 5\sqrt{2} = 7.07$ m and the angle $FSP = 45°$, i.e. F is 7.07 m from S in the direction $N45°E$.

23. **(A)**



The man starts from S and ends at F (refer to diagram).
$\theta = 180° - 60° = 120°$
Cosine rule:
$SF^2 = 5^2 + 3^2 - 2(5)(3)\cos\theta$
$= 34 - 30\cos 120° = 34 + 15$
$= 49$, or $SF = 7$ km.

24. (B)

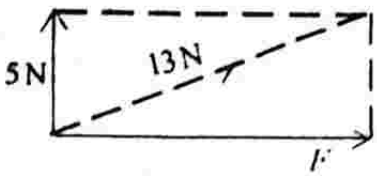


Referring to the diagram above, effective displacement of the boat along the edge PQ is PX. Since PXR is a right-angled triangle with $XR = 3$ and $PR = 5$ km, PX must be equal to 4 km.

25. (C) See revision notes.

26. (A) The resultant of the forces is $R = \sqrt{8^2 + 6^2} = 10$ N which makes angle θ with the north where $\theta = \tan^{-1}(6/8) = 37°$, i.e. R lies in the direction $N\,37°\,E$.

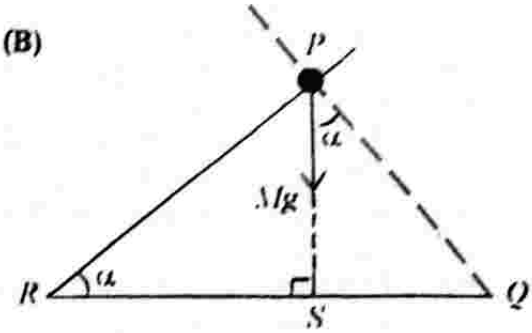
27. (C)



From the diagram, $F^2 = 13^2 - 5^2 = 169 - 25 = 144$, or $F = 12$ N.

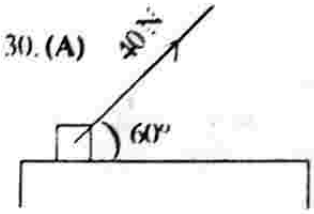
28. (A) The angle between the two forces must be zero, i.e. they lie in the same direction and $\cos\theta = 1.0$.

29. (B)



The weight Mg of the body acts vertically downwards (see figure above). Its resolved component along PQ (i.e. normal to the plane PR) is $Mg \cos SPQ$. From the geometry of the figure, $SPQ = PRQ = \alpha$. Hence the resolved component along PQ is $Mg \cos\alpha$. [Parallel to the plane, i.e. along PR, the resolved component is $Mg \sin\alpha$]

30. (A)



The effective horizontal force is the resolved component of force in the horizontal direction. This is equal to $40 \cos 60° = 40(1/2) = 20$ N.

Revision Check-list

Under this chapter a candidate should be able to

- distinguish between *fundamental* and *derived quantities*.
- classify familiar units as *fundamental* or *derived units*.
- derive the units of common physical quantities in terms of the fundamental units.
- distinguish between *scalars* and *vectors*.
- classify common physical quantities as vectors or scalars.
- specify appropriate istruments for measuring the dimensions of common objects.
- interprete correctly the readings on a pair of *vernier callipers* and a *micrometer screw gauge*.
- specify the margin of error involved in the measurement taken by any common measuring instrument.
- determine the *resolved component* of a vector along any specified direction.
- determine the *resultant* of two vectors.
- determine the *difference* of two vectors.

2 Motion

2.1 Types of Motion

- ***Motion*** is the time-dependent change in position associated with a body. Motion is usually classified into four broad types:
  - (a) ***Translational:*** Movement of the whole body from one position to another, e.g a falling stone.
  - (b) ***Rotational:*** The turning of a body around a fixed point, e.g. the blade of an electric fan.
  - (c) ***Oscillatory (or vibratory):*** To-and-fro movement about a central position, e.g. the bob of a pendulum.
  - (d) ***Random:*** Irregular movement which follows no definite pattern, e.g movement of players on a football field.
- In reality, objects in motion often exhibit more than one type of motion at the same time. The wheels of a moving car, for instance, undergo both translational and rotational motion.

2.2 Linear Motion

- This is movement along a straight line. The following terms are used to describe such a motion:
  Displacement (s): change in position along a specified direction.
  Velocity (v): change in displacement per unit time.
  Speed: the magnitude (but not direction) of velocity
  Acceleration (a): change in velocity per unit time.
  Uniform Motion: motion at constant velocity.
  Uniformly Accelerated Motion: motion at constant acceleration.
- If a body undergoing *uniform motion* covers a distance s in time t, the velocity is

$$v = \frac{s}{t} \qquad (2.1)$$

along the direction of displacement.

- If a body changes its velocity uniformly from an initial value u to a final value v within a time interval t (*uniform acceleration*), the acceleration is $a = (v-u)/t$ or

$$v = u + at \qquad (2.2)$$

- Other equations of motion which relate the quantities u, v, a, t and s are:

$$s = ut + \frac{1}{2}at^2 \qquad (2.3)$$

and $$v^2 = u^2 + 2as \qquad (2.4)$$

- Units: $s = [m]$, $t = [s]$, $u = [ms^{-1}]$, $v = [ms^{-1}]$, $a = [ms^{-2}]$.

2.3 Graphical Methods

- The slope of a distance-time plot gives the veloc of motion (Fig. 2.1).
- The *slope* of a velocity-time plot gives the accelerati (Fig. 2.2)

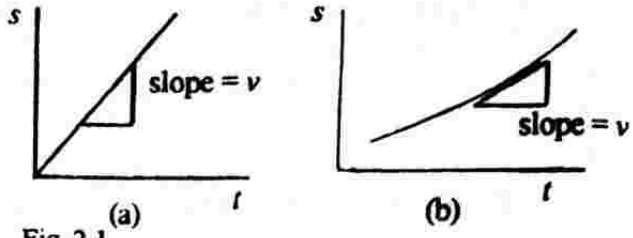


Fig. 2.1

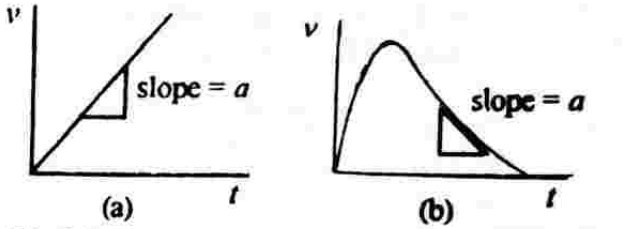


Fig. 2.2

- The *area* under a velocity-time plot gives the tota distance covered (Fig. 2.3)

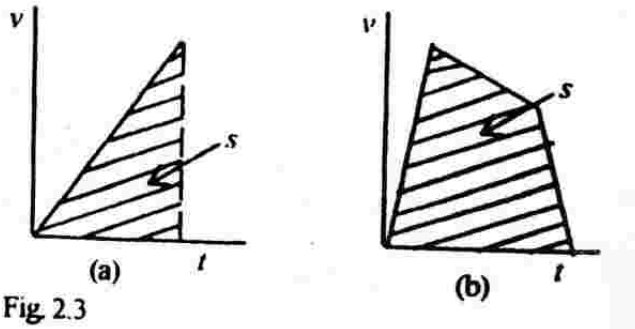


Fig. 2.3

2.4 Freely Falling Bodies

- A freely falling body does so under uniform acceleration. This acceleration is roughly constant (about 9.80 ms^{-2}) at all points near the earth's surface and it is called the **acceleration due to gravity (g)**.
- For a body in free fall, the equations of motion (2.2 - 2.4) are applicable provided:
  (i) a is set equal to g for downward motion
  (ii) a is set equal to $-g$ for upward motion.

2.5 Newton's Laws of Motion

- Motion occurs in response to a **force**, which may be defined as a push or pull. Newton's laws of motion are:
- **First Law**: *A body remains in its state of rest or uniform motion in a straight line unless a net external force acts upon it*
- **Second Law**: *A body which is subjected to a net*

external force (F) acquires an acceleration (a) which is directly proportional to the force and inversely proportional to the mass of the body.

- **Third Law**: *To every action (force) there is an equal and opposite force of reaction.*
- The first law introduces the concept of **inertia**, i.e. the reluctance of a body to change its state of rest or of uniform motion.
- The second law is written mathematically as $a = F/m$, or

$$F = ma \qquad (2.5)$$

where m is the mass of the body.

- To apply Newton's second law to a freely falling body, we set $a = g$ and $F = W$ (weight of the body) in eq. (2.5) to give

$$W = mg \qquad (2.6)$$

i.e. the weight of the body is the product of its mass and the acceleration due to gravity. The weight is also called the **force of gravity** on the body.

- The third law involves two separate bodies. Thus if body A exerts a force F_A on B, then B also exerts a force $F_B = -F_A$ on A.
- Units: m = [kg], F = [newtons], abbreviated to [N], W = [N]. In terms of the fundamental units, [N] = [kg.ms^{-2}].

2.6 Impulse and Momentum

- **The impulse** on a body is the product of the force (F) and the time (t) for which it acted, i.e.

$$\textit{Impulse} = Ft \qquad (2.7)$$

- The momentum of a body is the product of the mass (m) and velocity (v) of the body, i.e.

$$\textit{Momentum} = mv \qquad (2.8)$$

- For a body which is uniformly accelerated from an initial velocity u to a final velocity v in time t, $a = (v-u)/t$ and the force producing the acceleration is, from eq. (2.5).

$$F = \frac{m(v-u)}{t} = \frac{(mv-mu)}{t} \qquad (2.9)$$

- Since mu = initial momentum and mv = final momentum, eq. (2.9) states that the *rate of change of momentum is directly proportional to the net external force acting on the body*. This is an alternative statement of Newton's second law.
- We can re-write eq. (2.9) as

$$Ft = mv - mu \qquad (2.9a)$$

In other words, the impulse on a body is equal to the change in the body's momentum.

- The **principle of conservation of momentum** states that *the total momentum of two colliding bodies remains constant if no external forces act on the bodies.*
- If masses m_1, m_2 move with velocities u_1, u_2 before collision and with velocities v_1, v_2 after collision (Fig. 2.4):

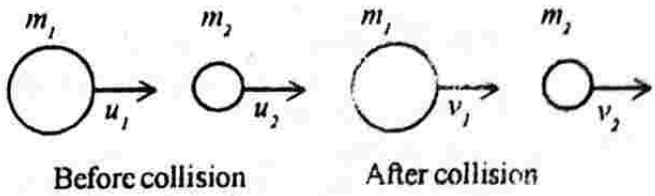


Fig. 2.4

total momentum before collision = $m_1u_1 + m_2u_2$
total momentum after collision = $m_1v_1 + m_2v_2$

Conservation of momentum gives :
total momentum before collision = total momentum after collision i.e.

$$m_1u_2 + m_2u_2 = m_1v_1 + m_2v_2 \qquad (2.10)$$

- Units: Impulse = [N.s] = [kg.ms^{-1}] = unit of momentum

2.7 Motion in a Circle

- Consider a body which moves in a circular path of radius r, centred at O. Let us suppose that the body moves at a constant speed (of magnitude v) while its direction of motion changes continuously as it moves round the circular path, i.e. the body is accelerating (Fig. 2.5). For such motion:

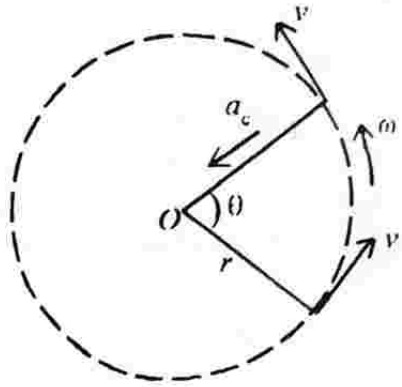


Fig 2.5

- **Angular velocity** (ω) = $\dfrac{\text{angular displacement}}{\text{time}} = \dfrac{\theta}{t}$
- **Tangential velocity** (v) = linear velocity in a tangential direction to the circular path.
- The relationship between v and ω is

$$v = r\omega \qquad (2.11)$$

- **Centripetal (or radial) acceleration (a_c)** = acceleration directed toward the centre (O) of the circular path.

$$a_c = \frac{v^2}{r} = r\omega^2 \qquad (2.12)$$

- By Newton's second law, the centripetal acceleration must be accompanied by a **centripetal force** (F_c), also directed toward the centre. Applying eq. (2.5) gives $F_c = ma_c$, or in view of eq. (2.12):

$$F_c = \frac{mv^2}{r} = mr\omega^2 \qquad (2.13)$$

for a body of mass m.

- **Period of rotation (T)** = time taken for the body to complete one revolution round the circle.

$$T = \frac{\text{circumference of circle}}{\text{tangential velocity}} = \frac{2\pi r}{v} = \frac{2\pi}{\omega} \qquad (2.14)$$

- **Frequency of rotation (f)** = number of revolutions per unit time

$$f = \frac{1}{T} = \frac{\omega}{2\pi} \qquad (2.15)$$

- **Units:** θ = [radians], abbreviated to [rad]
  ω = [rad.s^{-1}], F_c = [N], T = [s]
  f = [s^{-1}] or [hertz], abbreviated to [Hz]

2.8 Projectile Motion

- A ball kicked into the air at an angle θ to the horizontal moves in a path which is parabolic (Fig. 2.6). This is also true of a stone which is thrown upwards, or a bullet which is fired from a gun. A body which moves in this fashion is called *a projectile*.

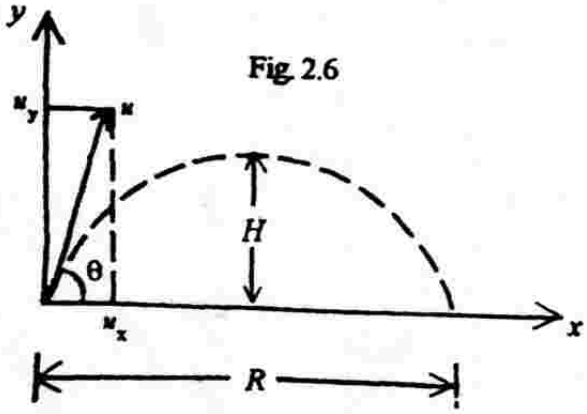


Fig. 2.6

- **Let u = initial velocity of the projectile, at an angle θ to the horizontal**
  H = maximum height reached by the projectile
  R = *range*, or the total horizontal distance covered by the projectile.
- **The motion of the projectile is considered to be made up of two components:**
  (1) **uniform horizontal motion, i.e. horizontal acceleration is zero.**
  (2) **free vertical motion under gravity, whose acceleration is thus equal to the acceleration due to gravity.**
- **The various parameters associated with the projectile motion are related as shown in the following table:**

Parameter	Horizontal(x) Component	Vertical (y) Component
Initial velocity	$u_x = u\cos\theta$	$u_y = u\sin\theta$
Acceleration	$a_x = 0$	$a_y = -g$ (upward motion) $a_y = g$ (downward motion)
Instantaneous velocity (eq. 2.2)	$v_x = u_x$	$v_y = u\sin\theta - gt$
Distance covered in time t (eq. 2.3)	$x = ut\cos\theta$	$y = ut\sin\theta - \frac{1}{2}gt^2$
Time to reach max. height (t_m)		$v_y = 0$ at max height $t_m = (u\sin\theta)/g$
Maximum height (H)		$y_{max} = H = \frac{u^2\sin^2\theta}{2g}$
Total time of flight (t_f)		$y = 0$ at end of flight $t_f = 2u\sin\theta/g$
Range	$R = ut_f\cos\theta = \frac{2u^2\cos\theta\sin\theta}{g}$	

2.9 Simple Harmonic Motion

- **Simple harmonic motion** (*SHM*) is an oscillatory (to-and-fro) motion in which the acceleration (a) is directly proportional to the displacement (x) from the equilibrium position and is directed towards that position.
- For a body undergoing *SHM*,

$$a = -\omega^2 x \qquad (2.16)$$

where ω^2 is the constant of proportionality and ω is the angular velocity of motion.

- Examples of *SHM* are:
  (i) the oscillation of a mass m attached to one end of a helical spring (of spring constant k) while the other end is fixed (Fig. 2.7), and
  (ii) the oscillation of a bob suspended from a light, inelastic string (of length L) the other end of which is fixed, or a ***simple pendulum*** (Fig. 2.8).

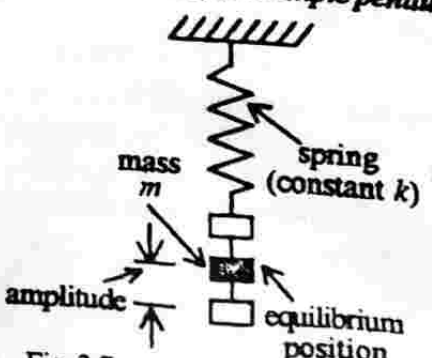


Fig. 2.7

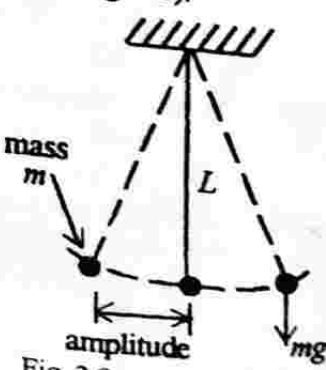


Fig. 2.8

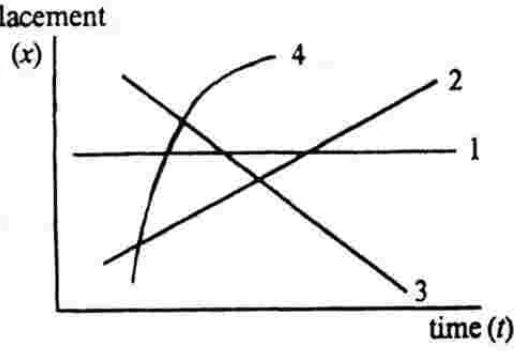
- Parameters associated with *SHM*:
  Amplitude (A) = maximum displacement from equilibrium position
  Period (T) = time to complete one cycle of oscillation
  Frequency (f) = number of oscillations per unit time
- The following parameters apply to the two systems illustrated in Figs. 2.7 and 2.8 :

Parameter	Helical Spring	Simple Pendulum
ω^2	$\frac{m}{k}$	$\frac{g}{l}$
Period $T = \frac{2\pi}{\omega}$	$2\pi\sqrt{\frac{m}{k}}$	$2\pi\sqrt{\frac{l}{g}}$
Frequency $f = \frac{\omega}{2\pi}$	$\frac{1}{2\pi}\sqrt{\frac{k}{m}}$	$\frac{1}{2\pi}\sqrt{\frac{g}{l}}$

True or False - Type Questions

1. Study the following types of motion and the classifications in bracket. Answer **True**(T) for each correct classification and **False**(F) for incorrect clasification.
   a. The prongs of a sounding tuning fork [vibratory]
   b. A loaded test tube floating upright in water, when slightly depressed and then released [translational]
   c. The moving skin of a talking drum [oscillatory]
   d. The turn-table of a record player [rotational]
   e. Molecules of a gas [vibratory]
   f. Balance wheel of a watch [oscillatory]
   g. The centre of a coin as it rolls down an inclined plane [rotational]
   h. A point on the surface of a spinning tennis ball in flight [vibratory]
   i. The bob of a swinging pendulum [oscillatory]

Answer **True** (T) or **False** (F) to Questions 2 to 9

2. 

The figure above shows the displacement - time graph for four different types of motion. The following deductions can be made from the graphs:
   a. Line 1 corresponds to an object at rest
   b. Line 2 corresponds to motion with constant positive acceleration
   c. Line 3 corresponds to motion in the negative x-direction
   d. Line 3 corresponds to motion with constant deceleration.
   e. Curve 4 corresponds to motion with negative acceleration.

3. a. Velocity may be defined as the slope of the displacement-time graph.
   b. Displacement is the area under an acceleration-time graph.
   c. For a body uniformly accelerated from rest, acceleration is the slope of the graph of displacement versus square of time.
   d. Acceleration is constant and positive during uniform motion.
   e. The velocity in uniform motion is given by the quotient of the displacement and time.

4. The inertia of a body may be defined as the
   a. reluctance to start moving if in a state of rest.
   b. reluctance to keep moving if already in motion.
   c reluctance to change its velocity if in uniform motion.
   d ability to overcome the earth's gravitational pull.
   e readiness to start moving if in a state of rest.

5. a. The net force on a body undergoing uniform motion is zero.
   b. If the net force on a body is zero, the body must be at rest.
   c. The acceleration produced on a body by a given force is inversely proportional to the mass of the body.
   d. The velocity of a freely falling body increases by 9.8 ms^{-2} in each second.
   e. A freely falling body covers equal distances in every second of fall.
   f. The thrust produced by a jet-propelled engine is equal and opposite to the force acting on the exhaust gases.
   g. When a gun is fired, the force of recoil (i.e.backward force) on the gun is equal in magnitude to the force with which the bullet leaves the barrel of the gun.
   h. Two objects of different masses are dropped at the same time from top of a tall building. Neglecting air resistance, the two bodies will reach the ground at the same time .
   i. The two bodies in (h) will hit the ground with different velocities.

6. A stone X is thrown vertically upward with velocity u. A second stone Y is projected with a velocity $2u$ at an

angle of 30° to the horizontal and a third stone Z is projected with velocity $2u$ at 60° to the horizontal.

a. The maximum height attained by X is greater than that of Y.
b. The time of flight is the same for both X and Y.
c. The vertical component of the velocity of Y at any instant is equal to the velocity of X at the same instant.
d. The range of Y is greater than that of Z.
e. The maximum height attained by Y is greater than Z.
f. The time of flight for Z is greater than for Y.

7. A body which moves at constant speed in a circle
a. has a constant velocity.
b. has a constant acceleration.
c. has an acceleration of constant magnitude but varying direction.
d. has an impressed force which is directed towards the centre of the circle.
e. will if the impressed force is eliminated, continue to move in a straight path along a direction tangential to the circle.

8. In *simple harmonic motion*
a. the acceleration is constant and directed towards a fixed point.
b. the acceleration varies linearly with distance from a fixed point and is directed towards the fixed point.
c. the path of the motion is always circular.
d. the acceleration is maximum at the equilibrium position.
e. the velocity is maximum at the equilibrium position
f. the velocity is zero when the displacement from the equilibrium position is equal to the amplitude.

9. For a simple pendulum
a. the period of oscillation depends *only* on the length of the string.
b. the frequency of oscillation is doubled if the length of the string is quadrupled.
c. the plot of the square of the period versus the length of the string is linear with the slope equal to $4\pi^2/g$.
d. the motion of the bob is simple harmonic.
e. the frequency of oscillation is reduced if a heavier bob is used.

Answers to True or False - Type Questions

1. a (T)
b (F) The test tube performs an up-and-down motion, which is *oscillatory*.
c (T)
d (T)
e (F) The molecules are in *random* motion
f (T)
g (F) The *centre* of the coin undergoes *translational* motion only as it rolls down the plane. Other points on the coin perform translational and rotational motion.
h (F) The ball undergoes *rotational* motion (due to the spin) and *translational* motion (since it is in flight).
i (T)

2. a (T) Note that the slope of each of the graphs represents the velocity, which in this case is zero.
b (F) This is motion under constant velocity, or uniform motion.
c (T) The slope is negative, hence this is uniform motion in the negative x-direction.
d (F) Since the slope is constant, the acceleration is zero.
e (T) The slope (i.e. velocity) decreases with time, indicating a negative acceleration.

3. a (T)
b (F) Displacement is the area under a velocity-time graph while the area under an acceleration-time graph represents velocity
c (F) $s = {}^1/_2at^2$ for a body accelerated from rest. The slope of s vs t^2 gives *one-half* of the acceleration.
d (F) Acceleration is *zero* during uniform motion.
e (T) For uniform motion, $v = s/t$.

4. a (T)
b (F) It is the reluctance to *stop* moving if already in motion.
c (T)
d (F)
e (F) See (a) above.

5. a (T) Uniform motion implies that there is *no* acceleration.
b (F) The body is either at rest, or in *uniform* motion.
c (T) This is Newton's second law, $a = F/m$.
d (T) Change in velocity, $v - u = gt = (9.8 \times 1) = 9.8\ ms^{-1}$ for $t = 1\ s$.
e (F) Since $s = {}^1/_2gt^2 = 5t^2$ for a body starting to fall freely from rest, then $s = 5\ m$ for the 1st second of fall, $s = 15$ m for the second, $s = 30$ m for the third second, etc.
f (T) Because there is no externally impressed force, the total force on the system is zero. Hence the force on the exhaust gases in one direction must be bala-

nced by an equal and opposite force on the engine.

g (T) See (f) above.

h (T) Note from (e) above that the distance covered by a falling body is independent of its mass.

i (F) The velocity in free fall depends only on the time and the acceleration due to gravity, *not* on the mass of the body.

6. a (F) Applying the equation of motion $v^2 = u^2 + 2as$: For X: $h = u^2/2g$.
For Y: the vertical component of velocity of projection is $2u\sin 30° = u$. Hence $h = u^2/2g$ [Note that the height attained depends only on the vertical component of velocity].

b (T) Since the initial vertical component of velocity is u, all other characteristics of the vertical component of motion are identical to those of a body projected vertically upwards with velocity of u. [Note that the time of flight is twice the time to reach maximum height].

c (T) See (b) above

d (F) Range = horizontal component of velocity x time of flight
For Y: Range = $(2u\cos 30°)(2 \times 2u\sin 30°/g)$
For Z: Range = $(2u\cos 60°)(2 \times 2u \sin 60°/g)$
The two ranges are equal in this case.

e (F) For Z: vertical component of velocity of projection is $2u \sin 60° = 1.73u \Rightarrow h = (1.73\,u)^2/2g$, which is greater than for Y (see (a) above).

f (T) From (d) above, the time of flight for Z ($= 4u \sin 60°/g$) is greater than for Y ($= 4u \sin 30°/g$). In general, both the maximum height and the time of flight *increase* as the vertical component of velocity of projection *increases*.

7. a (F) The magnitude of the velocity (i.e. the speed) is constant but the direction is changing.

b (F) The acceleration has a constant magnitude but varying direction (see (c) below)

c (T) The magnitude of the acceleration is $|v^2/r|$ which is constant but it is always directed towards the centre of the circle. Hence its direction changes as the body moves from one point to the other on the circle.

d (T) This is the *centripetal* force.

e (T) This is Newton's first law of motion.

8. a (F) The magnitude of the acceleration depends on the distance from the fixed point.

b (T) Acceleration $a = -\omega^2 x$ i.e. a varies linearly with x, since ω^2 is constant for a given *S.H.M.*.

c (F)

d (F) At the equilibrium position, $x = 0 \Rightarrow a = 0$. (i.e. the acceleration is zero).

e (T)

f (T) This is the point at which the oscillating body changes direction. The acceleration is maximum at this point.

9. a (T) It also depends on the acceleration due to gravity, which is roughly constant on the earth's surface.

b (F) The frequency is *inversely proportional* to the square root of the length. If the length is quadrupled, the frequency is *halved*.

c (T) $T = 2\pi\sqrt{L/g} \Rightarrow T^2 = (4\pi^2/g)L$.

d (T) This is true for small angles of oscillation only.

e (F) The frequency and period of oscillation are independent of the mass of the bob.

SSCE/JME - Type Objective Questions

[Where necessary, take $g = 10\ ms^{-2}$]

1. A man runs a distance of 1.0 km in 5 minutes. His average speed is
A. 20.0 ms^{-1} **B.** 16.7 ms^{-1} **C.** 3.3 ms^{-1} **D.** 0.3 ms^{-1}

2. A car travelling at a uniform speed of 100 kmh^{-1} spends 15 minutes moving from point A to point B along its route. The distance between A and B is
A. 50 km **B.** 25 km **C.** 15 km **D.** 10 km

3. A train with an initial velocity of 20 ms^{-1} is subjected to a uniform deceleration of 2 ms^{-2}. The time required to bring the train to a complete halt is
A. 5 s **B.** 10 s **C.** 20 s **D.** 40 s

4. A body accelerates uniformly from rest at 3 ms^{-1}. Its velocity after travelling a distance of 24 m is
A. 144 ms^{-1} **B.** 72 ms^{-1} **C.** 36 ms^{-1} **D.** 12 ms^{-1}

5. The time taken for the body in question 4 to cover the distance of 24 m is
A. 4 s **B.** 8 s **C.** 16 s **D.** 32 s

6. A body accelerates uniformly from rest at 6 ms^{-2} for 8 seconds and then decelerates uniformly to rest in the next 5 seconds. The magnitude of the deceleration is
A. 9.6 ms^{-2} **B.** 19.2 ms^{-2}
C. 24.0 ms^{-2} **D.** 48.0 ms^{-2}

7. A body undergoing a uniformly-accelerated motion has two points (1s, 10 ms^{-1}) and (20 s, 48 ms^{-1}) on the velocity - time graph of its motion. The acceleration of the body is
A. 0.26 ms^{-2} B. 0.50 ms^{-2}
C. 2.00 ms^{-2} D. 4.80 ms^{-2}

8. A motorist travelling at 72 kmh^{-1}, on siting a STOP road sign applies the brakes such that under constant deceleration the car is brought to a stop within a distance of 50 m. The magnitude of the deceleration is
A. 50 ms^{-2} B. 25 ms^{-2} C. 8 ms^{-2} D. 4 ms^{-2}

9. Two bodies X and Y start from rest and move with uniform accelerations of a and $4a$ respectively. If the bodies cover the same distance in times t_x and t_y, then the ratio of t_x to t_y is
A. 1:4 B. 1:2 C. 2:1 D. 4:1

10. A car starting from rest moves with a uniform acceleration of 6 ms^{-2}. The distance it covers in the fourth second of its motion is
A. 21 m B. 27 m C. 48 m D. 96 m

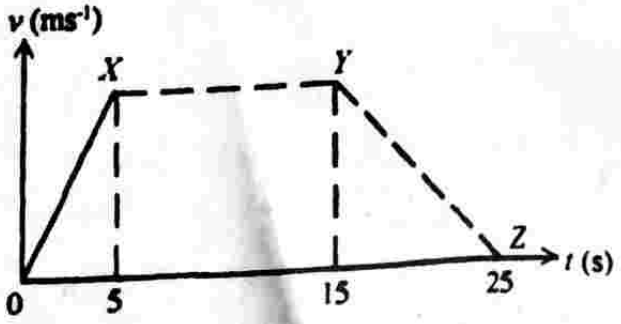
11. A fruit drops from the top of a tree 20 m tall. The time it takes the fruit to reach the ground is
A. 5.0 s B. 4.0 s C. 2.5 s D. 2.0 s

12. The velocity of the fruit (in question 11) just before it hits the ground is
A. 40 ms^{-1} B. 20 ms^{-1} C. 10 ms^{-1} D. 5 ms^{-1}

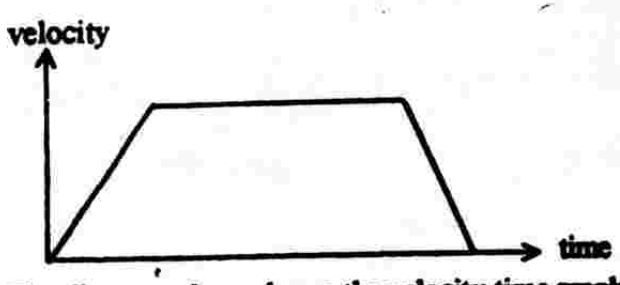
13. A ball is thrown vertically upwards from the ground with an initial velocity of 20 ms^{-1} The maximum height reached by the ball is
A. 7.5 m B. 10.0 m C. 20.0 m D. 22.5 m

14. The time spent in the air by the ball in question 13 is
A. 2 s B. 4 s C. 5 s D. 10 s

15. A ball is thrown vertically upwards from the top of a building with velocity of 10 ms^{-1}. If it takes 4 s for the ball to reach the ground level, the height of the building is
A. 5 m B. 40 m C. 45 m D. 50 m

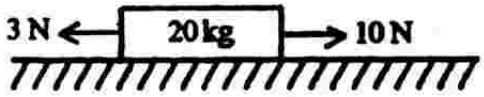
16.


The diagram above shows the velocity-time graph for a moving body. If the total distance covered by the body is 350 m, the acceleration during the segment $0X$ of the body's motion is
A. 4.0 ms^{-2} B. 7.5 ms^{-2} C. 8.0 ms^{-2} D. 15.0 ms^{-2}

17.


The diagram above shows the velocity-time graph of a truck which accelerates uniformly from rest at 2 ms^{-2} for 10 s, maintains a steady velocity for 30 s and is then brought to rest in 5 s under a uniform retardation. The total distance travelled is
A. 1,500 m B. 1,200 m C. 900 m D. 750 m

18. The average velocity for the journey in question 17 is
A. 16.7 ms^{-1} B. 20.0 ms^{-1} C. 25.0 ms^{-1} D. 33.3 ms^{-1}

19.


The diagram above shows a body of mass 20 kg under forces of 10 N and 3 N acting in opposite directions. The acceleration of the body is
A. 0.15 ms^{-2} B. 0.35 ms^{-2} C. 0.50 ms^{-2} D. 2.86 ms^{-2}

20. A motorist driving a motor car of mass 750 kg at a speed of 108 kmh^{-1}, suddenly observes a stationary dog 130 m ahead. If he applies a retarding force of 2,250 N through the brakes, the car will stop
A. immediately after the motorist notices the dog
B. 30 m before reaching the dog
C. 10 m after hitting the dog
D. 20 m after hitting the dog

21. A block of mass 5.0 kg at rest on a smooth horizontal surface is subjected to horizontal force of 20 N. The velocity of the block after 3 s is
A. 4.0 ms^{-1} B. 7.5 ms^{-1} C. 12.0 ms^{-1} D. 15.0 ms^{-1}

22. A body of mass 3 kg initially at rest is subjected to two mutually perpendicular forces of 9 N and 12 N. The acceleration of the body is
A. 0.2 ms^{-2} B. 3.0 ms^{-2} C. 4.0 ms^{-2} D. 5.0 ms^{-2}

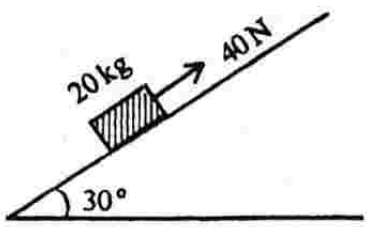
23. A 500 g mass initially at rest is subjected to a force F. If the object attains a speed of 12 ms^{-1} after

moving a distance 60 m, the value of F is
A. 0.6 N B. 1.2 N C. 3.0 N D. 6.0 N

24. The acceleration of a body which slides down freely on a smooth plane inclined at 60° to the horizontal is
A. 5.00 ms^{-2} B. 7.50 ms^{-2} C. 8.66 ms^{-2} D. 10.00 ms^{-2}

25. A war-plane on a level flight releases a bomb X. Twenty seconds later, it releases a second bomb Y. The bomb Y will reach the ground
A. at the same time with X
B. 10 s after X
C. 20 s after X
D. 40 s after X

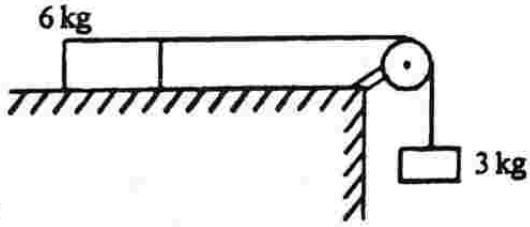
26.



A body of mass 20 kg slides down on a plane inclined at 30° to the horizontal (see diagram above). If a constant resisting force of 40 N acts on the body, its acceleration down the plane is
A. 2 ms^{-2} B. 3 ms^{-2} C. 5 ms^{-2} D. 10 ms^{-2}

27. A stationary block of mass 5 kg is set in motion by a force of 60 N. The object attains a speed of 9 ms^{-1} in time t. The value of t is
A. 0.38 s B. 0.50 s C. 0.75 s D. 1.50 s

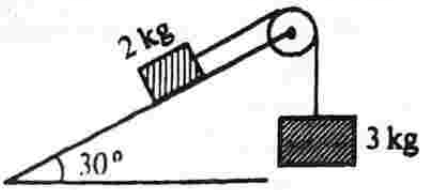
28.



Two blocks of masses 3 kg and 6 kg are connected by a light inextensible string which passes over a smooth pulley as shown in the diagram. Assuming the 6 kg mass is sitting on a smooth surface, the bodies will accelerate at
A. 10.0 ms^{-2} B. 6.7 ms^{-2} C. 5.0 ms^{-2} D. 3.3 ms^{-2}

29. If the coefficient of friction of the surface in question 28 is 0.5, the bodies will accelerate at
A. 0 ms^{-2} B. 1.7 ms^{-2} C. 3.3 ms^{-2} D. 5.0 ms^{-2}

30.



A 2 kg mass on a smooth inclined plane is connected over a smooth pulley to a 3 kg mass as shown in the diagram above. The acceleration of the system is
A. g B. $3g/4$ C. $g/2$ D. $2g/5$

31. A boy of mass 40 kg stands on weighing scale inside a lift. As the lift starts to ascend with an acceleration of 1.5 ms^{-2}, its reading will be
A. 46 kg B. 40 kg C. 34 kg D. 30 kg

32. A mass of 5 kg is suspended from the ceiling of a lift with a light inextensible string. As the lift moves upward with an acceleration of 2 ms^{-2}, the tension in the string is
A. 25 N B. 40 N C. 50 N D. 60 N

33 A girl of mass 50 kg stands on a scale inside a lift which descends at constant velocity. The reading indicated by the scale is
A. less than 50 kg B. equal to 50 kg
C. greater than 50 kg D. zero

34. An elevator of mass 1,200 kg moves vertically downwards with an acceleration of 1.0 ms^{-2}. The tension in the suspending cable is
A. 13.2 kN B. 12.0 kN C. 10.8 kN D. 10.0 kN

35. If the suspending cable of the elevator of question 34 can safely withstand a maximum tension of 15.6 kN the maximum upward acceleration of the elevator is
A. 1.0 ms^{-2} B. 1.5 ms^{-2} C. 2.5 ms^{-2} D. 3.0 ms^{-2}

36. A body of mass m_1 moving with a velocity of u collides with a stationary body of mass m_2. Both bodies move together after the collision with a velocity of
A. $\frac{m_1u}{m_1-m_2}$ B. $\frac{m_1u}{m_1+m_2}$ C. $\frac{m_2u}{m_1+m_2}$ D. $\frac{m_2u}{m_1-m_2}$

37. A body of mass 5 kg moving with a velocity of 20 ms^{-1} due south hits a stationary body of mass 3 kg. If they move together after collision with a velocity v due south, the value of v is
A. 20.0 ms^{-1} B. 15.0 ms^{-1} C. 12.5 ms^{-1} D. 12.0 ms^{-1}

38. A ball of mass 800 g moving horizontally with a speed of 5 ms^{-1} hits a vertical wall and rebounds with the same speed. The impulse experienced by the ball is
A. 0 $kgms^{-1}$ B. 2 $kgms^{-1}$ C. 4 $kgms^{-1}$ D. 8 $kgms^{-1}$

39. A footballer taking a penalty kick applies a force of 100 N for 0.03 s on a ball of mass 150 g. The ball moves off with a speed of
A. 50 ms^{-1} B. 25 ms^{-1} C. 20 ms^{-1} D. 10 ms^{-1}

40. A constant force of 25 N acts on a body of mass 3 kg for 2 s. The change in velocity of the body is
A. 150.0 ms^{-1} B. 75.0 ms^{-1}
C. 50.0 ms^{-1} D. 16.7 ms^{-1}

41. A gun of mass 6 kg fires a 40 g bullet at a speed of 120 ms^{-1}. The recoil speed of the gun is
A. 0.8 ms^{-1} B. 1.0 ms^{-1} C. 1.2 ms^{-1} D. 1.6 ms^{-1}

42. A particle of mass m initially at rest splits into two. If one of the particles of mass m_1 moves with velocity v_1, the second particle moves with velocity
A. $\frac{m_1v_1}{m-m_1}$ B. $\frac{m_1v_1}{m_1-m}$ C. $\frac{m_1v_1}{m}$ D. $\frac{mv}{m-m_1}$

43. 50 g of fuel is burnt each second in a rocket engine and ejected as a gas with a speed of 4,000 ms^{-1}. The thrust on the rocket is
A. 20 N B. 80 N C. 200 N D. 500 N

44. The exhaust gases ejected at a speed of 800 ms^{-1} from a jet engine produce a thrust of 560 N. The mass of gases ejected every second is
A. 0.70 kg B. 1.43 kg C. 7.00 kg D. 14.29 kg

45. An object moves round a circle of radius 20 m with a linear constant speed of 5 ms^{-1}. The object's angular speed is
A. 0.25 $rads^{-1}$ B. 0.50 $rads^{-1}$
C. 4.00 $rads^{-1}$ D. 100 $rads^{-1}$

46. A stone tied to the end of a string revolves in a horizontal circle of radius 5 m with an angular speed 3 $rads^{-1}$. The tangential velocity with which the stone will move off if the string breaks is
A. 0.6 ms^{-1} B. 1.7 ms^{-1} C. 7.5 ms^{-1} D. 15.0 ms^{-1}

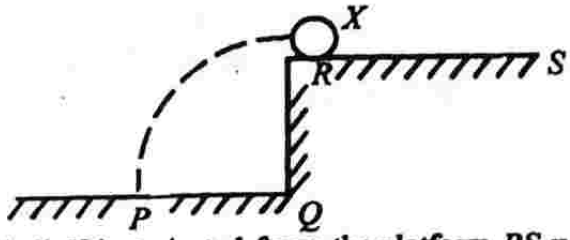
47. A particle of mass 5×10^{-6} kg revolves in a circle with a radial acceleration of 8×10^5 ms^{-2}. The centripetal force on the particle is
A. 6.25×10^{-12} N B. 4.00×10^{-2} N
C. 4.00×10^{0} N D. 1.60×10^{11} N

48. A body moves with a constant speed of 2.0 ms^{-1} along a circular path. If the angular speed of the body is 1.2 $rads^{-1}$, the acceleration towards the centre of the circle is
A. 0.60 ms^{-2} B. 1.67 ms^{-2} C. 2.40 ms^{-2} D. 4.80 ms^{-2}

49. A body of mass 500 g moves with a speed of 4 ms^{-1} in a circular path of radius 5 m. The centripetal force on the body is
A. 8.00 N B. 1.60 N C. 0.80 N D. 0.16 N

50. The frequency of the body in question 49 in cycles per second is
A. 0.13 B. 0.25 C. 0.80 D. 1.60.

51. A ball is thrown with an initial velocity V at an angle α to the horizontal. The time taken to reach maximum height is
A. $\frac{V}{g\sin\alpha}$ B. $\frac{V\cos\alpha}{g}$ C. $\frac{V\sin\alpha}{g}$ D. $\frac{V\sin\alpha}{2g}$

52.


A ball X is projected from the platform RS with a horizontal velocity of 14 ms^{-1}. If it takes 0.5 s for the ball to fall freely from R to P (see diagram), the distance PQ is
A. 28.0 m B. 14.5 m C. 9.5 m D. 7.0 m

53. A stone projected horizontally with a velocity of 15 ms^{-1} from the top of a building lands at a horizontal distance of 60 m from the building. The height of the building is
A. 120 m B. 80 m C. 40 m D. 20 m

54. A stone projected with a velocity of 50 ms^{-1} from the ground level hits the ground 5 s later. The angle of projection is
A. 0° B. 30° C. 45° D. 60°

55. The range of the projectile in question 54 is
A. 125 m B. $125\sqrt{2}$ m C. $125\sqrt{3}$ m D. 250 m

56. The maximum height reached by the stone in question 54 is
A. 31.25 m B. 62.50 m C. 93.75 m D. 125.00 m

57. The horizontal component of the stone's velocity when it hits the ground is
A. 25.0 ms^{-1} B. 37.5 ms^{-1} C. 43.3 ms^{-1} D. 50.0 ms^{-1}

58. To obtain the maximum horizontal range, a projectile must be fired at an angle θ to the horizontal which is equal to
A. 90° B. 60° C. 45° D. 30°

59. The assumptions made in a simple pendulum experiment are that:
I. the suspending string is inextensible
II. the angle of oscillation is small
III. the bob has a very small mass
IV. the length of the string is short.
Which of the above statements are correct?

A. I and II only B. III and IV only
C. I,II and III only D. I,II,III and IV

60. The period of oscillation of a simple pendulum which makes 75 oscillations in one minute is
A. 0.13 s B. 0.80 s C. 1.00 s D. 1.25s

61. The frequency of oscillation of a simple pendulum can be reduced by
A. increasing the mass of the bob
B. reducing the mass of the bob
C. increasing the length of the string
D. reducing the length of the string

62. A body in simple harmonic motion has an angular speed of 4.4 $rads^{-1}$. The period of motion is
A. 0.70 s B. 1.43 s C. 3.14 s D. 4.40 s

63. The length of a simple pendulum is plotted against the square of the corresponding period. The slope of the graph is equal to
A. $\frac{g^2}{4\pi}$ B. $\frac{\pi}{4g^2}$ C. $\frac{4\pi^2}{g}$ D. $\frac{g}{4\pi^2}$

64. Two simple pendula P and Q make oscillations of 200 and 300 oscillations respectively in equal times. If the period of P is 1.2 s, the period of Q is
A. 0.60 s B. 0.80 s C. 1.25 s D. 1.80 s

65. When the length of the inextensible string of a simple pendulum is increased by a factor of 4, its period is
A. increased by a factor of 4
B. increased by a factor of 2
C. decreased by a factor of 4
D. decreased by a factor of 2

66. A simple pendulum of length 0.64 m has a period of 2.4 s. The period of a simple pendulum of length 0.36 m is
A. 1.4 s B. 1.8 s C. 3.2 s D. 4.3 s

Answer Key

1. C	12. B	23. A	34. C	45. A	56. A
2. B	13. C	24. C	35. D	46. D	57. C
3. B	14. B	25. C	36. B	47. C	58. C
4. D	15. B	26. B	37. C	48. C	59. A
5. A	16. A	27. C	38. D	49. B	60. B
6. A	17. D	28. D	39. C	50. A	61. C
7. C	18. A	29. A	40. D	51. C	62. B
8. D	19. B	30. D	41. A	52. D	63. D
9. C	20. D	31. A	42. B	53. B	64. B
10. A	21. C	32. D	43. C	54. B	65. B
11. D	22. D	33. B	44. A	55. C	66. B

Solutions to Objective Questions

1. **(C)** Average speed = distance/time = 1,000/(5 x 60) = 3.3 ms^{-1}

2. **(B)** Distance = speed x time = (100 x 10^3/3600)(15 x 60) = 25 x 10^3 m, or 25 km

3. **(B)** $u = 20\ ms^{-1}$, $a = -2\ ms^{-2}$, $v = 0$
$v = u + at \Rightarrow t = (v-u)/a = (0-20)/(-2) = 10$ s

4. **(D)** $v^2 = u^2 + 2as = 0 + 2(3)(24) = 144$, $v = 12\ ms^{-1}$

5. **(A)** $t = (v-u)/a = (12-0)/3 = 4$ s

6. **(A)** Maximum velocity attained, $v = u + at = 0 + (6)(8) = 48\ ms^{-1}$. For the deceleration stage, $u = 48\ ms^{-1}$, $v = 0$, $t = 5$ s $\Rightarrow a = (v-u)/t = (0 - 48)/5 = -9.6\ ms^{-2}$

7. **(C)** $a = \frac{v_2 - v_1}{t_2 - t_1} = \frac{48-10}{20-1} = \frac{38}{19} = 2\ ms^{-2}$

8. **(D)** $u = 72\ kmh^{-1} = 72{,}000/3600 = 20\ ms^{-1}$, $s = 50$ m, $v = 0$, $v^2 = u^2 + 2as \Rightarrow a = (v^2 - u^2)\ 2s$
$= (0-400)/(2 \times 50) = -4.0\ ms^{-2}$

9. **(C)** For X : $S_x = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}at_x^2$
For Y : $S_y = \frac{1}{2}a_y t_y^2 = \frac{1}{2}(4a)t_y^2 = 2at_y^2$
Since $S_x = S_y$, $\frac{1}{2}at_x^2 = 2at_y^2$ or $t_x/t_y = \sqrt{4} = 2$
Hence $t_x : t_y = 2:1$

10. **(A)** After 3 s, $s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(6)(3)^2 = 27$ m
After 4 s, $s = \frac{1}{2}(6)(4)^2 = 48$ m
Distance covered in fourth second = 48 - 27 = 21 m

11. **(D)** $u = 0$, $s = 20$ m, $a = g = 10\ ms^{-2}$
$s = ut + \frac{1}{2}at^2$, or $20 = \frac{1}{2}(10)t^2$
$t = \sqrt{4} = 2$ s

12. **(B)** $v^2 = u^2 + 2as = 0 + 2(10)(20) = 400$, or $v = 20\ ms^{-1}$

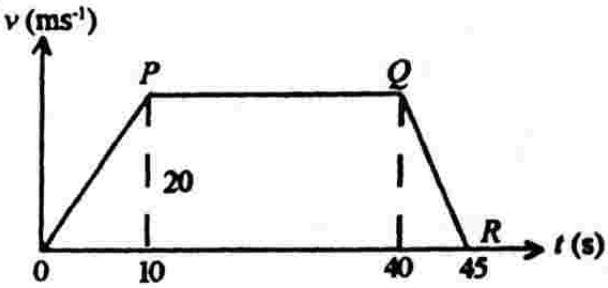
13. **(C)** $u = 20\ ms^{-1}$, $a = -g = -10\ ms^{-2}$, $v = 0$ at max height
$v^2 = u^2 + 2as \Rightarrow 0 = 400 + 2(-10)(s)$. Hence $s = 20$ m

14. **(B)** $t = (v-u)/a = (0-20)/(-10) = 2$ s.
Time spent in air = 2 x 2 = 4 s.

15. **(B)** Let s = dist. from top of building to max. height attained by the ball and h = height of the building
For the ball's *upward* flight:
$t = (v - u)/a = 0-10/(-10) = 1$ s, $v = 0$
$v^2 = u^2 + 2as \Rightarrow s = -u^2/2a = -(10)^2/2(-10) = 5$ m
For the ball's *downward* flight.
$t = 4-1 = 3$ s, $u = 0$
$s + h = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(10)(3)^2 = 45$ m
$\Rightarrow h = 45-5 = 40$ m

16. **(A)** The maximum velocity attained = v_m = height of trapezium $OXYZ$. Dist. travelled = area of the trapezium: $350 = \frac{1}{2}v_m(OZ + XY) = \frac{1}{2}v_m(25+10)$, or $v_m = 20\ ms^{-1}$. Acceleration = slope of $OX = 20/5 = 4\ ms^{-1}$.

17. **(D)**



The v-t diagram is re-drawn above, labelled.
Since the slope of OP is 2 ms^{-2}, the height of the trapezium $OPQR = 20\ ms^{-1}$
Distance travelled = area of the trapezium
$= \frac{1}{2}(OR + PQ) \times 20 = \frac{1}{2}(45 + 30) \times 20 = 750$ m

18. **(A)** Average velocity = distance /time
= 750 / 45 = 16.7 ms^{-1}

19. **(B)** Net force to the right, $F = 10-3 = 7$ N
Newton's *second* law : $F = ma$
$\Rightarrow a = F/m = 7/20 = 0.35\ ms^{-2}$

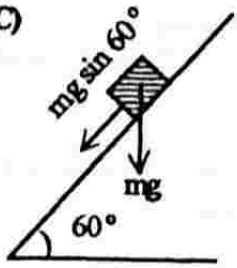
20. **(D)** Car's deceleration, $a = F/m = 2250/750 = 3\ ms^{-2}$
Initial speed, $u = 108\ kmh^{-1} = 108 \times 10^3/3600 = 30\ ms^{-1}$
Final speed, $v = 0$. The car will stop in distance s where
$v^2 = u^2 + 2as \Rightarrow 0 = (30)^2 + 2(3)\ s$,
or $s = 150$ m, i.e. the car will go 20 m past the dog before stopping.

21(C) Acceleration of the block, $a = F/m = 20/5 = 4\ ms^{-2}$
$v = u + at = 0 + (4)(3) = 12\ ms^{-1}$.

22. **(D)** Resultant force on the body, $F = \sqrt{9^2 + 12^2} = 15$ N
Acceleration $a = F/m$
$= 15/3 = 5\ ms^{-2}$

23. **(A)** $u = 0$, $v = 12\ ms^{-1}$, $s = 60$ m
$v^2 = u^2 + 2as \Rightarrow 144 = 0 + 2a(60)$
or $a = 1.2\ ms^{-2}$
$F = ma = (0.5)(1.2) = 0.6$ N

24. (C)



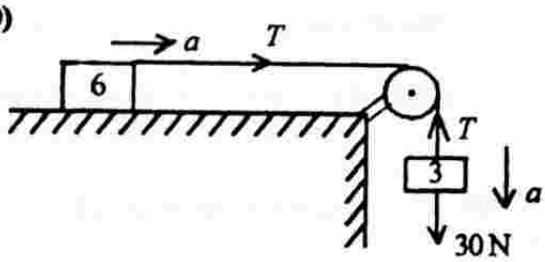
The resolved component of the body's weight along the plane is $F = mg\sin 60° = ma$ or $a = g\sin 60° = 10(0.866)$ $= 8.66\ ms^{-2}$ (see diagram).

25. (C) Since the altitude of the plane is the same in both cases, both bombs will spend the same time in the air. Hence Y which is released 20 s after X, will also land 20 s after X.

26. (B) The resolved component of the weight down the plane is $20g\sin 30°$, or 100 N. Net force on the mass is $F = 100 - 40 = 60$ N down the plane
Hence $a = F/m = 60/20 = 3\ ms^{-2}$

27. (C) $a = F/m = 60/5 = 12\ ms^{-2}$
$v = u + at \Rightarrow 9 = 0 + 12t$, or $t = 9/12 = 0.75$ s

28. (D)



Applying Newton's *second* law to the 3 kg mass (which has a weight of 30 N)

$30 - T = 3a$ . . . . . (1)

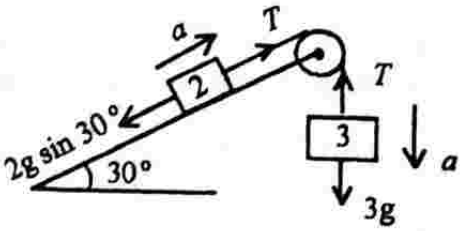
where T = tension in the string. For the 6 kg mass:

$T = 6a$ . . . . . (2)

Solving equations (1) and (2) simultaneously gives $a = 3.3\ ms^{-2}$

29. (A) Here, a frictional force of μmg, or $0.5 \times 6 \times 10 = 30$ N acts to the left on the 6 kg mass. Hence eq. (2) in Q. 28 becomes $T - 30 = 6a$.
Combining this with eq.(1) gives $a = 0$

30. (D)



For the 3 kg mass:

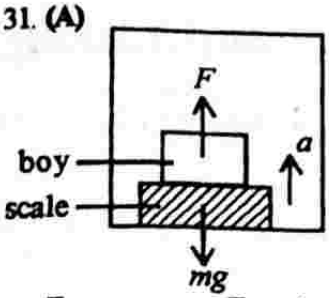
$3g - T = 3a$ . . . . . (1)

for the 2 kg mass, $T - 2g\sin 30° = 2a$, or

$T - g = 2a$ . . . . . (2)

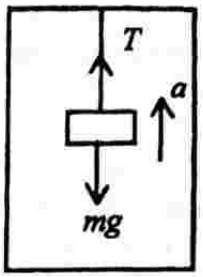
Combining eqs.(1) and (2) gives $a = 2g/5$.

31. (A)



The two forces acting on the scale are the boy's weight (mg) acting downwards and the force of reaction (F) upwards. The reading indicated by the scale is F. Applying Newtons second law: Net upward force = ma
$F - mg = ma$, or $F = m(g+a) = 40(10+15) = 460$ N, which is equivalent to a mass of 46 kg.

32. (D)



The forces acting on the mass are the tension in the string (upwards) and the weight, mg of the body. Applying Newton's second law: $T - mg = ma$
$T = m(g+a) = 5(10+2) = 60$ N

33. (B) At constant velocity (acceleration = 0) the scale reading is equal to the actual mass of the girl.

34. (C) Refer to the diagram of Q.32 (above) but with the acceleration a directed downwards. From Newton's second law, $mg - T = ma$ or $T = m(g-a) = 1200(10-1) = 10{,}800$ N, or 10.8 kN.

35. (D) For upward acceleration, $T = m(g+a)$ (see Q.32) $1{,}200(10+a) \leq 15{,}600$, or $a \leq 3.0\ ms^{-1}$.

36. (B) Initial momentum $= m_1u + m_2(0) = m_1u$
Final momentum $= (m_1 + m_2)v$
Initial momentum = Final momentum
$(m_1 + m_2)v = m_1u$, or $v = m_1u/(m_1 + m_2)$

37. (C) Initial momentum $= 5(20) + 3(0) = 100\ kgms^{-1}$
Final momentum $= (5+3)v = 8v$
$8v = 100$, or $v = 12.5\ ms^{-1}$

38. (D) Initial momentum $= (0.8)(5) = 4.0\ kgms^{-1}$
Final momentum $= (0.8)(-5) = -4.0\ kgms^{-1}$
(The rebound velocity is negative since it is in opposite direction to the original velocity)
Impulse on ball = change in momentum
$= 4.0 - (-4.0) = 8.0\ kgms^{-1}$

39. (C) Impulse on ball = Force x time = (100)(0.03) = 3 Ns
Change in momentum $= mv = 0.15v$
$0.15v = 3$, or $v = 20\ ms^{-1}$

40. (D) Impulse on the body = 25 x 2 = 50 Ns
Change in momentum = mass x change in velocity
$\Rightarrow$ change in velocity $= 50/m = 50/3 = 16.7\ ms^{-1}$

41. **(A)** Initial momentum = 0
Final momentum = $(0.04)(120) + 6v = 6v + 4.8$
where v is the velocity of the gun.
$6v + 4.8 = 0$, or $v = 4.8/6 = 0.8\ ms^{-1}$

42. **(B)** Initial momentum = 0
Final momentum = $m_1v_1 + (m - m_1)v$
where $m - m_1$ and v are the mass and velocity of the second particle respectively.
$m_1v_1 + (m - m_1)v = 0$, or $v = m_1v_1/(m_1 - m)$

43. **(C)** Thrust(force) on rocket = rate of change of momentum of the gas = mass ejected per second x velocity
$= 0.05\ kgs^{-1} \times 4{,}000\ ms^{-1} = 200\ N$

44. **(A)** Thrust = mass ejected per second x velocity.
Mass ejected per second = Thrust/velocity
$= 560/800 = 0.70$ kg.

45. **(A)** Angular speed, $\omega = v/r = 5/20 = 0.25\ rads^{-1}$

46. **(D)** Tangential velocity, $v = r\omega = 5(3) = 15\ ms^{-1}$

47. **(C)** Centripetal force = mass x radial acceleration
$= (5 \times 10^{-6})(8 \times 10^5) = 4.0\ N$

48. **(C)** Radial acceleration $= r\omega^2 = (r\omega)(\omega) = v\omega$
$= (2.0)(1.2) = 2.4\ ms^{-2}$

49. **(B)** Centripetal force $= mv^2/r = (0.5)(4)^2/5 = 1.6\ N$

50. **(A)** $\omega = v/r = 4/5 = 0.80\ rads^{-1}$.
Frequency $= \omega/2\pi = 0.80 \times 7/44 = 0.13$ cycles/sec.

51. **(C)** Consider the vertical component of motion :
$v = u + at$, where $u = V\sin\alpha$, $a = -g$ and $v = 0$
$0 = V\sin\alpha - gt$, or $t = (V\sin\alpha)/g$

52. **(D)** Consider the horizontal component of motion :
In 0.5 s, the ball travels a horizontal distance
$= vt = (14)(0.5) = 7.0$ m

53. **(B)** Time of flight of the stone $= \dfrac{\text{horizontal distance}}{\text{horizontal velocity}}$
$= 60/15 = 4$ s
Within this time, the stone falls vertically through a distance $h = ut + \frac{1}{2}at^2 = 0 + \frac{g}{2}t^2 = (10/2)(4)^2 = 80$ m
= hieght of building.

54. **(B)** Consider the vertical component of motion :
it takes the stone 2.5 s to reach maximum height.
From problem 51 above, $\sin\alpha = gt/V = (10)(2.5)/50 = \frac{1}{2}$
or $\alpha = 30°$

55. **(C)** Horizontal component of velocity $= V\cos\alpha$
$= (50)(\sqrt{3}/2) = 25\sqrt{3}\ ms^{-1}$
Range = horizontal velocity x time of flight
$= (25\sqrt{3})(5) = 125\sqrt{3}\ ms^{-1}$

56. **(A)** Vertical component of motion : $v = 0$, $u = V\sin\alpha$
$= 50\sin 30° = 25\ ms^{-1}$, $a = -g = -10\ ms^{-2}$
s = maximum height attained
$v^2 = u^2 + 2as \Rightarrow 0 = 625 + 2(-10)s$
or $s = 31.25$ m

57. **(C)** Horizontal component of velocity $= V\cos\alpha = 50\cos 30° = 43.3\ ms^{-1}$ and this remains constant throughout the projectile's motion.

58. **(C)** Range = horizontal velocity x time of flight
Time of flight $= (2V\sin\alpha)/g$ (see Problem 51)
Range $= (V\cos\alpha)(2V\sin\alpha)/g = (V^2\sin 2\alpha)/g$
This has a maximum value of V^2/g when $2\alpha = 90°$
or $\alpha = 45°$

59. **(A)** The *diameter* of the ball, not necessarily its mass, must be small.

60. **(B)** Period = time to complete one oscilliation
$= 60/75 = 0.08$ s

61. **(C)** Frequency $= \dfrac{1}{T} = \dfrac{1}{2\pi}\sqrt{\dfrac{g}{L}}$
Hence frequency *decreases* as L *increases*.

62. **(B)** $T = \dfrac{2\pi}{\omega} = \dfrac{44/7}{4.4} = 1.43$ s

63. **(D)** $T = 2\pi\sqrt{L/g} \Rightarrow T^2 = (4\pi^2/g)L$
or $L = (g/4\pi^2)T^2$. The plot of L vs T^2 is a straight line with a slope of $g/4\pi^2$.

64. **(B)** Period of P, $T_p = t/200$ and period of Q, $T_q = t/300$ where t is the time for P and Q to make 200 and 300 oscillations respectively.
$T_p/T_q = 300/200 = 1.5$
If $T_p = 1.2$ s, $T_q = 1.2/1.5 = 0.80$ s

65. **(B)** $T_1 = 2\pi\sqrt{L/g}$ and $T_2 = 2\pi\sqrt{4L/g} = 4\pi\sqrt{L/g}$
Hence $T_2 = 2T_1$, i.e. period is doubled.

66. **(B)** $\dfrac{T_2}{T_1} = \sqrt{\dfrac{L_2}{L_1}}$

$\dfrac{T_2}{2.4} = \sqrt{\dfrac{0.36}{0.64}} = \sqrt{\dfrac{36}{64}} = \dfrac{3}{4}$

$T_2 = 3/4 \times 2.4 = 1.8$ s

Revision Check-list

Under this chapter, the candidate should be able to

- classify the different *types of motion*.
- define the terms *velocity, acceleration, momentum* and *impulse*.
- state and apply *Newton's laws of motion*.
- define the term *inertia*.
- interprete simple graphs on rectilinear motion.
- explain why and how the *acceleration due to gravity* varies on the earth's surface.
- state and apply the *principle of conservation of momentum*.
- relate *impulse* to change in *momentum*.
- explain the basic features of *circular motion*
- define *centripetal acceleration* and *centripetal force*.
- solve simple problems on *projectile motion*.
- explain the basic features of *simple harmonic motion*.
- define the terms *amplitude, period* and *frequency* of simple harmonic motion.
- describe an experiment to determine the acceleration due to gravity using a simple pendulum.

3 Equilibrium of Forces

3.1 Concurrent Forces

- Since force is a vector quantity, the **resultant** of a group of forces is the *vector sum* of the forces.
- A body under concurrent forces (i.e. whose lines of action pass through a common point) is in equilibrium if the resultant of the forces on the body is zero.
- For forces F_1, F_2 and F_3 to be in equilibrium (Fig.3.1a):

$$\underline{F}_1 + \underline{F}_2 + \underline{F}_3 = 0 \qquad (3.1)$$

- The vector addition of the three forces is illustrated in Fig. 3.1b where the **closed** triangle shows that the vector sum of the forces is zero.

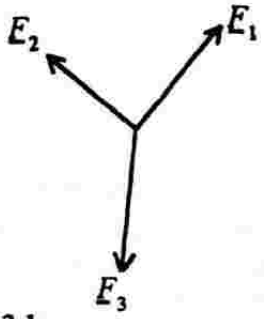


Fig. 3.1a

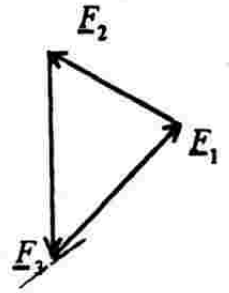


Fig. 3.1b

- The **equilibrant** of a group of forces is the force which is required to bring the body to equilibrium. The equilibrant is thus equal, but opposite in direction, to the resultant.
- The resultant of two forces F_1 and F_2 in Fig. 3.2 is $\underline{R}$ while the equilibrant is F_3 such that

$$\underline{F}_1 + \underline{F}_2 = \underline{R} \qquad (3.2)$$

and

$$\underline{F}_3 = -\underline{R} \qquad (3.3)$$

- The forces on a body can be resolved into two mutually perpendicular directions.
- For the body to be in equilibrium, the sum of the resolved components along each direction must be equal to zero.
- Thus for the system of forces shown in Fig. 3.3, the sum of the resolved components along the positive X direction is

$$\Sigma F_x = F_1\cos\theta_1 - F_2\cos\theta_2 - F_3\cos\theta_3 = 0 \qquad (3.4)$$

and

$$\Sigma F_y = F_1\sin\theta_1 + F_2\sin\theta_2 - F_3\sin\theta_3 = 0 \qquad (3.5)$$

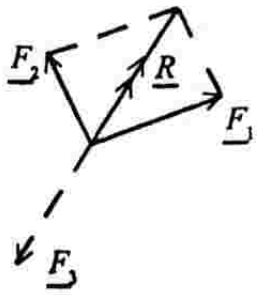


Fig. 3.2

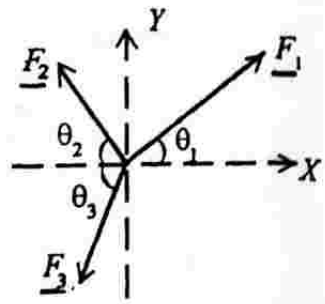


Fig. 3.3

3.2 Parallel Forces

- The **moment** of a force about a point is the rotational effect produced by the force about that point.
- It is defined as the product of the force and its perpendicular distance from that point.
- For a body subjected to a system of parallel (non-concurrent) forces to be in equilibrium:
  1. the algebraic sum of all the components of all the forces resolved along any direction must be zero, and
  2. the sum of the anticlockwise moments about any point must be equal to the sum of the clockwise moments about that point.
- For the lever system shown in Fig. 3.4 to be in equilibrium, condition (1) gives, upon resolving forces vertically:

$$F_1 - F_2 + F_3 = 0 \qquad (3.6)$$

while condition (2) gives, upon taking moments about O,

$$F_1 a = F_3 b \qquad (3.7)$$

- A couple consists of two equal and opposite parallel forces. The moment of a couple is equal to the product of one of the forces and the perpendicular distance between the forces. For the couple shown in Fig. 3.5

$$\textbf{Moment of Couple} = Fd \qquad (3.8)$$

- Unit: Moment = [N.m].

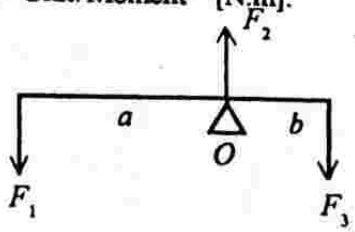


Fig. 3.4

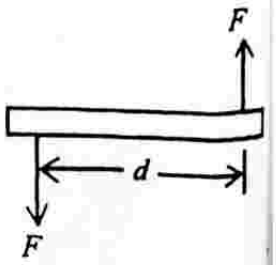
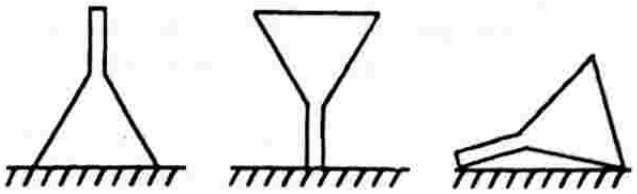


Fig. 3.5

3.3 Centre of Gravity and Stability

- Any object can be considered to be made up of tiny particles.
- The force of gravity pulls down on every particle of the object.
- However, if allowed to fall, the object falls as if its whole weight were concentrated at just one point inside it. This point is its **centre of gravity.**
- For a body with a regular shape such as a sphere or a uniform rod, the centre of gravity is located at the geometrical centre of the body.
- **Stable equilibrium**: A body is in stable equilirium if, when slightly displaced, it returns to its original position. Example: an object with a wide base (Fig.3.6a)
- **Unstable equilibrium**: A slight disturbance causes the body to tip over.
  Example: an object with a narrow base (Fig. 3.6b)
- **Neutral equilibrium**: The body remains in its new position when slightly displaced. Example: a funnel lying on its side (Fig. 3.6c)



(a) stable equilibrium (b) unstable equilibrium (c) neutral equilibrium

Fig. 3.6

3.4 Friction

- Whenever one body is made to (or about to) slide over the surface of another body, a **frictional force** acts opposite to the direction of motion.
- Consider a body A which is just about to slide over the surface of B (Fig. 3.7). The forces acting on the body are:
  (1) the weight of the body (W) and the normal reaction N, in the vertical direction, and
  (2) the applied force F and the frictional force F_r along the horizontal direction.
- If μ_s = coeficent of static friction
  F_r = limiting (static) frictional force, and
  N = normal reaction, the

$$\mu_s = \frac{F_r}{N} \tag{3.9}$$

- When the body is in motion, the coefficient of kinetic (or sliding) friction (μ_k) is given by the quotient of the dynamic frictional force and the normal reaction.
- The coefficient of kinetic friction is usually lower than that of static friction.
- Note that the coefficient of friction, being a ratio of forces, bears no unit.

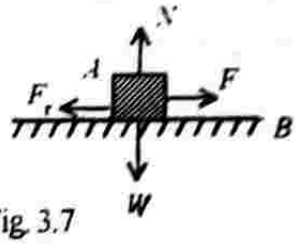


Fig. 3.7

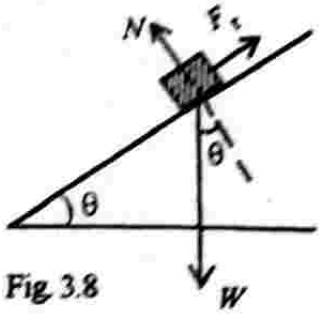


Fig. 3.8

3.5 Inclined Plane

- The forces acting on a body which is about to slide down an inclined plane of angle θ are shown in Fig. 3.8.
  For equilibrium:
  (1) the sum of the components of all the forces resolved parallel to the plane must be zero, and
  (2) the sum of the components of the forces resolved normal to the plane must be zero.
- These two conditions give

$$F_r - W\sin\theta = 0 \tag{3.10}$$

and

$$N - W\cos\theta = 0 \tag{3.11}$$

- Eqs. (3.10) and (3.11) are solved simultaneously to give

$$\mu = F_r/N = \tan\theta \tag{3.12}$$

for a body about to slide down a rough plane inclined at angle θ to the horizontal.

True or False - Type Questions

Answer **True** (T) or **False** (F) to the following questions.

1. Three non-parallel, coplanar forces which are represented both in maginitude and direction by the three sides of a triangle taken in order
   a. have their lines of action meeting at a point.
   b. can rotate a body about its axis.
   c. can make a body move in a straight line at constant speed.
   d. can make a body move randomly.
   e. can make a body oscillate about an equilibrium position.
   f. will maintain a body in equilibrium.
   g. will have the magnitude of any one force being equal to the magnitude of the resultant of the other two.

h. will have any one force being the equilibrant of the other two.

2. The following quantities are forces :

a. Tension	e. Weight
b. Upthrust	f. Mass
c. Impulse	g. Thrust
d. Friction	h. Centre of gravity

3. For a body in static equilibrium under parallel forces
   a. the sum of all the forces must be zero.
   b. the total clockwise moment about any point is equal to the total anticlockwise moment about the same point.
   c. the total force in one direction is equal to the total force in the opposite direction.
   d. the sum of the resolved components of forces along one direction equals the sum of the resolved components in a perpendicular direction.
   e. the body can undergo rotational but not translational motion.

4. The following are classified as *contact* or *field* forces:

a. Tension [*contact*]	f. Thrust [*field*]
b. Electric [*field*]	g. Magnetic [*contact*]
c. Electrostatic[*contact*]	h. Friction [*contact*]
d. Reaction [*contact*]	i. Upthrust [*field*]
e. Gravitational [*field*]	j. Surface tension [*contact*]

5. A pair of equal, opposite, non-collinear parallel forces acting on a body
   a. will produce rotational motion on the body.
   b. will produce translational motion on the body.
   c. will maintain the body in equilibrium.
   d. is a couple.
   e. is an impulse.

6. The frictional force between two surfaces in contact
   a. depends on the nature of the surfaces.
   b. depends on the area of contact between the surfaces.
   c. acts in the direction of motion.
   d. exists only when there is relative motion or tendency for motion.
   e. depends on the normal reaction between the two surfaces.
   f. increases as the force tending to move the surfaces relative to each other increases until relative motion actually starts.
   g. is higher when the bodies are in relative motion than when stationary.
   h. decreases if the surfaces are lubricated.
   i. is always a disadvantage because it opposes motion.
   j. is sometimes a disadvantage
   k. is sometimes useful.
   l. is less for kinetic friction than for static friction.
   m. is less for sliding friction than for rolling friction.

Answers to True or False - Type Questions

1. a **(T)** If the lines of action do not meet at a point, the forces cannot be represented by the three sides of a closed triangle.
   b **(F)** The body is in equilibrium, hence the net force or moment acting on it is zero.
   c **(T)** A body moving at a constant speed in straight line is in equilibrium, i.e. the net force on it is zero.
   d **(F)** See (b) above.
   e **(F)** See (b) above.
   f **(T)**
   g **(T)** Note that the emphasis here is on *magnitude*.
   h **(T)** See revision notes.

2. a **(T)**
   b **(T)**
   c **(F)** Impulse is the product of force and time.
   d **(T)**
   e **(T)**
   f **(F)** Note the distinction between *mass* and *weight*.
   g **(T)**
   h **(F)** The centre of gravity is a *point* in the body through which the weight apparently acts.

3. a **(F)** The *vectorial* sum of the forces is zero.
   b **(T)**
   c **(T)**
   d **(F)** Note that the question is concerned with resolved components in two *perpendicular* directions.
   e **(F)** Since the resultant moment on the body is zero, it cannot undergo rotational motion.

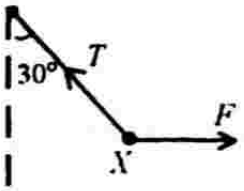
4. a **(T)**
   b **(T)**
   c **(F)** *Electrostatic* is the same as *electric* force. Direct contact is not required.
   d **(T)**
   e **(T)** Note that an object suspended in air, i.e. which makes no direct contact with the earth is subject to the earth's gravitational pull (its *weight*)
   f **(F)** Thrust is a forward force which is exerted on a body, for instance, by an engine in *contact* with the body.
   g **(F)** Two magnets will repel or attract each other even when not in contact.
   h **(T)**
   i **(F)** Upthrust is a *contact* (upward) force exerted by a liquid on a body immersed in it.
   j **(T)**

5. a (T) There is a resultant moment on the body.
b (F) The resultant force is zero.
c (F) The body is not in equilibrium in view of (a) above.
d (T)
e (F)

6. a (T) This depends on the *smoothness* (or *roughness*) of the surfaces.
b (F)
c (F) It opposes motion or the tendency for motion.
d (T) A body under no action of a force is not subject to friction.
e (T) Frictional force F is proportional to the normal reaction.
f (T)
g (F) The kinetic frictional force (when the body is in motion) is lower than the limiting static frictional force (just before motion starts).
h (T)
i (F) It is sometimes an advantage. Movement on the surface of the earth, for instance, would be impossible without friction. (Note the difficulty in moving on a slippery surface with a low coefficient of friction).
j (T) Friction causes wear and tear on surfaces in relative motion and in contact. It also causes appreciable energy loss in the form of heat in machines, thus limiting the efficiency.
k (T) See (i) above
l (T) See (g) above
m (F) It is actually *easier to roll* a heavy drum, for instance, than to make it slide on the ground, i.e. the frictional force is *less* for rolling than for sliding friction.

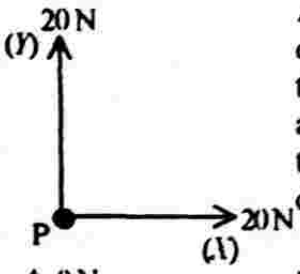
SSCE/JME - Type Objective Questions

1. A nail is pulled from a wall with a string tied to the nail. If the string is inclined at angle of 30° to the wall and the tension in the string is 50 N, the effective force used in pulling the nail is
A. 25 N **B.** $25\sqrt{3}$ N **C.** 50 N **D.** $50\sqrt{3}$ N

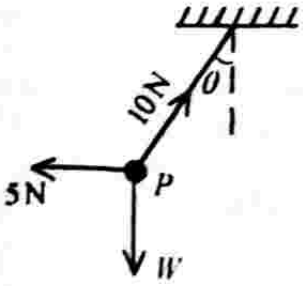
2. 

The body X shown in the diagram has a mass of 6 kg and is held in equilibrium by a string and a horizontal force F. The tension T in the string is [g = 10 ms^{-2}].
A. $4\sqrt{3}$ N **B.** 12 N **C.** $40\sqrt{3}$ N **D.** 120 N

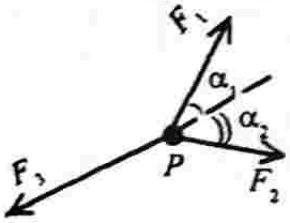
3. The magnitude of F in question 2 is
A. $2\sqrt{3}$ N **B.** 6 N **C.** $20\sqrt{3}$ N **D.** 60 N

4. 

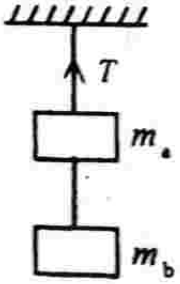
A particle P is maintained in equilibrium under the action of two forces 20 N along X, 20 N along Y (see diagram) and a third force F (not shown in the diagram). The force F is
A. 0 N **B.** 40 N at 45° to X
C. $20\sqrt{2}$ N at 45° to X **D.** $20\sqrt{2}$ N at 225° to X

5. 

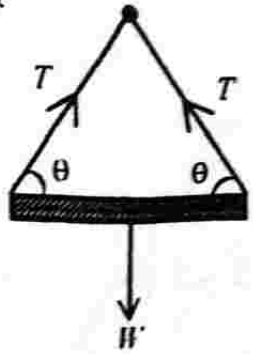
A particle P of weight W is in equilibrium under the system of forces shown in the diagram. The values of W and θ are, respectively
A. 5 N and 60° **B.** $5\sqrt{3}$ N and 30°
C. $5\sqrt{5}$ N and 60° **D.** 15 N and 30°

6. 

A particle P is in equilibrium under the action of three forces F_1, F_2 and F_3 as shown in the diagram. Which of the following equations are correct?
I. $F_1 \cos \alpha_1 = F_2 \cos \alpha_2$
II. $F_1 \sin \alpha_1 = F_2 \sin \alpha_2$
III. $F_3 - F_1 \cos \alpha_1 - F_2 \cos \alpha_2 = 0$
IV. $F_1 + F_2 + F_3 = 0$
A. I and II only **B.** II and III only
C. II and IV only **D.** II, III and IV only.

7. 

Two bodies of masses m_a and m_b are connected to the ceiling as shown in the diagram. The tension in the upper string is
A. $m_a g$ **B.** $m_b g$
C. $(m_a - m_b)g$ **D.** $(m_a + m_b)g$

8. 

The diagram shows a uniform plank of weight W supported by two strings each inclined at an angle of θ to the horizontal. If T is the tension in each string, which of the following statements is (are) correct?
I. T increases as θ increases
II. T decreases as θ increases
III. T is maximum when θ is 90°

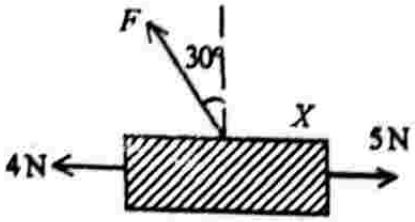
IV. T is minimum when θ is 90°

A. I only B. II only
C. I and III only D. II and IV only

9. If $W = 12$ N and $\theta = 30°$ in the diagram of question 8, then T is

A. 6 N B. $6\sqrt{3}$ N C. 12 N D. 24 N

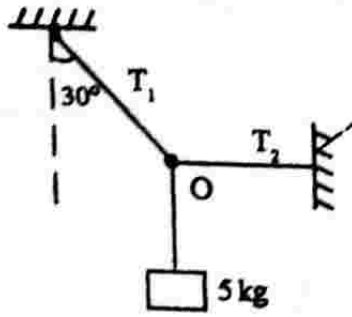
10.



A body X of weight W is maintained in equilibrium under the action of two horizontal forces 5 N and 4 N and a third force F inclined at 30° to the vertical (see diagram above). The value of W is

A. $\sqrt{3}/3$ N B. $\sqrt{3}/2$ N C. $\sqrt{3}$ N D. $2\sqrt{3}$ N

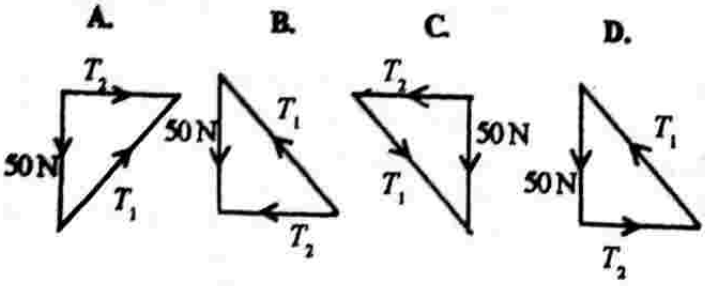
11.



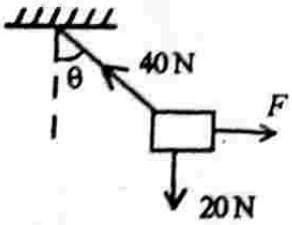
If the system of forces shown in the diagram is in equilibrium, the tension T_2 is equal to [$g = 10$ ms^{-2}]

A. $100/\sqrt{3}$ N
B. $50/\sqrt{3}$ N
C. $150/\sqrt{3}$ N
D. 50 N

12. Which of the following force diagrams correctly illustrates the forces acting at the point O in question 11?



13.



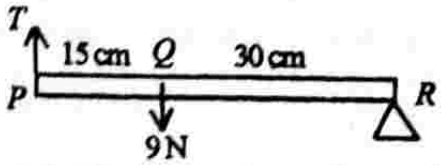
For what values of F and θ will the forces shown in the diagram be in equilibrium?

A. 60 N and 60°
B. 60 N and 30°
C. $20\sqrt{3}$ N and 60°
D. $20\sqrt{3}$ N and 30°

14. A metre rule pivoted at its centre has masses m_1 and m_2 placed at the 20 cm and 65 cm marks respectively. If the metre rule balances horizontally, the ratio m_2/m_1 is

A. 2 B. 3/2 C. 2/3 D. 1/2

15.



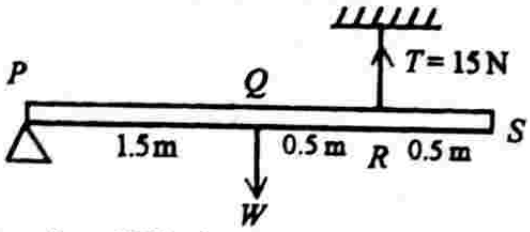
A rod PR is balanced on a pivot at the end R while a string is used to support the rod at P (see diagram). The weight of the rod, 9 N, acts at a point Q where $QR = 30$ cm and $PQ = 15$ cm. The tension T in the string is

A. 3 N B. 6 N C. 9 N D. 12 N

16. A uniform metre rod of weight 40 N has a piece of metal of weight 20 N attached to one of its ends. The centre of gravity of the system from the weighted end is

A. 8.4 cm B. 16.7 cm C. 25.0 cm D. 33.3 cm

17.



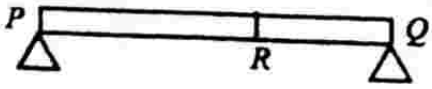
The value of W in the diagram shown above is

A. 7.5 N B. 15.0 N C. 20.0 N D. 30.0 N

18. The reaction at the pivot P in question 17 is

A. 5.0 N B. 7.5 N C. 10.0 N D. 15.0 N

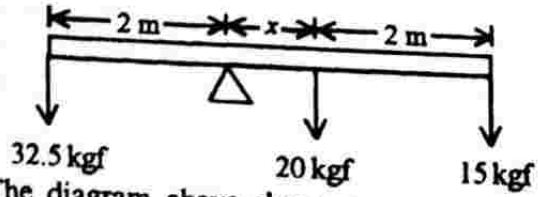
19.



The figure shows a uniform beam PQ of length 5 m weight 100 N which is supported at both ends. When a boy of weight 400 N stands at a point R on the beam, the reactions at P and Q are 130 N and 370 N respectively. The distance RQ is

A. 1.00 m B. 1.25 m C. 1.50 m D. 1.63 m

20.



The diagram above shows a see-saw with three boys of weights 32.5 kgf, 20 kgf and 15 kgf sitting on it. If the see-saw is exactly horizontal and of negligible weight, the value of x is

A. 0.5 m B. 1.0 m C. 1.5 m D. 2.0 m

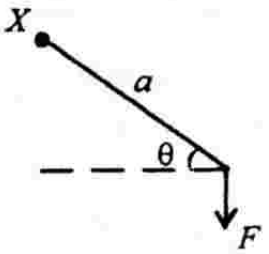
21. If the 20 kgf boy [in question 20] gets off the see-saw, how far to the right should the 32.5 kgf boy move in order to restore a balance?

A. 0.50 m B. 0.62 m C. 0.75 m D. 1.38 m

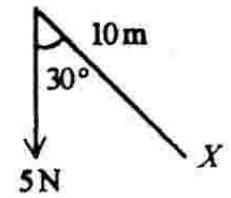
22. A uniform beam of length 4 m and mass 20 kg is supported at both ends. A girl of mass 40 kg stands on the beam at a distance of 1.5 m from one of the supports. The reactions at the supports are
A. 150 N, 250 N **B.** 200 N, 200 N
C. 250 N, 350 N **D.** 300 N, 300 N

23. Weights of 0.2 N and 0.5 N are placed at the 30 cm and 80 cm marks respectively on a uniform metre rule. If the metre rule balances horizontally on a knife edge at the 60 cm mark, the weight of the metre rule is
A. 0.1 N **B.** 0.3 N **C.** 0.4 N **D.** 0.7 N

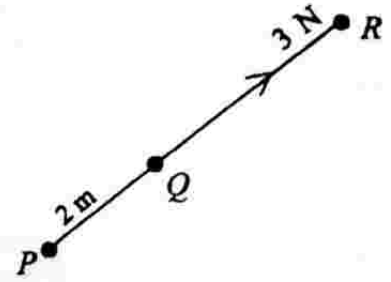
24. A uniform metre rod of mass 1.5 kg is pivoted at one end. A weight of 7 N is placed at the centre of the rod. The vertical force which should be applied at the other end to maintain the rod in equilibrium in the horizontal position is
A. 22.0 N **B.** 11.0 N **C.** 10.5 N **D.** 8.5 N

25. 

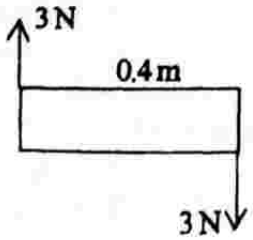
In the diagram shown, the moment of the force F about the point X is
A. $Fa \sin\theta$ **B.** $Fa \tan\theta$
C. $Fa/\cos\theta$ **D.** $Fa \cos\theta$

26. 

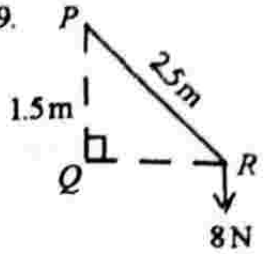
In the diagram shown, the moment of the 5 N force about the point X is
A. 25 Nm **B.** $25\sqrt{3}$ Nm
C. 50 Nm **D.** $50\sqrt{3}$ Nm

27. 

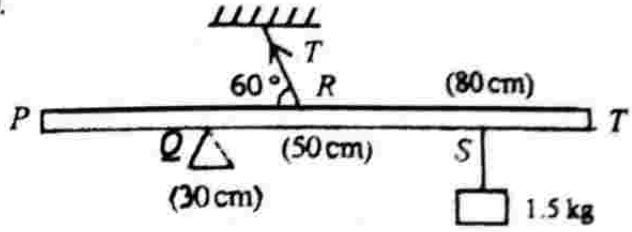
If $PQ = 2$ m, the moment of the 3 N force about the point P in the diagram is
A. 6 Nm
B. 5 Nm
C. 1 Nm
D. 0

28. 

The magnitude of the couple produced by two forces each of 3 N acting on the opposite sides of the rectangular plate shown in the diagram is
A. 0.6 Nm **B.** 1.2 Nm
C. 2.4 Nm **D.** 3.6 Nm

29. 

In the diagram, the difference between the moment about P of the 8 N force and its moment about Q is
A. 0 **B.** 4 Nm
C. 8 Nm **D.** 16 Nm

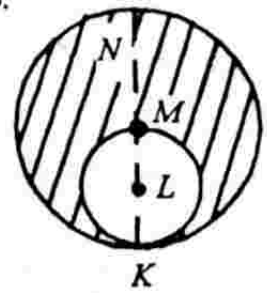
30. 

A light uniform metre rule PT pivoted at Q, the 30 cm mark, has a block of mass 1.5 kg suspended at the 80 cm mark (see diagram above). The metre rule is maintained in equilibrium by a string attached at the point R, the 50 cm mark. The tension T in the string is
A. 12.5 N **B.** 25 N **C.** $25\sqrt{3}$ N **D.** 50 N

31.

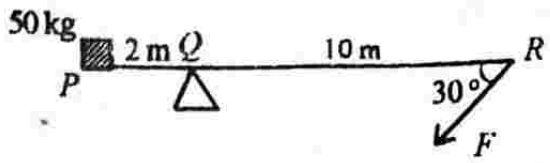
A uniform rod of weight 100 N is pivoted at the right end while the left end is suspended by a string at an angle of 30° to the rod. If the rod is horizontal, the tension in the string is
A. 25 N **B.** 50 N **C.** 75 N **D.** 100 N

32. A mass of 10 g is attached to the 0 cm mark of a light metre rule while a mass of 40 g is attached to the other end (the 100 cm) mark. The centre of gravity of the system is located at the
A. 20 cm mark **B.** mid-point of the metre rule
C. 60 cm mark **D.** 80 cm mark

33. 

The diagram shows a uniform circular object of centre M and diameter KN from which a circular section of centre L and diameter KM has been removed. KL is a straight line. The centre of gravity of the resulting body is located
A. at L **B.** at M
C. between K and M **D.** between M and N

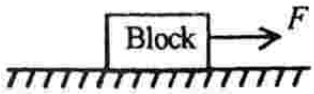
34.



A load of mass 50 kg placed at the end P of a light beam PQR is to be lifted by applying a force F at the end R. If the beam is pivoted at Q and F is inclined at 30° to the beam, the minimum value of F needed to lift the load is

A. 100 N **B.** 200 N **C.** $200\sqrt{3}$ N **D.** 400 N

35.



A block at rest on a horizontal surface is pulled by a horizontal force F as shown in the figure above. Which of the following statements are correct? The force of friction

I. is directed to the right
II. is directed to the left
III. increases as F increases until the block starts to move
IV. increases if a second identical block is placed on top of the block.

A. I and III only **B.** II and IV only
C. II and III only **D.** II, III and IV only

36. The force required to just make a 6 kg object move along a horizontal surface where the coeeficient of friction is 0.25 is

A. 150.0 N **B.** 24.0 N **C.** 15.0 N **D.** 1.5 N

37. A force of 8.75 N is applied to a mass of 3.5 kg placed on a horizontal surface. If the coefficient of friction between the mass and the surface is 0.2, the acceleration of the mass is

A. 0.5 ms^{-2} **B.** 1.0 ms^{-2} **C.** 1.5 ms^{-2} **D.** 2.0 ms^{-2}

38. A book of mass 150 g is pushed against a vertical wall with a horizontal force of F N. If the coefficient of friction between the book and the wall is 0.15, the minimum value of F required to hold the book in place is

A. 10 N **B.** 100 N **C.** 1,000 N **D.** 1,500 N

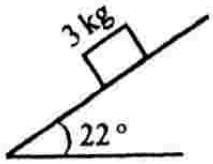
39. A horizontal force of 10 N is required to just slide a block of mass 4 kg on a horizontal platform. The coefficient of limiting friction between the block and the platform is

A. 0.25 **B.** 0.40 **C.** 0.50 **D.** 0.80

40. A crate of mass 25 kg moving with a speed of 3 ms^{-1} on a rough horizontal floor is brought to rest after sliding a distance of 2.5 m on the floor. The coefficient of sliding friction between the crate and the floor is

A. 0.09 **B.** 0.18 **C.** 0.36 **D.** 0.54

41.



The diagram shows a block of mass 3 kg just at the point of sliding down the plane inclined at an angle of 22° to the horizontal. The forces acting on the block in a direction parallel to the inclined plane are

A. 30 sin 22° and the normal reaction
B. 30 cos 22° and the normal reaction
C. 30 sin 22° and the force of friction
D. 30 cos 22° and the force of friction

42. The coefficient of static friction between the block and the plane in question 41 is

A. cos 22°/30 **B.** sin 22°/30
C. sin 22° **D.** tan 22°

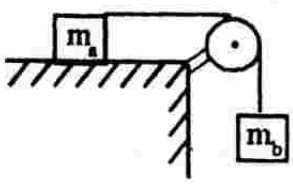
43. The limiting frictional force on a body of mass 4 kg resting on an inclined plane is 20 N. The angle of inclination θ of the plane is

A. 75° **B.** 60° **C.** 45° **D.** 30°

44. A 50 kg crate rests on a platform inclined at 30° to the horizontal. The coefficient of friction between the crate and platform is 0.2. The minimum force needed to prevent the crate from sliding down the incline is

A. 86.6 N **B.** 163.4 N **C.** 250.0 N **D.** 433.0 N

45.



Two masses m_a and m_b are connected together by a string which passes over a smooth pulley as shown in the diagram. The hanging mass m_b is adjusted until m_a is just at the point of sliding on the horizontal surface. The coefficient of friction between m_a and the table is

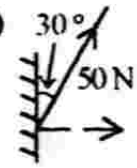
A. $m_a g/m_b$ **B.** $m_b g/m_a$ **C.** m_a/m_b **D.** m_b/m_a

Answer Key

1. **A**	8. **D**	15. **B**	22. **C**	29. **A**	36. **C**	43. **D**
2. **C**	9. **C**	16. **D**	23. **C**	30. **C**	37. **A**	44. **B**
3. **C**	10. **C**	17. **C**	24. **B**	31. **D**	38. **A**	45. **D**
4. **D**	11. **B**	18. **A**	25. **D**	32. **D**	39. **A**	
5. **B**	12. **D**	19. **A**	26. **A**	33. **D**	40. **B**	
6. **B**	13. **C**	20. **B**	27. **D**	34. **B**	41. **C**	
7. **D**	14. **A**	21. **B**	28. **B**	35. **D**	42. **D**	

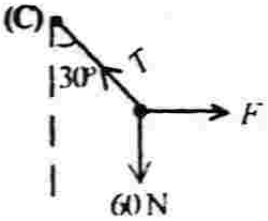
Solutions to Objective Questions

1. **(A)**



The effective force pulling on the nail is the resolved component of T normal to the wall $= T \sin 30° = 50 \sin 30° = 25$ N

2. **(C)**



Resolving forces in the vertical direction gives
$T\cos 30° = 60$, or $T\sqrt{3}/2 = 60$
$T = 120/\sqrt{3} = 120\sqrt{3}/3 = 40\sqrt{3}$ N

3. **(C)** Resolving forces horizontally gives
$F = T\sin 30° = 40\sqrt{3}(1/2) = 20\sqrt{3}$ N

4. **(D)** Resultant of the two forces $= 20\sqrt{2}$ N at 45° to X. The force F required is the *equilibrant* of the two forces, which is equal but *opposite* to the resultant, i.e. it is inclined at 225° to X.

5. **(B)** Resolving forces horizontally gives
$10 \sin\theta = 5$, $\sin\theta = 0.5$ and $\theta = 30°$
Resolving forces vertically gives $W =$
$10 \cos\theta = 10 \cos 30° = 10\sqrt{3}/2 = 5\sqrt{3}$ N

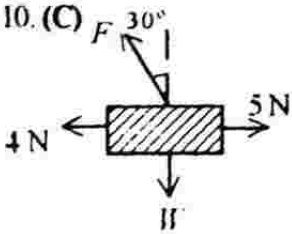
6. **(B)** (II) is obtained by resolving forces in the normal direction to F_3 and (III) by resolving in a direction parallel to F_3.

7. **(D)** The upper string supports a total weight of $(m_a + m_b)g$ which is numerically equal to the tension in the string.

8. **(D)** Resolving forces vertically gives $2T\sin\theta = W$, or $T = W/(2\sin\theta)$. As θ increases, $\sin\theta$ increases and T decreases. Also, the minimum value of T is $W/2$, for $\theta = 90°$ when $\sin\theta = 1$

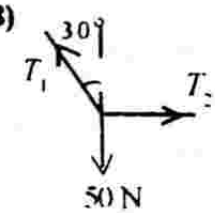
9. **(C)** $T = 12/(2\sin 30°) = 12$ N

10. **(C)**



Resolving forces horizontally gives $F\sin 30° + 4 = 5$ or $F = 2$ N. Resolving forces vertically gives $W = F\cos 30° = 2(\sqrt{3}/2) = \sqrt{3}$ N

11. **(B)**

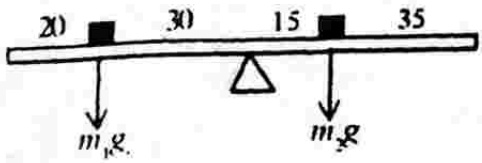


Resolve forces vertically: $T_1\cos 30° = 50$, or $T_1 = 50(2/\sqrt{3}) = 100/\sqrt{3}$. Resolve forces horizontally: $T_2 = T_1\sin 30° = (100/\sqrt{3})(½) = 50/\sqrt{3}$ N

12. **(D)** Only this diagram shows the arrows pointing in the right directions.

13. **(C)** Resolve vertically:
$40\cos\theta = 20$, $\cos\theta = 0.5$, or $\theta = 60°$
Resolve horizontally:
$F = 40\sin\theta = 40\sin 60° = 40(\sqrt{3}/2) = 20\sqrt{3}$ N

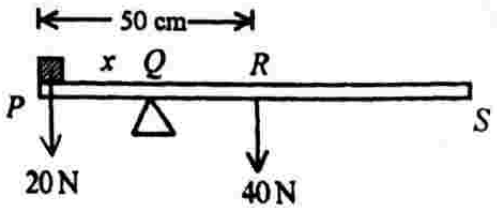
14. **(A)**



Taking moments about the pivot: $30\,(m_1g) = 15\,(m_2g)$ or $m_2/m_1 = 2$.

15. **(B)** Taking moments about R : $9(30) = T(45)$, or $T = 270/45 = 6$ N

16. **(D)**

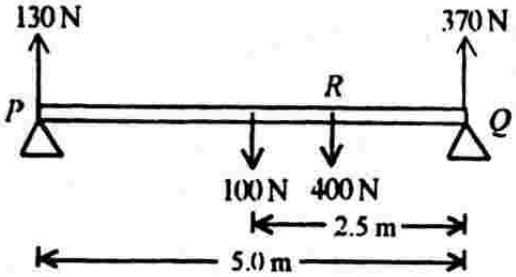


The centre of gravity is the point (Q) at which the rod will balance horizontally on a pivot. If $PQ = x$, then $QR = 50 - x$. Taking moments about Q,
$20x = 40\,(50 - x)$
$60x = 2000$, or $x = 33.3$ cm

17. **(C)** Take moments about P:
$1.5\,W = T\,(1.5 + 0.5) = 1.5(2) = 30$
$W = 30/1.5 = 20$ N

18. **(A)** If F = (upward) force of reaction at P, taking moments about Q gives
$F\,(1.5) = T\,(0.5) = 15\,(0.5) = 7.5$, or $F = 7.5/1.5 = 5$ N
[Alternatively, the sum of upward forces is equal to W, the downward force. Hence $F + 15 = 20$, or $F = 5$ N]

19. **(A)**

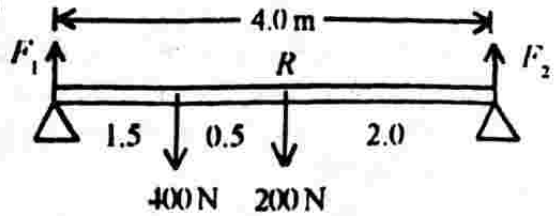


Take moments about Q: $QR(400) + 100(2.5) = 130(5.0)$
$400QR + 250 = 650$, or $QR = 1.0$ m

20. **(B)** Take moments about the pivot:
$20x + 15(2 + x) = 32.5(2)$
$35x = 65 - 30 = 35$, or $x = 1.0$ m

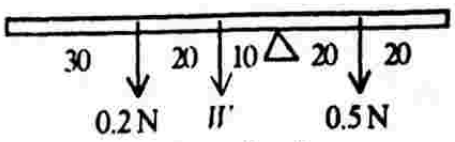
21. **(B)** Let the 32.5 kgf boy move to the right a distance y. Taking moments about the pivot gives :
$32.5(2 - y) = 15(2 + x) = 15(3) = 45$
$32.5y = 65 - 45 = 20$,
$y = 20/32.5 = 40/65 = 8/13 = 0.62$ m

22. **(C)**



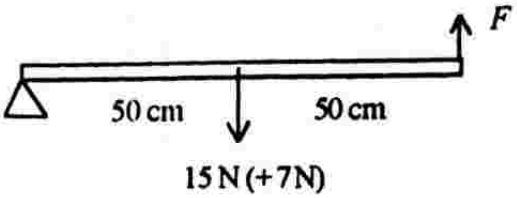
If F_1, F_2 are the reactions at the supports, then taking moments about F_2 gives
$4\,F_1 = 400(2.5) + 200(2.0) = 1400$, or $F_1 = 350$ N
The sum of the upward forces is equal to the sum of the downward forces, i.e. $F_1 + F_2 = 400 + 200 = 600$, or $F_2 = 600 - F_1 = 600 - 350 = 250$ N.

23. **(C)**



Taking moments about the pivot:
$10W + 0.2(20 + 10) = 0.5(20)$
$10W + 6 = 10$, or $W = 0.4$ N

24. **(B)**



Weight of rod $= mg = 1.5 \times 10 = 15$ N
Taking moments about the pivot gives
$22(50) = F(100)$, or $F = 11$ N.

25. **(D)** If the line of action of force F is projected upwards, the perpendicular distance of F from X is $a\cos\theta$. Moment of F about $X = (a\cos\theta)(F)$
$= Fa\cos\theta$

26. **(A)** The perpendicular distance of the 5 N force from X is $10\sin 30° = 5$ m. Moment about $X = (5\text{ N})(5\text{ m}) = 25$ Nm.

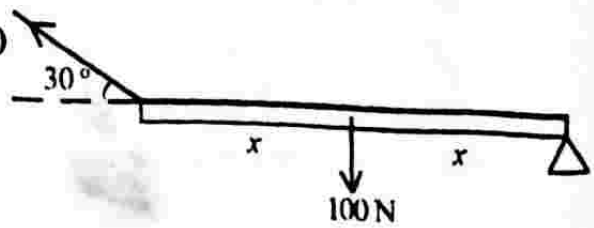
27. **(D)** The line of action of the 3 N force passes through the point P; the moment of the force about this point is thus zero.

28. **(B)** Couple = Force x perpendicular distance
$= 3(0.4) = 1.2$ Nm.

29. **(A)** Moment of the 8 N force about $P = 8 \times QR$
Moment of the 8 N force about $Q = 8 \times QR$
Hence the difference between the moments is zero.

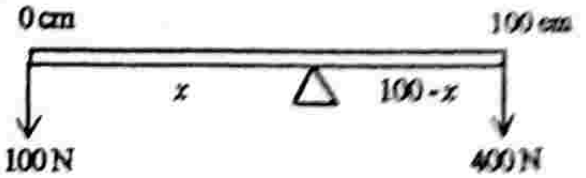
30. **(C)** Since the metre rule is light, its weight is negligible. Taking moments about Q gives
$T\sin 60°\,(QR) = 15\,(QS)$
$T\,(\sqrt{3}/2)\,(20) = 15\,(50) = 750$
$T = 75\sqrt{3} = 75\sqrt{3}/3 = 25\sqrt{3}$ N

31. **(D)**



Take moments about the pivot:
$T\sin 30°(2x) = 100(x)$, or $T = 100$ N

32. **(D)**



The centre of gravity is the point at which the metre rule (of negligible weight) will balance horizontally on a pivot. Taking moments about the pivot:
$100x = 400(100 - x)$
$500x = 40{,}000$ or $x = 80$ cm

33. **(D)** Before the removal of part of the object, its centre of gravity is at the centre M. After the removal, the centre of gravity shifts to a point between M and N.

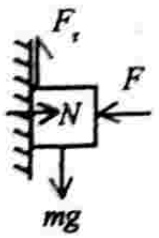
34. **(B)** Take moments about Q : $F\sin 30°(QR) = 500(PQ)$
$F(0.5)(10) = 500(2)$, or $F = 200$ N.

35. **(D)** The force of friction opposes the force F and increases as F increases until motion starts. If a second identical block is placed on the block, the normal reaction (N) is doubled and since $F_r = \mu N$, the frictional force is also doubled.

36. **(C)** $F = F_r = \mu N = \mu mg = (0.25)(6)(10) = 15$ N

37. **(A)** Limiting frictional force $F_r = \mu mg = (0.2)(3.5)(10) = 7$ N. Net force on the mass $= F - F_r = 8.75 - 7 = 1.75$ N
Acceleration = Net force/mass $= 1.75/3.5 = 0.5$ ms^{-2}

38. **(A)**

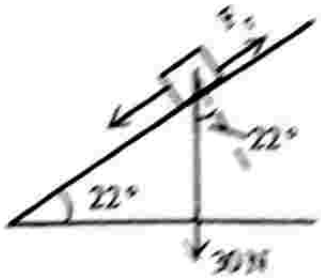


The book tends to slide down the wall, hence the frictional force F_r acts upwards. From the diagram, $F_r = mg$. Also, the normal reaction N on the book must be equal to the force F. Hence $F_r = \mu N = \mu F$, i.e. $mg = \mu F$, or $F = mg/\mu = (0.15)(10)/0.15 = 10$ N

39. **(A)** As the block is just about to start sliding,
$F = F_r = \mu mg \Rightarrow 10 = \mu(4)(10)$, or $\mu = 0.25$

40. **(B)** Acceleration of the crate, a, is found from the equation $v^2 = u^2 + 2as$, where $u = 3$ ms^{-1}, $v = 0$ and $s = 2.5$ m
Hence $a = -u^2/2as = -9/5$ ms^{-2}
Retarding force $= F_r = ma = (25)(9/5) = 45$ N
But $F_r = \mu mg \Rightarrow \mu = F_r/mg = 45/250 = 0.18$

41. **(C)**



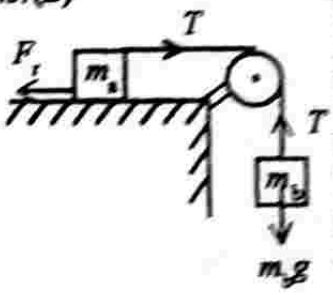
The forces acting on the block parallel to the incline are the resolved component of its weight down the plane, which is equal to $30\sin 22°$ and the frictional force F_r which acts in the opposite direction, i.e. up the plane.

42. **(D)** Normal reaction $= 30\cos 22°$ and $F_r = 30\mu\cos 22°$
But F_r must be equal to the resolved component of the weight of the block down the plane, i.e.
$30\mu\cos 22° = 30\sin 22°$ or $\mu = \sin 22°/\cos 22° = \tan 22°$

43. **(D)** The limiting frictional force is equal to the resolved component of the weight of the body down the plane, i.e. $20 = mg\sin\theta = 40\sin\theta$
$\sin\theta = 0.5$, or $\theta = 30°$

44. **(B)** Limiting frictional force $= \mu mg\cos\theta = (0.2)(500)\cos 30° = 86.6$ N. Resolved component of the weight of the crate down the plane $= mg\sin\theta = 500\sin 30° = 250$ N.
The limiting frictional force is not sufficient to keep the crate from sliding down, hence an additional force of $250 - 86.6$, or 163.4 N is required.

45. **(D)**



Referring to the diagram,
T = tension in the string
For the mass m_s:
$T = m_s g$ ..... (i)
For the mass m_h:
$T = F_r = \mu m_h g$ ..... (ii)
From (i) and (ii) $\mu m_h g = m_s g$,
or $\mu = m_s/m_h$

Revision Check-list

At the end of this chapter the candidate should be able to :

- determine the *resultant* and *equilibrant* of two forces.
- draw a *triangle of forces* for a body in equilibrium under the action of three concurrent, non-parallel forces.
- state and apply the *conditions for equilibrium* for a body under two or more coplanar, parallel or non-parallel forces.

- determine the *moment* of a force about any specific point.
- explain what is meant by the term *centre of gravity* and the associated phenomena of *stable, unstable* and *neutral* equilibrium.
- explain the laws governing friction between two solid surfaces.
- indicate the forces acting on a body resting on an inclined plane, including the *frictional force* and the *normal reaction*.
- relate the *coefficient of friction* to the angle of an inclined plane for a body just at the point of sliding down the plane.
- state the *advantages and disadvantages* of friction.
- explain how friction may be reduced between two surfaces in relative motion.
- describe *experiments* to determine
  - (1) the centre of gravity of an irregularly-shaped object.
  - (2) the coefficient of friction between two solid surfaces.

4 Work, Energy and Power

4.1 Work

- Work is said to be done when a force moves a body across a certain distance in the direction of the force.
- If the force (F) is applied in the direction of the displacement (s), ***work done*** (W) is the product of the force and the displacement (Fig. 4.1a), i.e.

$$W = Fs \qquad (4.1)$$

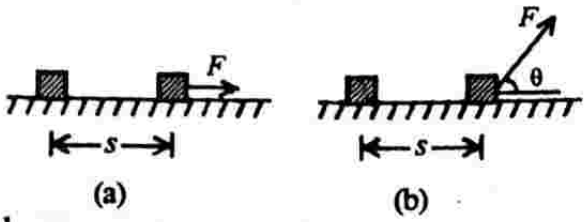


Fig. 4.1

- If the force is inclined at an angle θ to the displacement (Fig. 4.1b), the work done is the resolved component of the force in the direction of displacement, multiplied by the displacement, i.e.

$$W = Fs\cos\theta \qquad (4.2)$$

- When the force is plotted against distance, the work done is the area under the curve.
  Unit: Work = [N.m] = [joule], abbreviated to [J].

4.2 Energy

- **Energy** is the capacity of a body to do work.
- **Kinetic energy** is the energy acquired by a body due to its motion.
- The k.e. (E_k) of a moving body is equal to the product of half the mass (m) of the body and the square of its velocity (v), i.e.

$$E_k = \tfrac{1}{2}mv^2 \qquad (4.3)$$

- **Potential energy** is the energy acquired by a body by virtue of its position or state.
- **Gravitational potential energy** (E_p) is the p.e. possessed by a body by virtue of its height above the ground level.
- For a body of mass m which is held at a height h above the ground,

$$E_p = mgh \qquad (4.4)$$

- Unit: Energy = [J]

4.3 Conservation of Energy

- **The law of conservation of energy** states that energy cannot be created or destroyed; it can only be converted from one form to another.
- Work-energy conversion: If the work done on a body is all utilized in setting it in motion, then

Work done = change in kinetic energy (4.5)

- *K.E.-P.E.* conversion: A mass m which is thrown vertically upward with an initial velocity u and climbs to height h has the following values of energy associated with it:

	Ground level	Height h
K.E.	$\tfrac{1}{2}mu^2$	0
Grav. P.E.	0	mgh
Total Energy	$\tfrac{1}{2}mu^2$	mgh

- By law of conservation of energy, total energy remains constant, i.e.

$$\tfrac{1}{2}mu^2 = mgh, \text{ or } u^2 = 2gh \qquad (4.6)$$

- Similar k.e. - p.e. conversions also take place, for instance, during the periodic motion of a simple pendulum (Fig. 4.2) or a helical spring (Fig 4.3).

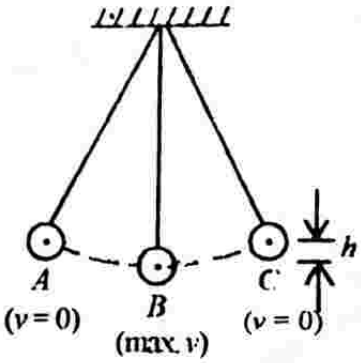


Fig. 4.2

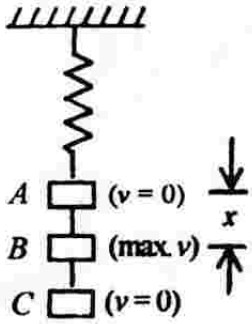


Fig. 4.3

- The values of the k.e. and p.e. at the positions indicated in the figures are listed below (v is the maximum velocity, which occurs at the equilibrium position).

Position	Simple Pendulum	Helical Spring
B (equilibrium)	P.E. = 0 K.E. = $\tfrac{1}{2}mv^2$	P.E = 0 K.E. = $\tfrac{1}{2}mv^2$
A, C	P.E. = mgh K.E. = 0	P.E. = $\tfrac{1}{2}kx^2$ K.E. = 0

4.4 Power

- Power is the rate of doing work, or of expending energy.

- If an amount of work W is done in time t, the power developed is

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} = \frac{W}{t} \quad (4.7)$$

- Since $W = Fs$, Power $= Fs/t = Fv$, i.e.

$$\text{Power} = \text{Force} \times \text{Speed} \quad (4.8)$$

for a body undergoing uniform motion.
- Unit: Power = $[Js^{-1}]$ = [watt], abbreviated to [W].

4.5 Newton's Law of Universal Gravitation

- This law states that *any two bodies in the universe exert a force of attraction on each other which is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them.*
- For two bodies of masses m_1 and m_2 separated by distance r, the gravitational force is

$$F_g = \frac{Gm_1m_2}{r^2} \quad (4.9)$$

where G is the universal gravitational constant.
- The value of G is constant for all bodies in the universe and is equal to 6.67×10^{-11} N.m^2.kg^{-2}.
- For a body of mass m which is located near the earth's surface, the gravitational force is

$$F_g = \frac{Gmm_e}{r_e^2} \quad (4.10)$$

where m_e = mass of the earth and r_e = radius of the earth.
- Since F_g is also equal to mg, the body's weight, $mg = Gmm_e/r_e^2$ or

$$g = Gm_e/r_e^2 \quad (4.11)$$

near the earth's surface.
- In general, the acceleration due to gravity g, at any distance r from the centre of the earth is

$$g = Gm_e/r^2 \quad (4.12)$$

4.6 Gravitational Potential

- The gravitational potential at a point in a gravitational field is the work done in bringing a body of unit mass from infinity to that point.
- In the earth's gravitational field, the gravitational potential(V) at a distance r from the centre of the earth (of mass m_e) is

$$V = -\frac{Gm_e}{r} \quad (4.13)$$

- It is clear from eq. (4.13) that:
  (1) the potential at infinity ($r \to \infty$) is zero, and
  (2) the potential decreases (becomes more negative) as the body is moved closer to the centre of the earth.
- **Unit V = [Jkg^{-1}].**

4.7 Escape Velocity

- In order to move an object of mass m from the earth to infinity, work must be done against the force of gravity.
- A body thus moved has escaped from the earth's gravitational field.
- Imagine that the object is projected vertically upward at an initial velocity v from the earth's surface:

Initial k.e.of object = $\frac{1}{2}mv^2$,

Work required to move the object (of mass m) from the earth's surface (i.e .distance r_e from the earth's center) to infinity = Gmm_e/r_e.

By the law of conservation of energy.
Work done = initial k.e. of object
$Gmm_e/r_e = \frac{1}{2}mv^2$ or

$$v = \sqrt{\frac{2Gm_e}{r_e}} = \sqrt{2gr_e} \quad (4.14)$$

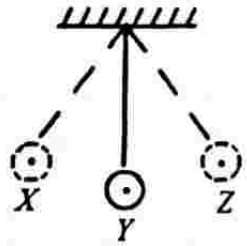
True or False - Type Questions

Answer *True* (T) or *False* (F) to the following questions

1. As a body released from a certain height falls freely under gravity:
   a. its potential energy decreases.
   b. its kinetic energy increases linearly with the distance of fall.
   c. its mechanical energy increases.
   d. its kinetic energy at its half-way point is equal to half of its initial energy.
   e. work is done against gravity.

2. A catapult is used to project a stone at an angle θ to the horizontal.

a. The elastic potential energy of the catapult is converted to kinetic energy of the stone at the point of release.
b. The kinetic energy of the stone is constant throughout its flight.
c. For a given speed and angle of projection, the kinetic energy of the stone at any point during the flight depends only on its altitude.
d. The stone has its maximum kinetic energy at the highest point in its trajectory.
e. The maximum potential energy attained by the stone increases as the angle θ increases.

3. 

The diagram illustrates a swinging pendulum with an equilibrium position Y and extreme positions X and Z.

a. The mechanical energy of the bob at X is equal to that at Y.
b. The kinetic energy of the bob at Z is zero.
c. The bob has its maximum potential energy at Y.
d. The potential energy of the bob at X is equal to that at Y.
e. The potential energy of the bob at X is equal to its kinetic energy at Y.
f. Work is done against gravity as the bob moves from Z to Y.
g. The work done in moving the bob from Y to X is equal to its kinetic energy at Y.

4. Power can be defined as the
a. ability to do work.
b. rate of doing work.
c. product of force and velocity.
d. product of force and time.
e. product of force and distance.
f. capacity to exert a force.
g. energy expended per unit time.
h. rate of change of momentum.

5. a. The absolute value of the gravitational potential associated with a body at a fixed distance from the body increases if the body's mass is increased
b. The gravitational potential near a body decreases as the distance from the body increases.
c. The gravitational force of attraction between two bodies is doubled if the distance separating the bodies is halved.
d. The gravitational force of attraction between two spherical bodies having equal densities is increased by a factor of 64 if the radius of each of the bodies is doubled.
e. At a point in space where the distance from the earth's surface is equal to the earth's radius, the acceleration due to gravity is equal to one-half of its value near the earth's surface.
f. The weight of an object at the top of a mountain is less than its weight measured at sea level.
g. The acceleration due to gravity on an object near the earth's surface depends on the mass of the earth and the mass of the object.
h. In moving an object of unit mass from the earth's surface to infinity, work must be done on the object.

Answers to True or False - Type Questions

1. a **(T)** $P.E. = mgh$, and h decreases as the body falls.
b **(T)** Let H = initial height, h = present height and x = distance of fall = $H - x$
Present k.e. = initial p.e. - present p.e.
$= mgH - mgh = mg(H-h) = mgx$,
which varies linearly with x.
c **(F)** Neglecting the air resistance, its mechanical energy, which is the sum of the potential and kinetic energies, is constant.
d **(T)** At the half - way point ($x = H/2$), half of the original potential energy has been converted into kinetic energy.
e **(F)** Work is actually done *by*, rather than *against* gravity. [Note that the body falls without the application of an external force outside the force of gravity].

2. a **(T)** The energy stored in the elastic string of the catapult is converted into the k.e. of the stone.
b **(F)** The kinetic energy depends on the stone's velocity, which varies during the flight.
c **(T)** The sum of the k.e. and p.e. is constant. The p.e. depends only on the altitude, and thus also the k.e.
d **(F)** The maximum k.e. is attained at the point of release, at which the velocity is highest.
e **(T)** The maximum p.e. depends on the maximum height attained, which increases with θ (see chapter 2).

3. a **(T)** The mechanical energy of the bob, which is the sum of its p.e. and k.e., is constant.
b **(T)** Note that the velocity is zero at X and Z.

c **(F)** The maximum p.e. is attained at X and Z, the *highest* points.

d **(F)** The p.e. of the bob at Y is zero.

e **(T)** At X or Z, the bob has only potential energy which is fully converted into kinetic energy at Y.

f **(F)** Work is done *by* gravity as the bob moves from Z to Y, and against gravity as the bob moves from Y to Z.

g **(T)** In moving from Y to X, work is done against gravity which is equal to the bob's k.e. at Y.

4. a **(F)**

b **(T)**

c **(T)** Power = Work/time = Force x displacement/time
= Force x velocity

d **(F)** This is *impulse*.

e **(F)** This is *work*.

f **(F)**

g **(T)** The definition of power is the work done or energy expended per unit time.

h **(F)** This is *force* [Newton's second law].

5. a **(T)** Grav. potential, $V = -Gm/r$. The absolute value of this, or Gm/r, increases as m increases.

b **(F)** V is a negative quantity which becomes less negative (i.e. increases) as r increases.

c **(F)** Grav. force, $F_g \propto 1/r^2$. Hence if r is halved, F_g is *quadrupled*.

d **(T)** $F_g \propto m_1 m_2$, and since mass = density (d) x volume(v) and $v \propto r^3$, where r is the radius, $F_g \propto r_1^3 r_2^3$. If r_1 and r_2 are doubled, F_g is increased by a factor of $2^3.2^3$, or 64.

e **(F)** On the earth's surface, $g_s = Gm_e/r_e^2$ and at a point in space, distance r_e from the earth's surface, the distance from the earth's *centre* is $2r_e$ and $g = Gm_e/(2r_e)^2 = Gm_e/4r_e^2 = g_s/4$, i.e. the acceleration due to gravity is *one-quarter* of its value on the earth's surface.

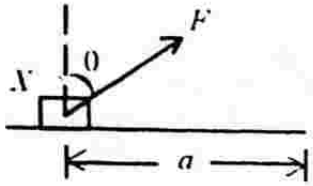
f **(T)** Since $g = Gm_e/r^2$ and r is larger at the top of the mountain, g is correspondingly smaller and the object's weight, mg, is smaller.

g **(F)** g depends only on the mass of the earth, and not on that of the object ($g = Gm_e/r_e^2$).

h **(T)** This work, which is done against the pull of gravity, must be equal to the initial k.e. of the object which gives it an initial velocity which is equal to the *escape velocity*.

SSCE/JME - Type Objective Questions

[Take g = 10 ms^{-2}]

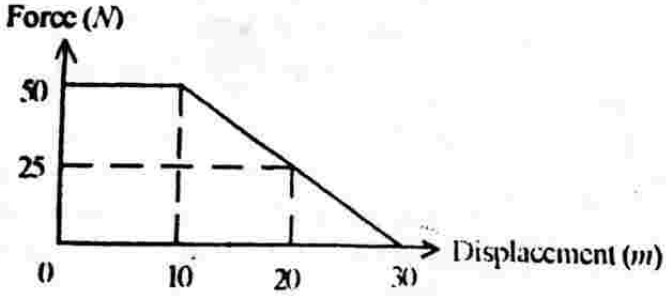
1. 

A force F applied to a body X moves the body through the distance a as shown in the diagram. The work done by the force F is

A. Fa **B.** $Fa\cos\theta$ **C.** $Fa\sin\theta$ **D.** $Fa/\cos\theta$

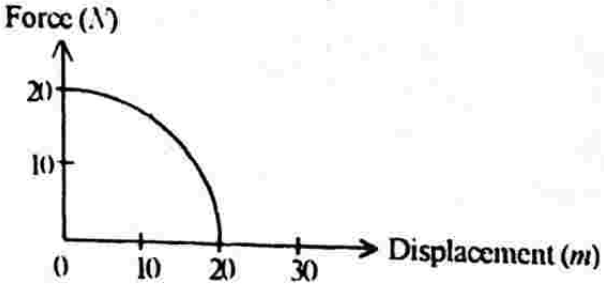
2. A boy of weight 300 N climbs to the top of a hill of height 20 m. The work done by the boy against the force of gravity is

A. 6000 J **B.** 600 J **C.** 320 J **D.** 15 J

3. 

The diagram above shows the force versus displacement graph for a body. The work done on the body during the first 20 m of motion is

A. 1000 J **B.** 875 J **C.** 750 J **D.** 500 J

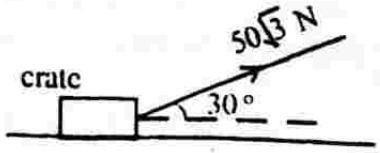
4. 

The force vs displacement graph of a body is given by the quadrant of a circle, shown in the diagram above. The work done by the force in moving the body through a distance of 20 m is

A. 400π J **B.** 200π J **C.** 100π J **D.** 50π J

5. A body initially at rest is accelerated at the rate of 0.2 ms^{-2} for 5 s under a constant force of 50 N. The work done on the body is

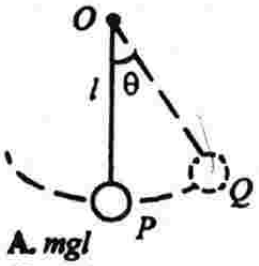
A. 10 J **B.** 50 J **C.** 125 J **D.** 250 J

6. 

A force of $50\sqrt{3}$ N applied to a crate at 30° to the horizontal surface is used to drag the crate through

a distance of 7 m along the surface. If the work done in dragging the crate is 175 J, the frictional force between the crate and the floor is

A. $5\sqrt{3}$ N B. 17.5 N C. 25.0 N D. 50.0 N

7. 

A simple pendulum of length l has a bob of mass m (see diagram). As the bob moves from position P to position Q, the work done against gravity is

A. mgl B. $mgl \sin\theta$
C. $mgl \cos\theta$ D. $mgl(1-\cos\theta)$

8. An object is acted upon by two forces 3 N and 5 N inclined at 60° to each other. If the object is moved through a distance of 6 m by the resultant force, the work done is

A. 42 J B. 35 J C. 30 J D. 18 J

9. A car of mass 800 kg initially at rest is accelerated at the rate of 4 ms^{-2}. The kinetic energy of the car after 5 seconds is

A. 6.40×10^3 J B. 2.56×10^4 J
C. 1.60×10^5 J D. 6.40×10^5 J

10. An object of mass 20 kg is released from a height of 10 m above the ground level. The kinetic energy of the object just before it hits the ground is

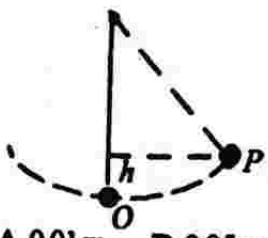
A. 4,000 J B. 2,000 J C. 500 J D. 200 J

11. A bullet of mass 40 g travelling at 300 ms^{-1} strikes a target normally and penetrates a distance of 20 cm in the target before coming to rest. The average force exerted on the bullet by the target is

A. 90 N B. 400 N C. 900 N D. 9,000 N

12. An object slides down an inclined plane from an initial height of 30 m. Its velocity at the foot of the plane is 20 ms^{-1}. The percentage of its initial potential energy which is dissipated as heat is

A. $33^1/_3$% B. 50 % C. $66^2/_3$% D. 75 %

13. 

A simple pendulum has a velocity of 1 ms^{-1} at O and zero velocity at P, which is at a height h above O. The value of h is

A. 0.01 m B. 0.05 m C. 0.1 m D. 0.5 m

14. A crate of mass 60 kg is dragged up a smooth plane inclined at 30° to the horizontal. If the final height of the crate above the ground level is 5 m, the force F applied parallel to the plane to drag the crate is

A. 150 N B. 240 N C. 300 N D. 600 N

15. A 70 kg man ascends a flight of stairs of height 4 m in 7 s. The power expended by the man is

A. 40 W B. 100 W C. 280 W D. 400 W

16. A pump lifts water into an overhead tank at a height of 12 m at the rate of 5 kgs^{-1}. The power of the pump is

A. 60 W B. 600 W C. 720 W D. 1200 W

17. A 40 kg girl climbing a flight of stairs expends energy at the rate of 50 W. The time taken for her to reach a height of 20 m is

A. 16 s B. 32 s C. 80 s D. 160 s

18. An engine develops a power of 750 W while moving a car at constant velocity 3 ms^{-1}. The force exerted on the car by the engine is

A. 83.3 N B. 250.0 N C. 750.0 N D. 2250.0 N

19. An object of mass 12 kg is held at a height of 5 metres above the ground for 30 seconds. The work done within this period is

A. 600 J B. 200 J C. 60 J D. 0

20. A car of mass M kg is accelerated uniformly from rest by an engine of power P. The minimum time it will take to attain a speed V is

A. MV/P B. $MV/2P$ C. $MV^2/2P$ D. MV^2/P

21. A water pump of 1.2 kW rating pumps 480 kg of water into an overhead tank at a height of 5 m in 30 seconds. The efficiency of the pump is

A. 90.0% B. 80.0% C. 66.7% D. 62.5%

22. 24 kJ of heat is produced by the combustion of a certain quantity of petrol in an engine rated at 10 W. If one-quarter of this heat is converted into mechanical energy, the engine will run for

A. 10 min B. 40 min C. 100 min D. 400 min

23. A stone of mass 50 g projected vertically upwards from the ground acquires a velocity of 12 ms^{-1} at a height of 20 m. The initial kinetic energy of the stone is

A. 3.6 J B. 10. 0 J C. 13.6 J D. 27.2 J

24. The maximum height attained by the stone in question 23 is

A. 108.8 m B. 54.4 m C. 40.8 m D. 27.2 m

25. If M and R are the mass and radius of the earth respectively and G is the universal gravitational constant, the earth's gravitational potential at an altitude H above the ground level is

A. $\frac{-GM}{H}$ B. $\frac{-GM}{R+H}$ C. $\frac{-GM}{2H}$ D. $\frac{-GM}{R-H}$

26. An object having a mass of 24 kg on earth is taken to a planet where the acceleration due to gravity is one-half of its value on earth. The mass of the object on the planet is
A. 12 kg B. 24 kg C. 36 kg D. 48 kg

27. An object of mass 40 kg will experience a gravitational force of 68 N on a planet on which the intensity of the gravitational field is
A. 0.4 Nkg^{-1} B. 1.7 Nkg^{-1}
C. 9.8 Nkg^{-1} D. 2,720 Nkg^{-1}

28. The mass of a certain planet P is one-hundredth that of the earth while its radius is one-quarter of the earth's radius. If the acceleration due to gravity on the earth is 10 ms^{-2}, then its value on P is
A. 0.10 ms^{-2} B. 0.40 ms^{-2}
C. 1.60 ms^{-2} D. 2.50 ms^{-2}

29. The escape velocity of a body on the surface of a planet of radius R and mass M is [G = universal gravitational constant]
A. $\sqrt{2GR}$ B. $\sqrt{2GR}$ C. $\sqrt{2GM/R}$ D. $\sqrt{2GM/R}$

30. The radius of the earth is 6.4×10^6 m and the acceleration due to gravity is 10.0 ms^{-2}. The escape velocity of a rocket launched from the earth's surface is
A. 4.2 kms^{-1} B. 4.0 kms^{-1}
C. 11.3 kms^{-1} D. 25.3 kms^{-1}

Answer Key

1. C	6. D	11. D	16. B	21. C	26. B
2. A	7. D	12. A	17. D	22. A	27. B
3. B	8. A	13. B	18. B	23. C	28. C
4. C	9. C	14. C	19. D	24. D	29. D
5. C	10. B	15. D	20. C	25. B	30. C

Solutions to Objective Questions

1. **(C)** The resolved component of F in the horizontal direction is $F\sin\theta$. Work done = $(F\sin\theta)(a) = Fa\sin\theta$.

2. **(A)** Workdone = potential energy gained
= weight x height = 300 x 20 = 6,000 J.

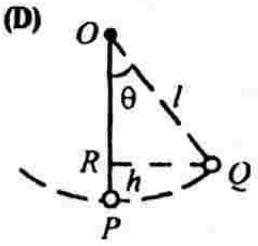
3. **(B)** Work done = area under the force - displacement graph.
Work done for the first 10 m = 50 x 10 = 500 J
Work done for the next 10 m = ½(50 + 25) x 10 = 375 J
Total work done for the first 20 m = 500 + 375 = 875 J

4. **(C)** Work done = area of the quadrant = $\pi r^2/4$, where r is the radius of the quadrant = 20 m. Hence, work done = $\pi(20)^2/4 = 100\pi$ J

5. **(C)** Body's displacement after 5 s = $\frac{1}{2}at^2 = \frac{1}{2}(0.2)(5)^2$
= 2.5 m
Work done = Force x displacement = 50 x 2.5 = 125 J.

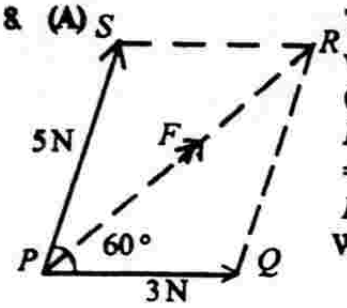
6. **(D)** Resolved component of applied force along the horizontal direction = $50\sqrt{3}(\cos 30°) = 50\sqrt{3}(\sqrt{3}/2)$ = 75 N. If F_r = frictional force, then
Work done = $(75 - F_r)$ x displacement
i.e. $175 = (75 - F_r) \times 7$, or $F_r = 50$ N

7. **(D)**



Work done against gravity in moving the bob from P to $Q = mgh$, where h = height of Q above $P = RP$. From the triangle ORQ, $OR = l\cos\theta$
$h = RP = OP - OR = l - l\cos\theta$
$= l(1 - \cos\theta)$
$\Rightarrow$ Work done = $mgl(1 - \cos\theta)$.

8. (A)



The resultant force F is given by the cosine formula (see diagram):
$F^2 = 5^2 + 3^2 - 2(5)(3)\cos PSR$
$= 25 + 9 - 30\cos 120° = 49$, or
$F = 7$ N
Work done $= F \times$ displacement
$= 7 \times 6 = 42$ J

9. (C) Velocity of the car after 5 s, $v = at = 4(5) = 20$ ms^{-1}
K.E. of the car $= \frac{1}{2}mv^2 = \frac{1}{2}(800)(20)^2 = 1.6 \times 10^5$ J

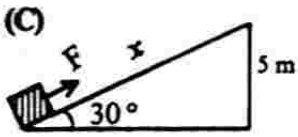
10. (B) K.E. of the object just before landing = P.E. at the initial height $= mgh = 20(10)(10) = 2{,}000$ J

11. (D) K.E. of the bullet $= \frac{1}{2}mv^2 = \frac{1}{2}(0.04)(300)^2 = 1{,}800$ J. This is equal to the work done by the bullet in penetrating the target = force x distance penetrated, i.e. $1800 = F \times 0.20$, or $F = 9{,}000$ N.

12. (A) Initial P.E. of the object $= mgh = m(10)(30)$
$= 300m$ J, where m = mass of the object in kg.
K.E. of the object at the foot of the incline $= \frac{1}{2}m(20)^2$
$= 200m$ J.
Energy dissipated $= 300m - 200m = 100m$ J, which is $(100m / 300m) \times 100\%$, or $33\frac{1}{3}\%$ of the initial P.E.

13. (B) K.E. at O = P.E. at P
$\frac{1}{2}mv^2 = mgh \Rightarrow h = v^2/2g = (1)^2/20 = 0.05$ m.

14. (C)



Referring to the diagram, the distance up the inclined plane is $x = 5/\sin 30° = 10$ m
Work done by the force $F = Fx = 10F$ J
Final P.E of the crate $= mgh = (60)(10)(5) = 3{,}000$ J
Hence $10F = 3000$ or $F = 300$ N.

15. (D) Work done by the man $= mgh = (70)(10)(4) = 2{,}800$ J
Power expended = Work/time $= 2{,}800/7 = 400$ W

16. (B) Power = work done by the pump in 1 second
= mass of water raised per second x g x h
$= (5)(10)(12) = 600$ W

17. (D) Work done by the girl in reaching a height of 20 m is $mgh = 40(10)(20) = 8{,}000$ J. At the rate of 50 W, or 50 Js^{-1}, time taken to expend 8,000 J is $8000/50 = 160$ s

18. (B) Work done by the engine in 1 second
= force x displacement $= F \times 3 = 3F$, where F = force.
This is equal to 750 J, which is the energy expended per second. Hence $3F = 750$, or $F = 250$ N.

19. (D) Since the object undergoes no displacement within the period specified, work done is zero.

20. (C) Acceleration $a = V/t$, where t = time
Distance covered $= \frac{1}{2}at^2 = \frac{1}{2}(V/t)t^2 = \frac{1}{2}Vt$
Force $= Ma = MV/t$

$$\text{Power, } P = \frac{\text{Force x distance}}{\text{time}} = \frac{(MV/t) \times (\frac{1}{2}Vt)}{t} = \frac{MV^2}{2t}$$

or $t = MV^2/2P$
[Alternatively, K.E. after time $t = \frac{1}{2}MV^2$, hence the power developed $= P = \frac{1}{2}MV^2/t$, or $t = MV^2/2P$].

21. (C) Power delivered by the pump $= mgh/t$
$= 480(10)(5)/30 = 800$ W
Efficiency of the pump $= 800/1200 = 66.7\%$

22. (A) Amount of heat converted into mechanical energy $= 24 \times \frac{1}{4} = 6$ kJ $= 6{,}000$ J. An engine rated at 10 W, or 10 Js^{-1} will run for $6{,}000/10 = 600$ s, or 10 minutes.

23. (C) P.E. at the height of 20 m $= mgh = (0.05)(10)(20)$
$= 10$ J
K.E. at the height of 20 m $= \frac{1}{2}MV^2 = \frac{1}{2}(0.05)(12)^2$
$= 3.6$ J
Initial K.E. of the stone = total energy at the height of 20 m $= 10 + 3.6 = 13.6$ J

24. (D) At the maximum height H, P.E. $= mgH = 13.6$ J
$\Rightarrow H = 13.6/mg = 13.6/(0.05 \times 10) = 27.2$ m

25. (B) Grav. potential $V = -GM/r$, where r = distance from the centre of the earth $= R + H$.
Hence $V = -GM/(R + H)$.

26. (B) The *mass* of a body is a constant, independent of the gravitational field. Only the *weight*, which is the product of mass and acceleration due to gravity, varies with gravitational field.

27. (B) Intensity of the gravitational field

$$= \frac{\text{Gravitational force}}{\text{mass of object}} = \frac{68}{40} = 1.7\,\text{Nkg}^{-1}$$

28. (C) Acceleration due to gravity on the earth,

$g_e = \frac{Gm_e}{r_e^2}$ where m_e and r_e are the mass and the radius of the earth respectively. Acceleration due to gravity on the planet P is

$$g_p = \frac{Gm_p}{r_p^2}$$

where $m_p = m_e/100$ and $r_p = r_e/4$ Hence,

$$g_p = \frac{G(m_e/100)}{(r_e/4)^2} = \frac{0.16Gm_e}{r_e^2} = 0.16\,g_e$$

$= 0.16 \times 10 = 1.6\ ms^{-2}$

29. **(D)** It is important not to confuse this equation with the alternative expression $v = \sqrt{2g_eR}$.

30. **(C)** Escape velocity $v = \sqrt{2gr_e} = \sqrt{2(10)(6.4 \times 10^6)}$, $= 10^3\sqrt{128} = 11.3 \times 10^3\ ms^{-1}$, or $11.3\ kms^{-1}$

Revision Check-list

Under this chapter, the candidate should be able to

- define the terms *work, kinetic energy* and *potential energy.*
- state and apply the law of *conservation of energy.*
- describe work-energy conversions and K.E. - P.E. conversions for systems such as a body in free fall under gravity, an oscillating pendulum, a projectile, etc, and perform simple calculations on them.
- define and solve simple problems on *power.*
- state and apply *Newton's law of universal gravitation*
- express the acceleration due to gravity on the earth's surface in terms of the mass and radius of the earth.
- explain why and how the acceleration due to gravity varies with altitude.
- define the term *gravitational potential* and how it varies with distance from the body.
- understand what is meant by the term *escape velocity* and perform simple calculations for its evaluation.

5 Simple Machines

5.1 Definition

- A **machine** is a device which enables mechanical work to be performed in a convinient way, e.g the lifting of a heavy load with a relatively small force.
- Examples of simple machines include the **lever** the **pulley system**, the **wheel and axle**, the **inclined plane** and the **screw**.

5.2 The Lever

- The **lever** consists of a rigid bar which is pivoted on a fulcrum (Fig. 5.1).
- The **load** (W) is often closer to the fulcrum than the **effort** (i.e. the applied force F).
- For such a machine,

Mechanical Advantage (*M.A.*) $= \dfrac{\text{Load}}{\text{Effort}}$
(or *Force Ratio*)

$$M.A. = \frac{W}{F} \qquad (5.1)$$

Velocity Ratio (*V.R.*) $= \dfrac{\text{Distance moved by effort}}{\text{Distance moved by load}}$

$$V.R. = \frac{d_E}{d_L} \qquad (5.2)$$

where d_E and d_L are the distances moved by the effort and the load, respectively.

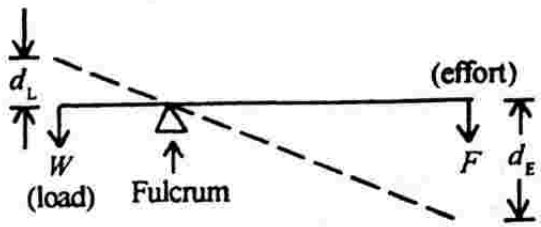


Fig. 5.1

- In the absence of friction, the work done by the machine (e.g. in raising a load) must be equal to the work done on it (through the effort).
- However, because of friction, the work done by the machine is always less than the work done on it.
- The efficiency of a machine is defined as

Efficiency $= \dfrac{\text{work done on load}}{\text{work done by effort}}$, or

$$\textbf{Efficiency} = \frac{W \times d_L}{F \times d_E} = \frac{W/F}{d_E/d_L} = \frac{M.A.}{V.R.} \qquad (5.3)$$

- Units: M.A., V.R. and efficiency bear no units.

5.3 Pulley Systems

- Fig. 5.2 shows a typical pulley system (often referred to as the **block and tackle**) consisting of four pulleys, two on the *fixed* upper block, and two on the *movable* lower block. The load W is to be raised by an effort F.
- Since the tension in all parts of the rope is equal to F, it follows that:
  the total upward force on the lower block is $4F$ and the downward force on the lower block is W.
  To raise the load, $W = 4F$, or **M.A.** $= W/F = 4$

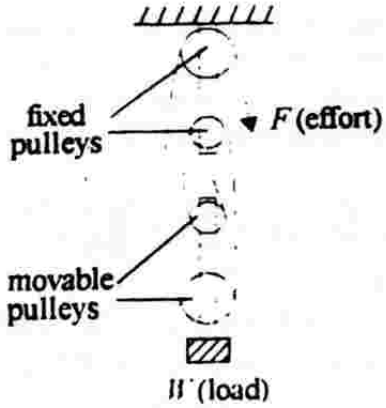


Fig. 5.2

- Note that the *ideal* M.A. is equal to *the number of ropes supporting the lower block.*
- In reality, the M.A. is always less than this because of the friction in the system. However, the V. R. is always equal to the number of ropes supporting the lower block. In Fig. 5.2, V. R. = 4.

5.4 Wheel and Axle

- The **wheel and axle** consists of a wheel of radius R mounted on an axle of radius r (Fig. 5.3)

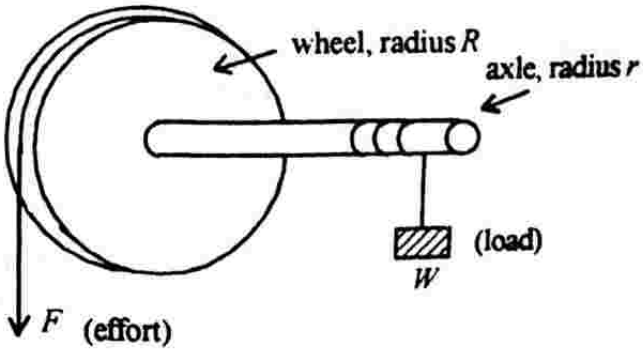


Fig. 5.3

- The load is borne by the axle while the effort is applied on the wheel. For each revolution of the system:
  Work done by effort $= 2\pi RF$
  Work done on load $= 2\pi rW$

$$\text{Efficiency} = \frac{2\pi rW}{2\pi RF} = \frac{W \times r}{F \times R}, \text{ or}$$

$$\textbf{Efficiency} = \frac{W/F}{R/r} \qquad (5.4)$$

- Note that M.A. = W/F while V.R. = R/r
- The bicycle makes use of this principle.

5.5 Inclined Plane

- Consider a load W which is moved through a distance l on a plane inclined at an angle θ to the horizontal (Fig. 5.4):
  Work done by effort = Fl
  Work done on load = Wh

$$\textbf{Efficiency} = \frac{Wh}{Fl} = \frac{W/F}{l/h} \qquad (5.5)$$

with M.A. = W/F and V.R. = l/h

- For a frictionless plane, $Wh = Fl$ and

$$\frac{W}{F} = \frac{l}{h} = \frac{1}{\sin\theta} \qquad (5.6)$$

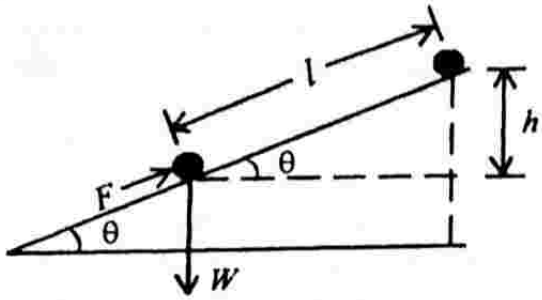


Fig. 5.4

5.6 Gears

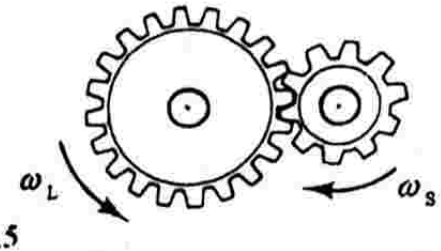


Fig. 5.5

- A load can be moved by driving a **gear** attached to it through another gear on which the effort is applied.
- Gears are toothed wheels used to alter the velocity ratio, and sometimes, the direction of rotation (Fig 5.5).
- For two gears *in mesh* the large gear has a greater number of teeth than the small gear.
- The velocity ratio is the ratio of the angular speed of one to that of the other. If
  ω_L = angular speed of large gear
  ω_s = angular speed of small gear
  n_L = number of teeth on large gear
  n_s = number of teeth on small gear

$$\textbf{Velocity Ratio} = \frac{\omega_s}{\omega_L} = \frac{n_L}{n_s} \qquad (5.7)$$

- Note that the *smaller* gear always rotates *faster*.

5.7 The Screw

- The *screw* is a simple machine in which a rotational motion of the effort is converted to a linear motion of the load (Fig. 5.6)

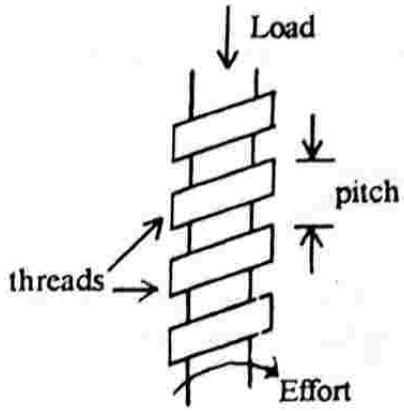


Fig. 5.6

- The threads of a screw form a spiral inclined plane such that as the screw is rotated once, it advances the distance between consecutive threads, also called the *pitch* of the screw.
- In a **screw jack**, the load is moved up or down by a distance equal to the pitch when the screw is turned through one complete circle by a handle (also called a *tommy bar*).
- If L = length of tommy bar, then
  Work input = Effort distance x Effort = $2\pi LF$, and
  Work output = Load x distance moved by load
  = Wp, where p is the pitch of the screw.

True or False - Type Questions

Answer ***True*** **(T)** or ***False*** **(F)** to the following questions

1. A machine may be used
   a. as a force multiplier.
   b. as a speed multiplier.
   c. as an energy multiplier.
   d. as a displacement multiplier.
   e. to change the direction of a force.

2. a. For a machine which multiplies force, the dis-

tance moved by the effort is always greater than the distance moved by the load.

b. For a machine which is 100% efficient, the distance moved by the effort is equal to the distance moved by the load.

c. In a frictionless machine the mechanical advantage is equal to the velocity ratio.

d. In a frictionless machine the useful work done by the machine is equal to the total work input into the machine.

e. The mechanical advantage of a machine may be less than, equal to or greater than the velocity ratio.

3. As friction increases in a machine
   a. the mechanical advantage decreases
   b. the velocity ratio decreases
   c. the efficiency decreases
   d. the work input into the machine for a given work output increases.
   e. the effort required to move a given load increases.

4. The following machines apply the lever principle :
   a. Wheelbarrow
   b. Sugar tongs
   c. Nutcrackers
   d. Single pulley
   e. Inclined plane
   f. Scissors
   g. Pliers
   h. Screw jack
   i. Claw hammer

5. a. As the slope of an inclined plane increases, the velocity ratio decreases.
   b. The efficiency of an inclined plane decreases as the slope increases.
   c. The effort required to push a given load up an inclined plane increases as the slope increases.
   d. The mechanical advantage of a smooth inclined plane depends on the ratio of the length to the height of the plane.
   e. For a plane inclined at 30° to the horizontal, the mechanical advantage cannot exceed 2.

6. The following systems may be classified as *simple machines*.
   a. Hydraulic press
   b. Thermocouple
   c. Electric heater
   d. Scissors
   e. Magnetic relay
   f. Horizontal plane
   g. The human fore arm
   h. Tweezers

Answers to True or False - Type Questions

1. a (T) A machine is a force multiplier when the load is greater than the effort.
   b (T) Gears, for instance are used to reduce or increase speed.
   c (F) Energy must be conserved in a machine. When frictional effects are taken into account, the energy output of a machine is less than the work input into the machine.
   d (T) In a bicycle (wheel and axle) for instance, a little movement of the pedal results in a large movement of the wheels.
   e (T) In pulley systems, a downward force is used to move a load upward.

2. a (T) For a force multiplier, $M.A. > 1$ and $V.R. > 1$
   But $V.R. = \dfrac{\text{Distance moved by effort}}{\text{Distance moved by load}} > 1$
   Hence distance moved by effort is greater than distance moved by load.
   b (F) The ratio of the distance moved by the effort to that moved by the load is the *velocity ratio*, not efficiency.
   c (T) If the machine is frictionless, efficiency = 100% and $M.A. = V.R.$
   d (T) Efficiency $= \dfrac{\text{Useful work output of machine}}{\text{Work input into machine}}$
   $= 1$ for a frictionless machine.
   e (F) $M.A. < V.R.$ if the efficiency is less than 100% and $M.A. = V.R.$ if the efficiency is 100%.
   $M.A.$ can never be greater than V.R.

3. a (T) The highest $M.A.$ is obtained for a frictionless machine.
   b (F) $V.R.$ depends only on the size and shape of the parts of the machine, and not on friction.
   c (T) Efficiency is 100% if there is no friction.
   d (T) If friction increases, *more* work has to be done by the effort in order to obtain the same useful work output from the machine.
   e (T) As friction increases, a greater part of the effort has to be used in overcoming friction. [Alternatively, *Effort* = *Load*/$M.A.$, which increases as $M.A.$ decreases]

4. a (T) b (T) c (T)
   d (F) e (F) f (T)
   g (T) h (F) i (T)

5. a (T) $V.R. = l/h = 1/\sin\theta$ where θ = angle of inclination of the plane. $V.R.$ decreases as θ increases.
   b (F) Efficiency depends on the degree of roughness of the surface of the inclined plane, and not on the slope.
   c (T) For a frictionless plane, for instance, $W/F = l/h$, or $F = Wh/l = W\sin\theta$, which increases as θ increases. This is true even if the plane is rough.
   d (T) For a *smooth* plane, $M.A. = V.R.$, which is

equal to l/h.

e (T) $V.R. = 1/\sin 30^o = 2$. If the plane is rough, $M.A. < V.R.$ and if smooth, $M.A. = V.R. = 2$.

6. A system can be classified as a *simple machine* if
(i) an effort is applied to move a load, and
(ii) work can be done more conveniently with the use of the system. In view of this, the answers are :

a (T)	b (F)	c (F)
d (T)	e (F)	f (F)
g (T)	h (T)	

In (d), (c) and (e) no effort is applied to move a load while (f) does not satisfy condition (ii) above.

SSCE/JME - Type Objective Questions [g = 10 ms^{-2}]

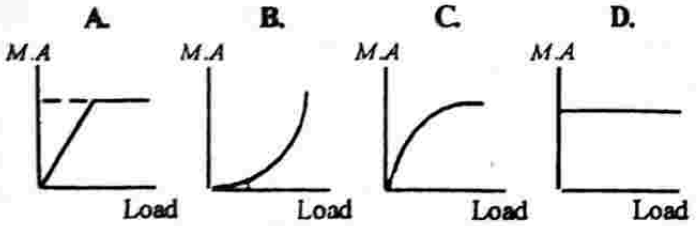
1. A machine has an efficiency of 75%. The work done when the machine is used to raise a load of 50 kg through a vertical distance of 6 m is
A. 4000 J **B.** 3000 J **C.** 2250 J **D.** 500 J

2. A machine with an efficiency of 60% is used to overcome a load of 60 N through the application of a force of 40 N. The mechanical advantage of the machine is
A. 0.4 **B.** 0.9 **C.** 1.5 **D.** 2.5

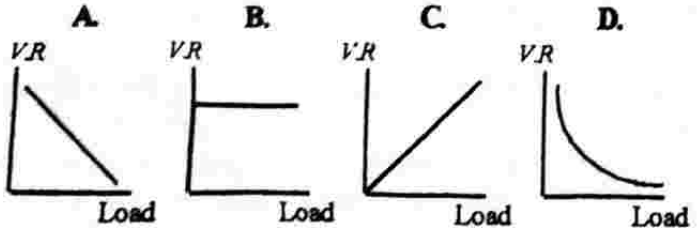
3. The velocity ratio of the machine in question 2 is
A. 4.17 **B.** 2.50 **C.** 1.50 **D.** 0.67

4. A machine having a velocity ratio of 4 requires a weight of 20 kg to overcome a weight of 60 kg. The efficiency of the machine is
A. $33^1/_3$% **B.** 60% **C.** 75% **D.** 90%

5. The variation of machanical advantage with load for a simple machine with a velocity ratio of 4 is correctly illustrated as

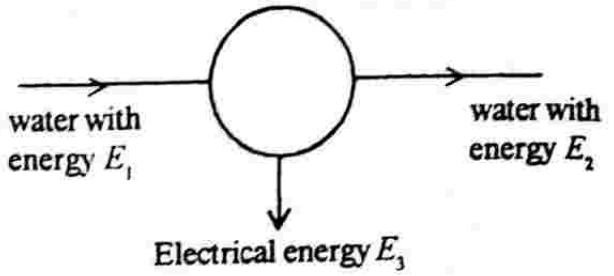


6. The variation of velocity ratio with load for a simple machine is correctly illusrated as



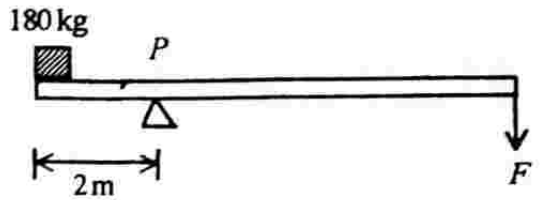
7. 500 J of work is required by a machine to raise a load of 250 N through a vertical distance of 1.6 m. The efficiency of the machine is
A. 80% **B.** 75% **C.** 67% **D.** 50%

8.



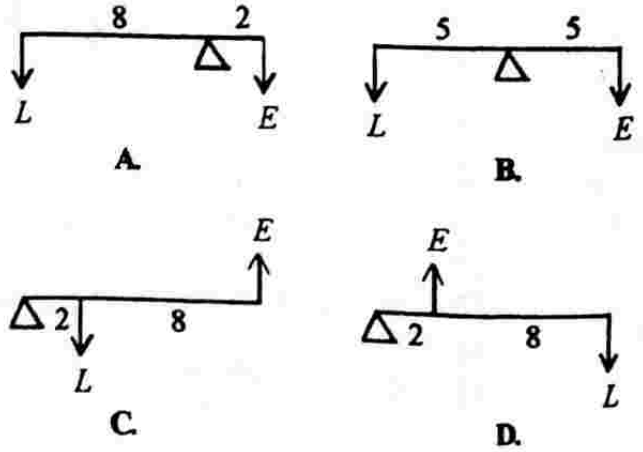
The diagram above represents the energy flow through a hydroelectric power. The efficiency of energy conversion is
A. $\frac{E_2}{E_1}$ **B.** $\frac{E_3}{E_1}$ **C.** $\frac{E_3}{E_1+E_2}$ **D.** $\frac{E_2+E_3}{E_1}$

9.



A lever of length 10 m is used to lift a load of mass 180 kg (see diagram above). The pivot P is 2 m from the load. If the efficiency of the lever is 90%, the force F required to lift the load is
A. 50 N **B.** 405 N **C.** 450 N **D.** 500 N

10. Which of the following levers has the greatest mechanical advantage? (The numbers indicated are the relative distances)



11. A pulley system has three pulleys in the fixed block and two in the movable block. Its velocity ratio is
A. 5 **B.** 4 **C.** 3 **D.** 2

12. If the pulley system in question 11 has an efficiency of 72%, the mechanical advantage of the system is
A. 36.0 B. 7.2 C. 5.0 D. 3.6

13. A pulley system has a velocity ratio of 6 and an efficiency of 75%. The effort needed to lift a load of mass 135 kg is
A. 1013 N B. 300 N C. 225 N D. 30 N

14. A block and tackle system made up of five pulleys is used to raise a load of 700 N with an effort of 200 N. The efficiency of the system is
A. 29 % B. 57 % C. 70 % D. 85%

15. If the block and tackle system in question 14 is used to lift the load through a height of 5 m, the work done in overcoming friction is
A. 1,500 J B. 2,500 J C. 3,500 J D. 5,000 J

16.

The block and tackle system shown in the diagram is used to lift a load W with an effort E. Neglecting friction and the weight of the pulleys and the cord, the ratio E/W is
A. 4 B. $^1/_4$ C. 2 D. $^1/_2$

17. If $W = 240$ N and the efficiency of the machine in question 16 is 60%, the effort is
A. 36 N B. 60 N C. 100 N D. 144 N

18. A wheel and axle is used to raise a weight of 720 N with an effort of 200 N. If the radii of the wheel and the axle are 40 cm and 10 cm respectively, the efficiency of the machine is
A. 60% B. 72% C. 80% D. 90%

19. If the load in question 18 is raised through a vertical distance of 5 m, the work done against friction is
A. 4,000 J B. 3,600 J C. 1,000 J D. 400 J

20. The wheel and the axle of a wheel-and-axle have radii 50 cm and 10 cm respectively. If one-fifth of the work done by the effort is used in overcoming friction, an effort of 500 N applied to the wheel will raise a load of
A. 2,500 N B. 2,000 N C. 1,000 N D. 500 N

21. The velocity ratio of a plane inclined at an angle of θ to the horizontal is
A. $\sin\theta$ B. $\tan\theta$ C. $1/\sin\theta$ D. $1/\tan\theta$

22. A plane which is inclined at an angle of 30° to the horizontal has a velocity ratio of
A. 2.00 B. 1.00 C. 0.87 D. 0.50

23. A body of mass 20 kg is pushed up a smooth plane inclined at an angle of 30° to the horizontal. The force needed to push the body up the plane is
A. 200 N B. 100 N C. 20 N D. 10 N

24. If the efficiency of the plane in question 23 had been 75%, the force required to push the body up the plane is
A. 267 N B. 150 N C. 133 N D. 75 N

25. A force of 100 N is used to push a body up a plane inclined at an angle of 15° to the horizontal. If one-half of the work done by the force is used in over coming friction, the weight of the body in *newtons* is
A. $\frac{50}{\sin 15^\circ}$ B. $50 \sin 15^\circ$ C. $\frac{100}{\sin 15^\circ}$ D. $100 \sin 15^\circ$

26. Two intermeshing gear wheels have 25 and 75 teeth respectively. If the smaller wheel rotates at 60 rev.s^{-1}, the larger wheel rotates at
A. 20 rev.s^{-1} B. 180 rev.s^{-1}
C. 1500 rev.s^{-1} D. 4500 rev.s^{-1}

27. A screw jack has a pitch of 0.5 cm and a tommy bar of length 20 cm. The velocity ratio is
A. 40π B. $40/\pi$ C. 80π D. $80/\pi$

28. A spanner P of length 25 cm is used to turn a screw of pitch 3 mm through one complete rotation. A second spanner Q of length 30 cm is also used to turn the same screw through a complete rotation. The ratio of the velocity ratios of P to Q is
A. 5 : 6 B. 6 : 5 C. 2 : 5 D. 5 : 2

29. The handle of a screw jack of pitch 4 mm turns through a circle of radius 21 cm when the jack is used to raise a load. If $\pi = 22/7$, the velocity ratio of the jack is
A. 66 B. 165 C. 264 D. 330

30. If the jack in question 29 is used to raise a load of 5,940 kg through a height of 10 cm and the efficiency of the jack is 60%, the effort applied is
A. 30 N B. 300 N C. 500 N D. 3,000 N

31. The work done in overcoming friction in the screw jack of question 30 is
A. 3,564 J B. 3,960 J C. 5,940 J D. 9,900 J

Answer Key

1. A	7. A	13. B	19. D	25. A	31. B
2. C	8. B	14. C	20. B	26. A	
3. B	9. D	15. A	21. C	27. C	
4. C	10. C	16. B	22. A	28. A	
5. C	11. A	17. C	23. B	29. D	
6. B	12. D	18. D	24. C	30. B	

Solutions to Objective Questions

1. **(A)** Work done in raising the load = mgh = (50)(10)(6) = 3,000 J

$$\text{Efficiency} = \frac{\text{work done in raising the load}}{\text{work input into the machine}}$$

$\Rightarrow$ work input to the machine = $\frac{3000}{0.75}$ = 4,000 J

2. **(C)** M.A. = Load/effort = 60/40 = 1.5

3. **(B)** Efficiency = M.A./V.R.
$\Rightarrow$ V.R = M.A./Efficiency = 1.5/0.6 = 2.50

4. **(C)** M.A. = Load/effort = 60/20 = 3
Efficiency = M.A./V.R. = 3/4 = 75%

5. **(C)** For very small loads, and in *real* machines (with appreciable friction), M.A. initially increases with load and then remians constant. [If the machine were frictionless with 100% efficiency, for instance, M.A. = 4 = velocity ratio (option D)].

6. **(B)** The V.R. depends only on the size and shape of the machine parts, and *not* on load.

7. **(A)** Work input into machine = 500 J
Work output of machine = weight x height = 250 x 1.6 = 400 J.

$$\text{Efficiency} = \frac{400}{500} \times 100\% = 80\%$$

8. **(B)** $$\text{Efficiency} = \frac{\text{Useful energy output from machine}}{\text{Energy input into machine}}$$
$= E_3/E_1$ [Note that E_2 is wasted energy]

9. **(D)** $$\text{V.R.} = \frac{\text{Effort distance}}{\text{Load distance}} = \frac{8}{2} = 4$$
M.A. = V.R. x efficiency = 4 x 0.90 = 3.6
Effort = Load / M.A. = 1,800/3.6 = 500 N

10. **(C)** A detailed calculation is not necessary here, once it is recognized that the one with the largest V.R. also has the largest M.A. (If they were all 100% efficient, M.A. = V.R.)

11. **(A)** Velocity Ratio = number of pulleys = 5

12. **(D)** M.A. = V.R. x Efficiency = 5 x 0.72 = 3.6

13. **(B)** M.A. = V.R. x Efficiency = 6 x 0.75 = 4.5
Effort = Load/M.A. = 1350/4.5 = 300 N

14. **(C)** M.A. = 700/200 = 3.5. V.R. = 5
Efficiency = 3.5/5 = 0.70. or 70%

15. **(A)** Work done in lifting the load = weight x height = 700 x 5 = 3,500 J

$$\text{Efficiency} = \frac{\text{Work done on load}}{\text{Work input into machine}}$$

$$\text{Work input} = \frac{\text{Work done on load}}{\text{Efficiency}} = \frac{3000}{0.70} = 5{,}000.$$

Work done against friction
= work input - work done on load
= 5,000 - 3,500 = 1,500 J

16. **(B)** If the machine is frictionless and the weights of the components are negligible, efficiency is 100%. Thus M.A = V.R. = number of pulleys = 4. Hence M.A. = W/E = 4, or E/W = 1/4.

17. **(C)** M.A. = V.R. x Efficiency = 4 x 0.60 = 2.4
But M.A. = W/E ⇒ E = W/M.A. = 240/2.4 = 100 N.

18. **(D)** M.A. = Load / Effort = 720/200 = 3.6
V.R. = R/r = 40/10 = 4.0
Efficiency = M.A./V.R. = 3.6/4.0 = 0.90, or 90%

19. **(D)** Work done on the load = 720 x 5 = 3600 J
Work done by the effort = $\frac{\text{Work done on load}}{\text{Efficiency}}$
= 3,600/0.90 = 4,000 J
Work done against friction = 4,000 - 3,600 = 400 J.

20. **(B)** If one-fifth (or 20%) of the work done by the effort is expended on friction, efficiency = 80%
V.R. = 50/10 = 5.0
M.A. = V.R. x Efficiency = 5 x 0.80 = 4.0
Load = M.A. x Effort = 4.0 x 500 = 2,000 N

21. **(C)** V.R. = l/h = 1/sin θ (See revision notes)

22. **(A)** V.R. = 1/sin 30° = 1/0.50 = 2.00

23. **(B)** V.R. = 1/sin 30° = 2.0
Since the plane is smooth, i.e frictionless,
M.A. = V.R. = 2.0
Effort = Load/M.A. = 20(10)/2 = 100 N

24. **(C)** M.A. = V.R. x Efficiency = 2.0 x 0.75 = 1.5
Effort = Load/M.A. = 200/1.5 = 133.3 N

25. **(A)** V.R = 1/sin 15°
Efficiency = 50% = 0.50
M.A. = V.R. x Efficiency = 0.50/sin 15°
Load = M.A. x Effort = $\frac{0.50}{\sin 15^0} \times 100 = \frac{50}{\sin 15^0}$ N

26. **(A)** V.R. = $\frac{n_L}{n_S} = \frac{75}{25} = 3$ (See revision notes)
But V.R. = ω_S/ω_L
⇒ $\omega_L = \omega_L = \omega_S$/V.R. = 60/3 = 20 rev. s^{-1}

27. **(C)** V.R. = $\frac{\text{distance moved by effort}}{\text{pitch}} = \frac{2\pi L}{\text{pitch}}$,
where L = length of tommy bar
⇒ V.R. = $\frac{2\pi(20)}{0.5} = 80\pi$,

28. **(A)** For P : V.R. = $2\pi(25)/0.3 = 50\pi/0.3$
For Q : V.R. = $2\pi(30)/0.3 = 60\pi/0.3$
Ratio of V.R. of P to V.R. of Q = 50 : 60 = 5 : 6

29. **(D)** Distance moved by effort = $2\pi R = 2\pi(21)$
= 42π cm
V.R. = 42π/pitch = $42\pi/0.4$ = 330

30. **(B)** M.A. = Efficiency x V.R. = 0.60 x 330 = 198
Effort = Load/M.A. = 5,940(10)/198 = 300 N

31. **(B)** Work done in raising the load
= mgh = 5940(10) (0.10) = 5,940 J. Since this represents 60% of the work done by the effort, work done by effort = 5940/0.60 = 9,900 J
Work done against friction = 9,900 - 5,940 = 3,960 J.

Revision Check-list

Under this chapter the candidate should be able to

- define the term *simple machine* and cite examples.
- define *mechanical advantage*, *velocity ratio* and *efficiency*.
- evaluate the *M.A*, *V.R.* and *efficiency* for simple machines.
- relate the M.A and V.R. to the *number of ropes supporting the lower fixed block* in a pulley system.
- appreciate the effect of *friction* on the M.A and the efficiency of a machine.
- relate the V.R. of an inclined plane to the slope.
- relate the M.A. and efficiency of an inclined plane to the degree of smoothness of the plane.
- relate the angular speeds of intermeshing gears to the number of teeth on each gear.

6 Elasticity

6.1 Hooke's Law

- If a tensile load is applied to a wire or bar, it becomes extended.
- Fig. 6.1 shows the typical shape of the *force* versus *extension* plot for such a material.
- The plot is linear for small values of force (and extension), but is non-linear for large values.
- ***Hooke's law*** states that *the extension is directly proportional to the applied force provided the elastic limit is not exceeded*. The region in which Hooke's law is applicable in Fig. 6.1 is *OE*.
- Mathematically, Hooke's law is written as

$$F = kx \qquad (6.1)$$

where F is the applied force, x is the extension and k is the **force constant** (also called **elastic constant**) of the material.

- The unit of k is [Nm^{-1}].

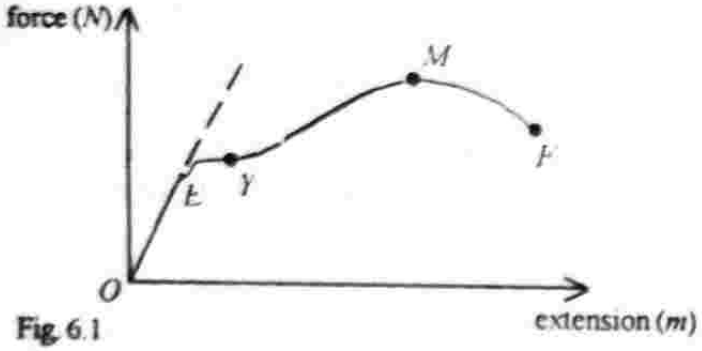


Fig. 6.1

- The following terms are defined in reference to the figure:

Elasticity: the ability of a material to return to its original shape and dimensions upon removal of the applied force. This ability varies from one material to another.

Elastic Limit (E): the load above which the material no longer recovers its original shape and dimensions upon removal of the load.

Yield Point (Y): the load at which the material begins to show a substantial deviation from Hooke's law, i.e. the beginning of *plastic deformation*

Maximum Load(M): the maximum load which the material is able to support.

Fracture Point(F) : the load at which the material breaks into two, i.e. it fractures.

6.2 Stress and Strain

- Stress is defined as the force acting on a unit cross-sectional area of the material. If a tensile force F is applied on a material of cross-sectional area A,

$$\text{Tensile stress} = \frac{\text{tensile force}}{\text{cross-sectional area}} = \frac{F}{A} \qquad (6.2)$$

- **Strain** is the ratio of the extension (x) to the original length (L), i.e.

$$\text{Tensile strain} = x/L \qquad (6.3)$$

- Units: Stress = [Nm^{-2}], strain has no units.

6.3 Young's Modulus

- The ***Young's modulus of elasticity*** is the ratio of tensile stress to tensile strain within the elastic region, i.e.

$$\text{Young's modulus } (E) = \frac{\text{tensile stress}}{\text{tensile strain}}$$

or in view of eqs. (6.2) and (6.3)

$$E = \frac{F/A}{x/L} = \frac{FL}{Ax} \qquad (6.4)$$

Unit: E = [Nm^{-2}]

6.4 Work Done on a Stretched Wire or Bar

- The work done when a wire or bar undergoes an extension x under an applied force F is
Work done = average force x extension, or

$$\text{Work done} = \tfrac{1}{2}Fx = \tfrac{1}{2}kx^2 \qquad (6.5)$$

in view of eq. (6.1).

- The *elastic potential energy*, or the energy stored in an elastic bar or spring is equal to the work done in stretching the bar by a distance x i.e.

$$\text{Elastic potential energy} = \tfrac{1}{2}kx^2 \qquad (6.6)$$

- When Hooke's law is obeyed, the work done is the area under the force vs extension plot (Fig. 6.2).

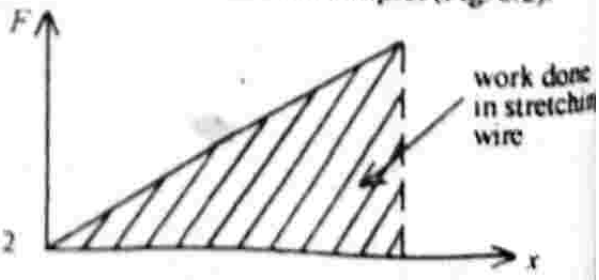


Fig. 6.2

True or False - Type Questions

Answer *True* (T) or *False* (F) to the following questions:

1. a. The elastic limit is the load at which an elastic material breaks.
   b. Within the elastic limit. the strain in a wire doubles if the stress is doubled.
   c. The slope of the force vs. extension plot for an elastic string is equal to the Young's modulus of the string.
   d. The area under the force vs. extension plot is equal to the potential energy stored in a stretched elastic string.
   e. The slope of the stress vs. strain plot during elastic deformation is a constant which varies from one material to another.
   f. If two wires of identical dimensions are subjected to the same stress, the one with the higher Young's modulus will show a larger strain.
   g. The Young's modulus for rubber is higher than for steel.
   h. If a piece of wire is stretched until its length doubles, the stress in the wire is equal to the Young's modulus.
   i. The force constant of an elastic string depends on the length and diameter of the string.
   j. If the tension in an elastic rod is doubled while the overall length of the rod is held constant, the energy stored in the rod is doubled.

2. For a loaded spiral spring :
   a. the length of the spring is proportional to the load, provided the deformation is elastic.
   b. the contraction as the spring is unloaded is proportional to the load removed.
   c. the strain increases linearly with stress until the spring breaks.
   d. the spring is elastic only if it regains its original shape and dimensions upon removal of the load.
   e. Hooke's law is always applicable.
   f. extension is no longer proportional to the load beyond the elastic limit.
   g. the energy stored in the spring is doubled if the extension is doubled.

3. The Young's modulus for a wire depends on the
   a. load on the wire.
   b. extension in the wire under a given load.
   c. diameter and length of the wire.
   d. stress in the wire.
   e. nature of the material from which the wire is made.

Answers to True or False - Type Questions

1. a (F) the elastic is the load beyond which the extension is no longer proportional to the load.
   b (T) Strain is directly proportional to stress.
   c (F) The slope is k, the force constant. This should not be confused with the Young's modulus E, which is the slope of the *stress vs strain* plot.
   d (T) See revision notes.
   e (T) This constant is the Young's modulus.
   f (F) $\text{Strain} = \dfrac{\text{Stress}}{\text{Young's modulus}}$
   Hence the wire with the higher modulus should show less strain
   g (F) If steel and rubber are subjected to the same stress, the steel shows less strain and hence higher modulus [Remember that Young's modulus = stress/strain].
   h (T) As the length of the wire doubles, extension = original length. Hence strain = 1 and stress = Young's modulus x strain = Young's modulus.
   i (T) The basic property of an elastic material which does not vary with dimension is the Young's modulus E. However, we can express the force F in an elastic wire as $F = EA\,x/L$ [see equation 6.4].
   By comparing this with the equation $F = kx$, k can be expressed as $k = EA/L$, i.e. the force constant increases with A and decreases as L increases.
   j (T) If the length is constant and F is doubled, x is constant. The stored energy which is equal to $\frac{1}{2}Fx$, is doubled.

2. a (F) It is the *extension*, not the length, that varies linearly with the load.
   b (T) Contraction is negative extension.
   c (F) The strain increases linearly with stress only up to the *elastic limit*.
   d (T) This is the definition of *elastic deformation*.
   e (F) Hooke's law is only applicable below the elastic limit.
   f (T)
   g (F) Energy stored = $\frac{1}{2}kx^2$. If x is doubled, the energy stored is *quadrupled*.

3. Young's modulus depends only on the type of material from which the wire is made. It is independent of the dimensions of the wire, or the stress and strain in the wire. In view of this, the answers are
   a (F) b (F) c (F) d (F) e (T)

SSCE/JME - Type Objective Questions

1. A spiral spring extends by 5 cm under a load of 60 N. When the load is replaced by a steel block, the new extension is 7 cm. The weight of the steel block is
A. 12 N B. 43 N C. 84 N D. 96 N

2. A 20 g wt. causes an extension of 0.72 cm in a spring. The extension caused by a load of 80 g. wt., assuming Hooke's law is obeyed by the spring, is
A. 0.18 cm B. 0.36 cm C. 1.44 cm D. 2.88 cm

3. With a mass of 25 g hung from its end, the total length of a spring is 15 cm. When the mass is increased to 40 g, the total length of the spring is 18 cm. The unstretched length of the spring is
A. 9.0 cm B. 10.0 cm C. 12.0 cm D. 12.5 cm

4. The total length of the spring in question 3 when it supports a mass of 15 g is
A. 11 cm B. 12 cm C. 13 cm D. 14 cm

5. An elastic string stretches to a total length of 30 cm under a load of 500 N. With an additional load of 100 N, the string stretches by a further 2 cm. The natural length of the string is
A. 25 cm B. 24 cm C. 20 cm D. 15 cm.

6. A spring has a total length of 17.5 cm under a load of 250 g and 20.0 cm under a load of 300 g. The extension of the spring per unit load is
A. 5×10^{-5} mN^{-1} B. 8×10^{-5} mN^{-1}
C. 5×10^{-2} mN^{-1} D. 8×10^{-2} mN^{-1}

7. The force constant in question 6 is
A. 12.5 Nm^{-1} B. 20.0 Nm^{-1}
C. 1.25×10^{4} Nm^{-1} D. 2.00×10^{4} Nm^{-1}

8. A spring with a force constant of 3×10^{3} Nm^{-1} is used to measure the mass of an object. If the spring extends by 5 cm when the object is hung from it, the mass of the object is
A. 600 kg B. 150 kg C. 60 kg D. 15 kg

9. An elastic spring of length 20 cm stretches by 7 mm under a load of 50 N. The strain in the string is
A. 1.75×10^{-1} B. 1.75×10^{-2}
C. 3.5×10^{-2} D. 7.0×10^{-2}

10. An elastic string of force constant 2000 Nm^{-1} undergoes a strain of 0.02 under load of 20 N. The natural length of the string is
A. 50 cm B. 75 cm C. 100 cm D. 200 cm

11. A force F applied to an elastic string of length L and cross-sectional area A results in an extension x. If E is the Young's modulus of the string, then
A. $F = EAL/x$ B. $F = EAx/L$
C. $F = EAx^2/L$ D. $F = EA/Lx$

12. A wire of cross-sectional area of 6×10^{-5} m^2 and length 50 cm stretches by 0.2 mm under a load of 3,000 N. The Young's modulus for the wire is
A. 8×10^{10} Nm^{-2} B. 1.25×10^{11} Nm^{-2}
C. 2.5×10^{11} Nm^{-2} D. 5×10^{11} Nm^{-2}

13. A wire of diameter 2.8 mm supports a weight W. If the tensile stress in the wire is 2×10^{7} Nm^{-2}, the value of W is [$\pi = {}^{22}/_{7}$]
A. 123.2 N B. 98.4 N C. 56.0 N D. 49.2 N

14. If the wire in question 13 has a Young's modulus of 2×10^{10} Nm^{-2} and an unstretched length of 100 cm, the extension is
A. 10 mm B. 5 mm C. 2 mm D. 1 mm

15. A spring of natural length l extends to a new length L under tensile force F. If Hooke's law applies, the work done in stretching the spring is
A. $\frac{1}{2}FL$ B. $\frac{1}{2}Fl$ C. $\frac{1}{2}F(L-l)$ D. $F(L-l)$

16. An elastic string of length 20 cm extends to 24 cm when it supports a weight of 50 N. The energy stored in the string is
A. 1 J B. 2 J C. 5 J D. 10 J

17. As the tension in an elastic string is increased from 100 N to 180 N, the string extends by 10 cm. The work done in increasing the tension in the string is
A. 8 J B. 10 J C. 14 J D. 18 J

18. The potential energy stored in a spring of force constant 2×10^{4} Nm^{-1} which is acted upon by a force of 600 N is
A. 3 J B. 9 J C. 18 J D. 90 J

19. An object of mass 20 kg is dropped on a spring which is placed 5 m below. If the spring has a force constant of 5×10^{4} Nm^{-1}, the maximum compression of the spring is
A. 1.0 m B. 0.5 m C. 0.2 m D. 0.04 m

20. A stone of mass 20 g is projected vertically upward with a catapult whose rubber cord has a force constant of 72 Nm^{-1}. If the tension in the cord at the point of release is 36 N, the velocity of projection of the stone is
A. 30 ms^{-1} B. 24 ms^{-1} C. 6 ms^{-1} D. 3 ms^{-1}

21. The maximum height attained by the stone in question 20 is
A. 4.5 m B. 9.0 m C. 18.0 m D. 45.0 m

Answer Key

1. C	5. C	9. C	13. A	17. C	21. D
2. D	6. C	10. A	14. D	18. B	
3. B	7. B	11. B	15. C	19. C	
4. C	8. D	12. B	16. A	20. A	

Solutions to Objective Questions

1. **(C)** Force constant $k = F/x = 60/5 = 12\ \text{Ncm}^{-1}$
Weight of steel block $= k \times 7 = 12 \times 7 = 84$ N.

2. **(D)** Force constant $k = F/x = 20/0.72$ g.wt/cm
For a load of 80 g.wt,
extension $= 80/k = (80/20) \times 0.72 = 2.88$ cm.

3. **(B)** When the mass is increased by 15 g, the spring extends by 3 cm. Force constant = 15/3 = 5 g.wt/cm. The initial 25 g thus stretches the spring by 25/5, or 5 cm to give a total length of 15 cm. The unstretched length is 15 - 5, or 10 cm.

4. **(C)** A mass of 15 g stretches the spring by 15/5, or 3 cm. The total length of the spring is thus 10 + 3, or 13 cm.

5. **(C)** A load of 100 N causes an extension of 2 cm, hence the force constant is $100/2 = 50\ \text{Ncm}^{-1}$. The extension under a force of 500 N is 500/50 = 10 cm, and the natural length of the string is 30 - 10 = 20 cm.

6. (C) As the load increases by 300 - 250, or 50 g, the extension increases by 20 - 17.5, or 2.5 cm. The extension per unit load is thus
$2.5\ \text{cm}/0.5\ \text{N} = (2.5 \times 10^{-2}/0.5)\ \text{mN}^{-1} = 5 \times 10^{-2}\ \text{mN}^{-1}$

7. **(B)** Force constant = 0.5N/ 2.5 cm
$= 0.5/(2.5 \times 10^{-2})\ \text{Nm}^{-1} = 20\ \text{Nm}^{-1}$

8. **(D)** Weight of the object $= kx = (3 \times 10^3)(0.05) = 150$ N
Mass of the object $= 150/g = 150/10 = 15$ kg.

9. **(C)** Strain = extension/original length = 0.7 cm/20 cm
$= 3.5 \times 10^{-2}$

10. **(A)** Extension, $x = F/k = 20/2000 = 0.01$ m
Strain $= 0.02 = x/L$
Hence $L = x/0.02 = 0.01/0.02 = 0.5$ m, or 50 cm.

11. **(B)** Stress $= F/A$ and strain $= x/L$
Young's modulus, $E = \dfrac{\text{stress}}{\text{strain}} = \dfrac{F}{A} \div \dfrac{x}{L} = \dfrac{FL}{Ax}$
or $F = EAx/L$

12. **(B)** Stress $= F/A = 3000/(6 \times 10^{-5}) = 5 \times 10^7\ \text{Nm}^{-2}$
Strain $= x/L = (0.2 \times 10^{-3})/(0.50) = 4 \times 10^{-4}$
Young's modulus, $E = 5 \times 10^7/4 \times 10^{-4} = 1.25 \times 10^{11}\ \text{Nm}^{-2}$

13. **(A)** Cross-sectional area of wire,
$A = \dfrac{\pi d^2}{4} = \dfrac{22}{7} \times \dfrac{1}{4} \times (2.8 \times 10^{-3})^2 = 6.16 \times 10^{-6}\ \text{m}^2$
Force = stress x area $= (2 \times 10^7)(6.16 \times 10^{-6}) = 123.2$ N

14. **(D)** Strain = Stress/Young's modulus
$= 2 \times 10^7/2 \times 10^{10} = 10^{-3}$
Extension = strain x original length $= 10^{-3} \times 100$ cm
$= 10^{-1}$ cm = 1 mm.

15. **(C)** Extension $= L - l$ and the average force $= F/2$
Work done = average force x extension $= \frac{1}{2}F(L-l)$

16. **(A)** Energy stored = work done on string
$= \frac{1}{2}Fx = \frac{1}{2}(50)(0.04) = 1$ J

17. **(C)** Average force in the string $= (100 + 180)/2 = 140$ N
Work done = average force x extension
$= 140 \times 0.10 = 14$ J

18. **(B)** Extension $x = F/k = 600/2 \times 10^4 = 3 \times 10^{-2}$ m
Potential energy stored = work done on spring
$= \frac{1}{2}Fx = \frac{1}{2} \times 600 \times 3 \times 10^{-2} = 9$ J

19. **(C)** Potential energy of object $= mgh = 20(10)(5) = 1000$ J
Neglecting friction, this is wholly converted into the elastic P.E of the spring $= \frac{1}{2}kx^2$. Hence
$\frac{1}{2}(5 \times 10^4)x^2 = 1000$, or $x^2 = 1/25$, and $x = 1/5 = 0.2$ m

20. **(A)** Extension of the rubber, $x = F/k = 36/72 = 0.5$ m
The elastic potential energy, $\frac{1}{2}kx^2$, of the stretched rubber is converted into the kinetic energy, $\frac{1}{2}mv^2$, of the stone. Hence
$\frac{1}{2}mv^2 = \frac{1}{2}kx^2$, or $v^2 = (k/m)x^2 = (72/0.02)(0.5)^2$
$= 3600(0.5)^2$, or $v = 60 \times 0.5 = 30\ \text{ms}^{-1}$.

21. **(D)** $\frac{1}{2}kx^2 = mgh$, or $h = kx^2/2mg$
$= \dfrac{72(0.5)^2}{2(0.02)(10)} = 45$ m.

Revision Check-list

Under this chapter, the candidate should be able to

- define the terms *elasticity*, *elastic limit*, *yield point* and *plastic deformation*.
- state *Hooke's law* and the condition under which it applies.
- define the term *force constant*.
- define the terms *stress*, *strain* and *Young's modulus of elasticity*.
- relate the *energy stored* in a stretched wire to the work done on the wire.
- solve simple energy conversion problems involving *elastic potential energy*, *kinetic energy* and *gravitational potential energy*.
- describe an experiment to determine Young's modulus for a wire.

7 Hydrostatics

7.1 Pressure in Liquids

- **Density** is defined as the *mass per unit volume* of a substance.
- For an object of mass m which occupies volume V, the density (d) is

$$d = \frac{m}{V} \qquad (7.1)$$

- **Pressure** is *the normal force* exerted on a *unit area* of a surface.
- The pressure (P) at the base of the container which is filled to height h with a liquid of density d is

$$P = hdg \qquad (7.2)$$

where g is the acceleration due to gravity.

- Pressure depends on the density and height of a liquid column, and **not** on the shape of the container or total volume of liquid.
- Pressure acts in all directions.
- Units: d = [kg.m^{-3}], h = [m], P = [Nm^{-2}] = [*pascal*], abbreviated to [Pa].

7.2 Atmospheric Pressure

- The earth is surrounded by an air belt which is often referred to as the *atmosphere*.
- The atmosphere is several kilometres high.
- **Atmospheric pressure** is the weight of air which is supported by a unit area of the earth's surface.
- Its value is approximately 1.013 x 10^5 Pa, and this is referred to as 1 *atmosphere*.
- The atmospheric pressure of 1 atmosphere is equivalent to the pressure which will be exerted at the bottom of a mercury column of height 760 mm or a water column of height 10.3 m.
- Atmospheric pressure decreases with altitude: its value on the top of a mountain, for instance, is less than at sea level.

7.3 The Siphon

- **The siphon** is a bent tube used for transferring liquid from one container to another one at a lower level (Fig. 7.1).
- The tube is first filled with the liquid to be transferred, and the liquid is allowed to drain from the right arm (XB) under gravity, thus creating a vacuum in XB.
- More liquid is then forced into the tube by atmospheric pressure acting at A, thus ensuring continuous flow of liquid.
- The liquid flows under a pressure difference hdg, which means that B must be lower than A in order for the siphon to continue functioning.
- The operating principle of the siphon is made use of in the modern toilet's water cistern and in drawing liquid from a reservoir which is not easily accessible.

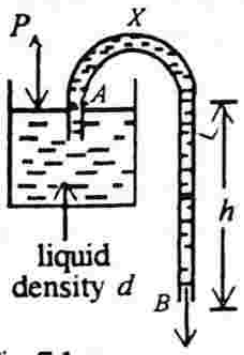


Fig. 7.1

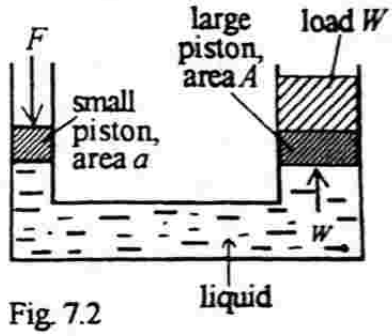


Fig. 7.2

7.4 Transmission of Pressure

- The principle of transmission of pressure, or ***Pascal's principle***, states that *any pressure applied to a liquid which is confined in a container will be transmitted equally to all parts of the container.*
- Hydraulic machines which make use of this principle include:
  (i) the **hydraulic press**, used for lifting heavy loads,
  (ii) the **hydraulic jack**, used for lifting cars, and
  (iii) the **hydraulic brake**, used in slowing down or stopping moving automobiles.
- In the hydraulic press, (Fig.7.2), a force F applied on a small piston of cross-sectional area a, generates a pressure F/a which is transmitted through the liquid to the large piston of area A.
- The large piston thus feels an upward force which is equal to pressure x area, or $(F/a)A$.
- This force is also equal to the weight (W) which is to be lifted, i.e. $W = (F/a)A$, or

$$\frac{W}{F} = \frac{A}{a} \qquad (7.3)$$

- The hydraulic press is thus a *force multiplier* (*i.e a simple machine*) with a mechanical advantage (W/F) which is equal to the ratio of cross-sectional areas of the two pistons.

7.5 Measurement of Pressure

- A **manometer** is used to measure gas pressure.
- The gas is admitted to one end of a U-tube which is partly filled with a liquid of density d while the other end of the tube is open to the atmosphere (Fig. 7.3).

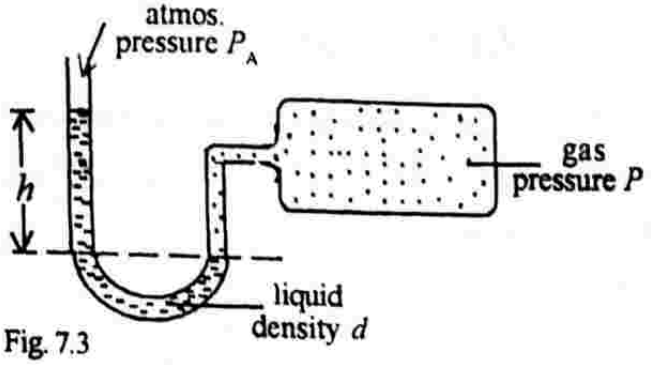


Fig. 7.3

- If the liquid in the open arm rises to a height h above that on the other arm, the pressure of the gas is

$$P = P_A + hdg \qquad (7.4)$$

where P_A is the atmospheric pressure.

- A ***sphygmomanometer*** is used to measure blood pressure.
- A ***barometer*** is used to measure atmospheric pressure. The various types of barometer include:
  (i) the ***simple (Torricellian) barometer***, which consists of a tube filled with mercury and inverted into a dish;
  (ii) the ***Fortin barometer***, which is similar to the simple barometer, except that a leather bag is used in place of the dish of mercury;
  (iii) the ***aneroid barometer***, which does not make use of mercury or any other liquid. It consists of a pa- partially evacuated and sealed metal can which contracts or expands in response to changes in atmospheric pressure. This type is used as an altimeter to measure the *altitude* (i.e. height above sea level) of an airplane.

7.6 Relative Density

- The ***relative density***, R.D. (or ***specific gravity***) of a substance is the ratio of the density of the substance to the density of water.
- If d = density of substance and d_w = density of water,

$$\text{Relative Density} = \frac{d}{d_w} \qquad (7.5)$$

- The relative density of water is 1.0.
- All metals and most solids have R.D. greater than 1, while air and several liquids have R.D. less than 1.
- Units: R.D. bears ***no*** units.

7.7 Upthrust and Archimedes' Principle

- An object immersed in a liquid experiences an upward force which is called the ***upthrust*** or ***buoyancy***.
- The upthrust is due to the difference in pressure between the upper and the lower faces of the object, the pressure being greater at the lower face.
- ***Archimedes' principle*** states that a *body immersed in a fluid experiences an upward force (upthrust) which is equal to the weight of the fluid displaced.*

Any immersed body thus experiences two forces (1) its true weight(W) acting vertically downward, and (2) the upthrust (F_u) acting vertically upward (Fig 7.4):

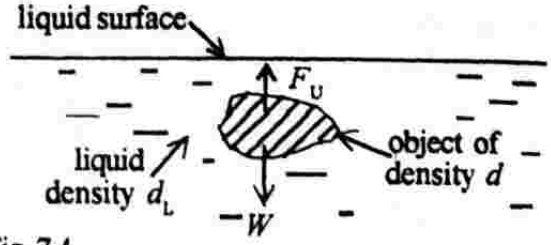


Fig. 7.4

- If d_o is the density of the object and V is the volume immersed, W = mass x g = (density x volume) x g, or

$$W = d_o V g \qquad (7.6)$$

F_u = weight of liquid displaced
= mass of liquid displaced x g, or

$$F_u = (d_L V)g \qquad (7.7)$$

for a liquid of density d_L.

- The net downward force, which is also called the ***apparent weight***, is equal to $W - F_u$, or

$$\text{Apparent weight} = (d_o - d_L)Vg \qquad (7.8)$$

- It follows that:
  (i) an object which is *denser than the liquid* ($d_o > d_L$) has a positive apparent weight, and therefore sinks in the liquid;
  (ii) an object which is *less dense than the liquid* ($d_o < d_L$) has a negative apparent weight, and *rises* in the liquid;
  (iii) as the object rises to the liquid's surface, the volume of liquid displaced decreases, resulting in a decrease in the upthrust while the true weight remains constant;
  (iv) a point is eventually reached at which the upthrust becomes just equal to the true weight, i.e. the apparent weight is zero, and the object ***floats*** partially submerged in this position. This leads to the ***principle of flotation***: *a floating body displaces a weight of fluid which is equal to its own weight.*

7.8 The Simple Hydrometer

- A **hydrometer** is used to measure the density of a liquid.
- It consists of a tall tube which is weighted at one end so that it floats in an upright position.
- The level to which it sinks in any liquid depends on the density of the liquid: the *denser* the liquid, the *less* it sinks.
- A scale is marked on the side of the tube from which the density is read off directly.

7.9 Surface Tension

- The molecules of a liquid are held together by ***cohesive (intermolecular) forces.***
- This causes the liquid surface to act like a stretched elastic membrane.
- This is why a steel razor blade or a needle can be floated on water surface, even though the density of steel is higher than that of water. The blade or the needle is prevented from piercing the water surface by cohesive forces between the molecules near the surface.
- These surface forces are described by the term ***surface tension.***
- Specifically, the surface tension of a liquid is the *surface force per unit length along a direction perpendicular to the surface.*

7.10 Viscosity

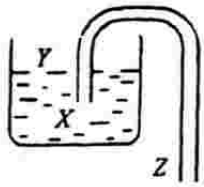
- In a moving liquid, the molecules in one layer exert cohesive forces on molecules in the adjacent layer.
- This results in a frictional force between the two layers.
- The term ***viscosity*** is used to describe *friction in fluids*.
- There are three forces acting on a solid object which is made to fall in a liquid:
  (1) the object's weight (downwards)
  (2) the upthrust (upwards)
  (3) the frictional force or ***viscous drag*** (upwards)
- Initially, the body accelerates as its weight is more than the upthrust and the viscous drag combined.
- As the viscous drag increases with increasing velocity, a point is reached at which the weight just balances the two upward forces, and the velocity becomes constant.
- This constant velocity is called the ***terminal velocity.***

True or False - Type Questions

Answer ***True*** (T) or ***False*** (F) to the following questions.

1. ***Density*** of a solid may be defined as
   a. the mass of the solid compared to the mass of an equal volume of water.
   b. the mass of a unit volume of the solid.
   c. the amount of water displaced when a unit mass of the solid is immersed in it.
   d. the weight of a unit volume of the solid.
   e. the volume of a unit mass of the solid.

2. The *pressure* at any point in a liquid
   a. is proportional to distance of the point below the surface of the liquid.
   b. is the same at the same level in the liquid.
   c. varies with the shape of the containing vessel.
   d. is exerted equally in all directions.
   e. varies with the diameter of the containing vessel.
   f. increases with the specific gravity of the liquid.
   g. increases with the temperature of the liquid.
   h. depends on the acceleration due to gravity.

3. 

The figure shows an inverted U-tube used to draw liquid from a reservoir filled to level *Y* For the liquid to flow out of *Z* :
   a. the U -tube must be completely filled with liquid.
   b. *Z* should be lower than *Y* but higher than *X*, the other end of the U - tube.
   c. *Z* should be at the same level as *X*.
   d. *X* should be lower than *Y*.
   e. the atmospheric pressure must be greater than zero, i.e the device cannot function in *space*.

4. Mercury is a better *barometric fluid* than water because
   a. it needs no colouring.
   b. it has a low vapour pressure.
   c. it has a high boiling point.
   d. its specific gravity is much greater than 1.
   e. it expands uniformly.
   f. it does not wet glass.
   g. it is a good conductor of heat.

5. A piece of cork floats in water because
   a. there is no upthrust on it when it is completely immersed in water.
   b. the upthrust on it when completely immersed in water is equal to its weight in air.
   c. the upthrust on it when completely immersed in water is greater than its weight in air.
   d. its specific gravity is less than 1.
   e. the surface of the water acts like an elastic skin.
   f. the viscous force on it is greater than its weight in air.

6. A metal object is suspended on a spring balance and gradually lowered into water :
   a. The spring balance records the apparent weight of the object.
   b. The reading on the spring balance is equal to the weight of the object in air plus the upthrust.
   c. The reading on the spring balance decreases as the object is lowered into the water because the density of water is less than that of the object.
   d. The reading on the spring balance decreases because the object experiences an upthrust which increases as the fraction submerged increases.

e. The reading on the spring balance increases because the object displaces a certain amount of water.
f. The reading on the spring balance increases because of the viscous force on the object.
g. The reading on the spring balance falls to zero when the object is fully immersed in water.
h. When fully immersed, the upthrust on the object is equal to the weight of the object in air divided by its relative density.

7. Viscosity in a liquid
a. varies with the nature of the liquid.
b. increases with temperature
c. varies with the relative velocity between the liquid and an object moving through it.
d. opposes the gravitational force for a ball falling through the liquid.
e. opposes the upthrust on a ball falling through the liquid.
f. exists only when a solid body moves through a liquid.
g. places a certan upper limit on the velocity which may be acquired by an object falling in a liquid.
h. is a measure of the resistance to flow of the liquid.

Answers to True or False - Type Questions

1. Density is simply the mass of a unit volume of substance. In view of this, the answers are
a (F) b (T) c (F) d (F) e (F)

2. a (T) This is the depth h in the liquid.
b (T) At a constant value of h inside a liquid, the pressure is also constant.
c (F) Pressure is insensitive to the shape or the diameter of the vessel.
d (T) See revision notes.
e (F) See (c) above
f (T) Pressure at a given depth increases with the density and hence the specific gravity of the liquid.
g (F) Because density decreases with temperature, pressure actually *decreases* with increasing temperature.
h (T) See revision notes.

3. a (T)
b (F) Z should be lower than either X or Y. Liquid flows under the pressure hdg, where h is the difference between levels of X and Z.
c (F) See (b) above.
d (T)
e (T) In *space*, the pressure at Y is zero, as is the pressure at Z. A difference of pressure cannot be established to keep the liquid running. (However, a liquid such as mercury may be kept running due to its large *cohesive forces*).

a (T) This makes it easily visible.
b (T) It does not vaporise easily, thus the space above the mercury column is nearly a perfect vacuum and the barometer gives accurate readings.
c (F) Although mercury has a higher boiling point, this is not critical since pressure measurements are normally made at room temperature.
d (T) Hence the height of the mercury column (76 cm) for normal atmospheric pressure is much less than that of water (1,034 cm).
e (F) Temperature changes are not critical for the barometer.
f (T) This ensures accurate readings as the mercury does not cling to the glass wall.
g (F) Same reason as (e) above.

5. a (F) The two forces acting on the cork when fully immersed are its *weight in air* (downwards) and the *upthrust* (upwards). The cork floats because the upward force (upthrust) exceeds the downward force (its weight).
b (F) See (a) above.
c (T) See (a) above.
d (T) If its specific gravity is less than 1, its density is less than that of water.
e (F) This is the phenomenon of *surface tension*, which has nothing to do with the principle of flotation.
f (F) Viscous force comes into play only if the cork and the water are in relative motion.

6. a (T) This is also the tension in the spring.
b (F) The reading is equal to the weight of the object in air minus the upthrust (the two act in opposite directions).
c (F) See (d) below.
d (T) As the fraction of the object immersed increases, the weight of water displaced (which is equal to the upthrust) increases, and the object's apparent weight decreases.
e (F) See (d) above.
f (F) Viscous force has nothing to do with the apparent weight.
g (F) The density of any metal is greater than that of water, hence the apparent weight in water is greater than zero.
h (T) When fully immersed,

$$\text{relative density} = \frac{\text{weight of the object in air}}{\text{weight of water displaced}}$$

$$= \frac{\text{weight of the object in air}}{\text{upthrust on the object}}$$

$$\text{Hence upthrust} = \frac{\text{weight of the object in air}}{\text{relative density}}$$

7. a **(T)** Viscosity varies from one liquid to another.
   b **(F)** Viscosity actually *decreases* with increasing temperature. [Note that hot oil pours more readily (i.e it is less viscous) than cold oil].
   c **(T)** This is a little tricky. While the viscosity of the liquid itself is constant, the viscous force exerted on an object moving through it increases with increasing velocity.
   d **(T)** Viscous force acts upwards, gravitational force downwards.
   e **(F)** Both viscous force and upthrust act upwards.
   f **(F)** Viscous force also exists between adjacent layers of the fluid in relative motion, such as when a liquid is poured.
   g **(T)** This upper limit is the *terminal velocity*.
   h **(T)** See revision notes.

SSCE/JME - Type Objective Questions [g = 10 ms⁻²]

1. Cold oil of volume 600 cm^3 has a density of 0.9 gcm^{-3}. When heated, the density of the oil decreases to 0.6 gcm^{-3}. The volume of the heated oil is
   A. 324 cm^3 **B.** 400 cm^3 **C.** 720 cm^3 **D.** 900 cm^3

2. The relative densities of gold, silver, copper and zinc are given as 19.3, 10.5, 8.9 and 7.1 respectively. A piece of ornamental metal weighs 0.445 kg and displaces 5×10^{-5} m^3 when completely immersed in water. The metal is
   A. zinc **B.** copper **C.** silver **D.** gold

3. Seawater has specific gravity of 1.03. Neglecting the atmospheric pressure, the force exerted by seawater on the hatch door of a submarine of area 0.8 m^2 at a depth of 300 m is
   A. 2.47×10^6 N **B.** 2.47×10^3 N
   C. 3.86×10^6 N **D.** 3.86×10^3 N

4. Oil of mass 0.5 g and relative density 0.5 forms a thin film of area 0.25 m^2 on the surface of water. The thickness of the oil film is
   A. 2.5×10^{-7} m **B.** 4.0×10^{-7} m
   C. 2.5×10^{-6} m **D.** 4.0×10^{-6} m

5. The pressure of a gas supports 0.7 m of mercury of relative density 13.3. The height of a water column which the gas pressure will support is
   A. 0.7 m **B.** 1.9 m **C.** 9.3 m **D.** 19.0 m

6. The volume of water which has the same mass as 5.4 m^3 of petrol of relative density 0.72 is
   A. 7.5 m^3 **B.** 6.0 m^3 **C.** 4.8 m^3 **D.** 3.9 m^3

7. A circular membrane lies 24 cm below the open surface of a pool of mercury of relative density 13.6. If the barometric height is 76 cm of mercury, the pressure on the membrane is
   A. 3.26×10^4 Nm^{-2} **B.** 1.03×10^5 Nm^{-2}
   C. 1.36×10^5 Nm^{-2} **D.** 1.36×10^7 Nm^{-2}

8. Points X and Y are located at 30 m and 70 m respectively below the surface of a lake. If the atmospheric pressure is 10 m of water, the ratio of the pressure at X to that at Y is
   A. 3 : 7 **B.** 7 : 3 **C.** 1 : 2 **D.** 2 : 1

9. A stone of volume 3.08 cm^3 is lowered into a measuring cylinder containing water. If the diameter of the cylinder is 14 mm, the water level will rise by ($\pi = {}^{22}/_{7}$)
   A. 20.0 mm **B.** 15.0 mm **C.** 2.2 mm **D.** 2.0 mm

10. A water tank of cross-sectional area 2.5 m^2 and height 3 m contains 5.0 m^3 of water. If the density of water is 10^3 kgm^{-3}, the force on the base of the tank is
    A. 2.0×10^4 N **B.** 3.0×10^4 N
    C. 5.0×10^4 N **D.** 7.5×10^4 N

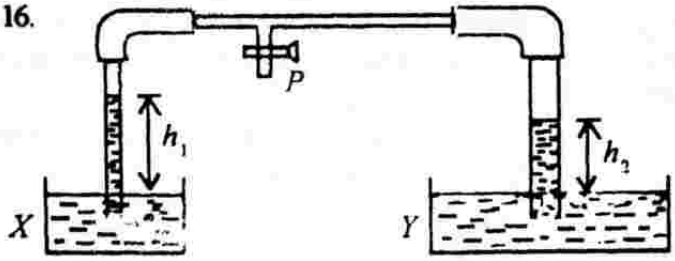
11. 2 m^3 of liquid X of density 1.0×10^3 kgm^{-3} is mixed with 3 m^3 of liquid Y of density 0.8×10^3 kgm^{-3}. The relative density of the mixture is
    A. 0.80 **B.** 0.88 **C.** 0.90 **D.** 1.00

12. A tank of dimensions 3 m x 2 m x 1.5 m is filled with water of density 10^3 kgm^{-3} and sealed. Neglecting the weight of the tank, the maximum pressure which the tank can maintain on the supporting surface is
    A. 1.5×10^4 Nm^{-2} **B.** 2.0×10^4 Nm^{-2}
    C. 3.0×10^4 Nm^{-2} **D.** 6.5×10^4 Nm^{-2}

13. A 50 litre petrol tank of mass 12 kg is filled with petrol of relative denstiy 0.70. The mass of the filled tank is
    A. 15.5 kg **B.** 25.0 kg **C.** 35.0 kg **D.** 47.0 kg

14. A rectangular tank of base 2 m x 1.5 m and height 3 m is filled with 7.5×10^3 kg of a liquid. The pressure at the the middle of the tank is
    A. 1.25×10^4 Nm^{-2} **B.** 2.50×10^4 Nm^{-2}
    C. 7.50×10^4 Nm^{-2} **D.** 3.75×10^5 Nm^{-2}

15. A tank of capacity 27 m^3 initially filled with water is drained at the rate of 5 kgs^{-1}. If the density of water is 10^3 kgm^{-3}, the time it takes to empty the tank is
A. 13.5min **B.** 54 min **C.** 90 min **D.** 135 min

16.


In the diagram above, the diameter of the tube in container Y is twice that of the tube in X. If $h_1 = 2h_2$ then the ratio of the density of liquid X to that of Y is
A. 1 : 2 **B.** 2 : 1 **C.** 1 : 4 **D.** 4 : 1

17. The normal atmospheric pressure at sea level is 10^5 Nm^{-2}. If the atmosphere has a uniform density of 1 kgm^{-3}, the height of the atmosphere is
A. 10^5 m **B.** 10^4 m **C.** 10^3 m **D.** 10^2 m

18. If the pressure in a confined liquid is changed at any point, the change is transmitted equally to all points in the liquid. This principle is called
A. Archimedes' principle **B.** Flotation principle
C. Pascal's Law **D.** Boyle's law

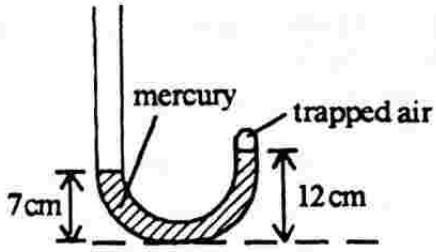
19. A hydraulic press has pistons of areas 0.2 m^2 and 0.9 m^2 respectively. When a force of 300 N is exerted on the small piston, the force on the large piston is
A. 66.7 N **B.** 270 N **C.** 675 N **D.** 1,350 N

20. An effort of 500 N exerted on a hydraulic press is just sufficient to move a load of 2,000 N. If the diameter of the small piston is 10 cm, that of the large piston is
A. 15 cm **B.** 20 cm **C.** 40 cm **D.** 80 cm

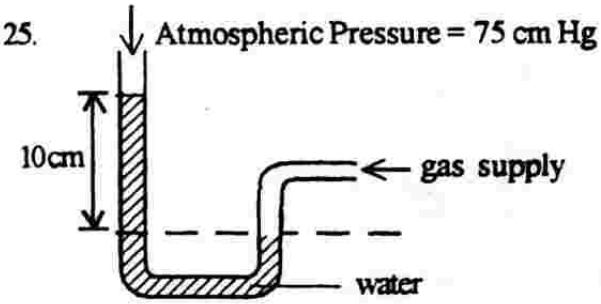
21. A barometer can be used to measure
I. the height of a mountain
II. the dew point
III. the specific gravity of a liquid
IV. the depth of a mine.
Which of the above statements are correct?
A. I and II only **B.** III and IV only
C. I and IV only **D.** I, III and IV only

22. Which of the following devices can be used to measure pressure?
I. Hydrometer II. Hygrometer
III. Aneroid barometer IV. Altimeter
A. I and II only **B.** III and IV only
C. III only **D.** II, III and IV only

23. Which of the following devices is most suitable for measuring altitude?
A. Mercury barometer **B.** Aneroid barometer
C. Mercury manometer **D.** Fortin barometer

24.


The pressure exerted by the trapped air in the diagram above when the atmospheric pressure is 76 cm Hg is
A. 88 cm Hg **B.** 83 cm Hg **C.** 81 cm Hg **D.** 71 cm Hg

25.


The diagram above shows a water manometer which is used to measure the pressure of a gas supply on a day when the atmospheric pressure is 75 cm Hg. If mercury has a specific gravity of 13.6, the gas pressure is
A. 65 cm of water **B.** 85 cm of water
C. 1.010 cm of water **D.** 1,030 cm of water

26 An airline pilot records the pressure of the air outside his plane as 60 cm of mercury while the atmospheric pressure at the ground level is 76 cm of mercury. If the relative densities of mercury and air are 13.6 and 1.36 x 10^{-3} respectively, the height of the plane above the ground is
A. 1.6 km **B.** 6.0 km **C.** 7.6 km **D.** 16.0 km

27. Which of the following forces act(s) on a piece of wood which is floating on water?
I. Weight II. Viscosity III. Upthrust
A. I only **B.** I and II only
C. I and III only **D.** I, II and III

28. A body which weighs 50 N in air displaces 3.7 kg of water when partially immersed in water. The upthrust on the body is
A. 8.7 N **B.** 13.0 N **C.** 37.0 N **D.** 87.0 N

29. A solid object weighs 750 N in air and 525 N when completely immersed in a liquid of relative density 0.75. The volume of the solid is
A. 0.03 m^3 **B.** 0.07 m^3 **C.** 0.3 m^3 **D.** 0.7 m^3

30. A body of density 8×10^3 kgm^{-3} weighs 160 N in air. The apparent weight of the body when completely immersed in water of density 10^3 kgm^{-3} is
A. 20 N B. 140 N C. 160 N D. 180 N

31. An object weighs 30 N in air and 21 N in water. The weight of the object when completely immersed in a liquid of relative density 1.4 is
A. 25.2 N B. 17.4 N C. 12.6 N D. 9.0 N

32. A stone weighs 40 N when completely immersed in water and 30 N when completely immersed in a liquid of relative density 2.0. The weight of the stone in air is
A. 10 N B. 35 N C. 50 N D. 70 N

33. A metal object of relative density 9.0 and volume 2×10^{-4} m^3 is completely immersed in water. Its apparent weight is
A. 18 N B. 16 N C. 4.5 N D. 2.0 N

34. A solid object of volume 60 cm^3 and density 4.0 gcm^{-3} is suspended from a spring balance with half of its volume immersed in water of density 1.0 gcm^{-3}. The reading on the spring balance is
A. 120 g B. 180 g C. 210 g D. 240 g

35. An object of mass m and volume v suspended from a string is completely immersed in a liquid of density d. The tension in the string is
A. mg B. dvg C. $(m + dv)g$ D. $(m - dv)g$

36. A cylindrical piece of wood of mass 200 g and uniform cross-sectional area 40 cm^2 floats upright in water of density 1.0 gcm^{-3}. The length of the wood immersed in water is
A. 5 cm B. 10 cm C. 20 cm D. 40 cm

37. A piece of wood of uniform cylindrical cross-section floats upright in a liquid of relative density 0.8 with one - sixth of its height above the liquid. If placed in water, the fraction of its height above the water level will be
A. 1/3 B. 1/5 C. 4/5 D. 5/6

38. A solid cube of side 50 cm and mass 75 kg floats in a liquid with $^1/_3$ of its height above the liquid surface. The relative density of the liquid is
A. 0.33 B. 0.50 C. 0.67 D. 0.90

39. A plastic object floats in water with 0.6 of its volume submerged and in oil with 0.75 of its volume submerged. The density of the oil is
A. 750 kgm^{-3} B. 800 kgm^{-3}
C. 1,000 kgm^{-3} D. 1,250 kgm^{-3}

40. A metal of real weight 10 N weighs 8 N in water and 8.5 N in a liquid L. The relative density of L is
A. 0.75 B. 0.80 C. 0.85 D. 1.33

41. A solid object weighs 24 g in air, 16 g in water and 20 g in oil. The ratio of the density of the solid to that of the oil is
A. 2 B. 3 C. 4 D. 6

42. A block of ice floats in water in a container. When the ice is completely melted, the water level in the container will
A. rise B. fall
C. remain the same D. first rise and then fall.

43. A metal cube of side 0.2 m suspended on a string is completely immersed in water of density 1,000 kgm^{-3}. The upthrust on the cube is
A. 800 N B. 80 N C. 16 N D. 8 N

44. A solid object floats in liquid X of relative density 0.9 but sinks in liquid Y of relative density 0.7. It can be inferred that the
A. volume of X displaced is less than that of Y
B. volume of X displaced is greater than that of Y
C. weight of X displaced is less than that of Y
D. weight of X displaced is greater than that of Y

45. A plastic object floats in water at room temperature. If the water is heated, the part of the plastic above the water level will
A. decrease because the density of water decreases
B. increase because the density of water decreases
C. decrease because the density of water increases
D. increase because the density of water increases

46. The relative density of the acid in a car battery can be measured with a
A. hygrometer B. manometer
C. hydrometer D. barometer

47. The relative density of a powdery substance can be measured using a beam balance and a
A. burette B. pipette
C. measuring cylinder D. density bottle

48. A specific gravity bottle of mass 20 g weighs 28 g when filled with water and 30 g when filled with a liquid X. The relative density of X is
A. 0.80 B. 0.93 C. 1.25 D. 1.50

49. Which of the following has the highest surface tension?
A. Cold water B. Hot water
C. Oily water D. Soapy water

50. Which of the following additions will not reduce the surface tension of water?
A. Detergent B. Grease C. Alcohol D. Camphor

51. Certain insects can move about on the surface of water without sinking because
A. water is denser than such insects.
B. the insects have tiny legs.
C. the upthrust on the insects is greater than their weight.
D. the water surface acts like an elastic membrane.

52. Which of the following substances has the highest viscosity at room temperature?
A. Water B. Kerosene C. Palm oil D. Alcohol

53. A thin liquid film is trapped between two closely spaced glass plates. The force necessary to pull the plates apart will increase if the
I. surface tension of the liquid is increased
II. distance between the plates is increased
III. area of contact between the liquid and the plates is increased
IV. surface tension of the liquid is reduced.
Which of the above statements are correct?
A. I and III only B. II and IV only
C. I, II and III only D. II, III and IV only

54. In which of the following phenomena is surface tension important?
A. The floating of a boat in water
B. The floating of a steel wire in water
C. The floating of a balloon in air
D. The floating of a plastic sphere in water.

55. A body of mass m falls through a liquid. If V is the viscous force and U the upthrust, then at the terminal velocity
A. $V = mg/U$ B. $V - U = mg$
C. $V + mg = U$ D. $V + U = mg$

56. A loaded tube of uniform cross-sectional area 2.0 cm^2 floats upright in water with 10.5 cm of its length immersed and then in a liquid L with 12.0 cm of its length immersed. If the density of water is 1.0 gcm^{-3}, the mass of the tube is
A. 5.25 g B. 10.50 g C. 21.00 g D. 42.00 g

57. The relative density of the liquid L in question 56 is
A. 0.875 B. 0.900 C. 1.143 D. 1.200

Answer Key

1. D	11. B	21. C	31. B	41. D	51. D
2. B	12. C	22. B	32. C	42. C	52. C
3. A	13. D	23. B	33. B	43. B	53. A
4. D	14. A	24. D	34. C	44. D	54. B
5. C	15. C	25. D	35. D	45. A	55. D
6. D	16. A	26. A	36. A	46. C	56. C
7. C	17. B	27. C	37. A	47. D	57. A
8. C	18 C	28. C	38. D	48. C	
9. A	19. D	29. A	39. B	49. A	
10. C	20. B	30. B	40. A	50. B	

Solutions to Objective Questions

1. **(D)** Mass of cold oil = density x volume = 0.9(600) = 540 g
Mass of hot oil = $0.6V$, where V is the volume of the hot oil. Since the mass remains constant, $0.6V = 540$, or $V = 900\ cm^3$

2. **(B)** Density of metal = mass/volume = $0.445/(5 \times 10^{-5})$ = 8.9×10^3 kg
Relative Density = $8.9 \times 10^3/(1 \times 10^3) = 8.9$
Hence the metal is *copper*.

3. **(A)** Density of seawater = $1.03 \times 10^3\ kgm^{-3}$
Pressure at a depth of 300 m = hdg
$= (300)(1.03 \times 10^3)(10) = 3.09 \times 10^6\ Nm^{-2}$
Force on hatch door of area $0.8\ m^2$ = pressure x area
$= 3.09 \times 10^6(0.8) = 2.47 \times 10^6$ N

4. **(D)** Volume of the oil = mass/density
$= \dfrac{0.5 \times 10^{-3}\ kg}{0.5 \times 10^3\ kgm^{-3}} = 10^{-6}\ m^3$
Thickness of oil film = volume/area
$= 10^{-6}/0.25 = 4 \times 10^{-6}$ m

5. **(C)** Pressure of gas = $h_m d_m g = h_w d_w g$, where subcripts m and w refer to mercury and water respectively.
$\Rightarrow h_w/h_m = d_m/d_w$ = R.D. of mercury
$h_w = h_m \times (R.D.)_m = 0.7 \times 13.3 = 9.31$ m

6. **(D)** Let susbcripts w and p stand for water and petrol, respectively.
Mass = $d_w V_w = d_p V_p$
$V_w = (d_p/d_w)V_p = (R.D.)_p \times V_p = 0.72 \times 5.4 = 3.9\ m^3$

7. **(C)** Pressure on membrane = Atmospheric pressure + hdg. Atmospheric pressure = $0.76dg$
$\Rightarrow$ Pressure on membrane = $(0.76 + 0.24)dg$
$= 1.00 \times 13.6 \times 10^3 \times 10 = 1.36 \times 10^5\ Nm^{-2}$

8. **(C)** Pressure at X, $P_x = (10 + 30)d_w g = 40 d_w g$
Pressure at Y, $P_Y = (10 + 70)d_w g = 80 d_w g$
$P_x/P_y = 40/80 = 1/2$

9. **(A)** Cross-sectional area of cylinder,
$A = \dfrac{\pi d^2}{4} = \dfrac{22}{7} \times \dfrac{1.4^2}{4}\ cm^2$
Volume of water displaced = $3.08\ cm^2$
The water level will rise by $3.08/A$
$= \dfrac{3.08 \times 7 \times 4}{22 \times 1.4^2} = 2.0$ cm = 20.0 mm

10. **(C)** Height of water in the tank = 5.0/2.5 = 2.0 m
Pressure at the base = $hdg = (2.0)(10^3)(10)$
$= 2 \times 10^4\ Nm^{-2}$
Force on the base = Pressure x Area = $(2 \times 10^4)(2.5)$
$= 5 \times 10^4$ N.

11. **(B)** Total mass of the mixture = mass of X + mass of Y
$= (2 \times 1.0 \times 10^3) + (3 \times 0.8 \times 10^3) = 4.4 \times 10^3$ kg
Total volume of the mixture = $2 + 3 = 5\ m^3$
Density of the mixture = mass/volume = $4.4 \times 10^3/5$
$= 8.8 \times 10^2\ kgm^{-3}$
R.D. of the mixture = $8.8 \times 10^2/(1 \times 10^3) = 0.88$

12. **(C)** The water exerts maximum pressure on the base when the longest side is placed vertically.
Pressure = $hdg = 3 \times 10^3 \times 10 = 3 \times 10^4\ Nm^{-2}$

13. **(D)** Mass of petrol = density x volume
$= 0.70 \times 10^3 \times 50 \times 10^{-3} = 35$ kg
[Note that 1 liter = $10^{-3}\ m^3$]
Mass of filled tank = 12 + 35 = 47 kg

14. **(A)** Weight of the liquid = $7.5 \times 10^3 \times 10 = 7.5 \times 10^4$ N
Pressure at the base = Weight/Area
$= 7.5 \times 10^4/(2 \times 1.5) = 2.5 \times 10^4\ Nm^{-2}$
Pressure at the middle of the tank = $2.5 \times 10^4/2$
$= 1.25 \times 10^4\ Nm^{-2}$

15. **(C)** Mass of the water = $(10^3)(27) = 2.7 \times 10^4$ kg
Time to empty the tank $= \dfrac{(2.7 \times 10^4)}{5}$ s
$= \dfrac{2.7 \times 10^4}{5 \times 60}$ min = 90 min

16. **(A)** If P_o = pressure on top of each liquid column, then
$P_o + h_1 d_x g = P_o + h_2 d_y g$ = Atmospheric pressure
$\Rightarrow h_1 d_x = h_2 d_y$ or $d_x/d_y = h_2/h_1 = 1/2$

17. **(B)** Atmospheric pressure = $hdg = 10^5\ Nm^{-2}$. Hence $h(1)(10) = 10^5$, or $h = 10^4$ m

18. **(C)** This is *Pascal's law of the transmissibility of pressure*.

19. **(D)** $W/F = A/a = 0.9/0.2 = 4.5$
$W = 4.5F = 4.5 \times 300 = 1350$ N

20. **(B)** $A/a = W/F = 2{,}000/500 = 4$
If D and d are the diameters of the large and small pistons respectively, then $D^2/d^2 = 4$, or $D/d = 2$
hence $D = 2(10) = 20$ cm

21. **(C)** Since pressure varies with altitude or depth, a barometer (which measures pressure) can be used to measure the height of a mountain or the depth of a mine. Dew point is measured with a *hygrometer*

while specific gravity is measured with a *hydrometer*.

22.**(B)** See problem 21 above. The *altimeter* is an aneroid barometer which has been calibrated to measure altitude.

23.**(B)** See problem 22 above and the revision notes

24.**(D)** Since the liquid column is higher on the right arm, pressure of trapped air = atmos. pressure - height difference = 76 - 5 = 71 cm Hg

25.**(D)** Gas pressure = Atmos. pressure + height difference.
Atmos. pressure = 75 cm Hg = 75 x 13.6
= 1,020 cm of water.
$\Rightarrow$ Gas pressure = 1,020 + 10 = 1,030 cm of water

26.**(A)** Pressure difference = 76 - 60 = 16 cm of mercury
$= 16 \times 13.6/(1.36 \times 10^{-3})$ cm of air
$= 1.6 \times 10^5$ cm = 1.6 km

27.**(C)** Viscosity refers to the frictional force which operates when one part of a liquid moves relative to another, or when a solid moves through a liquid.

28.**(C)** Upthrust = weight of water displaced = 3.7 x 10
= 37 N

29.**(A)** Weight of liquid displaced = Upthrust = 750 - 525
= 225 N
Volume of the object = Volume of liquid displaced
= mass of liquid/density of liquid
$= 22.5 \text{ kg}/(0.75 \times 10^3 \text{ kgm}^{-3}) = 0.03 \text{ m}^3$

30.**(B)** Mass of the body = 160/10 = 16 kg
Volume of the body = mass/density = $16/(8 \times 10^3)$
$= 2 \times 10^{-3} \text{ m}^3$ = volume of water displaced.
Mass of water displaced = volume x density of water
$= 2 \times 10^{-3} \times 10^3 = 2$ kg
Weight of water displaced = Upthrust = 20 N
Apparent weight = 160 - 20 = 140 N

31.**(B)** Weight of water displaced = Upthrust = 30 - 21 = 9 N. Mass of water displaced = 9/10 = 0.9 kg
Volume of object = Volume of water displaced
= mass/density $= 0.9/10^3 = 9 \times 10^{-4} \text{ m}^3$
This is also the volume displaced in a liquid of density $1.4 \times 10^3 \text{ kgm}^{-3}$.
Mass of liquid displaced $= (9 \times 10^{-4})(1.4 \times 10^3) = 1.26$ kg
Weight of liquid displaced = 12.6 N = Upthrust in liquid
Apparent weight = 30 - 12.6 = 17.4 N

32.**(C)** Let W = weight of the stone in air
Upthrust in water = W - 40 = weight of water displaced
Mass of water displaced = $(W - 40)/10$
$= 0.1(W - 40)$ kg
Volume of water displaced $= \dfrac{0.1(W-40)}{d_w}$
where d_w = density of water
Similarly, volume of liquid displaced $= \dfrac{0.1(W-30)}{d_L}$

where d_L = density of liquid.
Since the volume displaced in each case is equal to the volume of the object,

$$\frac{0.1(W-40)}{d_w} = \frac{0.1(W-30)}{d_L}$$

$$W - 30 = \frac{d_L}{d_w}(W - 40) = 2.0\,(W - 40)$$

or $W = 50$ N

33.**(B)** Mass of metal object = density x volume
$= (9 \times 10^3)(2 \times 10^{-4}) = 1.8$ kg
Mass of water displaced = volume x density of water
$= (2 \times 10^{-4})(10^3) = 0.2$ kg
Upthrust = 0.2(10) = 2 N
Real weight of object = 1.8(10) = 18 N
Apparent weight = 18 - 2 = 16 N

34.**(C)** Real mass of the object = 60 x 4.0 = 240 g
With half of its volume immersed in water, mass of water displaced = volume x density of water
$= (30 \text{ cm}^3)(1.0 \text{ gcm}^{-3}) = 30$ g
Apparent mass = 240 - 30 = 210 g
= reading on spring balance.

35.**(D)** Real weight of object = mg
Mass of liquid displaced = dv
Weight of liquid displaced = dvg = Upthrust
Tension in the string = Apparent weight of object
$= mg - dvg = (m - dv)g$

36.**(A)** Mass of water displaced = mass of wood
= 200 g
Volume of water displaced = mass/density = 200/1.0
$= 200 \text{ cm}^3$ = volume of wood submerged.
Length of wood submerged = volume/cross-sectional area = 200/40 = 5 cm

37. **(A)** Fraction of wood above the liquid is 1 - 1/6, or 5/6. If V = volume of wood and d_L = density of liquid, mass of wood = mass of liquid displaced
$= 5/6(Vd_L)$
If f = fraction of the wood exposed when floating in water, fraction submerged in water = $1 - f$ and mass of wood $= (1 - f)Vd_w$, where d_w = density of water.
Hence $\frac{5}{6}Vd_L = (1 - f)Vd_w$

$$1 - f = \frac{5}{6}\cdot\frac{d_L}{d_w} = \frac{5}{6}(\text{R.D of liquid}) = \frac{5}{6} \times 0.8 = \frac{2}{3}$$

or $f = 1/3$

38.**(D)** Volume of liquid displaced = $\frac{2}{3}(0.5)^3$ m^3
Mass of liquid displaced = mass of floating cube = 75 kg

Density of liquid $= \frac{\text{mass}}{\text{volume}} = \frac{75}{\frac{2}{3}(0.5)^3} = 0.9 \times 10^3$ kgm^{-3}

R.D. of liquid $= \frac{0.9 \times 10^3}{1.0 \times 10^3} = 0.9$

39.**(B)** If V = volume of the object, volume of water displaced = $0.6V$. Mass of water displaced = $0.6Vd_w$. Similarly, mass of oil displaced = $0.75\,Vd_o$, where subscripts w and o refer to water and oil respectively. The mass displaced in each case is equal to the mass of the object. Hence,
$0.6Vd_w = 0.75Vd_o$
$d_o = (0.6/0.75)d_w = (0.6/0.75) \times 1{,}000$ kgm^{-3}
$= 800$ kgm^{-3}

40.**(A)** Upthrust in water = 10 - 8 = 2.0 N. This is equal to the weight of water displaced = Vd_wg, where V = vol. of metal, d_w = density of water and g = acc. due to gravity. Hence
$Vd_wg = 2.0$.....(i)
Upthrust in liquid L = 10 - 8.5 = 1.5 N = *wt* of liquid displaced. Hence
$Vd_Lg = 1.5$.....(ii)
From eqs. (i) and (ii), $d_L/d_w = 1.5/2.0 = 0.75$

41.**(D)** Mass of solid = $d_sV = 24$ g
Mass of oil displaced = $d_oV = 24 - 20 = 4$ g
$\frac{d_sV}{d_oV} = \frac{24}{4}$, or $\frac{d_s}{d_o} = 6$

42.**(C)** Let d_i, V = density and volume of ice and d_w = density of water. When ice floats, mass of water displaced = mass of ice = d_iV.
Volume of water displaced = d_iV/d_w
When ice melts, volume of water formed = mass of ice/density of water = d_iV/d_w. Since the volume of water displaced is the same in both cases, the water level remains the same.

43.**(B)** Volume of water displaced = $(0.2)^3 = 8 \times 10^{-3}$m^3
Mass of water displaced = $(8 \times 10^{-3})(1000) = 8$ kg.
Weight of water displaced = 80 N = upthrust.

44.**(D)** In X, upthrust is equal to the weight of the object while in Y, upthrust is less than the weight. Hence upthrust in Y must be less than upthrust in X i.e. weight of Y displaced is less than weight of X displaced.

45. **(A)** The object sinks further into the water because the density of the water decreases with increasing temperature. [Note that the variation of the density of the plastic with temperature has been ignored].

46.**(C)** See revision notes.

47.**(D)**

48.**(C)** Let V = volume of bottle
Density of water = $(28 - 20)/V = 8/V$
Density of X = $(30 - 20)/V = 10/V$
R.D. of $X = \frac{10/V}{8/V} = 1.25$

49.**(A)** Surface tension decreases with temp. Soap and oil additions reduce the surface tension of water. Olive oil for instance, has a lower surface tension than water.

50.**(B)** All except grease, reduce the surface tension of water.

51.**(D)** The surface tension of the water causes the surface to act like an elastic skin on which light insects can move without sinking. It is for the same reason that a *steel needle*, a *razor blade* or a piece of *wire gauze* can be made to lie on the water surface, even though steel is denser than water.

52.**(C)** Palm oil pours more sluggishly than any of the other liquids at room temperature.

53.**(A)** The force is opposed by surface tension forces, the magnitude of which is proportional to the total length of the line of contact between the liquid surface and the glass. This line becomes longer as the area of contact increases.

54.**(B)** Each of the others is made possible by the fact that the density of the object is less than that of the fluid in which it floats.

55.**(D)** The weight of the body acts downwards while the upthrust acts upwards. The viscous force acts upwards since the body is falling downwards. For the velocity to remain constant, the total upward force ($V+U$) must be equal to the weight (mg).

56.**(C)** Volume of water displaced = $2.0 \times 10.5 = 21.0$ cm^3
Mass of water displaced = volume x density of water = $21.0 \times 1.0 = 21.0$ g = mass of tube.

57.**(A)** Volume of liquid L displaced = $2 \times 12.0 = 24.0$ cm^3
Mass of L displaced = $24.0 \times d_L$, where d_L = density of liquid L. Since the mass of L displaced is also equal to the mass of the tube, $24.0\,d_L = 21.0$, or $d_L = 21/24 = 7/8 = 0.875$.

Revision Check-list

At the end of this chapter. the candidate should be able to

- define *density*, *relative density* and *pressure*.
- appreciate what is meant by *atmospheric pressure* and how it varies with altitude.
- explain the mode of operation of a *siphon*.
- state *Pascal's law* of transmission of pressure and some of its applications.
- solve simple problems on the *hydraulic press*.
- describe how pressure is measured with a *manometer* and the various forms of *barometers*.
- explain the relative advantages of mercury as a barometric fluid.
- understand the origin of *upthrust* on a body immersed in a fluid.
- state *Archimedes' principle* and the *principle of flotation*.
- understand what is meant by *apparent weight*.
- explain the features and uses of a *hydrometer*.
- explain the terms *surface tension* and *viscosity* of a liquid and relate these to the intermolecular forces in the liquid.
- cite examples illustrating the effects of surface tension and viscosity
- state methods by which the surface tension of a liquid may be reduced.
- explain the term *terminal velocity*, for a body falling in a liquid.
- describe experiments (along with the necessary precautions) to
  (1) verify Archimedes' principle.
  (2) demonstrate the existence of surface tension in a liquid.
  (3) determine the terminal velocity of a metal ball falling through a liquid.

8 Temperature and Thermal Expansion

8.1 Temperature and Thermometers

- **Temperature** is a measure of the degree of **hotness** or **coldness** of a body. On a microscopic scale, temperature is directly related to the motion of the body's molecules.
- In fluids in which the molecules move about randomly, an increase in the average speed (or kinetic energy) of the molecules is manifested as a rise in temperature.
- For a solid body, an increase in temperature is associated with the increase in average speed (or k.e.) of vibration of the molecules.
- A **thermometer** is a device with which the temperature of a body can be measured.
- Direct temperature measurements are based on any of the easily measurable properties of matter that change uniformly with temperature. Examples include:
  - (i) the *expansion of a fixed mass of liquid*, as in the mercury-in-glass thermometer;
  - (ii) the *change in pressure of a fixed volume of gas*, as in the constant volume gas thermometer;
  - (iii) the *change of electromotive force with temperature*, as in the thermocouple; and
  - (iv) the *change in the electrical resistance of a fine piece of wire*, as in the resistance thermometer.

8.2 Temperature Scales

- A scale of temperature is a scale based on any *thermometric property* of a substance.
- To calibrate a temperature scale, at least two standard (fixed) points are required. The two fixed points normally used are the temperature of melting ice (**ice point**) and that of boiling water (**steam point**) under standard atmospheric pressure.
- The common temperature scales in use are:
  - (1) the **Centigrade** (or **Celsius**) scale, on which the ice point and the steam point are 0°C and 100°C respectively, with the interval between the two fixed points divided into 100 equal divisions, called **degrees**;
  - (2) the **Fahrenheit** scale, on which the fixed points are 32°F and 212°F respectively, with the interval between them divided into 180 equal divisions;
  - (3) the **Absolute (Kelvin)** scale, on which the fixed points are 273 K and 373 K respectively, with the interval divided into 100 equal divisions.
- Each division on the absolute scale is equal to a division on the centigrade scale.
- The lowest possible temperature is zero (0 K) on the absolute scale, which is equivalent to -273°C on the centigrade scale.
- Fig. 8.1 illustrates the interrelationship between the various scales. In general, the temperature T_x on any scale X can be determined once the two fixed points X_0 and X_{100} are specified. The relationships are:

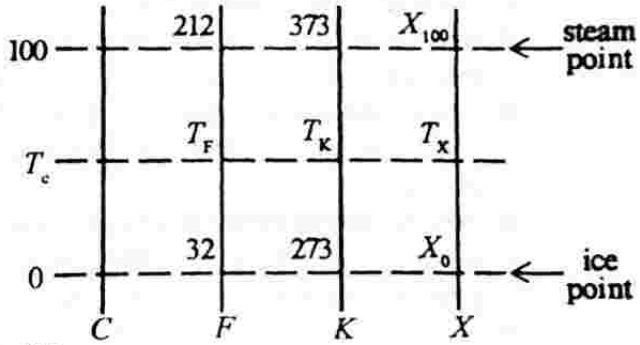


Fig. 8.1

- Between C and F:

$$\frac{T_c}{100} = \frac{T_F - 32}{180} \tag{8.1}$$

- Between K and C:

$$T_k = T_c + 273 \tag{8.2}$$

- Between X and C:

$$\frac{T_x - X_0}{X_{100} - X_0} = \frac{T_c}{100} \tag{8.3}$$

- Between X and F:

$$\frac{T_x - T_0}{X_{100} - X_0} = \frac{T_F - 32}{180} \tag{8.4}$$

8.3 Choice of Thermometric Liquids

- For liquid-in-glass thermometers, some of the desirable properties of the liquid are that it should:
  - (1) be a good conductor of heat,
  - (2) be opaque,
  - (3) have a regular expansion over a wide temperature range,
  - (4) have a high coefficient of expansion,
  - (5) have a low melting point and high boiling point, and
  - (6) have a low specific heat capacity.
- *Mercury* and *alcohol* are two liquids which are generally used in thermometers.
- Mercury expands regularly and has a high boiling point, hence can be used up to fairly high temperatures. However, it has a relatively high freezing point (-39°C), hence cannot be used for low temperature work.
- Alcohol's expansion is not quite as regular as mercury's, but its freezing point is low (-115°C), hence

it can be used at low temperatures. However, alcohol cannot be used at high temperatures because of its low boiling point (78°C).

8.4 Linear Expansion

- Most substances expand when heated. For a solid rod or bar, this manifests as an increase in length.
- The **linear expansivity** of a solid is defined as the *fractional increase in length per degree rise in temperature*.
- For a substance of initial length L_i which increases its length to L_f upon a temperature rise θ, the mean linear expansivity (α) is

$$\alpha = \frac{L_f - L_i}{L_i \theta} \qquad (8.5)$$

- The expansion of metals is used in the construction of a **bimetallic strip**, which consists of equal lengths of two different metal strips riveted together.
- Due to the different linear expansivities of the two metals, the strip bends as it is heated and this is used in operating a switch.
- This is the principle of operation of a **thermostat**, which is used, for instance, to regulate the temperature of an electric (pressing) iron.
- Unit: $\alpha = [(°C)^{-1}]$ or $[K^{-1}]$.

8.5 Area and Volume Expansion

- For a solid material in the form of a plate, the **mean superficial (or area) expansivity** is the fractional *increase in area per degree rise in temperature*. For a plate of initial area A_i which expands to A_f upon a temperature rise θ, the mean superficial expansivity (β) is

$$\beta = \frac{A_f - A_i}{A_i \theta} \qquad (8.6)$$

- **The mean cubical (or volume) expansivity** of a solid, liquid or gas is the *fractional increase in volume per degree rise in temperature*.
- For a substance of initial volume V_i which expands to V_f upon a temperature rise θ, the cubical expansivity (γ) is

$$\gamma = \frac{V_f - V_i}{V_i \theta} \qquad (8.7)$$

- The Interrelationships between the linear, superficial and cubical expansivities are

$$\beta = 2\alpha \qquad (8.8)$$

and

$$\gamma = 3\alpha \qquad (8.9)$$

- Units: Both β and γ bear units of $[(°C)^{-1}]$ or $[K^{-1}]$.

8.6 Anomalous Expansion of Water

- Water is an unusual liquid in the sense that its volume decreases (i.e. it contracts) as its temperature is raised from 0°C to 4°C. Beyond 4°C, the behaviour of water is normal in that its volume increases (i.e. it expands) with temperature (Fig. 8.2).

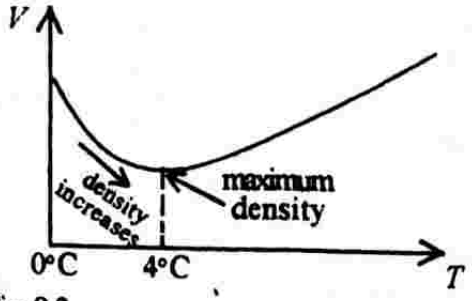


Fig. 8.2

- The anomalous behaviour of water between 0°C and 4°C is one of the reasons why water is not suitable as a thermometric liquid. Also, the expansion of water with temperature is not regular even above 4°C.
- The anomalous expansion is useful in very cold climates for the preservation of aquatic life. When it is so cold that the surfaces of ponds and lakes are frozen, the water below the surface remains liquid and fish can still stay alive.

8.7 Boyle's Law

- **Boyle's law** states that *for a fixed mass of gas at constant temperature, the pressure (P) is inversely proportional to the volume (V)*. Thus $P \propto 1/V$, or

$$PV = \text{constant} \qquad (8.10)$$

- The plot of P versus $1/V$ is linear for a fixed mass of gas at fixed temperature (Fig. 8.3).

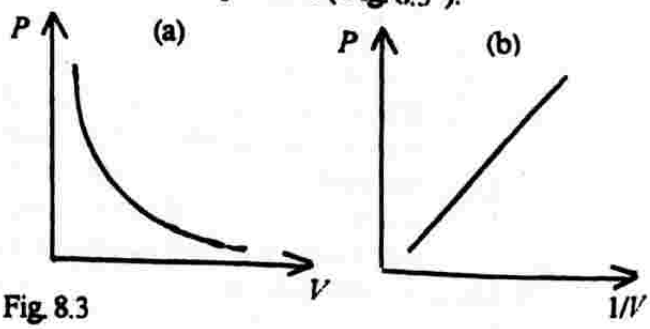


Fig. 8.3

8.8 Charles' Law

- **Charles' Law** states that *for a fixed mass of gas at constant pressure, the volume (V) is directly proportional to the absolute temperature (T)*, i.e. $V \propto T$.

or

$$\frac{V}{T} = \text{constant} \qquad (8.11)$$

- The plot of V versus T is linear for a fixed mass of gas at constant pressure (Fig. 8.4).

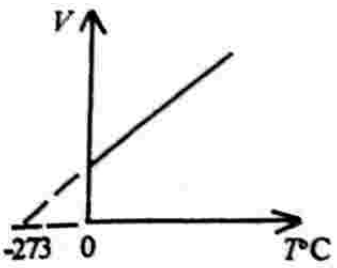


Fig. 8.4

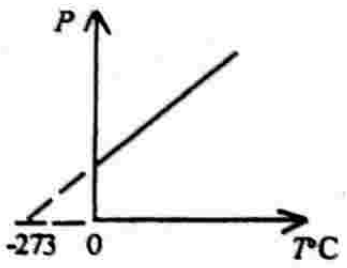


Fig. 8.5

8.9 Absolute Zero of Temperature

- If the volume of a fixed mass of gas is kept constant while the temperature is varied, the pressure (P) will be found to increase by 1/273 of its value at 0°C for every degree rise in temperature. This is sometimes referred to as the **pressure law**.
- The plot of P versus T is linear with an intercept of -273°C on the temperature axis(Fig. 8.5). The significance of this point is that if a gas were to be cooled to -273°C, the pressure should drop to zero.
- This temperature is called the *absolute zero of temperature*, or *zero Kelvin* (0 K).

8.10 Ideal Gas Equation

- When the pressure, volume and temperature of a gas are all varying, the gas laws could be combined to give what is usually referred to as the **ideal gas equation**.

$$\frac{PV}{T} = \text{constant} \qquad (8.12)$$

- If a fixed mass of gas initially with pressure P_1, volume V_1 and temperature T_1 changes its state to pressure P_2, volume V_2 and temperature T_2, the ideal gas equation gives

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad (8.12a)$$

- Note that all temperatures should be converted to absolute (Kelvin) values before plugging into the equations.

True or False - Type Questions

Answer *True*(T) or *False* (F) to the following questions.

1. The following properties can be used to measure the temperature of a substance :
   a. Pressure of a gas
   b. Volume of a gas
   c. Expansion of water
   d. Electrical resistance of a metallic conductor
   e. Volume of a liquid
   f. Colour of a substance
   g. Electromotive force
   h. Electric current
   i. Brightness of a lamp filament
   j. Photoelectric current
   k. Expansion of metals

2. The advantages of mercury over alcohol as a thermometric liquid are that mercury
   a. is opaque.
   b. has a higher thermal conductivity.
   c. has a higher thermal expansivity.
   d. has a higher density.
   e. does not wet glass.
   f. has a lower freezing point.
   g. has a higher boiling point.
   h. has a higher specific heat capacity.
   i. expands more uniformly with temperature.
   j. is cheaper than alcohol.

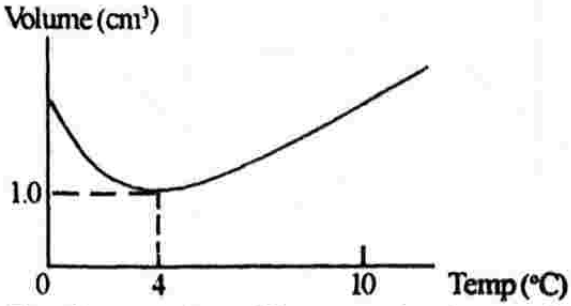
3. a. The *ice point* of a thermometer is determined by inserting the bulb of the thermometer in a block of ice.
   b. The *steam point* of a thermometer is determined by inserting the bulb of the thermometer in boiling water.
   c. A clinical thermometer has to be shaken before and after each temperature measurement because mercury does not respond rapidly to temperature changes.
   d. The sensitivity of a *liquid-in-glass* thermometer can be increased by reducing the bore of the tube.
   e. In *Six's maximum and minimum thermometer*, the maximum temperature is determined by the expansion of mercury and the minimum temperature by the contraction of alcohol.
   f. The size of a division on the Celsius scale is equal

to the size of a division on the Fahrenheit scale.
g. The size of a division on the Kelvin scale is 9/5 times the size of a division on the Fahrenheit scale.
h. When a mercury - in - glass thermometer is placed in a hot liquid, the mercury level first descends and then rises.

4. The response time of a liquid - in - glass thermometer will be short if the
a. bulb is large and thick-walled.
b. bulb is small and thick-walled.
c. bulb is small and thin-walled.
d. stem is long and thin.
e. bore is large.
f. liquid is a good conductor of heat.
g. liquid is of high density.
h. liquid has a high heat capacity.

5. The thermal expansion of a solid is an *advantage* in
a. fire alarms.
b. fitting of tyres on wheels.
c. balance wheel of a watch.
d. the construction of steel rail lines.
e. thermostats.
f. bimetallic thermometers.
g. the pouring of hot liquids into thick glass containers.
h. the construction of large steel bridges.

6. Thermostats are used in
a. electric laundry irons.
b. refrigerators and freezers.
c. pressure cookers.
d. electric water heaters
e. aquaria for tropical fish
f. heated apartments
g. electric bells
h. horns
i. air - conditioners
j. greenhouses
k. ovens

7. 

The diagram above illustrates the changes in the volume of 1 g of water as it is heated from 0° C to 10° C. From the graph, it can be deduced that :
a. the density of water first decreases and then increases during the heating.
b. water has its maximum density at 4° C.
c. the mass of water first decreases and then increases during the heating.
d. the cubic expansivity of water is negative between 0° C and 4° C.
e. water expands as it is cooled from 4° C to 0° C.
f. water expands as it solidifies at 0° C.
g. water expands uniformly when heated from 4° C to 10° C.

Answers to True or False - Type Questions

1. a **(T)** As in a *constant volume gas thermometer*.
b **(T)** As in a *constant pressure gas thermometer*.
c **(F)** Water does not expand uniformly with temperature.
d **(T)** As in a platinum resistance thermometer.
e **(T)** As in a mercury - in - glass, or alcohol - in - glass thermometer.
f **(F)** The colour of a substance is not directly related to its temperature.
g **(T)** As in a *thermocouple*.
h **(T)** Same as (g) above.
i **(T)** As in an *optical pyrometer*, which is used to measure very high temperatures.
j **(F)** The current produced in photoelectric effect has nothing to do with temperature.
k **(T)** As in a *bimetallic thermometer*.

2. a **(T)** Hence it is easily visible, while alcohol is transparent.
b **(T)** It responds more quickly to temperature changes.
c **(F)** The thermal expansivity of alcohol is about six times that of mercury.
d **(F)** Although mercury has a higher density than alcohol, it is actually a *disadvantage* because it means a higher thermal capacity in which case the thermometer will more quickly cool the substance whose temperature is being measured.
e **(T)** Alcohol which wets glass clings to the wall of the tube as the liquid level falls during the measurement of low temperatures. This introduces some error into the thermometer reading.
f **(F)** Alcohol freezes at -115°C, which is lower than the freezing pont of mercury (-39°C). Hence alcohol thermometers are more suitable for measuring very low temperatures.
g **(T)** Mercury boils at 357° C, compared to alcohol's 78° C. Hence mercury thermometers are more suitable for measuring high temperatures.
h **(F)** Mercury actually has lower specific heat capacity, which is an advantage in view of (d) above. [Note that the thermal capacity is the product of

the mass and the specific heat capacity].

i (T) The expansion of alcohol is somewhat irregular

j (F) Mercury is much more expensive than alcohol.

3. a (F) The bulb is inserted into an ice - water mixture. Note that the temperature of a block of ice may be much lower than the freezing temperature of water.

b (F) The bulb is inserted in steam a little above the level of the boiling water. [The temperature of the boiling water itself is somewhat affected by the presence of impurities].

c (F) The thermometer has to be shaken to move the mercury thread past the constriction after temperature measurement.

d (T) As the volume of the liquid is constant, a smaller bore will give a larger increase in the length of the liquid column for a given rise in temperature. [Volume = cross - sectional area of the bore x length of liquid column].

e (T)

f (F) The size of a division is the same on the Celsius and Kelvin scales, but is 9/5 times the size of a division on the Fahrenheit scale.

g (T) See (f) above

h (T) As the thermometer is placed in a hot liquid, heat reaches the glass tube before the mercury. As the glass expands, the mercury level drops but later rises as the mercury absorbs heat and expands.

4. The response time of a liquid - in - glass thermometer is reduced if

(i) the glass is thin to ensure quick passage of heat through it to the liquid;

(ii) the bulb is small such that heat can quickly reach all parts of the liquid, which also has a small volume; and

(iii) the conductivity of the liquid is high so that heat is quickly conducted to all parts of the liquid. In view of the above, the answers are

a (F) b (F) c (T) d (F) e (F) f (T) g (F) h (F)

5. a (T) A fire alarm makes use of a bimetallic strip to close an electric circuit when temperature exceeds a certain value.

b (T) Metal tyres of railway locomotives expand when heated and are then fitted over the wheels. They grip the wheels very tightly as they cool down.

c (F) The expansion of metallic parts of the watch leads to errors when the temperature rises. This is compensated for by the use of bimetallic strips of brass and steel.

d (F) Gaps must be left between successive rails to allow for thermal expansion.

e (T) Thermostats make use of *bimetallic strips*.

f (T) *Bimetallic thermometers* have the bimetallic strip as their major component.

g (F) This results in the cracking of the thick glass containers because of uneven expansion of the glass. [Heat is not conducted to all parts of the glass wall quickly enough, glass being a poor conductor].

h (F) These are usually mounted on rollers to allow for expansion and prevent possible collapse of the bridge.

6. Thermostats are used where it is desirable to maintain a system at a certain steady temperature. The answers are thus

a (T) b (T) c (F) d (T) e (T) f (T)
g (F) h (F) i (T) j (T) k (T)

7. a (F) Since density is inversely proportional to volume, the density of water actually *increases* as it is heated from 0° C to 4° C and *decreases* from 4°C to 10° C.

b (T) See (a) above.

c (F) The mass of water is constant.

d (T) The *change in volume* is negative as water is heated from 0° C to 4° C.

e (T) The volume of water increases as it is cooled from 4° C to 0° C

f (F) Although this is actually true, *it cannot be deduced from the graph*.

g (F) If the expansion were to be uniform, the graph should be perfectly *linear* for temperatures above 4° C.

SSCE/JME - Type Objective Questions

1. The temperature 45°C is the same as

A. 25°F B. 57°F C. 81°F D. 113°F

2. The lower fixed point corresponds to a length of 20 mm on the stem of a thermometer while the upper fixed point corresponds to 160 mm. The temperature corresponding to a length of 48 mm is

A. 20.0°C B. 30.0°C C. 41.7°C D. 50.0°C

3. The ice and steam points on a thermometer correspond to X and 80 mm respectively. A temperature of 60°C corresponds to 52 mm on the thermometer. The value of X is

A. 4 mm B. 8 mm C. 10 mm D. 20 mm

4. The two fixed points in a thermometer are 60 mm apart. When the thermometer reads 48 mm above

the ice point, the temperature is
A. 80°C **B.** 72°C **C.** 60°C **D.** 48°C

5. The ice and steam points on a temperature scale are 50 mm and 190 mm respectively. The reading on this scale when the temperature is 70°C is
A. 98 mm B. 138 mm C. 140 mm D. 148 mm

6. A thermometer with an arbitrary scale Y registers -50°Y at the lower fixed point and +70°Y at the upper fixed point. The Celsius temperature corresponding to 30°Y is
A. 42.9°C **B.** 50.0°C **C.** 66.7°C **D.** 75.0°C

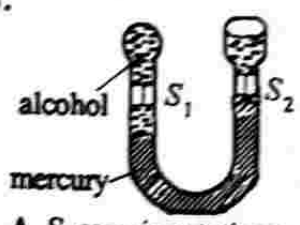
7. The temperature of -93°C corresponds to an absolute temperature of
A. 366 K **B.** 293 K **C.** 273 K **D.** 180 K

8. A faulty mercury - in - glass thermometer has 1.5°C and 103.0°C as its ice and steam points respectively. When the true temperature is 40°C the reading on the thermometer is
A. 42.7°C **B.** 42.1°C **C.** 40.6°C **D.** 39.1°C

9. A platinum resistance thermometer has resistances of 5.25 Ω and 9.75 Ω at 0°C and 100°C respectively. When the resistance is 8.25 Ω, the temperature is
A. 63.6°C **B.** 66.7°C **C.** 75.0°C **D.** 84.6°C

10. A constant volume gas thermometer indicates a pressure of 250 mm Hg at the ice point and 750 mm Hg at the steam point. The temperature when the thermometer indicates a pressure of 450 mm Hg is
A. 40 K **B.** 233 K **C.** 313 K **D.** 333 K

11.



The diagram shows a Six's maximum and minimum thermometer with steel indexes S_1 and S_2. When the temperature of the surrounding falls
A. S_1 remains stationary while S_2 moves upwards
B. S_1 moves upwards while S_2 remains stationary
C. S_1 moves downwards while S_2 moves upwards
D. S_1 moves upwards while S_2 moves downwards

12. A thermocouple works on the principle of
A. variation of *emf* with *temperature*
B. variation of *volume* with *temperature*
C. variation of *resistance* with temperature
D. variation of *pressure* with temperature

13. A wire of length 5 m is heated from a temperature of 10°C to 60°C. If it undergoes a change of length of 20 mm, the linear expansivity of the wire is
A. $8 \times 10^{-4}\ K^{-1}$ **B.** $4 \times 10^{-4}\ K^{-1}$
C. $8 \times 10^{-5}\ K^{-1}$ **D.** $4 \times 10^{-5}\ K^{-1}$

14. A metal rod of length L is subjected to a temperature rise of θ. If its final length is $1.05L$, its linear expansivity is
A. $\frac{1.05}{\theta}$ **B.** $\frac{1}{1.05\theta}$ **C.** $\frac{1}{20L}$ **D.** $\frac{1}{20\theta}$

15. A telegraph wire of length 100.0 m at 30°C has a linear expansivity of $2 \times 10^{-5}\ K^{-1}$. The length of the wire at a temperature of -10°C is
A. 100.08 m **B.** 100.04 m **C.** 99.96 m **D.** 99.92 m

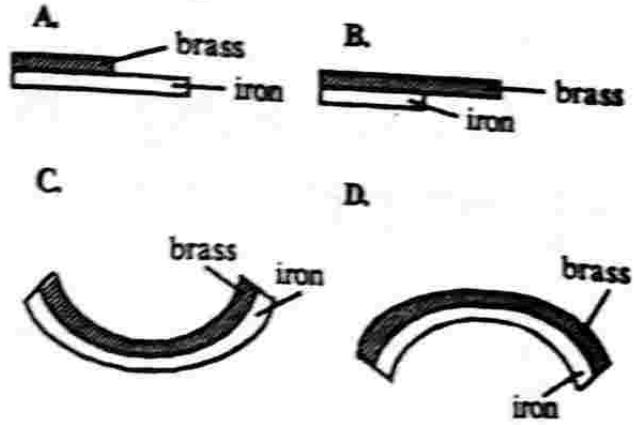
16. A steel bridge is 500 m in length. If the temperature varies from a day-time high of 30°C to a night-time low of 5°C, and the linear expansivity of steel is $1.2 \times 10^{-5}\ K^{-1}$, the daily variation in the length of the bridge is
A. 0.15 cm **B.** 1.50 cm **C.** 15.00 cm **D.** 1,500 cm

17. The linear expansivity of aluminium is approximately twice that of steel. A piece of aluminium and a piece of steel undergo the same increase in length per degree rise in temperature. The ratio of the original length of aluminium to that of steel is
A. 0.5 **B.** 1.0 **C.** 1.5 **D.** 2.0

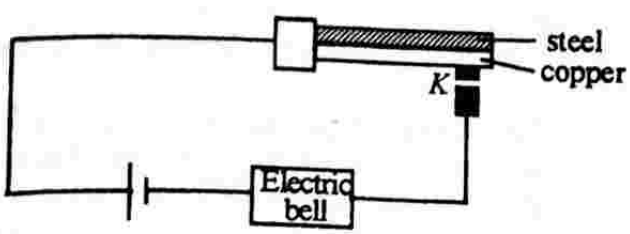
18. Steel bars each 2 m long, are used to construct a rail line. The linear expansivity of steel is $1.2 \times 10^{-5}\ K^{-1}$ and the maximum daily variation in temperature is 40°C. The safety gap that must be left between successive bars is
A. 0.48 mm **B.** 0.96 mm **C.** 4.80 mm **D.** 9.60 mm

19. The diameter of a steel plug is 2.5 cm at 25°C. If the linear expansivity of steel is $1.2 \times 10^{-5}\ K^{-1}$, the temperature at which the plug will fit exactly into a hole of constant diameter 2.499 cm is
A. -33.3°C **B.** -8.3°C **C.** 8.3°C **D.** 33.3°C

20. Which of the following diagrams correctly illustrates the shape of a bimetallic strip made of brass and iron after heating?



21.



The above diagram shows a fire alarm which is to be activated by the bimetallic strip of steel and copper. Steel has a lower linear expansivity than copper. In the event of fire, the key K will

A. close the circuit
B. open further
C. remain in the same position
D. alternately close and open the circuit

22. A square plate of side 10 cm is made of a metal of linear expansivity $2 \times 10^{-5}\ K^{-1}$. As the plate is heated from 30°C to 100°C, the area of one face of the plate will increase to

A. 100.1 cm^2 **B.** 100.3 cm^2 **C.** 101.4 cm^2 **D.** 102.8 cm^2

23. A metal cube of volume V and linear expansivity α is heated through a temperature rise of T. The increase in volume of the cube is

A. $3\alpha VT$ **B.** $2\alpha VT$ **C.** αVT **D.** $\alpha VT/3$

24. A metal cube of side 5 cm and linear expansivity $2 \times 10^{-5}\ K^{-1}$ is moved from an ice - water mixture into boiling water. The increase in the volume of the cube is

A. 0.25 cm^3 **B.** 0.50 cm^3 **C.** 0.75 cm^3 **D.** 1.50 cm^3

25. A glass bottle of initial volume $2 \times 10^4\ cm^3$ is heated from 20°C to 50°C. If the linear expansivity of glass is $9 \times 10^{-6}\ K^{-1}$, the volume of the bottle at 50°C is

A. 20,005.4 cm^3 **B.** 20,008.1 cm^3
C. 20,013.5 cm^3 **D.** 20,016.2 cm^3

26. A glass flask of volume 1,000 cm^3 filled with mercury is heated from 30°C to 80°C. If the cubic expansivity of glass and mercury are $2.4 \times 10^{-4}\ K^{-1}$ and $1.8 \times 10^{-4} K^{1}$ respectively, the apparent increase in volume of mercury is

A. 3.0 cm^3 **B.** -3.0 cm^3 **C.** 9.0 cm^3 **D.** 12.0 cm^3

27. A density bottle of volume 500 cm^3 is filled with a liquid and heated from 20°C to 60°C. If 7.5 cm^3 of liquid is expelled, the apparent cubic expansivity of the liquid is

A. $7.50 \times 10^{-5}\ K^{-1}$ **B.** $1.88 \times 10^{-4}\ K^{-1}$
C. $3.75 \times 10^{-5}\ K^{-1}$ **D.** $7.50 \times 10^{-4}\ K^{-1}$

28. A brass ball of volume 1,000 mm^3 is moved from room temperature (30°C) to an ice - water mixture at 0°C. If the linear expansivity of brass is $2 \times 10^{-5}\ K^{-1}$, the new volume of the ball is

A. 1,001.8 mm^3 **B.** 1,000.6 mm^3
C. 999.4 mm^3 **D.** 998.2 mm^3

29. A fixed mass of gas occupies a volume of 1,200 cm^3 at a temperature of 27°C. The change in volume as the gas is cooled at constant pressure to 0°C is

A. 108 cm^3 **B.** 216 cm^3 **C.** 273 cm^3 **D.** 300 cm^3

30. A gas occupies a certain volume at 27°C. If it is heated at constant pressure, its volume is exactly doubled at a temperature of

A. 54°C **B.** 219°C **C.** 327°C **D.** 600°C

31. A fixed mass of gas at standard temperature and pressure is heated at constant volume. The temperature at which its pressure becomes equal to 228 cm of mercury is

A. 819°C **B.** 546°C **C.** 273°C **D.** 0°C

32. A gas occupies a volume of 819 cm^3 at 0°C. If the gas is cooled at constant pressure, the temperature at which its volume drops to 480 cm^3 is

A. -113°C **B.** -56.5°C **C.** 0°C **D.** 160°C

33. A certain mass of gas exerts a pressure of 20 Nm^{-2} at a temperature of 127°C. If the gas is heated while maintaining its volume constant, the pressure exerted by the gas at 254°C is

A. 10.00 Nm^{-2} **B.** 26.35 Nm^{-2}
C. 33.18 Nm^{-2} **D.** 40.00 Nm^{-2}

34. A tyre is pumped to a pressure of 30 Nm^{-2} at 27°C. When the tyre heats up to 54°C the new pressure, assuming no change in volume, is

A. 60.0 Nm^{-2} **B.** 54.0 Nm^{-2}
C. 45.8 Nm^{-2} **D.** 32.7 Nm^{-2}

35. An air bubble of volume 1 cm^3 initially at a depth of 15 m below the water surface rises to the surface. If the atmospheric pressure is equal to 10 m of water, the volume of the bubble just before it reaches the water surface is

A. 0.25 cm^3 **B.** 0.67 cm^3 **C.** 1.50 cm^3 **D.** 2.50 cm^3

36. The equation $P^aV^bT^c$ = constant reduces to *Boyle's law* if

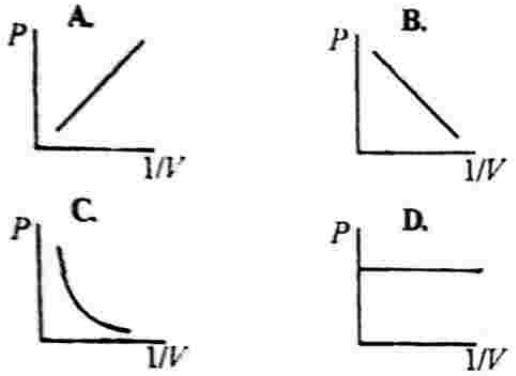
A. $a = 1, b = 0$ and $c = 0$ **B.** $a = 1, b = 1$ and $c = 0$
C. $a = 0, b = 0$ and $c = 1$ **D.** $a = 1, b = 1$ and $c = 1$

37. The equation in question 36 reduces to *Charles' law* if

A. $a = 1, b = 0$ and $c = 1$ **B.** $a = 0, b = 1$ and $c = 1$
C. $a = 0, b = 1$ and $c = -1$ **D.** $a = 1, b = 1$ and $c = 0$

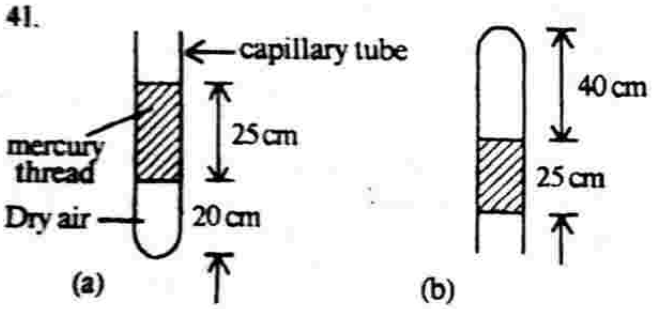
38. The product of pressure (P) and volume (V) has the unit of
A. force **B.** power **C.** impulse **D.** work

39. In an experiment on gases the pressure (P) of the gas is plotted against the reciprocal of the volume ($1/V$) of the gas at constant temperature. Which of the following graphs correctly illustrates the relationship between P and $1/V$?



40. At the *absolute zero* of temperature
I. thermal motion ceases
II. the pressure of a gas is zero
III. the mass of a gas is zero
IV. ice melts
Which of the above statements are correct?
A. I and II only **B.** III and IV only
C. I, II and III only **D.** II, III and IV only.

41.



Dry air is trapped by a pellet of mercury of length 25 cm in a uniform capillary tube (see diagram above). With the open end uppermost (a) the length of the air column is 20 cm. When the capillary tube is inverted (b) the length of the air column increases to 40 cm. The atmospheric pressure is
A. 73 cm Hg **B.** 74 cm Hg **C.** 75 cm Hg **D.** 76 cm Hg

42. If the tube in question 41(a) is held horizontally, the length of the air column will be
A. 30.0 cm **B.** 26.7 cm **C.** 25.0 cm **D.** 22.5 cm

43. If the capillary tube with its contents in question 41(a) is heated from 27°C to a temperature T such that the length of the air column increases to 24 cm, the value of T is
A. 32.4°C **B.** 87.0°C **C.** 250.0°C **D.** 360.0°C

44. A fixed mass of gas occupying a certain volume has its pressure reduced to 25 percent of its original value while the temperature is maintained constant. The ratio of the new volume to the original volume is
A. 2 : 1 **B.** 1 : 2 **C.** 1 : 4 **D.** 4 : 1

45. A little quantity of air is trapped on top of the mercury column in a barometer. When the volume of the trapped air is 7.5 cm^3 and the atmospheric pressure is 76 cm, the barometer reads 74.0 cm. When the volume of the trapped air is 10 cm^3 and the barometer reads 73.0 cm, the correct atmospheric pressure is
A. 75.5 cm **B.** 75.0 cm **C.** 74.5 cm **D.** 74.0 cm

46. The volume of a certain mass of gas is doubled while its absolute temperature is halved. The pressure of the gas
A. remains unchanged
B. is halved
C. increases by a factor of 4
D. decreases by a factor of 4

47. A certain mass of gas is trapped in a tube of volume V at a temperature of 27°C. If the pressure on the gas is doubled such that its volume is reduced to 75 percent of its original value, the new temperature of the gas is
A. -73.0°C **B.** 40.5°C **C.** 177.0°C **D.** 450.0°C

48. The pressure of a fixed mass of gas is reduced from three atmospheres to 1 atmosphere, while its temperature increases from -73°C to 127°C. The ratio of the final volume of the gas to its initial volume is
A. 6 : 1 **B.** 1 : 6 **C.** 3 : 2 **D.** 2 : 3

49. A certain mass of gas at -123°C occupies a volume of 10 m^3 under a pressure of 4×10^5 Nm^{-2}. If the gas occupies a volume of 20 m^3 at 27°C, its pressure is
A. 8×10^5 Nm^{-2} **B.** 4×10^5 Nm^{-2}
C. 2×10^5 Nm^{-2} **D.** 1×10^5 Nm^{-2}

50. A certain mass of gas occupies a volume of 3×10^4 cm^3 at 31°C under a pressure of 76 cm of mercury. When the pressure is reduced to 50 cm of mercury and the temperature is increased to 127°C, its volume is
A. 3×10^4 cm^3 **B.** 4×10^4 cm^3
C. 6×10^4 cm^3 **D.** 1.2×10^5 cm^3

Answer Key

1. D	9. B	17. A	25. D	33. B	41. C	49. B
2. A	10. C	18. B	26. B	34. D	42. B	50. C
3. C	11. B	19. B	27. C	35. D	43. B	
4. A	12. A	20. D	28. D	36. B	44. D	
5. D	13. C	21. B	29. A	37. C	45. C	
6. C	14. D	22. B	30. C	38. D	46. D	
7. D	15. D	23. A	31. B	39. A	47. C	
8. B	16. C	24. C	32. A	40. A	48. A	

Solutions to Objective Questions

1. **(D)** $\frac{T_F - 32}{180} = \frac{T_c}{100}$, or
$T_F = 32 + {}^9/_5 T_C = 32 + {}^9/_5(45) = 113°F$

2. **(A)** $\frac{T_C}{100} = \frac{48 - 20}{160 - 20} = \frac{28}{140} = 0.2$,
or $T_C = 20°C$

3. **(C)** $\frac{52 - X}{80 - X} = \frac{60}{100} = 0.6$
$52 - X = 48 - 0.6X$, or $X = 4/0.4 = 10$ mm

4. **(A)** $\frac{T_C}{100} = \frac{48}{60} = 0.8$, or $T_C = 80°C$

5. **(D)** If X = reading on the scale, then
$\frac{X - 50}{190 - 50} = \frac{70}{100} = 0.7$, or
$X = 140(0.7) + 50 = 98 + 50 = 148$ mm

6. **(C)** $\frac{T_C}{100} = \frac{30 - (-50)}{70 - (-50)} = \frac{80}{120} = 0.667$, or
$T_C = 66.7°C$

7. **(D)** $T_K = T_C + 273 = (-93) + 273 = 180$ K

8. **(B)** $\frac{T - 1.5}{103 - 1.5} = \frac{40}{100} = 0.4$, or
$T - 1.5 = 101.5 \times 0.4 = 40.6$
$T = 40.6 + 1.5 = 42.1°C$

9. **(B)** $\frac{T_C}{100} = \frac{R_T - R_0}{R_{100} - R_0} = \frac{8.25 - 5.25}{9.75 - 5.25} = \frac{3.00}{4.50} = 0.667$,
or $T_C = 66.7°C$

10. **(C)** $\frac{T_C}{100} = \frac{P_T - P_o}{P_{100} - P_o} = \frac{450 - 250}{750 - 250} = 0.4$
or $T_C = 40°C$
$T_K = 40 + 273 = 313$ K

11. **(B)** As the temperature falls, both the alcohol and the mercury columns contract. The concave meniscus of the alcohol in the left arm drags the steel index S_1 upwards as the meniscus moves upwards. However, the steel index S_2 is unaffected by the downward motion of the mercury meniscus, which is convex. S_1 indicates the minimum temperature and S_2 the maximum temperature.

12. **(A)** In a *thermocouple*, two wires made of different metals are joined together at one end while the other ends are connected to an electric current meter. As the temperature of the joined end changes, an emf is set up between the open ends which result in a flow of current through the meter. The emf or electric current varies linearly with temperature change.

13. **(C)** $\alpha = \frac{\Delta L}{L_i \theta} = \frac{20 \times 10^{-3}}{5(50)} = 8 \times 10^{-5}\ K^{-1}$

14. **(D)** $\alpha = \frac{\Delta L}{L_i \theta} = \frac{1.05L - L}{L\theta} = \frac{0.05}{\theta} = \frac{1}{20\theta}$

15. **(D)** $\Delta L = \alpha L_i \theta = (2 \times 10^{-5})(100)(-10 - 30) = -8 \times 10^{-2}$ m
$L_f = L_i + \Delta L = 100 - 0.08 = 99.92$ m

16. **(C)** $\Delta L = \alpha L_i \theta = (1.2 \times 10^{-5})(500)(30 - 5)$
$= 1.5 \times 10^{-1}$ m, or 15 cm

17.(A) Let the subscripts a and s stand for aluminium and steel respectively.
$\Delta L_a = \alpha_a L_a(1) = \alpha_s L_s(1)$
$L_s/L_a = \alpha_a/\alpha_s = 1/2 = 0.5$

18.(B) Safety gap = increase in length of each steel bar
$= \alpha L_i\theta = (1.2 \times 10^{-5})(2)(40)$
$= 9.6 \times 10^{-4}$ m, or 0.96 mm

19.(B) $\Delta L = 2.499 - 2.5 = -0.001$ cm

Temp. change, $\theta = \dfrac{\Delta L}{L_i} = \dfrac{0.001}{(1.2 \times 10^{-5})(2.5)} = 33.3°C$

Temperature required = 25 - 33.3 = - 8.3°C

20.(D) This question requires a knowledge of the relative linear expansivities of brass and iron, i.e. that brass has a higher expansivity and hence must be on the convex side of the curved bimetallic strip. Note that options (A) and (B) are ruled out because the metals are joined together in a bimetallic strip and can not slide past each other.

21.(B) The bimetallic strip, upon heating, will bend away from the key, since copper expands more than steel. If the steel and copper were interchanged, the strip will bend towards the key and close the circuit upon heating.

22.(B) Area expansivity, $\beta = 2\alpha = 2(2 \times 10^{-5}) = 4 \times 10^{-5} K^{-1}$
Change in area, $\Delta A = \beta A_i\theta = (4 \times 10^{-5})(100)(70)$
$= 0.28$ cm^2. New area = 100 + 0.28 = 100.28 cm^2

23.(A) Volume expansivity, $\gamma = 3\alpha$
Change in volume, $\Delta V = \gamma V_i\theta = (3\alpha)(V)(T) = 3\alpha VT$

24.(C) $\gamma = 3\alpha = 6 \times 10^{-5} K^{-1}$
original volume $V_i = (5)^3 = 125$ cm^3
$\Delta V = \gamma V_i\theta = (6 \times 10^{-5})(125)(100 - 0) = 0.75$ cm^3

25.(D) $\gamma = 3\alpha = 2.7 \times 10^{-5} K^{-1}$
$\Delta V = \gamma V_i\theta = (2.7 \times 10^{-5})(2 \times 10^4)(30) = 16.2$ cm^3
Final volume = 20,000 + 16.2 = 20,016.2 cm^3

26. (B) For the glass: $\Delta V_g = \gamma_g V\theta = (2.4 \times 10^{-4})(1{,}000)(50)$
$= 12.0$ cm^3
For the mercury: $\Delta V_m = \gamma_m V\theta = (1.8 \times 10^{-4})(1{,}000)(50)$
$= 9.0$ cm^3
Since the glass expands more than the mercury, the apparent increase in volume of the mercury is 9.0 - 12.0 = -3.0 cm^3 [The negative sign shows that the mercury actually appears to have reduced in volume].

27.(C) $\gamma = \dfrac{\Delta V}{V_i\theta} = \dfrac{7.5}{500(40)} = 3.75 \times 10^{-4} K^{-1}$

28.(D) $\Delta V = \gamma V_i\theta = (6 \times 10^{-5})(1{,}000)(-30) = -1.8$ mm^3
Final volume = 1,000 - 1.8 = 998.2 mm^3

29.(A) At constant pressure, $V_1/T_1 = V_2/T_2$
$V_1 = 1{,}200$ cm^3, $T_1 = 300$ K, $T_2 = 273$ K
$\dfrac{1{,}200}{300} = \dfrac{V_2}{273}$, or $V_2 = 1{,}092$ cm^3
Change in volume = 1,200 - 1,092 = 108 cm^3

30.(C) Let V = volume of the gas at 27°C, or 300 K
Charles' law: $\dfrac{V}{300} = \dfrac{2V}{T}$, or
$T = 600$ K = 327°C

31.(B) Standard temperature and pressure are 273 K and 76 cm of mercury, respectively. At constant volume,
$P_1/T_1 = P_2/T_2$
$76/273 = 228/T_2$, or $T_2 = 819$ K = 546°C

32.(A) $V_1/T_1 = V_2/T_2 \Rightarrow 819/273 = 480/T_2$
or $T_2 = 160$ K = (160 - 273)°C = -113°C

33.(B) At constant volume, $P_1/T_1 = P_2/T_2$
where $T_1 = 400$ K and $T_2 = 527$ K
$20/400 = P_2/527$, or $P_2 = 26.35$ Nm^{-2}.

34.(D) $P_1/T_1 = P_2/T_2 \Rightarrow 30/300 = P_2/327$
or $P_2 = 32.7$ Nm^{-2}.

35.(D) At constant temperature, $P_1V_1 = P_2V_2$
$V_1 = 1$ cm^3 at $P_1 = (15 + 10) = 25$ m of water
$P_2 = 10$ m close to the water surface
$\Rightarrow V_2 = P_1V_1/P_2 = (25)(1)/10 = 2.5$ cm^3

36.(B) The equation $P^aV^bT^c$ = constant becomes PV = constant (*Boyles' law*) if $a = 1$, $b = 1$ and $c = 0$

37.(C) The equation $P^aV^bT^c$ = constant becomes V/T = constant (*Charles' law*) if $a = 0$, $b = 1$ and $c = -1$

38.(D) Pressure = Force/Area.
Hence pressure x volume = force x volume/area
= force x length = [work].

39.(A) Since PV = constant, P = constant$(1/V)$
Hence P is directly proportional to $1/V$, with a positive slope.

40.(A) At the absolute zero of temperature, the kinetic energy of the molecules of a gas is zero, i.e. all molecular motion ceases. A gas cooled to absolute zero at constant volume should exert *no* pressure (See revision notes).

41.(C) At constant temperature $P_1V_1 = P_2V_2$
P_1 = pressure of air column with the open end up = $P_a + 25$ cm, where P_a = atmospheric pressure.
V_1 = volume of air column = $20A$ cm² where A is the cross-sectional area of the tube.
$P_2 = P_a - 25$, when the capillary tube is inverted, and $V_2 = 40A$ cm².
Hence $(P_a + 25)(20A) = (P_a - 25)40A$, or $P_a = 75$ cm.

42.(B) In the horizontal position, the pressure acting on the air column is atmospheric pressure = 75 cm.
$P_1V_1 = P_2V_2 \Rightarrow (75 + 25)(20A) = 75\,(AL_2)$, where L_2 is the length of the air column in the horizontal position.
Hence $L_2 = 2{,}000/75 = 26.7$ cm.

43.(B) Pressure of the air column is constant during the heating. Hence $V_1 / T_1 = V_2 / T_2$
$20A / 300 = 24A/T$, or
$T = 360$ K = 87°C.

44.(D) Let V_1, P_1 = original volume and pressure resp.
P_2 = new pressure = $0.25P_1$
$P_1V_1 = P_2V_2 \Rightarrow P_1V_1 = 0.25P_1(V_2)$, or
$V_2/V_1 = 1/0.25 = 4$

45. (C) P_1 = initial pressure of trapped air = 76 - 74 = 2.0 cm Hg
V_1 = initial volume of trapped air = 7.5 cm³
V_2 = final volume of trapped air = 10 cm³
P_2 = final pressure of trapped air
$P_1V_1 = P_2V_2 \Rightarrow (2)(7.5) = P_2(10)$, or $P_2 = 1.5$ cm
Correct atmospheric pressure = barometer reading + trapped air pressure = 73 + 1.5 = 74.5 cm.

46.(D) $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
where $V_2 = 2V_1$, $T_2 = T_1/2$
Hence $\frac{P_1V_1}{T_1} = \frac{P_2(2V_1)}{T_1/2}$, or $P_2 = P_1/4$.

47.(C) Let P, V = initial pressure and volume of the gas, respectively. Final volume = $0.75V$, final pressure = $2P$.
$P_1V_1/T_1 = P_2V_2/T_2$
$PV/300 = (2P)(0.75V)/T_2$, or
$T_2 = 300 \times 1.5 = 450$ K = 177°C

48.(A) $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Rightarrow \frac{(3)(V_1)}{200} = \frac{(1)(V_2)}{400}$
or $V_2/V_1 = 6$

49.(B) $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
$\frac{(4 \times 10^5)(10)}{150} = \frac{P_2(20)}{300}$, or
$P_2 = 4 \times 10^5$ Nm⁻²

50.(C) $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
$\frac{(76)(3 \times 10^4)}{304} = \frac{(50)V_2}{400}$, or
$V_2 = 6 \times 10^4$ cm³

Revision Check-list

At the end of this chapter, the candidate should be able to:

- define the term *temperature* and relate it to molecular motion.
- recall the *physical properties* used for temperature measurement.
- describe various types of *thermometers* and their relative merits and demerits.
- distinguish between different *temperature scales*.
- explain what is meant by the *lower* and *upper fixed points*.
- list the desirable properties of a *thermometric fluid*.
- compare *mercury* and *alcohol* as thermometric fluids.
- explain the terms *linear*, *area* and *cubic expansivities* and solve simple problems on them.
- list the advantages and disadvantages of *thermal expansion*.
- explain the *anomalous expansion of water* between 0°C and 4°C.
- state *Boyle's* and *Charles' laws* for gases and solve simple problems on them.
- explain what is meant by the *absolute zero* of temperature.
- state and apply the *ideal gas equation*.
- describe experiments(along with the necessary precautions) to
  (1) determine the boiling point of a small quantity of liquid.
  (2) determine the fixed points for a mercury-in-glass thermometer.
  (3) determine the linear expansivity of a bar.
  (4) determine the real and apparent cubic expansivities of a liquid.
  (5) illustrate the relationship between any two of the three gas properties : pressure, volume and temperature while the third is held constant.

9 Heat and Vapours

9.1 Heat Capacity

- **Heat** is a form of energy which is associated with the motion of atoms or molecules of a body.
- The addition of heat to a substance often results in an increase in the average kinetic energy of its molecules, i.e. a rise in temperature.
- The quantity of heat needed to raise the temperature of a substance by 1 Celsius degree varies from one substance to another. A given mass of lead requires less heat than the same mass of water.
- The **specific heat capacity** (or simply, **specific heat**), c, of a substance is the *quantity of heat required to raise the temperature of a unit mass of the substance by 1 Celsius degree*. To raise the temperature of a mass m of the substance from T_1 to T_2, the heat needed is

$$Q = mc(T_2 - T_1) \qquad (9.1)$$

- **The heat capacity (or thermal capacity) of a substance** is the *quantity of heat needed to raise the temperature of the whole substance by 1 Celsius degree*, i.e.

$$\text{Heat capacity} = mc \qquad (9.2)$$

Units: Q = [Joules] or [J], c = [$Jkg^{-1}K^{-1}$] or [$Jkg^{-1}(°C)^{-1}$]
Heat capacity = [JK^{-1}] or [$J(°C)^{-1}$]

9.2 Method of Mixtures

- If a hot body is brought into thermal contact with a cold body, heat energy flows from the hot to the cold body until they reach a common final temperature. If no heat is lost to the surroundings, then:
  Heat released by hot body = Heat absorbed by cold body.
- If a hot body is transferred into a cold liquid in a container (or calorimeter), some of the heat is absorbed by the calorimeter. In that case:
  Heat released by hot body = Heat absorbed by cold body + Heat absorbed by calorimeter.

9.3 Heating and Cooling Curves

- Matter exists as solid, liquid or gas. These various states are referred to as **phases**.
- For water the three phases are *ice*, *water* and *steam* respectively.
- The particular phase in which a substance will be found depends on the temperature.
- Fig. 9.1 shows the typical **heating curve** (of temperature versus time) for a solid substance as it is heated into the vapour (gas) phase.

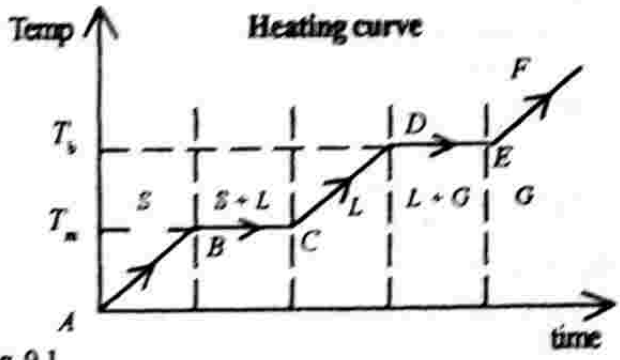


Fig. 9.1

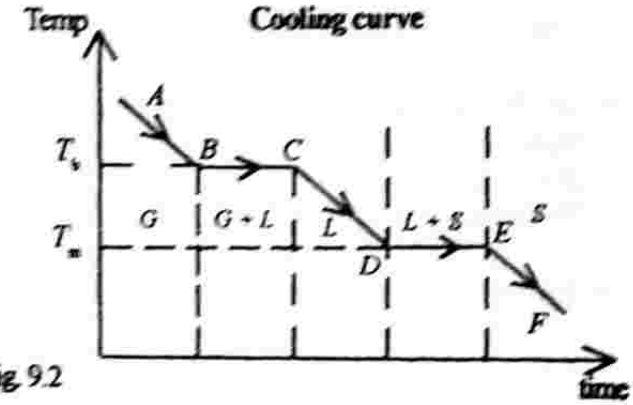


Fig. 9.2

AB: Substance is in the solid (S) phase, and its temperature increases as it is heated.
BC: Substance exists as a mixture of solid and liquid (*L*) phases; the temperature remains constant at T_m (the *melting point*) until all the solid has been converted to liquid.
CD: Substance is in the liquid phase, and its temperature increases as it is heated.
DE: Substance exists as a mixture of liquid and gaseous (*G*) phases; the temperature is constant at T_b (boiling point) until all the liquid has been converted into gas (or vapour).
EF: Substance is in the gaseous phase; the temperature again increases as it is heated.

- If a substance initially in the gaseous phase is cooled the **cooling curve** of Fig. 9.2 results.
- The cooling process is the reverse of the heating process. The temperature of the substance decreases as it is cooled in the gaseous phase (*AB*), remains constant at T_b until all the gas *condenses* into liquid phase(*BC*), decreases as cooling continues in the liquid phase (*CD*), remains constant at T_m until all the liquid has *solidified* (*DE*) and subsequently decreases as the solid is cooled further (*EF*).

9.4 Latent Heat

- In Figs. 9.1 and 9.2, it will be noted that the temperature of the substance remains constant whenever it changes from one phase to another, even though heat is being added to or removed from it.

- The **specific latent heat of fusion** (L_f) is the *heat required to melt a unit mass of a substance without a change in temperature.*
- The **specific latent heat of vaporisation** (L_v) is the *heat required to vaporise a unit mass of a substance without a change in temperature.*

- The heat required to change the phase of mass m of the substance is

$$Q_f = mL_f \tag{9.3}$$

for fusion, and

$$Q_v = mL_v \tag{9.4}$$

for vaporization.
Units: L_f and L_v bear units of [J.kg^{-1}]

9.5 Evaporation and Boiling

- **Evaporation** involves the escape of molecules from a liquid surface.
- Evaporation occurs at **all** temperatures.
- When there is no external source of heat, the latent heat of vaporization is taken from the liquid itself, which cools down as a result. In other words, *evaporation results in cooling.*
- This principle is made use of, for instance,
  (i) by our own body, which cools down when sweat is evaporated from the surface of the skin: the heat of vaporization is drawn from the body.
  (ii) in a refrigerator, in which a highly volatile liquid is made to evaporate while drawing its heat of vaporization from the inner compartment, which therefore gets colder.
- In **boiling**, bubbles of vapour formed inside the liquid continuously rise to the surface.
- Boiling takes place *throughout the liquid*, and at a *definite temperature*.
- As an example, a glass of water left on a table may become completely empty after several days due to evaporation. However, the water will boil *only* if it is heated to 100°C at standard atmospheric pressure.

9.6 Effects of Impurities and Pressure

- The presence of *impurities* will *decrease the melting point* of a substance.
- Impurities may either increase or decrease the boiling point of a substance, depending on the nature of the substance. Thus *the boiling point of water is decreased by alcohol*, but *increased by salt* additions.
- For substances which *expand as they solidify (or contract on melting)*, increasing the pressure *lowers* the melting point, e.g. ice.
- For substances which *contract on solidification*, (or expand on melting), increasing the pressure *raises* the melting point, e.g paraffin wax.
- Increasing the pressure *raises* the boiling point. This is the basis for the rapid cooking in a **pressure cooker**. Due to increased pressure, the boiling point of the cooking water is higher than 100°C, resulting in faster cooking.

9.7 Unsturated and Saturated Vapours

- The space above the liquid in a closed container which is partly filled with a liquid becomes richer and richer in vapour as the liquid evaporates.
- The pressure exerted by the vapour on the liquid surface is termed **vapour pressure**.
- As more liquid turns into vapour, some of the vapour also returns to the liquid.
- Initially, more liquid is converted into vapour than vapour into liquid, resulting in an increasing concentration of vapour and an increasing vapour pressure. The vapour at this stage is **unsaturated**.
- A point is eventually reached at which the amount of vapour being formed from the liquid just balances the amount of vapour re-entering into the liquid. The vapour is then said to be **saturated**, and the vapour pressure exerted is called **saturated vapour pressure (SVP)**.
- The *SVP* increases if the temperature of the liquid is increased (Fig. 9.3).

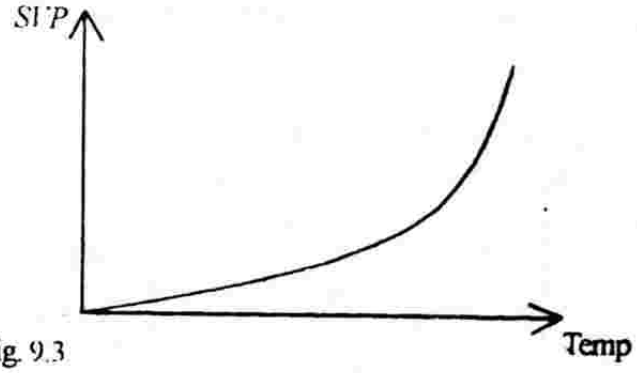


Fig. 9.3

- When the *SVP* becomes equal to the external pressure, the liquid boils. In other words, the *boiling point of a liquid is the temperature at which its SVP is equal to the external pressure.*
- The *SVP* of water, for instance, is 4.58 mm Hg at 0°C, 149 mm Hg at 60°C, and 760 mm Hg at 100°C.
- Water *boils* at 100°C which is the temperature at which its SVP becomes equal to the standard atmospheric pressure of 760 mm Hg.

9.8 Humidity

- Air is made up of nitrogen, oxygen, water vapour and other gases.
- **Humidity** is defined as the mass of water vapour in a unit volume of air. We feel dry air on a day when

the humidity is low (i.e. low water vapour content in the air), and hot and sticky on a day with high humidity.

- **Relative humidity (R.H.)** is defined as

$$\text{R.H.} = \frac{\text{mass of water vapour in air}}{\text{max. mass of water vapour possible at that temperature}} \times 100\% \quad (9.5)$$

9.9 Dew Point

- The amount of water vapour which air can hold decreases with decreasing temperature.
- If air is cooled, a temperature will be reached at which the air can no longer hold the amount of water vapour initially present, and some of the water vapour thus condenses (into water). The temperature at which this happens is the **dew point**.
- This condensation is easily obeserved (as mist) on a glass of cold water which is left standing in the open on a hot day. The cold glass cools the air in contact with it to a temperature at which the air becomes saturated with water vapour, and the excess water vapour in the air thus condenses on the glass.

True or False -Type Questions

Answer *True*(T) or *False* (F) to the following questions.

1. When equal masses of iron and water are supplied with equal quantities of heat :
   a. the iron becomes much hotter than the water because the specific heat capacity of iron is higher than that of water.
   b. the iron becomes much hotter than the water because the specific heat capacity of iron is less than that of water.
   c. the iron becomes much hotter than the water because iron is solid while water is liquid.
   d. the water becomes much hotter than the iron because the specific heat of water is higher than that of iron.
   e. the temperature rise in each substance is inversely proportional to the specific heat capacity of the substance.

2. A block of ice at -10°C is placed inside a container which is gradually supplied with heat.
   a. The temperature of the ice will rise until melting starts.
   b. The temperature of the ice will continue to rise until all the ice has melted.
   c. The temperature of the ice will remain constant during melting.
   d. As the ice melts, latent heat is absorbed and the volume increases.
   e. As the ice melts, latent heat is absorbed and the volume decreases.
   f. As the ice melts, latent heat is evolved and the volume decreases.
   g. The heat supplied to the ice during melting is the heat capacity of the ice.
   h. The temperature will rise after all the ice has melted.
   i. The heat used to raise the temperature of the water by 1°C after all the ice has melted is equal to the thermal capacity of the water.
   j. The heat used in raising the temperature of the ice from -10°C to 0°C is equal to the heat used in raising the temperature of the water from 0°C to 10°C.

3. a. The heat required to raise the temperature of a given mass of a substance by 1°C is its *specific heat capacity*.
   b. The heat required to change one kilogram of a substance from solid to liquid at a constant temperature is the specific latent heat of fusion of the substance.
   c. The heat required to change a substance from liquid to vapour at a constant temperature is the latent heat of vaporization of the substance.
   d. The specific heat capacity of a substance is independent of the mass of the substance.
   e. The thermal capacity of two litres of water is twice the thermal capacity of one litre of water.
   f. The specific latent heat of vaporization of two litres of water is twice the specific latent heat of vaporization of one litre of water.
   g. The specific latent heat of vaporization of a substance may be greater than or less than its specific latent heat of fusion, depending on the nature of the substance.
   h. The unit of specific latent heat is $Jkg^{-1}K^{-1}$.
   i. The unit of heat capacity is JK^{-1}.

4. The boiling point of a liquid depends on the
   a. nature of the liquid.
   b. volume of the liquid.
   c. external pressure.
   d. presence of impurities in the liquid.
   e. area of the exposed surface of the liquid.
   f. saturated vapour pressure of the liquid.
   g. relative humidity of the surrounding air.
   h. inter-molecular forces of cohesion in the liquid.

5. The rate of evaporation of a liquid depends on the
   a. temperature of the liquid.
   b. volume of the liquid.
   c. nature of the liquid.
   d. area of the exposed surface of the liquid.
   e. relative humidity of the surroundings.
   f. movement of air currents over the liquid's surface.
   g. dryness of the air in contact with the liquid.
   h. average kinetic energy of the molecules of the liquid.
   i. saturated vapour pressure of the liquid.
   j. atmospheric pressure.

6. a. Boiling and evaporation involve a change of state.
   b. Boiling and evaporation take place at a definite external pressure.
   c. Evaporation occurs only at the surface of the liquid.
   d. Boiling occurs throughout the liquid.
   e. Boiling and evaporation occur at a fixed temperature.
   f. Evaporation from a liquid results in the cooling of the liquid.
   g. A liquid is said to be *volatile* if its saturated vapour pressure is *low*.
   h. A liquid with low saturated vapour pressure will have a lower boiling point than one with high saturated vapour pressure.
   i. The saturated vapour pressure of a liquid depends on the external pressure.
   j. Water can be made to boil at room temperature if the external pressure is sufficiently reduced.
   k. If a mist forms on the outside surface of a glass of cold water left on a table, the temperature of the water must be lower than the dew point.
   l. A relative humidity of 100 percent means that the pressure of water vapour in the air is equal to the *saturated vapour pressure*.
   m. It is usual to feel "sticky and wet" on a day when the relative humidity is very low.

Answers to True or False - Type Questions

1. If Q is the heat supplied and subscripts i and w are used to denote iron and water respectively, then
   $Q = mc_i\Delta T_i = mc_w\Delta T_w$, or
   $$\frac{\Delta T_i}{\Delta T_w} = \frac{c_w}{c_i}$$
   The specific heat capacity of water (c_w) is greater than that of iron (c_i), hence $\Delta T_i > \Delta T_w$, i.e the iron becomes hotter than the water. In view of this, the answers are
   a (F) b (T) c (F) d (F) e (T)
   [Note that statement (e) is equivalent to the second equation above].

2. a (T) Temperature will rise as long as there is no change of state.
   b (F) Temperature will remain constant during melting.
   c (T) See (b) above
   d (F) Although latent heat is absorbed from the surroundings, the volume decreases since the density of water is higher than that of ice.
   e (T) See (d) above.
   f (F) Latent heat is *absorbed*, not evolved.
   g (F) Heat supplied during melting is the *heat of fusion* of ice.
   h (T) Temperature remains constant only during a phase change.
   i (T) This is the definition of *thermal capacity* (or *heat capacity*).
   j (F) The heat absorbed depends on the specific heat capacity of the substance, and that of water is higher than that of ice.

3. a (F) The term *specific* refers to a unit mass (or 1 kilogram) of the substance.
   b (T) This is the definition of *specific latent heat*.
   c (T) Since a *unit mass* is not specified, the term "specific" is not necessary.
   d (T) It is a constant for a given substance.
   e (T) Thermal capacity = mass x specific heat capacity. Since the mass of 2 litres of water is twice the mass of 1 litre, the thermal capacity of 2 litres is also twice the thermal capacity of 1 litre.
   f (F) The specific latent heat of vaporization is a constant for a given substance. It does *not* vary with quantity.
   g (F) The difference in internal (heat) energy between a vapour and its liquid is much greater than the difference in internal energy between a liquid and its solid. Hence the specific latent heat of vaporization is always *greater* than the specific latent heat of fusion.
   h (F) The unit of specific latent heat is Jkg^{-1}. Note that latent heat does not involve a temperature rise.
   i (T) *Specific* heat capacity, which involves a *unit mass*, has the unit of $Jkg^{-1}\,K^{-1}$.

4. a (T) The *nature* of the liquid determines such properties as its saturated vapour pressure and its inter-molecular cohesive forces, both of which affect the boiling point.
   b (F)
   c (T) Boiling point increases with increasing external pressure.

d (T) See revision notes.
e (F) Boiling is *not* a surface phenomenon.
f (T) The boiling point is the point at which the saturated vapour pressure becomes equal to the external pressure.
g (F) Boiling point is not affected by relative humidity.
h (T) The stronger the inter-molecular cohesive forces of a liquid, the higher is its boiling point.

5. a (T) Rate of evaporation increases with temperature.
b (F) Unless the area of the exposed surface changes [see (d) below].
c (T) Evaporation rate under a given environment varies from one liquid to another.
d (T) Evaporation is a surface phenomenon. The larger the exposed surface area, the higher is the rate of evaporation.
e (T) This is true for water but not necessarily true for other liquids. The rate of evaporation of a substance depends on the amount of the substance which is already present in vapour form in the surrounding environment.
f (T) Increased air current (or wind) results in increased rate of evaporation.
g (T) Same reason as (e) above. Note that dryness decreases as relative humidity increases.
h (T) This is a measure of the temperature of the liquid.
i (T) A liquid with high SVP evaporates faster than one with low SVP.
j (T) Evaporation rate will increase if the atmospheric pressure decreases appreciably. The rate of evaporation will be higher in a vacuum, for instance, than in air at atmospheric pressure. [This effect is ordinarily not apparent because the atmospheric pressure does not vary significantly].

6. a (T) Both involve a change from the liquid to the vapour state.
b (F) Both will take place at any external pressure.
c (T) See revision notes.
d (T) See revision notes.
e (F) For a given external pressure, boiling occurs at a fixed temperature. Evaporation occurs at all temperatures.
f (T) See revision notes.
g (F) A liquid evaporates fast, i.e. it is volatile if its *SVP* is high, and slowly if its *SVP* is low.
h (F) To answer this question correctly, it is important to remember that :
(1) SVP increases with temperature, and
(2) A liquid boils when its SVP becomes equal to the atmospheric pressure. A liquid with high *SVP* is thus likely to reach its boiling point at a lower temperature than one with low *SVP*.
i (F) The *SVP* is a property of the liquid which varies with temperature but *not* with external pressure.
j (T) Water will boil at any temperature at which the external pressure is made equal to the *SVP*.
k (T) The *dew point* is the temperature at which the mist just starts to form as the water is cooled.
l (T) The pressure of the water vapor in air can never exceed the *SVP*.
m (F) We feel "sticky and wet" when the relative humidity is *very high* because the rate of evaporation of sweat from the skin is then very low.

SSCE/JME - Type Objective Questions

1. A piece of iron of mass 100 g and specific heat capacity 460 $Jkg^{-1}K^{-1}$ cools from 70°C to 20°C. The heat released by the iron is
A. 2.3×10^6 J **B.** 9.2×10^5 J
C. 9.2×10^3 J **D.** 2.3×10^3 J

2. If the specific heat capacity of water is 4.2×10^3 $Jkg^{-1}K^{-1}$ and $g = 10$ ms^{-2}, the difference in temperature of the water between the top and bottom of a 210 m high waterfall is
A. 0.05°C **B.** 0.5°C **C.** 1.0°C **D.** 4.2°C

3. A cold water tap supplies water at 20°C and a hot water tap at 80°C. To obtain warm water at 40°C, the ratio of the mass of cold water to that of hot water to be mixed is
A. 2 : 1 **B.** 1 : 2 **C.** 4 : 1 **D.** 1 : 4

4. The quantity of heat needed to raise the temperature of a body by 1 K is the body's
A. internal energy **B.** specific heat capacity
C. latent heat of fusion **D.** thermal capacity

5. A metal object of mass 3.0 kg is heated from 25°C to 45°C in 10 minutes by an electric heater rated at 70 W. Neglecting heat loss to the surrroundings, the specific heat capacity of the metal is
A. 1.07×10^1 $Jkg^{-1}K^{-1}$ **B.** 4.2×10^2 $Jkg^{-1}K^{-1}$
C. 7.0×10^2 $Jkg^{-1}K^{-1}$ **D.** 4.2×10^3 $Jkg^{-1}K^{-1}$

6. A hot solid *X* is dropped into a certain quantity of water at room temperature. A hot solid *Y* of equal mass and at the same temperature as *X* is dropped into an equal quantity of water also at room temperature. If *X* causes a higher temperature rise in

the water than Y, then the
A. density of X is higher than that of Y
B. density of X is lower than that of Y
C. specific heat capacity of X is higher than that of Y
D. specific heat capacity of X is lower than that of Y

7. Two liquids X and Y having the same mass are supplied with the same quantity of heat. If the temperature rise in X is twice that of Y, the ratio of the specific heat capacity of X to that of Y is
A. 2 : 1 B. 1 : 2 C. 4 : 1 D. 1 : 4

8. A body of mass 120 g and specific heat capacity 400 $Jkg^{-1}K^{-1}$ loses 240 J of heat energy. The change in temperature of the body is
A. 5.0 K B. 4.5 K C. 2.0 K D. 0.5 K

9. An electric boiling ring is used to heat 800 g of water from 30°C to 90°C in 10 minutes. If 25 percent of the heat generated is lost to the surroundings and the specific heat capacity of water is 4,200 $Jkg^{-1}K^{-1}$, the power rating of the boiling ring is
A. 251 W B. 335 W C. 448 W D. 500 W

10. A body of specific heat capacity 900 $Jkg^{-1}K^{-1}$ initially held at a height of 90 m falls to the ground. Neglecting heat loss to the surrounding, the rise in temperature of the body on striking the ground is [$g = 10\ ms^{-2}$]
A. 0.5°C B. 1.0°C C. 2.0°C D. 5.0°C

11. 1 litre of hot water at temp T is added to 3 litres of cold water at a temperature of 30°C. If the final temperature of the mixture is 50°C, the value of T is
A. 56.7°C B. 80.0°C C. 110.0°C D. 150.0°C

12. A metal ball of mass 2 kg and at a temperature of 290°C is dropped into a certain quantity of water at 30°C. If the temperature of the mixture is 80°C and the specific heat capacities of the metal and the water are 450 $Jkg^{-1}K^{-1}$ and 4,200 $Jkg^{-1}K^{-1}$ respectively, the mass of the water is
A. 45 g B. 90 g C. 450 g D. 900 g

13. A 500 W immersion heater is used to heat a liquid of mass 500 g through a temperature rise of 50°C in 40 seconds. The specific heat capacity of the liquid is
A. 4,200 $JkgK^{-1}$ B. 1,600 $Jkg^{-1}K^{-1}$
C. 1,200 $Jkg^{-1}K^{-1}$ D. 800 $Jkg^{-1}K^{-1}$

14. The same quantity of heat which raises the temperature of a certain volume of water by 10°C also raises the temperature of an equal volume of oil by 20°C. If the relative density of the oil is 0.75, the ratio of the specific heat of oil to that of water is
A. 2 : 3 B. 3 : 2 C. 1 : 2 D. 2 : 1

15. Boiling water is added to a calorimeter of thermal capacity 105 JK^{-1} containing 500 g of water at 30°C. If the final temperature of the mixture is 70°C, and the heat capacity of water is 4.2 $Jg^{-1}°C^{-1}$, the amount of boiling water added is
A. 300.0 g B. 145.7 g C 29.1 g D. 14.6 g

16. Equal masses of two liquids X and Y at temperatures 30°C and 80°C respectively are mixed such that the temperature of the mixture is T. If the specific heat of X is twice that of Y, the value of T is
A. 45.0°C B. 46.7°C C. 55.0°C D. 62.5°C

17. Two containers P and Q of volumes V_p and V_q are filled with the same liquid at an initial temperature of 0°C. Both containers are heated such that the final temperature of P is twice that of Q. If V_p/V_q = 1/2, the ratio of the heat supplied to P and Q is
A. 1/4 B. 1/2 C. 1 D. 4

18. A mass 0.5 kg of water at 10°C is converted into ice at 0°C. The specific heat capacity of water is 4.2 $kJkg^{-1}°C^{-1}$ and the specific latent heat of fusion of ice is 334 $kJkg^{-1}$. The amount of heat extracted from the water is
A. 21 kJ B. 146 kJ C. 167 kJ D. 188 kJ

19. The specific heat capacity of water is 4.2 $Jg^{-1}K^{-1}$ and the specific latent heat of vaporization of water is 2.260 Jg^{-1}. The heat required to vaporize 200 g water initially at 80°C is
A. 16.8 kJ B. 452.0 kJ C. 468.8 kJ D. 937.6 kJ

20. A 6 Ω resistor which draws a current of 2 A takes 1 minute to evaporate 40 g of a liquid at its boiling point. The specific latent heat of vaporization of the liquid is
A. 36 Jg^{-1} B. 48 Jg^{-1} C. 72 Jg^{-1} D. 108 Jg^{-1}

21. One kilogram of boiling water at 100°C changes to ice at 0°C. If the specific latent heat of fusion of ice is $3.36 \times 10^5\ Jkg^{-1}$ and the specific heat capacity of water is 4,200 $Jkg^{-1}K^{-1}$, the heat extracted from the water is
A. 1.09×10^6 J B. 7.56×10^5 J
C. 4.20×10^5 J D. 3.36×10^5 J

22. A heater rated at 400 W is used to melt a 50 g block of ice at 0°C in one minute. If the specific latent of fusion of ice is 336 Jg^{-1}, how much of the heat supplied by the heater is lost to the surroundings?
A. 3,600 J B. 7,200 J C. 16,800 J D. 24,000 J

23. One kilogram of copper at a temperature of 840°C is transferred into a lagged container holding 1.5 kg

of ice at 0°C. The specific latent heat of fusion of ice = 3.36×10^5 Jkg^{-1} and the specific heat capacity of copper = 400 $Jkg^{-1}K^{-1}$. Neglecting the heat capacity of the container and the heat lost to the surroundings, the amount of ice left unmelted is

A. 1.00 kg B. 0.75 kg C. 0.50 kg D. 0.20 kg

24. The specific latent heat of vaporization of steam is 2.26×10^6 Jkg^{-1}. The difference in the quantity of heat released by 5 kg of steam and 5 kg of water which are both cooled from 100°C to 80°C is

A. 4.20×10^5 J B. 2.26×10^6 J
C. 4.20×10^6 J D. 1.13×10^7 J

25. An electric heater which draws a current of 20 A from a 12 V battery is used to convert 2 kg of ice at -10°C to water at 0°C. If the specific heat capacity of ice is 2.1 $kJkg^{-1}$ $°C^{-1}$ and the latent heat of fusion of ice is 3.33×10^5 Jkg^{-1}.the time taken to completely melt the ice is

A. 49.2 min B. 46.3 min C. 24.0 min D. 2.9 min

26. A heating coil rated at 1 kW is used to evaporate 700 g of water at 100°C. If the specific latent heat of vaporization of water = 2.3×10^6 Jkg^{-1}. the time taken to evaporate all of the water is

A. 1.61×10^2 s B. 1.61×10^3 s
C. 1.61×10^4 s D. 1.61×10^5 s

27. A certain quantity of ice at -20°C is heated to a temperature of 50°C. To determine the amount of heat absorbed. which of the following constants are required?

I. specific heat capacity of ice
II. specific heat capacity of water
II. specific latent heat of fusion of ice
IV. specific latent heat of vaporization of water

A. I and III only B. II and IV only
C. I,II and III only D. I, II, III, and IV

28. 10^6 J of heat is required to melt 500 g of a solid at its melting temperature of 80°C. The latent heat of fusion of the solid is

A. 2×10^3 Jkg^{-1} B. 5×10^5 Jkg^{-1}
C. 2×10^6 Jkg^{-1} D. 4×10^7 Jkg^{-1}

29. A person suffers a more severe burn from steam than from boiling water because

A. steam is at a higher temperature than boiling water
B. steam spreads more easily over the skin than boiling water
C. steam penetrates more deeply into the skin than boiling water
D. steam possesses greater heat energy per unit mass than boiling water.

30. A glass of soft drink can be cooled more effectively by adding melting ice than by adding the same mass of water at 0°C because

A. water has a higher specific heat capacity than ice
B. melting ice is at a lower temperature than the water
C. ice absorbs latent heat as it melts
D. ice makes better thermal contact than water.

31. A change of state is often accompanied by a change in

I. temperature II. density
III. internal energy IV. mass

Which of the above are correct?

A. I and III only B. II and III only
C. II and IV only D. II, III and IV only

32. A solid that changes directly into a gas upon heating is said to have undergone

A. evaporation B. vaporization
C. solidification D. sublimation

33. When the pressure of the vapour on top of an enclosed liquid is equal to the pressure of the atmosphere. the liquid is at its

A. boiling point B. dew point
C. freezing point D. evaporation point

34. When the atmospheric pressure is 750 mm of mercury. water will boil at

A. a temperature of 100°C
B. a temperature less than 100°C
C. a temperature greater than 100°C
D. any temperature if heated rapidly .

35. The boiling point of water of water on the top of a mountain is lower than at sea level because

A. atmospheric pressure is lower on the mountain
B. atmospheric pressure is higher on the mountain
C. the sun heats the water more effectively on the mountain
D. the relative humidity is lower on the mountain.

36. An increase in pressure

I. increases the freezing point of a substance
II. reduces the freezing point of a substance
III. increases the boiling point of a substance
IV. reduces the boiling point of a substance

Which of the above statements are correct?

A. I only B. II only
C. I and IV only D. II and III only

37. The saturation vapour pressure of a liquid depends on the

I. volume of the liquid
II. external pressure

III. temperature of the liquid
IV. nature of the liquid
Which of above statements are correct?
A. I and II only B. III and IV only
B. II, III and IV only D. I, II, III and IV

38. The vapour on top of an enclosed liquid is said to be saturated if
A. the rate of condensation of the vapour is greater than the rate of vaporization of the liquid
B. the rate of condensation of the vapour is less than the rate of vaporization of the liquid
C. the rate of condensation of the vapour is equal to the rate of vaporization of the liquid
D. there is neither condensation of the vapour nor vaporization of the liquid.

39. An instrument used to measure relative humidity is called a
A. hydrometer B. barometer
C. manometer D. hygrometer

40. The temperature at which the water vapour present in the air is just enough to saturate the air is the
A. steam point B. boiling point
C. ice point D. dew point

41. The formation of clouds results directly from
A. condensation B. sublimation
C. fusion D. vaporization

42. Food cooks faster in a pressure cooker than in an ordinary cooking pot because
I. the food is not affected by air convection currents
II. the boiling point of water is greater than 100°C in the pressure cooker
III. less heat escapes from the pressure cooker
IV. the vapour pressure is higher in the pressure cooker.
Which of the above statements are correct?
A. I and III only B. II and IV only
C. I, II and III only D. II, III and IV only

Answer Key

1. D	8. A	15. A	22. B	29. D	36. D
2. B	9. C	16. B	23. C	30. C	37. B
3. A	10. B	17. C	24. D	31. B	38. C
4. D	11. C	18. D	25. A	32. D	39. D
5. C	12. D	19. C	26. B	33. A	40. D
6. C	13. D	20. A	27. C	34. B	41. A
7. B	14. A	21. B	28. C	35. A	42. B

Solutions to Objective Questions

1. **(D)** $Q = mc\Delta T = (0.1)(460)(70 - 20) = 2{,}300$ J

2. **(B)** P.E. of water at 210 m above the ground level $= mgh = m(10)(210) = 2{,}100m$ joules. This is converted into internal energy in the form of heat as the water strikes the ground.
This internal energy $= mc\Delta T = m(4{,}200)\Delta T$ joules.
Hence $2100m = 4200m\Delta T$, or $\Delta T = 0.5$°C

3. **(A)** Let m_h, m_c = masses of hot and cold water respectively.
Heat released by hot water $= m_h c\,\Delta T = m_h c\,(80 - 40)$
$= 40m_h c$
Heat absorbed by cold water $= m_c c(40 - 20) = 20m_c c$
Hence $40m_h c = 20m_c c$, or $m_c/m_h = 2$

4. **(D)** The key to answering this question correctly is the candidate's ability to distinguish clearly between *specific heat capacity*, which refers to the heat needed to raise the temperature of a *unit mass* (or 1 kg) of the body by 1 K, and the *heat (or thermal) capacity*, which is the heat needed to raise the temperature of the *whole* body by 1 K.

5. **(C)** Heat absorbed by the metal object $= 3.0(c)(45 - 25) = 60c$ joules.

Heat released by the heater in 10 minutes
$= 70\ Js^{-1} \times (10 \times 60)s = 4.2 \times 10^4\ J$
$60c = 4.2 \times 10^4$, or $c = 700\ Jkg^{-1}K^{-1}$

6. **(C)** X which causes a higher temperature rise must have contained a greater quantity of stored heat energy. Since both X and Y were initially at the same temperature, the specific heat capacity for X must be greater than for Y.

7. **(B)** Heat supplied to $X = mc_x \Delta T_x$
Heat supplied to $Y = mc_y \Delta T_y$
$mc_x \Delta T_x = mc_y \Delta T_y \Rightarrow c_x/c_y = \Delta T_y / \Delta T_x = 1/2$

8. **(A)** Heat lost by the body $= 240 = 0.12(400)\Delta T$.
or $\Delta T = 240/48 = 5°C$.

9. **(C)** Heat supplied to the water in 10 minutes $= mc\Delta T$
$= (0.8)(4200)(60) = 2.01 \times 10^5$ J. This represents 75 percent of the heat generated in the boiling ring, hence heat generated $= 2.01 \times 10^5/0.75 = 2.688 \times 10^5$ J in 10 minutes.
Power rating = heat produced per second
$= \dfrac{2.688 \times 10^5 J}{10 \times 60\ s} = 448\ W$

10. **(B)** P.E. of the body $= mgh = m(10)(90) = 900m$ joules
This is converted into the internal energy of the body
$= mc\Delta T = m(900)\Delta T$
Hence $900m = 900m\ \Delta T$, or $\Delta T = 1.0°C$

11. **(C)** Lets m = mass of 1 liter of water and
$3m$ = mass of 3 liters of water
$m(c)(T - 50) = 3m(c)(50 - 30)$
$T - 50 = 60$, or $T = 110°C$

12. **(D)** Let m = mass of water
Heat lost by metal ball $= 2(450)(210)$ J
Heat gained by water $= m(4200)(50)$ J
$m(4200 \times 50) = 2(450 \times 210)$, or
$m = 0.9$ kg, or 900g.

13. **(D)** Heat released by the heater in 40 s $= 500 \times 40$
$= 2 \times 10^4$ J
Heat absorbed by the liquid $= 0.5(c)(50) = 25c$
Hence $25c = 2 \times 10^4$, or $c = 800\ Jkg^{-1}K^{-1}$

14. **(A)** If m = mass of the given volume of water, then $0.75\ m$ = mass of the same volume of oil.
For the water: $Q = mc_w(10)$, and
for the oil: $Q = 0.75mc_o(20)$
Hence $10mc_w = 15mc_o$ or $c_o/c_w = 2/3$.

15. **(A)** Let m = amount of hot water added in grams.
Heat absorbed by the cold water $= 500(4.2)(70-30)$
$= 84{,}000$ J. Heat absorbed by the calorimeter = heat capacity x temp. change $= 105 \times 40 = 4{,}200$ J.
Heat lost by boiling water $= m(4.2)(100 - 30) = 294m$ joules.
$294m = 4{,}200 + 84{,}000$, or $m = 88{,}200/294 = 300$ g.

16. **(B)** Heat gained by $X = mc_x(T - 30)$
Heat lost by $Y = mc_y(80 - T)$
$mc_x(T - 30) = mc_y(80 - T)$
$\dfrac{c_x}{c_y} = \dfrac{80 - T}{T - 30} = 2$
$80 - T = 2T - 60$, or $T = 140/3 = 46.7°C$

17. **(C)** Heat supplied to $P = m_p cT_p = dV_p cT_p = Q_p$
where d = density of the liquid and T_p = final temp.
Heat supplied to $Q = dV_q cT_q = Q_q$
$\dfrac{Q_p}{Q_q} = \dfrac{dV_p cT_p}{dV_q cT_q} = \dfrac{V_p T_p}{V_q T_q} = \frac{1}{2}(2) = 1$

18. **(D)** Heat released by the water as it cools from 10°C to 0°C $= mc\Delta T = 0.5(4.2)(10) = 21$ kJ.
Heat released by the water as it changes to ice at 0°C $= mL_F = 0.5(334) = 167$ kJ.
Total heat released $= 21 + 167 = 188$ kJ.

19. **(C)** Heat absorbed by the water as its temperature rises from 80°C to 100°C $= mc\Delta T = 200(4.2)(20) = 16{,}800$ J.
Heat absorbed by the water as it changes to steam at 100°C $= mL_v = 200(2260) = 452{,}000$ J
Total heat absorbed $= 16{,}800 + 452{,}000 = 468{,}800$ J. or 468.8 kJ.

20. **(A)** Heat supplied by the resistor in 60 s
$= I^2Rt = (2)^2(6)(60) = 1{,}440$ J.
Heat needed to vaporize 40 g of the liquid $= mL_v$
$= 40L_v$, with L_v in $[Jg^{-1}]$
Hence $40L_v = 1{,}440$, or $L_v = 36\ Jg^{-1}$

21. **(B)** Heat released by the boiling water as it cools from 100°C to 0°C $= mc\Delta T = (1)(4200)(100) = 4.2 \times 10^5$ J. Heat released as the water changes to ice at 0°C $= mL_f = (1)(3.36 \times 10^5)$ J
Total heat released $= (4.2 + 3.36) \times 10^5 = 7.56 \times 10^5$ J.

22. **(B)** Total heat supplied by the heater in one minute $= 400 \times 60 = 24{,}000$ J.
Heat used to melt 50 g of ice at 0°C $= mL_f = 50(336)$
$= 16{,}800$ J
Heat lost to the surroundings $= 24{,}000 - 16{,}800$
$= 7{,}200$ J

23. **(C)** Heat released by copper $= 1(400)(840) = 3.36 \times 10^5$ J. This heat is used to melt m kg of ice i.e. $mL_f = 3.36 \times 10^5$, or $m = 3.36 \times 10^5/(3.36 \times 10^5) = 1.0$ kg.
Mass of ice left unmelted $= 1.5 - 1.0 = 0.5$ kg.

24.**(D)** The difference is the heat released by the steam as it changes into water at 100°C = $mL_v = 5(2.26 \times 10^6) = 1.13 \times 10^7$ J.

25.**(A)** Heat supplied by the heater = $IVt = (20)(12)t = 240t$
Heat needed to raise the temp of 2 kg of ice from -10°C to 0°C = 2(2,100)(10) = 4.2×10^4 J.
Heat needed to melt the ice at 0°C = $mL_f = 2(3.33 \times 10^5 \text{ J}) = 6.66 \times 10^5$ J
Total heat needed = 7.08×10^5 J
$240t = 7.08 \times 10^5$, or $t = 7.08 \times 10^5 / (240 \times 60)$
= 49.2 minutes.

26.**(B)** Heat needed to evaporate the water= $mL_v = 0.7(2.3 \times 10^6) = 1.61 \times 10^6$ J
Heat supplied by coil = 1,000t, where t is the time taken.
Hence $1{,}000t = 1.61 \times 10^6$, or $t = 1.61 \times 10^3$ s.

27.**(C)** (I)is required to determine the heat absorbed in heating the ice from -20°C to 0°C.
(III) is needed to determine the heat absorbed in melting the ice at 0°C
(II) is needed to determine the heat absorbed in heating the water from 0°C to 50°C.

28.**(C)** Heat to melt the solid = $mL_f = 0.5L_f = 10^6$, or $L_f = 10^6/0.5 = 2 \times 10^6$ Jkg^{-1}. [Note that the melting temperature does *not* enter into the calculation].

29.**(D)** The internal (heat) energy of steam is equal to that of boiling water plus the latent heat of vaporization.

30.**(C)** The ice extracts its latent heat of fusion from the soft drink, which further cools down as a result.

31.**(B)** A change of state (e.g. melting) is accompanied by a change in volume (hence density) and also by a change in internal (heat) energy due to the latent heat of fusion (or vaporization). Mass and temperature remain constant.

32.**(D)** Evaporation and vaporization involve a change of state from liquid to vapour, while solidification is a change of state from liquid to solid.

33.**(A)** See revision notes.

34.**(B)** A reduction in external pressure (from 760 mm Hg) will make water boil at a temperature below 100°C. Conversely, an increased pressure will raise the boiling point of water above 100°C.

35.**(A)** See explanation to question 34 above.

36.**(D)** See revision notes.

37.**(B)** The saturation vapour pressure increases with temperature. It also varies from one liquid to another but it is independent of the volume of liquid or the external pressure.

38.**(C)** The vapour is saturated when it is in *dynamic equilibrium* with the liquid, i.e. when the amount of liquid being turned into vapour equals the amount of vapour turned into liquid.

39.**(D)** A hydrometer is used to measure *specific gravity*, a barometer to measure *air pressure* and a manometer to measure *gas pressure*.

40.**(D)** See revision notes.

41.**(A)** Condensation is the process by which water vapour turns into liquid water as the air temperatures drops below the dew point.

42.**(B)** The pressure inside a pressure cooker is higher than the atmospheric pressure. At a pressure of 2 atmospheres for instance, water boils at about 120°C, and food cooks faster at this temperature than at 100°C.

Revision Check-list

At the end of this chapter, the candidate should be able to:

- distinguish between *temperature* and *heat*
- state the effects of heat (other than expansion) on a substance.
- define the terms *specific heat capacity, heat capacity* and *specific latent heats of fusion and vaporization.*
- solve simple problems on the mixing of hot and cold substances.
- explain the temperature variation in a body as it is heated from a solid to a vapour phase and as it is cooled from the vapour to the solid phase.
- distinguish between *evaporation* and *boiling.*
- give examples of the applications of evaporation.
- state the factors which affect the melting and the boiling points of a substance, and their applications.
- distinguish between *saturated* and *unsaturated vapours.*

- explain the terms *vapour pressure* and *saturated vapour pressure* of a liquid.
- describe the variation of saturated vapour pressure with temperature.
- relate the saturated vapour pressure to the boiling point of a liquid.
- explain the terms *humidity*, *dew point* and *sublimation*.
- describe experiments (along with the necessary precautions) to
  (1) measure the (specific) heat capacity of a substance.
  (2) determine the (specific) latent heat of fusion of ice.
  (3) determine the (specific) latent of vaporization of water.

A B B
C B.C
I K N M O P Q R

10 Molecular Theory and Heat Transfer

10.1 Molecular Structure of Matter

- Matter is made up of tiny particles called **molecules**, which are in a continual state of motion.
- **In solids** the molecules
  (1) are arranged in regular patterns,
  (2) are tightly packed together,
  (3) are held together by strong forces of attraction called **cohesive forces**, and
  (4) are not free to move about, but merely vibrate about their mean positions.
- **In liquids**
  (1) the molecules are not arranged in any regular pattern;
  (2) the molecules are able to slide past one another;
  (3) cohesive forces between molecules, though present, are not as strong as in solids;
  (4) the molecules move at different speeds;
  (5) some of the faster molecules escape from the surface of the liquid, giving rise to *evaporation*.
- **In gases**
  (1) the molecules move about rapidly and randomly;
  (2) the molecules move at different speeds;
  (3) the molecules are farther apart than in solids or liquids; and
  (4) cohesive forces are very small.
- Solids are rigid, have fixed shapes and volume, and generally have higher densities than liquids and gases.
- A liquid has a definite volume but no definite shape. It takes on the shape of the container.
- A gas has no definite volume or shape. It will expand to fill the container.

10.2 Kinetic Theory of Gases

- The **kinetic theory** is used to explain the behaviour of gases, especially as revealed by the gas laws. The assumptions made in the theory are that:
  (1) a gas is composed of a large number of identical molecules moving at different speeds.
  (2) the molecules are small compared to the separation between molecules, hence the volume occupied by the molecules is small and negligible.
  (3) the molecules collide elastically (i.e. without loss of k.e.) with one another and with the walls of the container.
  (4) the time interval during which collision occurs is very small compared to the interval between collisions.
  (5) cohesive forces between molecules are small and negligible.
  (6) the pressure of the gas is due to the change in momentum of the molecules bombarding the walls of the container.
- Based on these assumptions, the *kinetic theory* yields

$$PV = \tfrac{1}{3}Nm\overline{v^2} \qquad (10.1)$$

where P = pressure of the gas
V = volume of the containing vessel
m = mass of each molecule
N = total numbers of molecules, and
$\overline{v^2}$ = average of the square of the different molecular velocities, or the *mean square velocity*.

- The square root of $\overline{v^2}$ is known as the **root-mean-square velocity**, v_{rms}.
- The kinetic theory is used to explain various observations regarding the properties of matter. These include:
- ***Temperature***: the *average k.e. per molecule* is directly proportional to the *absolute temperature*. A rising temperature indicates an increasing speed and k.e. of the molecules.
- ***Pressure***: is the combined force with which the gas molecules bombard a unit area of the wall, i.e. a pressure of 10 Nm^{-2} means that the molecules exert a combined force of 10 N on 1m^2 of the wall of the container.
- ***Absolute zero of temperature***: is the temperature at which the k.e. of the molecules should attain its minimum possible value (zero). It is the temperature at which all molecular motion should cease.
- ***Density***: is a measure of how tightly packed the molecules of a substance are. Solids have the highest densities since their molecules are most tightly packed, while gases, whose molecules are loosely packed have the lowest densities.
- ***Surface tension*** and ***Viscosity***: Both of these properties are due to the cohesive forces between the neighbouring molecules of a liquid (see sections 7.9 and 7.10).
- ***Capillarity***: If one end of a very thin glass (capillary) tube is immersed in a liquid such as water, the water rises to a higher level in the tube than in the container (Fig. 10.1a). The cohesive forces between molecules of different substances are called **adhesion** while those between molecules of the same substance are termed **cohesion**. The water rises in the glass tube because *the forces of adhesion between glass and water are greater than the forces of cohesion between water molecules*. For mercury in a glass tube, *the forces of cohesion between mercury molecules are greater than the forces of adhesion between mercury and glass*, and the mer-

cury is depressed in the tube as a result(Fig.10.1b). The phenomenon of *capillarity* is made use of in absorbent materials such as blotting paper, towel, cotton wool, wick, etc. It is also partly responsible for the rise of water from the soil through the roots and stems of plants.

- ***Cooling effects of evaporation***: Molecules of a liquid move with different speeds. Some of the more energetic (faster moving) molecules occasionally manage to overcome the cohesive forces at the liquid surface and escape from the surface into the vapour phase (evaporation). Since only the faster molecules escape, the average speed of the molecules remaining in the liquid state decreases, i.e. the liquid becomes *cooler*.

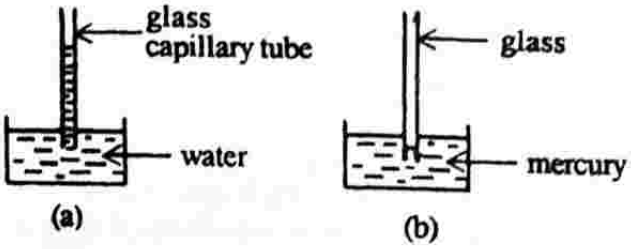


Fig. 10.1

- ***Diffusion***: If perfume is sprayed in one corner of a room, the scent is quickly picked up in another corner of the room. The (perfume) vapour has moved through the air in the room by ***diffusion***. This occurs largely through the movement of the molecules of the vapour through the air. Diffusion also occurs in liquids, although much more slowly than in gases. Diffusion in solids is virtually negligible at low temperatures but becomes appreciable at relatively high temperatures.

10.3 Conduction

- **Conduction** is the transfer of heat from one part of a body to another without the actual movement of any part of the body.
- If one end of a metal rod is dipped into a hot liquid, the other end soon becomes warmer and warmer as a result of the conduction of heat from the hot to the cold end.
- The molecules at the heated end acquire more energy and vibrate faster.
- These molecules collide with their neighbours and they too start to vibrate faster.
- The vibratory motion is eventually transmitted through the whole length of the rod, which shows up as a rise in temperature at the cooler end.
- Although conduction occurs in solids, liquids and gases, metals are by far the best **heat conductors** while gases are generally poor conductors, i.e. they are **heat insulators**.

Heat cannot be conducted through a vacuum.

10.4 Convection

- **Convection** is the transfer of heat from a hotter region of a fluid to a colder region through the actual motion of the fluid.
- In **natural convection** which occurs, for instance, when water is being heated on a stove, the water in contact with the hot base of the container rises because it is less dense than cold water.
- The cold, dense water moves down and a **convection current** is thus set up.
- In **forced convection** a hot fluid could be forced to circulate to a cold region (or vice-versa) through the action of a fan, for instance.
- Convection cannot occur in a vacuum.

10.5 Radiation

- **Radiation** is the transfer of heat between two bodies by means of **electromagnetic waves**.
- This mode of heat transfer does not require a material medium, i.e. *heat can be radiated through a vacuum*, as evidently occurs when the sun's heat is radiated through space to the earth.
- All surfaces emit energy in the form of electromagnetic waves.
- Heat is radiated as electromagnetic waves with wavelengths which are a little longer than that of light (**infrared radiation**).
- The intensity of heat radiated by a surface increases with:
  (1) the **area** of the surface, and
  (2) the **absolute temperature** of the surface.
- The heat radiated also depends on the colour and brightness of the surface: *black, dull surfaces* are generally *better radiators* of heat than *silvery and shiny surfaces*. Also, black surfaces are better *absorbers of radiant heat* than silvery, shiny surfaces.

10.6 Applications of Heat Transfer

- Cooking pots are made of metals because of their good conductivity.
- Their handles are, however, made of poor conductors such as wood or plastic so that they do not become too hot to hold.
- The engine of an automobile is cooled by **convection** in which cold water (stored in the *radiator*) is circulated to the hot parts of the engine where heat is removed.
- A fan continuously blows cold air unto the radiator (**forced convection**) to cool the water inside.
- A **thermos flask** is used to keep hot liquids from cooling down or cold liquids from getting warm. It consists of a double-walled vessel with a vacuum between the walls. The surfaces on either side of the vacuum are silvered and the vessel is covered

with a cork of low conductivity.

- When hot liquid is placed in the vessel, heat loss is limited as:
  (i) the vacuum prevents heat flow by conduction and convection,
  (ii) the silvery surfaces limit heat flow by radiation, and
  (iii) the cork limits heat flow by conduction.

True or False - Type Questions

Answer *True*(T) or *False* (F) to the following questions.

1. The following substances are classified as *crystals* or *amorphous* solids
   a. Sodium chloride (*crystal*)
   b. Lead (*crystal*)
   c. Germanium (*amorphous*)
   d. Silicon (*amorphous*)
   e. Copper (II) tetraoxosulphate (VI) (*crystal*)
   f. Glass (*amorphous*)
   g. Ice (*amorphous*)
   h. Carbon (*crystal*)
   i. Natural rubber (*amorphous*)
   j. Wood (*amorphous*)
   k. Steel (*crystal*)

2. The following deductions can be validly made from the kinetic - molecular theory of matter:
   a. Molecules of all matter are always in motion
   b. The molecules of a liquid move more freely than those of a solid.
   c. For a liquid at rest, the molecules of the liquid are also at rest.
   d. When a body is heated, the average speed of its molecules increases.
   e. The latent heat of vaporization represents the energy required to break the cohesive forces between neighbouring molecules of a liquid.
   f. The internal energy associated with a body is equal to the average kinetic energy of its molecules.
   g. If a gas in a closed container is heated, there will be an increase in the number of molecular collisions per unit time and a greater force will be exerted during each collision.
   h. The effect of gravity on the speed of the molecules of a gas is negligible.
   i. When a gas expands at constant temperature, its pressure decreases and the total kinetic energy of its molecules decreases.
   j. If two ideal gases are at the same temperature, the average kinetic energy of the molecules of one must be equal to the average kinetic energy of the molecules of the other.
   k. If two gases occupy equal volumes at the same temperature and pressure, the number of molecules in one must be equal to the number of molecules in the other.

3. The following are *assumptions* of the kinetic theory of gases:
   a. Molecules are continuously in random motion.
   b. Energy losses during molecular collisions are negligible.
   c. All molecules move with the same speed.
   d. The force exerted on any one molecule by neighbouring molecules is negligible in-between and during collisions.
   e. The total volume of all the molecules is negligible compared to the volume of the container.
   f. The separation between molecules is, on average, much greater than the dimensions of each molecule.
   g. The time elapsed during collisions is roughly equal to the time interval between collisions.
   h. The forces of attraction between the gas molecules and the wall of the container give rise to pressure.
   i. Molecules are, on average, not slowed down by collisions.

4. a. A hot cup of tea placed on a table loses heat by convection and radiation only.
   b. The human body loses heat to the surrounding air only by convection.
   c. Land and sea breezes are natural convection currents.
   d. The vacuum in a thermos flask prevents heat loss due to convection only.
   e. Convection occurs in liquids and gases but not in solids.
   f. Radiant heat cannot travel through a vacuum.
   g. Rough surfaces radiate heat better than polished surfaces.
   h. Dark surfaces absorb radiant heat better than bright surfaces.

Answers to True or False - Type Questions

1. a (T)
   b (T) All metals, including lead, are *crystalline*.
   c (F) Germanium, a semiconductor, is *crystalline*.
   d (F) Silicon, also a semiconductor, is *crystalline*.
   e (T)
   f (T)
   g (F) Ice is *crystalline*. Note that it has a definite melting point (0°C at normal atmospheric pressure).
   h (T) Diamond and graphite, two different forms of carbon, are both *crystalline*.
   i (T)
   j (T)
   k (T) Same reason as (b) above.

2. a (T)
   b (T) This is because cohesive forces are weaker in liquids.
   c (F) The molecules of a liquid are always in motion even when the liquid appears to stand still.
   d (T) The average speed of the molecules is a measure of the *temperature* of the body.
   e (T) Note that inter-molecular cohesive forces are virtually non-existent in gases (and vapours).
   f (F) The internal energy is equal to the *total* (not average) kinetic energy of the molecules.
   g (T) As the gas is heated, the average molecular speed as well as the momentum of each molecule increases. If molecules are moving faster within the same space, there must be more collisions per unit time. Furthermore the force exerted during each collision, or the change in momentum per unit time, will also increase.
   h (T) This explains why a gas will expand to fill its container. [If gravity were to affect the molecular speed, then some molecules moving upwards will eventually come to rest, and we may expect to find more gas at the bottom of a tall container than at the top, which is *not* so].
   i (F) The pressure decreases but the total kinetic energy remains constant since the temperature is constant.
   j (T) The average kinetic energy of a gas is equal to $3kT/2$, where k is the Boltzmann's constant and T is the absolute temperature. If T is the same for both gases, the average kinetic energy of their molecules must also be the same.
   k (T) From the equation $PV = nRT$, if P, V and T are identical for two gases, n must be the same for the gases. This is in fact *Avogadro's hypothesis*.

3. a (T)
   b (T)
   c (F) Different molecules move with different speeds.
   d (F) The force is negligible in-between collisions but not during collisions, which result in a change in momentum and in the effect known as *pressure* when such collisions are made with the wall of the container.
   e (T) Molecules are very *small* and spaced *far apart*.
   f (T) This is another way of stating (e) above.
   g (F) The time elapsed during collisions is negligible compared to the time interval between collisions.
   h (F) Pressure is the force exerted per unit area on the wall by the change in momentum of molecules which collide with the wall. This has nothing to do with forces of adhesion between the molecules and the wall.
   i (T) This is another way of stating (b) above.

4. a (F) The hot cup of tea loses heat by *conduction* through the walls of the cup, by *convection* to air currents in contact with the outer surface of the cup and *evaporation* from the exposed surface of the tea, and by *radiation* from all exposed surfaces of the cup and its content.
   b (F) The body loses heat by *conduction* through the skin, by *convection* from the skin surface and also by *radiation* from the skin surface. Considerable heat is also lost by the *evaporation* of sweat from the skin.
   c (T) The convection currents are set up as a result of density differences between cold and warm air.
   d (F) It also prevents heat loss by conduction.
   e (T)
   f (F) Heat is radiated through a vacuum, as the heating of the earth by the sun clearly shows.
   g (T) Polished, silvery surfaces are poor radiators of heat.
   h (T) Dark surfaces, which are good *emitters* of radiant heat, are also good *absorbers*. Bright surfaces are poor emitters and poor absorbers of radiant heat.

SSCE/JME - Type Objective Questions

1. The differences between a crystalline solid and an amorphous solid are that a crystalline solid
   I. has a regularly repeating structure while an amorphous solid does not.
   II. has a definite melting point while an amorphous solid does not.
   III. is always hard while an amorphous solid is always soft.
   IV. melts upon heating while an amorphous solid vaporizes upon heating.
   Which of the statements above are correct?
   A. I and II only B. III and IV only
   C. I, II and III only D. I, II and IV only

2. When a certain quantity of sugar is dissolved in water in a glass container, the level of the water does not change appreciably. Which of the following statements best explains this?
   A. The sugar molecule is smaller than the water molecule.
   B. The sugar molecules are absorbed by the water molecules.
   C. Water is a suitable solvent for sugar.
   D. The sugar molecules occupy the spaces between water molecules.

3. The concave meniscus of water in a glass tube is due to the fact that the
   A. adhesion between water and glass molecules is greater than the cohesion between water molecules.
   B. adhesion between glass and water molecules is smaller than the cohesion between water molecules.
   C. molecules of water near the glass are lighter than the molecules in the central part of the water column.
   D. weight of the water pulls down on the central part of the water column.

4. The following phenomena are evidences of the particle nature of matter *except*
   A. diffusion B. photoelectric effect
   C. diffraction D. Brownian motion

5. The action of a towel in drying the body after a bath is explained by
   A. diffusion B. capillarity
   C. osmosis D. evaporation

6. Evaporation of a liquid results in cooling because the
   A. volume of the liquid decreases.
   B. density of the liquid decreases.
   C. vapour pressure of the liquid decreases.
   D. average kinetic energy of the molecules of the liquid decreases.

7. Mercury which is spilled onto a glass surface forms ball-like shapes because
   A. mercury is a metal.
   B. the cohesive force between its molecules is greater than the adhesive force between mercury and glass molecules.
   C. the cohesive force between its molecules is less than the adhesive force between mercury and glass molecules.
   D. the viscosity of mercury is high.

8. If water is gradually added to a few grains of table salt in a glass cup and left unstirred, the whole water will eventually taste salty. This is due to
   A. diffusion B. osmosis
   C. capillarity D. convection

9. A vapour is said to be *saturated* when
   A. more molecules return to the liquid than leave it.
   B. more molecules return to the vapour than leave it.
   C. the number of molecules leaving the liquid for the vapour is equal to the number leaving the vapour for the liquid.
   D. the vapour pressure is equal to the atmospheric pressure.

10. According to the kinetic theory of gases, the collision of the gas molecules with the walls of the container is responsible for the
    A. pressure of the gas B. temperature of the gas
    C. viscosity of the gas D. density of the gas

11. In which of the following states will the average speed of the molecules of water be highest?
    A. Ice B. Water
    C. Water-steam mixture D. Steam

12. Temperature is the property of a body which is proportional to the
    A. total kinetic energy of its molecules.
    B. average kinetic energy of its molecules.
    C. average speed of its molecules.
    D. maximum speed of its molecules.

13. When a fixed mass of gas is cooled at constant volume, its pressure decreases because its molecules
    A. decrease in number.
    B. occupy a smaller space.
    C. collide less frequently with the walls of the con-

tainer
D. settle at the bottom of the container.

14. The density of a gas depends on the
A. speed of its molecules.
B. potential energy of its molecules.
C. volume of its molecules.
D. separation between its molecules.

15. The expansion of an ideal gas at constant temperature results in an increase in the
A. average separation between its molecules.
B. number of collisions between molecules per unit time.
C. number of molecules per unit volume.
D. average speed of its molecules.

16. A concrete floor feels colder than a rugged floor on a cold morning because
A. rug loses heat to the bare feet at a faster rate than concrete.
B. rug loses heat to the bare feet at a slower rate than concrete.
C. rug is a better conductor of heat than concrete.
D. concrete is a better conductor of heat than rug.

17. The following three substances are correctly listed in ascending order of their thermal conductivities as
A. glass, copper, steel B. steel, glass, copper
C. copper, steel, glass D. glass, steel, copper.

18. The mechanism of heat transfer from one point to another through the vibration of the molecules of the medium is called
A. convection B. conduction
C. radiation D. diffusion

19. A lagged steel bar of length 50 cm has its ends immersed in melting ice and boiling water. The temperature at a point 20 cm from the hot end is
A. 40°C B. 50°C C. 60°C D. 80°C

20. The transfer of heat by convection in a liquid is due to the
A. increased vibration of the molecules of the liquid about their mean positions.
B. translational motion of the molecules of the liquid.
C. expansion of the liquid as it is heated.
D. latent heat of vaporization of the liquid.

21. The heat from a fire in a room is transmitted to various parts of the room primarily by
A. convection B. conduction
C. diffusion D. radiation

22. Which of the under-listed colours of surfaces will radiate heat energy best?
A. Black B. White C. Red D. Yellow

23. On a hot and sunny day, the most comfortable colour of attire is
A. black B. white C. red D. blue

24. The heat from the sun reaches the earth's surface by the process of
A. convection B. conduction
C. radiation D. precipitation

25. Which of the following phenomena cannot be explained by the molecular theory of matter?
A. conduction B. convection
C. expansion D. radiation

26. Two identical kettles X and Y are filled with water at 100°C. The outside surface of X is painted black while that of Y is polished.
A. X cools faster because a blackened surface radiates heat faster than a polished surface.
B. X cools faster because it is a better conductor of heat.
C. Y cools faster because it is a better reflector of heat.
D. Y cools faster because a polished surface is a better radiator of heat than a blackened surface.

27. A thermos flask has a double-walled glass container in which heat losses are minimized by
I. evacuating the space between the glass walls.
II. silvering the surfaces on either side of the evacuated space.
III. covering the container with a cork of low thermal conductivity.
Which of the above measures minimize(s) heat loss by conduction?
A. I only B. I and II only
C. I and III only D. I, II and III.

28. Which of the measures listed in question 27 minimize(s) heat loss by convection?
A. I only B. II only
C. I and II only D. I and III only.

29. Which of the measures listed in question 27 minimize(s) heat loss by radiation?
A. I only B. II only
C. I and II only D. II and III only.

30. In an electric kettle the heating element is usually located near the bottom of the kettle because
I. cold water is denser than hot water.

II. heat is transmitted to all parts of the water primarily by convection.
III. heat is quickly conducted to all parts of the water.
IV. loss to the surroundings is minimized.
Which of the above statements are correct?
A. I and II only **B.** III and IV only
C. I, II and III only **D.** I, II and IV only

31. Cooking pots are usually made of metals because metals
A. have high coefficient of expansion.
B. have low specific heat capacity.
C. are poor radiators of heat.
D. are good conductors of heat.

32. A house whose roof is painted white feels cooler on a hot day than one whose roof is painted black because
A. white is a better conductor of heat than black.
B. black is a better conductor of heat than white.
C. white is a better reflector of heat than black.
D. black is a better reflector of heat than white.

33. Which of the following is *not* a suitable method for reducing heat loss from a hot metal ball?
A. Placing it in a vacuum.
B. Painting it black.
C. Placing it on a rubber support.
D. Wrapping it with cotton wool.

34. Diffusion
I. occurs in gases
II. occurs more slowly in liquids than in gases
III. never occurs in solids
IV. occurs at the same rate in all gases
Which of the above statements are correct ?
A. I and II only **B.** I,II and III only
C. I,II and IV only **D.** I,II,III and IV.

35. A bottle of perfume is opened in one corner of a room and the scent is soon picked up in another part of the room. The perfume moves through the air in the room by
A. convection **B.** evaporation
C. diffusion **D.** osmosis

Answer Key

1. A	7. B	13. C	19. C	25. D	31. D
2. D	8. A	14. D	20. B	26. A	32. C
3. A	9. C	15. A	21. D	27. C	33. B
4. C	10. A	16. D	22. A	28. A	34. A
5. B	11. D	17. D	23. B	29. B	35. C
6. D	12. B	18. B	24. C	30. A	

Solutions to Objective Questions

1. **(A)** An amorphous solid melts over a range of temperatures. Certain amorphous solids are harder than some crystals.

2. **(D)** Water molecules have large spaces between them into which the sugar molecules can fit without appreciably changing the overall volume of the water.

3. **(A)** The meniscus is convex if the forces of cohesion are greater than the forces of adhesion, as in mercury in a glass tube.

4. **(C)** *Diffusion* and *Brownian motion* are evidences of molecular motion. *Photoelectric effect* (i.e. the ejection of electrons from a metal surface by light quanta) is evidence that matter is made up of electrons and other particles. *Diffraction* is evidence of the wave-like nature of light.

5. **(B)** Water is pulled up the fine pores in the cotton

towel. This also explains the soaking of ink by blotting paper, the soaking of water by sugar, the soaking of kerosene by wick, and other similar phenomena.

6. **(D)** See revision notes.

7. **(B)** If adhesive forces outweigh cohesive forces, the liquid spreads out into a thin film (e.g. water on glass). The liquid is then said to "wet the surface". Thus water wets glass but mercury does not. This depends on the nature of the liquid as well as the solid surface. Water, for instance, does not wet wax.

8. **(A)** This is caused by the diffusion of salt molecules through the spaces between water molecules.

9. **(C)** See revision notes.

10. **(A)** Pressure is a direct measure of the rate of collision of the molecules of the gas with the walls of the container.

11. **(D)** The average speed is highest in the state in which the temperature is highest, i.e in *steam*. The speed is lowest in ice.

12. **(B)** Although the average speed is somewhat a measure of the (absolute) temperature, it is important to note that the *direct proportionality* exists only between the temperature and the *average kinetic energy* of the molecules. The total k.e. is equal to the internal (heat) energy of the body.

13. **(C)** The number of molecules in a *fixed mass* of gas remains constant. As the temperature of the gas is reduced, the momentum of its molecules is correspondingly reduced, resulting in *fewer* collisions with the walls of the container.

14. **(D)** As the separation between the molecules decreases, the total volume occupied by the gas decreases and its density (which is inversely proportional to the volume) increases

15. **(A)** See (14) above. It should be noted that the rate of collisions between molecules actually *decreases* as the gas expands.

16. **(D)** Concrete conducts heat away from the feet more quickly than the rug does, hence the "coldness" is felt more with the feet on concrete. Note that since the human body is at a higher temperature than the surroundings, the direction of heat flow is always from the feet to the concrete or the rug, and not the other way round.

17. **(D)** Metals are generally better conductors of heat than non-metals. The best heat conductors, in order, are *silver, copper, gold and aluminium*. Steel is a poorer conductor than copper. Glass (a non-metal) is the poorest conductor of the three listed substances.

18. **(B)** See revision notes.

19. **(C)** In a lagged (i.e. well insulated) steel bar, the temperature gradient is $\Delta T/L = (100 - 0))/50 = 2°C/cm$. The temperature at the hot end is 100°C and since this decreases by 2°C for every cm of bar, the temperature will decrease by 40°C at 20 cm from the hot end. The temperature at that point is thus $100 - 40 = 60°C$.

20. **(B)** Convection involves the direct translational motion of the molecules of the liquid.

21. **(D)** Although some heat is also transmitted by convection by the air currents in the room, radiation is the *predominant* mechanism of heat transfer.

22. **(A)** A black surface is the best radiator of heat, while a polished (silvery) surface is the poorest radiator.

23. **(B)** White, being the poorest radiator of heat, is also the poorest absorber of radiant heat (from the sun). Black, the best radiator, is also the best absorber of radiant heat. The white attire feels coolest while the black attire feels hottest.

24. **(C)** Radiation is the only mode of heat transfer which can occur through a vacuum (the space between the sun and the earth is mostly a vacuum).

25. **(D)** Conduction is heat transfer by *molecular vibration* and convection by *molecular motion*. Expansion involves an increase in the *separation between molecules*. A material medium is not necessary for heat transfer by radiation.

26. **(A)** As the kettles lose heat primarily by radiation, the blackened kettle radiates heat faster and thus cools down faster.

27. **(C)** Heat cannot be conducted through the evacuated space and the heat conducted through the cork is small because of its low thermal conductivity.

28. **(A)** Convection cannot occur in a vacuum. The two other measures are not relevant to convection.

29.(B) A silvered surface radiates very little heat. As heat can be radiated through a vacuum, measure (I) cannot reduce radiation. (III) is not relevant to radiation.

30.(A) As the water near the bottom of the kettle is heated, its density decreases. A convection current is set up as the warm water rises to the top while the cold water falls to the bottom of the kettle. Heat transfer by conduction is very slow in water, which is a poor conductor of heat.

31.(D) Being good conductors of heat,the metal pots permit quick transfer of heat from the fire to the food inside the pot.

32.(C) White is a poor absorber of radiant heat. Hence most of the heat incident upon a white surface is reflected. A black surface absorbs most of the heat incident upon it and reflects very little.

33.(B) The black paint will *increase* heat loss by radiation. A vacuum reduces heat loss by conduction and convection. The rubber support or the cotton wool reduces heat loss by conduction, both being poor conductors of heat.

34. (A) Diffusion occurs very slowly in solids at low temps., but becomes appreciable at high temps. The rate of diffusion of a gas decreases as its density increases [A light gas such as hydrogen, for instance, will diffuse faster than a heavier gas such as oxygen].

35.(C) Molecules of the perfume's vapour move through the air molecules by *diffusion*. This occurs even if the air in the room appears to be perfectly still (i.e.no convection). The process may, however, be speeded up by convection.

Revision Check-list

At the end this chapter, the student should be able to:

- explain the basic features of the *molecular theory of matter*.
- compare the molecular structures of solids, liquids and gases.
- distinguish between *crystalline* and *amorphous* solids.
- list the assumptions of the *kinetic theory of gases*.
- relate the temperature and pressure of a gas to molecular motion.
- use the kinetic theory to explain pressure-volume, volume-temperature and pressure-temperature relationships for an ideal gas.
- relate the properties *density, surface tension, viscosity, capillarity* and *diffusion* to molecular structure.
- explain why water wets glass while mercury does not.
- explain why evaporation causes cooling
- explain in terms of the molecular theory, what happens to the (latent) heat supplied to a substance undergoing a change of phase.
- explain the terms *conduction, convection* and *radiation* and relate them to molecular structure.
- classify common materials as good or poor conductors of heat.
- classify surfaces as good or poor emitters and absorbers of radiant heat.
- distinguish between *natural* and *forced convection*.
- state some important applications of the various heat transfer phenomena as in cooking pots, thermos flasks, etc.

11 Waves and Sound

11.1 Description of a Wave

- A *wave* is a disturbance which travels outward from its source, carrying energy along with it.
- A stone dropped into water, for example, sets up a circular ring of disturbance (up-and-down motion of water particles) which travels outward from the point at which the stone landed in the water (Fig 11.1). This disturbance is called a *water wave*.

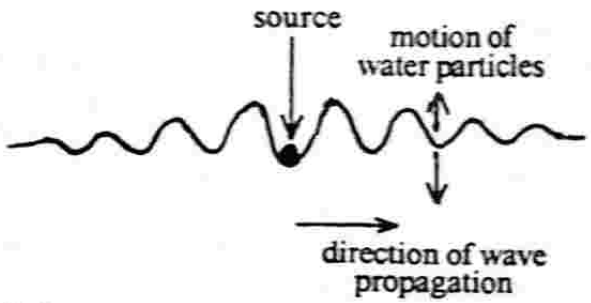


Fig. 11.1

- A *transverse wave* is one in which the particle displacements are perpendicular to the direction along which the wave travels. The water wave is a transverse wave since the up-and-down (vertical) motion of the water particles is perpendicular to the direction of wave propagation (horizontal, along the water surface).
- *Electromagnetic waves* (such as radio and light) are also transverse in nature, as the electric and magnetic vibrations are perpendicular to the direction of wave propagation.
- *A longitudinal wave* is one in which the particle displacements are parallel to the direction along which the wave travels. *Sound wave* is an example of a longitudinal wave.

11.2 Graphic Representation of a Wave

- Both transverse and longitudinal waves are represented by a sine curve (Fig. 11.2). The figure shows the displacement (y) of a vibrating particle of the medium as a function of the distance (x) from the source of the disturbance. The following parameters are defined with respect to the wave:
- *Crest* is the highest point on the wave.
- *Trough* is the lowest point on the wave.
- *Amplitude* (A) of the wave is the maximum displacement of a particle from its equilibrium position.
- *Wavelength* (λ) of the wave is the distance between any two successive corresponding points on the wave. It is the distance from crest-to-crest, or from trough-to-trough.

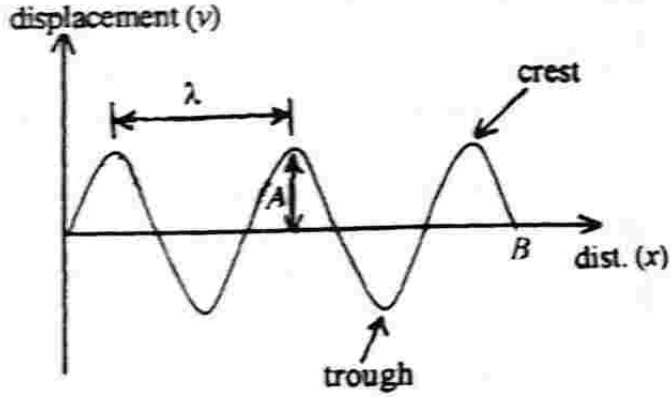


Fig. 11.2

- *Frequency* (f) is the number of complete vibrations per second at any given point.
- *Period* (T) is the time required for one complete vibration.
- *Velocity* (v) of the wave is the displacement through which the wave is propagated in one second.
- Mathematically, a wave travelling in the positive x-direction is expressed as:

$$y = A \sin\frac{2\pi}{\lambda}(vt - x) \qquad (11.1)$$

where t is the time

- The frequency, period, wavelength and wave velocity are related by the equations

$$f = \frac{1}{T} \qquad (11.2)$$

and

$$v = \frac{\lambda}{T} = f\lambda \qquad (11.3)$$

- *Units:* y, A, λ, x all have units of [m], $v = [\text{m.s}^{-1}]$, $T = [\text{s}]$, $t = [\text{s}]$
  f = [cycles per sec] = [hertz], abbreviated to [Hz].

11.3 Properties of Waves

- All known waves undergo the phenomena of *reflection, refraction, diffraction* and *interference*.
- *Reflection:* Waves are reflected upon encountering a barrier. If the barrier is plane, the *angle of incidence is equal to the angle of reflection*. The speed and wavelength of the waves remain unchanged as long as they remain in the same medium after reflection.
- *Refraction:* Waves undergo a change in wavelength, speed and direction upon crossing from one medium to another, but their frequency remains unchanged. This is known as *refraction*. If the waves cross from medium A to medium B, the *refractive index* of the medium B with respect to A

is equal to the velocity of the waves in A divided by their velocity in B.

- ***Diffraction:*** If waves encounter an obstacle whose dimension is about the same as the wavelength of the waves, they bend around the obstacles, i.e. they are ***diffracted***. Thus sound waves are diffracted around the corners of a building while radio waves are diffracted around hills.
- ***Interference*** results from the superposition of two or more wave-trains. ***Constructive interference*** occurs when the two waves match each other crest-for-crest and trough-for-trough, i.e. when they are in phase with each other. In this case the amplitude of the resulting wave is larger than that of either component wave. ***Destructive interference*** occurs when the two wave-trains are out of ***phase***, e.g. with the crest of one coinciding with the trough of the other. This results in a reduced or zero amplitude for the resulting wave.
- ***Polarization***: In a transverse wave such as light, the vibrations can be in any direction perpendicular to the direction of wave motion. It is possible, under certain circumstances, to restrict the vibrations to one direction only, while vibrations in the other transverse directions are cut off (Fig. 11.3). This phenomenon, known as ***polarization***, is possible only with transverse waves. Longitudinal waves *cannot* be polarized.

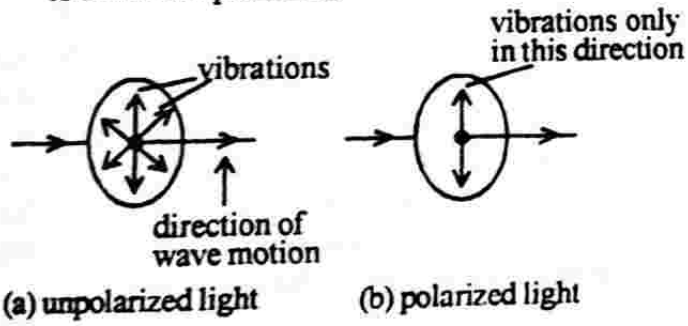


Fig. 11.3

- ***A stationary wave*** (also called ***standing wave***) is produced if two identical sets of waves travelling in opposite directions are super-imposed (Fig. 11.4). In a stationary wave, some points, called ***nodes*** (marked N) are permanently at rest. The points halfway between two consecutive nodes undergo maximum displacements, and are called ***antinodes*** (marked A).

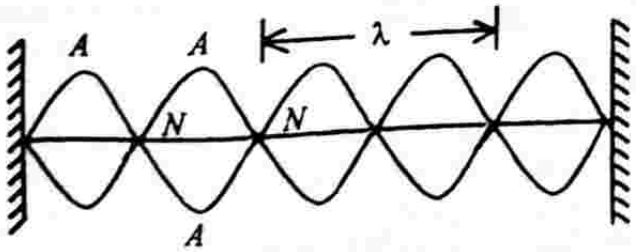


Fig. 11.4

11.4 Production and Propagation of Sound

- Sound waves are produced by vibrating bodies, e.g. a guitar string or a drum's surface.
- The to-and-fro motion of the vibrating body sets air particles next to it into vibration.
- This produces regions of compressed air (***compressions***) alternating with regions of rarefied air (***rarefactions***).
- These alternating series of compressions and rarefactions travel away from the source at a speed which is known as the ***speed of sound***.
- Sound requires a ***material medium*** for its propagation, i.e. *sound waves cannot travel in a vacuum*. In this respect sound waves differ from electromagnetic waves (such as light) which can travel in a vacuum.
- Waves which can only be propagated in material media are known as ***mechanical waves***.
- Sound waves travel through materials such as metals, concrete, water or glass *faster* than through air.

11.5 Speed of Sound

- The speed of sound *in air* is about 330 ms^{-1} at 0° C.
- It ***increases*** with ***increasing*** temperature. The speed of sound is about 1,500 ms^{-1} in water and about 5,000 ms^{-1} in steel at ordinary temperatures.
- For a gaseous medium, the speed of sound is not affected by gas pressure.

11.6 Reflection of Sound

- Like other waves, sound waves can be reflected and refracted.
- The reflection of sound waves from a plane barrier gives rise to an ***echo***. Suppose waves originating from a source are reflected back from a barrier which is at a distance d from the source after t seconds. The time taken for the original wave to travel from the source to the barrier is $t/2$ secs, and the velocity (v) of the wave thus $d/(t/2)$, or

$$v = \frac{2d}{t} \qquad (11.4)$$

- The determination of the velocity of sound is one of the important uses of an echo.

11.7 Interference of Sound

- When two sound waves of slightly different frequencies f_1 and f_2 are superimposed, ***beats*** of frequency $f_1 - f_2$ are produced.

11.8 Pitch and Intensity

- The ***pitch*** of a sound is a measure of the depth of its tone and this depends on the ***frequency*** of the sound.
- A deep (i.e low pitch) sound has a low frequency while a shrill (high pitch) sound has a high frequency.
- The human ear is capable of detecting sound waves of frequencies ranging from 20 Hz (low pitch) to 20,000 Hz (high pitch).
- Sound waves of frequency higher than 20,000 Hz are called ***ultrasonic*** waves.
- A dog-whistle emits ultrasonic sound, which can be heard by dogs but not by humans.
- The ***intensity*** or ***loudness*** of a sound wave at any point is a measure of the power transmitted by the wave through a unit area at that point. This increases with increasing amplitude of vibration of the waves.

11.9 Vibrating Strings

- ***Stringed musical instruments*** such as the ***guitar, violin*** or ***piano*** depend for their sound on the vibration of a wire or string.
- A ***stationary, transverse*** wave is set up in the string whose ***fundamental frequency*** (f_o) of vibration is given by

$$f_o = \frac{1}{2L}\sqrt{\frac{T}{m}} \qquad (11.5)$$

where L = length of wire in [m]
T = tension in the wire in [N], and
m = mass per unit length of wire in [kg.m^{-1}].

- The string can also be made to vibrate in such a way as to emit *overtones* (also called *harmonics*) of frequencies $2f_o$, $3f_o$, $4f_o$, ... which are referred to as the ***first overtone, second overtone, third overtone,*** ... respectively (Fig. 11.5).

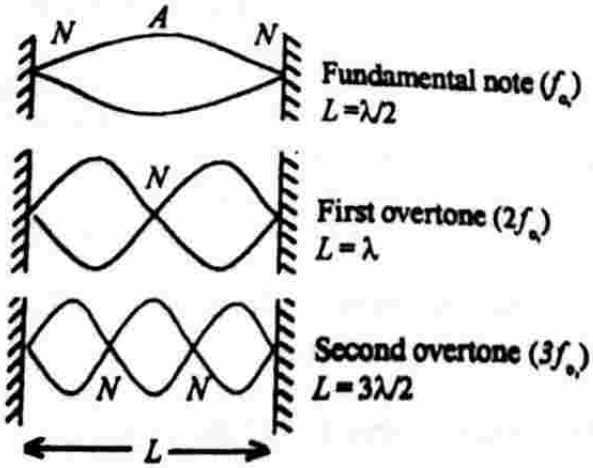


Fig. 11.5

11 10 Vibrating Air Columns

- The vibration of air columns inside a pipe forms the basis of the operation of ***wind instruments*** such as the ***trumpet, flute*** or ***pipe organ***.
- A column of air in a pipe has a natural frequency of vibration which depends on the length of the pipe. (The student can demonstrate this by blowing across two empty bottles of different lengths; the longer bottle emits a deeper, i.e. lower frequency, note).
- The notes result from ***stationary, longitudinal waves*** set up in the pipe with the closed end as a node and the open end as an antinode.
- Like vibrating strings, vibrating air columns also emit fundamental tones and overtones.
- In ***percussion instruments***, the notes are produced by bars, plates or stretched leather which are set into vibration by striking, as in **bells**, ***xylophones*** and ***drums***.

11.11 Forced Vibrations and Resonance

- Any body which is capable of vibrating has its own ***natural frequency*** of vibration.
- When such a body receives small impulses of the same frequency as the natural frequency, the body is set into ***forced vibration*** with a large amplitude. This phenomenon is called ***resonance***.
- Consider a tube which is partly filled with water such that the length of the air column above it can be varied by adjusting the water level (Fig. 11.6). If a ***tuning fork*** is made to vibrate near the open end, a loud sound is heard when the frequency of vibration of the tuning fork is equal to the natural frequency of vibration of the air column.

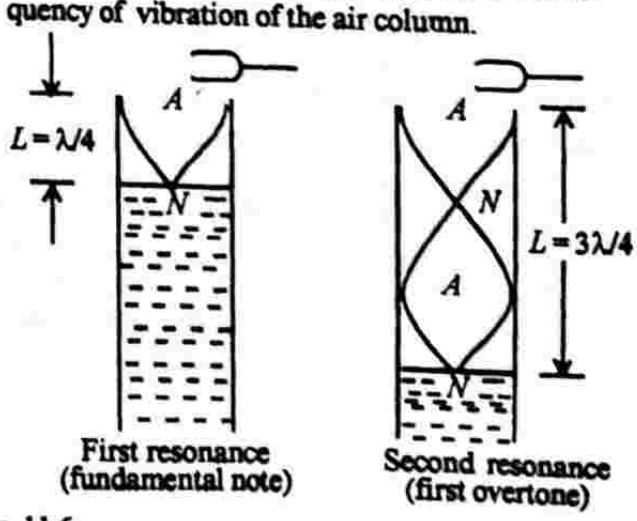


Fig. 11.6

- This resonance results from the formation of a stationary wave. The open end of the tube is an antinode (point of maximum displacement of particles) while the closed end (water surface) is a node

(point of zero displacement).

- The shortest air column which produces resonance has a length $L = \lambda/4$ and the velocity of sound is $v = f\lambda$, or

$$v = 4f_oL \qquad (11.6)$$

where f_o is the frequency of the tuning fork.

- If the length of the air column is increased by lowering the water level in the tube, a second resonance (first overtone) occurs at $L = 3\lambda/4$.
- The frequency of the overtones are odd multiples of the fundamental frequency ($3f_o$, $5f_o$, $7f_o$, ...)
- For a pipe open at both ends, antinodes are set up at both ends during resonance (Fig. 11.7)
- For such open pipes, $L = \lambda/2$ at the fundamental frequency while $L = \lambda$ at the first overtone.
- An open pipe produces overtone frequencies which are integral multiples of the fundamental frequency ($2f_o$, $3f_o$, $4f_o$, ...)

11.12 Quality of Sound

- Two notes of the same pitch and frequency will sound different if emitted by different instruments such as a flute and a piano.
- As already noted, each instrument emits overtones in addition to the fundamental frequency.

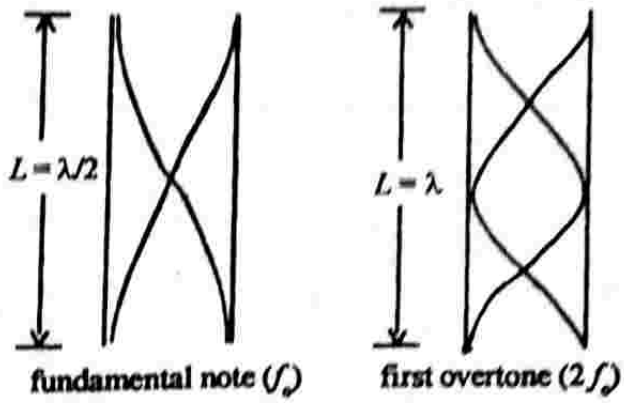


Fig. 11.7

- The combination of the fundamental note and the various overtones differs from one instrument to another.
- This characteristic, called the *quality* of the note, makes it possible for a listener to identify which particular instrument (e.g. a piano or a flute) played a note, without seeing the instrument.
- The *octave* of a note has a frequency which is twice the frequency of the note, i.e. if note C' is the octave of C, then $f_c' = 2f_c$.

True or False - Type Questions

Answer *True* (T) or *False* (F) to the following questions.

1. The wavelength of a waveform can be defined as the distance between
   a. successive troughs.
   b. a node and an adjacent antinode.
   c. successive nodes.
   d. two successive points that are exactly in phase.
   e. two successive points that are out of phase by π.

2. If a stick is made to oscillate up-and-down in the middle of a pool of water:
   a. longitudinal waves are set up in the water.
   b. water particles move outwards from the centre of disturbance.
   c. water particles move vertically up - and -down, but not sideways.
   d. energy is transmitted outwards from the centre of disturbance.
   e. the crests and troughs travel horizontally outwards from the centre of disturbance.
   f. the wave velocity is the distance covered by a water particle in one second.
   g. the wave velocity is the distance covered by any given crest in one second.
   h. the wave amplitude is the maximum distance covered by a water particle.
   i. the wavefronts are parallel to the direction of wave motion.

3. Some characteristics of longitudinal and transverse waves are that:
   a. the particles of the medium in which the wave travels oscillate in a direction perpendicular to that of wave motion in a transverse wave.
   b. the particles of the medium can oscillate along any direction in a longitudinal wave.
   c. the speed of a longitudinal wave changes as it crosses from one medium to another whereas that of a transverse wave remains unchanged.
   d. only transverse waves can be polarized.
   e. only longitudinal waves can interfere destructively.
   f. longitudinal waves are mechanical waves whereas transverse waves are not.

4. The following are examples of transverse waves:
   a. ripples on water.

b. sound waves in steel wire.
c. x-rays.
d. stationary waves in a resonance tube.
e. stationary waves in a vibrating string.

5. Some characteristics of a stationary wave are that:
a. it is formed whenever two waves travelling in opposite directions interfere in a medium.
b. it is formed when a wave travelling in a medium is reflected normally upon itself.
c. the node is always stationary while the antinode is a point of maximum displacement.
d. it can only be transverse, not longitudinal.
e. the distance between two successive points of maximum displacement is equal to the wavelength of the stationary wave.
f. the distance between a node and an adjacent antinode is equal to one-quarter of the wavelength.

The frequency of the note produced by a vibrating string
a. increases with the length of the string.
b. increases with the tension in the string.
c. decreases as the density of the string material increases.
d. varies with the amplitude of vibration.
e. varies with the cross-sectional area of the string.
f. is lowest in the fundamental mode

7 Sound
a travels faster in steel than in air.
b. is a mechanical and transverse wave.
c. can be reflected, refracted, diffracted and polarized.
d. can be produced only by a vibrating object.
e. can be transmitted through any material substance whether gas, liquid or solid.
f. is a longitudinal and electromagnetic wave.
g cannot be propagated through a vacuum.
h. travels faster in cold air than in hot air.
i travels with the same speed in air, regardless of air pressure or the frequency of the sound.

8 If a sound wave travelling in air moves into water,
a. its speed decresases while its wavelength increases.
b. its speed and wavelength increase.
c. its frequency decreases.
d. its speed increases while its frequency remains unchanged.
e. its direction remains unchanged.

9. Beats will be produced by two similar vibrating strings if
a. their lengths differ slightly.
b. the amplitudes of vibration differ slightly.
c. their lengths are equal.
d. their frequencies are equal.
e. the wavelengths of their waveforms differ slightly.
f. their densities differ slightly.

10. a. Musical notes are made up of combinations of sounds of regular or irregular frequency.
b. The loudness of sound is determined by its frequency.
c. The pitch of a note depends on the amplitude of its waveform.
d. The quality of sound produced by an instrument is determined by the combination of its overtones.
e. Two notes which are an octave apart have the same pitch.
f. If the note C' is an octave of C, then the wavelength of C is twice that of C'.
g. The fundamental note of an open pipe is an octave higher than that of a closed pipe of the same length.
h. A boy blowing air across the open end of an empty bottle produces a sound of higher speed if he blows harder.
i. A vibrating tuning fork produces a louder sound when its stem is pressed against a table top because the whole table then resonates with the tuning fork
j. The echo effect is significantly reduced in a well-furnished room because sound waves are effectively absorbed by the soft furnishing.

Answers to True or False - Type Questions

1 a (T)
b (F) The distance between a node and an adjacent antinode in a stationary wave is one-quarter of the wavelength.
c (F) The distance between successive nodes is $\lambda/2$.
d (T)
e (F) Two successive points which are out of phase by π are one-half of a wavelength apart.

2 a (F) Water waves are transverse.
b (F) Water particles oscillate up-and-down, but do not move sideways.
c (T) See (b) above.
d (T) The energy in the up-and-down motion is

propagated sideways along with the crests and troughs.

e (T)

f (F) The wave velocity is the distance covered by the disturbance (e.g. a crest) which moves sideways, not by particles of the medium, which merely oscillate up-and-down.

g (T)

h (T)

i (F) Wavefronts are perpendicular to the direction of wave motion, e.g. a circular crest is a wavefront in a water wave.

3. a (T)

b (F) The particles oscillate in the direction of wave motion in a longitudinal wave.

c (F) The speed of any wave, *longitudinal* or *transverse*, changes as it crosses from one medium to another. This is *refraction*.

d (T)

e (F) Interference is common to all waves.

f (F) Transverse waves such as water waves and vibrating strings are also mechanical.

4. a (T)

b (F) Sound waves are always longitudinal.

c (T) X-rays and other electromagnetic waves such as light and radio waves, are transverse.

d (F) Stationary waves in a resonance tube are longitudinal as the air particles vibrate along the length of the tube, which is also the direction of wave motion.

e (T)

5. a (F) The two waves travelling in opposite directions must have exactly the same amplitude and wavelength.

b (T) Both amplitude and wavelength of a wave remain unchanged when the wave is reflected. The reflected wave, which now travels in the opposite direction interferes with the original wave to form a stationary wave.

c (T)

d (F) Stationary waves in a resonance tube are longitudinal.

e (F) The distance between two successive points of maximum displacement, i.e.antinodes is one-half of the wavelength.

f (T)

6. Answers to (a) - (e) are easily deduced from the equation

$$f_o = \frac{1}{2L}\sqrt{\frac{T}{m}}$$

a (F) Frequency (f_o) is inversely proportional to the length, L

b (T) Frequency is directly proportional to the square root of the tension T.

c (T) The mass per unit length, m, increases with density. The frequency decreases as m increases, or as density increases.

d (F) The amplitude determines the intensity or loudness of sound, not the frequency.

e (T) The mass per unit length of string increases with the cross-sectional area (a thick string has a greater mass per unit length than a thin string). Since the frequency varies with m, it also varies with the cross-sectional area of the string.

f (T) The lowest possible frequency of vibration of a system is the *fundamental* frequency.

7. a (T)

b (F) Sound is a mechanical and *longitudinal* wave.

c (F) Sound, being a longitudinal wave, cannot be polarized.

d (T)

e (T)

f (F) Electromagnetic waves include x-rays, light and radio waves but *not* sound.

g (T)

h (F) The speed of sound in air increases with temperature.

i (T)

8. This is the phenomenon of refraction in which both the speed and wavelength of sound are higher in water than in air but the frequency remains unchanged. Also there is a change in the direction of wave motion.

a (F)

b (T)

c (F)

d (T)

e (F)

9. Beats are produced by two interfering sounds of slightly different frequencies. Any characteristic of the strings which results in slightly different frequencies will produce beats.

a (T) Slightly different lengths means slightly different frequencies.

b (F) Frequency is independent of amplitude.

c (F)

d (F)

e (T) Frequency varies inversely as the wavelength.

f (T) Frequency depends on the mass per unit length which varies with the density of the wire

10.a (F) Sounds of regular frequency produce musical notes while sounds of irregular frequency produce *noise*.

b (F) Loudness depends on the amplitude, *not* on the frequency.

c (F) Pitch depends on frequency, not on amplitude.

d (T)

e (F) The frequency of one is twice the frequency of the other, hence the pitch cannot be the same.

f (T) The frequency of C is twice that of C, hence the wavelength of C is twice that of C.

g (T) For a closed pipe, $\lambda = 4L$ while for an open pipe $\lambda = 2L$ for the fundamental note. The wavelength of the fundamental note for an open pipe is thus one-half of the wavelength for a closed pipe. Correspondingly, the frequency for the open pipe is twice that of a closed pipe, and is therefore an octave higher.

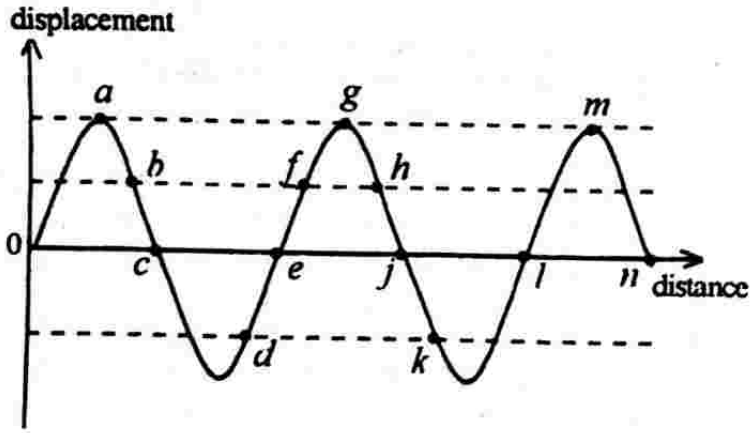
h (F) A harder blow means a larger amplitude, which will result in higher intensity (or loudness). The speed of sound in air is constant.

i (F) The table top is also set vibrating, and because its large surface is in contact with more air molecuules, a louder sound is emitted. Note that this has nothing to do with resonance.

j (T) The echo effect (*reverberation*) is due to the sound reflected by the walls of the room. Soft furnishings absorb much of the sound impinging on them and thereby reduce the intensity of sound reaching the walls.

SSCE/JME - Type Objective Questions

Questions 1-4 refer to the waveform shown in the figure below:



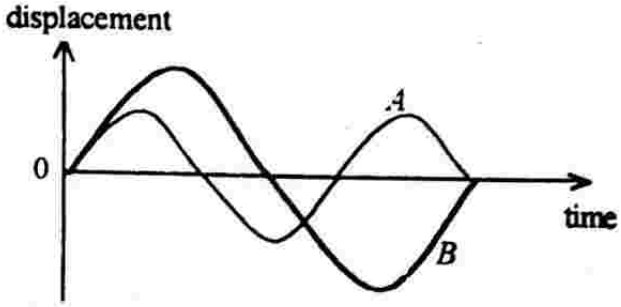
1. Which of the following distances is not equal to the wavelength of the wave?
   A. cj B. bh C. dk D. ag

2. Which of the following pairs of points are not exactly in phase?
   A. a and g B. c and e
   C. b and h D. g and m

3. The phase difference between points a and j is
   A. 0 B. $\pi/2$ C. π D. 2π

4. A second waveform having the same speed but twice the frequency of the waveform shown will have a wavelength equal to
   A. am B. cl C. jn D. ej

Questions 5-7 refer to the figure below:



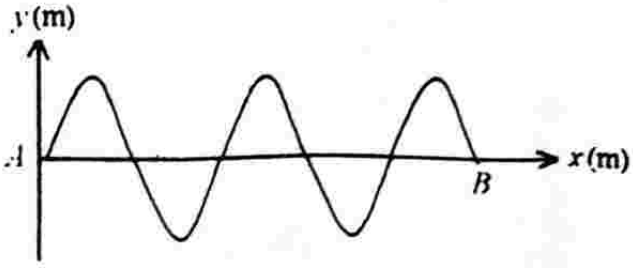
5. If the frequency of waveform A is 60 Hz, the period of waveform B is
   A. 0.025 s B. 0.25 s C. 40 s D. 60 s

6. The number of type-B waves passing a given point in the medium in 5 s is
   A. 40 B. 60 C. 200 D. 300

7. If the speed of the waves is 5 ms^{-1}, the distance between two successive particles of waveform A which are in phase is
   A. 12.5 cm B. 25 cm C. 8.33 cm D. 16.5 cm

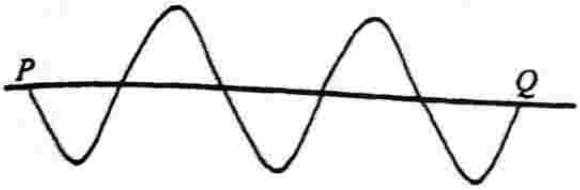
8. A flasher generates 3000 regular flashes in one minute. The period of the flashes is
   A. 50 s B. 20 s C. 0.50 s D. 0.02 s

9.



The diagram above shows part of the waveform of a wave travelling with a speed of 320 ms^{-1} in air. If the distance AB is 5 m, the frequency of the wave is
A. 64 Hz **B.** 160 Hz **C.** 640 Hz **D.** 1600 Hz

10.



In the waveform shown in the figure above, energy is transferred from P to Q in 5×10^{-3} s. The frequency of the wave is
A. 200 Hz **B.** 250 Hz **C.** 500 Hz **D.** 1000 Hz

11. The rotating disc in a siren has 42 holes and makes 30 revs. per second. The frequency of the sound emitted by the siren is
A. 1.4 Hz **B.** 30 Hz **C.** 420 Hz **D.** 1260 Hz

12. Water waves are generated by dropping stones at regular intervals at a point in a pool of water. The first crest reaches another point, 8 m away, in 4 s. If the distance between two successive crests is 0.5 m, the frequency of the wave is
A. 2 Hz **B.** 4 Hz **C.** 8 Hz **D.** 16 Hz

13. An anchored boat is hit by wave crests every 5 s. If the wave crests are 60 m apart, the velocity of the wave is
A. 12 ms^{-1} **B.** 6 ms^{-1} **C.** 0.83 ms^{-1} **D.** 0.41 ms^{-1}

14. The frequency of a wave having wavelength 20 cm and velocity 0.5 ms^{-1} is
A. 0.0025 Hz **B.** 0.025 Hz
C. 2.5 Hz **D.** 40.0 Hz

15. A wave is represented by the equation $y = 0.20 \sin [0.4\pi (x - 60t)]$, where x and y are in cm and t is in s. The velocity of the wave is
A. 120 cms^{-1} **B.** 60 cms^{-1} **C.** 24 cms^{-1} **D.** 4.8 cms^{-1}

16. The wavelength of the wave in problem 15 is
A. 5 cm **B.** 10 cm **C.** 24 cm **D.** 60 cm

17. A wave of period 0.02 s has a frequency of
A. 0.02 Hz **B.** 0.2 Hz **C.** 5 Hz **D.** 50 Hz

18. The velocity of a sound wave travelling in air is 330 ms^{-1}. If the period of the sound wave is 10^{-3} s, the distance between a rarefaction and an adjacent compression is
A. 0.33 cm **B.** 16.5 cm **C.** 33 cm **D.** 66 cm

19. A vibrating plate is used to generate waves in a pool of water. The distance between successive troughs is 7 cm and a crest travels from the vibrator to the edge of the pool, 52.5 cm away, in 2.5 s. The frequency of the vibrator is
A. 3.0 Hz **B.** 7.5 Hz **C.** 21.0 Hz **D.** 147.0 Hz

20. A radio station transmitting at a frequency of 200 kHz emits waves of wavelength 1.5 km. The velocity of the radio waves is
A. 3×10^2 ms^{-1} **B.** 3×10^3 ms^{-1}
C. 3×10^8 ms^{-1} **D.** 3×10^{10} ms^{-1}

21. If the speed of light in air is 3×10^8 ms^{-1}, the wavelength of radio waves transmitted by a radio station at a frequency of 1.2 MHz is
A. 0.004 m **B.** 25 m **C.** 40 m **D.** 250 m

22. A rarefaction and an adjacent compression of a sound wave travelling in air are separated by a distance of 15 cm. If the velocity of sound in air is 330 ms^{-1}, the frequency is
A. 11 Hz **B.** 22 Hz **C.** 1100 Hz **D.** 2200 Hz

23. If the speed of sound in air is 340 ms^{-1}, the period of vibration of sound waves of wavelength 1.7 m is
A. 0.005 s **B.** 0.02 s **C.** 0.05 s **D.** 200 s

24. A body emits 50 vibrations per second of waves travelling at 20 ms^{-1}. The wavelength of the wave is
A. 1000.0 m **B.** 100.0 m **C.** 2.5 m **D.** 0.4 m

25. A man hears a thunderstorm 3 s after observing the lightning flash. How far is he from the thunderstorm if the speed of sound in air is 330 ms^{-1}?
A. 990 m **B.** 495 m **C.** 330 m **D.** 165 m

26. A radio transmits at a frequency of 6×10^5 Hz. If the speed of the signals is 3×10^8 ms^{-1}, the wavelength is
A. 2×10^{-3} m **B.** 2×10^{-2} m **C.** 5×10^2 m **D.** 5×10^3 m

27. The echo from a sound wave sent out from a ship towards the seabed is received on the ship 1.6 s later. Taking the velocity of sound in water as 1.5 kms^{-1} the depth of the sea is
A. 1.20 km **B.** 1.50 km **C.** 2.40 km **D.** 3.60 km

28. A boy claps his hands at regular intervals such that the echo of a clap coincides with the next clap. If his claps are reflected by a cliff 110 m away and the speed of sound is 330 ms^{-1}, the frequency of clapping is
A. 1.0 Hz **B.** 1.5 Hz **C.** 2.0 Hz **D.** 3.0 Hz

29. A man shouts and receives the echo from a nearby

hill 2 s later. If the sound emitted by the man has frequency 250 Hz and wavelength 1.2 m, how far is he from the hill?
A. 1.200 m **B.** 600 m **C.** 300 m **D.** 150 m

30. Radio waves emitted from an antenna and reflected by an aircraft are picked up by a radar 0.005 s after emission. If the speed of light is 3×10^8 ms^{-1}, the distance of the aircraft from the antenna is
A. 250 km **B.** 750 km **C.** 1500 km **D.** 3000 km

31. A sound pulse projected vertically downwards into the earth is reflected from two different layers of the earth such that the echoes are received after 1.5 s and 1.8 s. If the speed of the pulse is 2000 ms^{-1}, the distance between the layers is
A. 1.800 m **B.** 1.500 m **C.** 600 m **D.** 300 m

32. A boy receives the echo of his clap reflected by a nearby hill 0.8 s later. If the speed of sound in air is 340 ms^{-1}, how far is he from the hill?
A. 66 m **B.** 136 m **C.** 264 m **D.** 528 m

33. The echo of a sound of wavelength 1.5 m and frequency 200 Hz emitted by a source is heard at the source 1.0 s later. The distance of the source from the reflector is
A. 75 m **B.** 150 m **C.** 300 m **D.** 600 m

34. Which of the following phenomena does **not** apply to longitudinal waves?
A. interference **B.** refraction
C. diffraction **D.** polarization

35. It is customary to cover the walls and ceilings of a standard auditorium with perforated pads in order to
A. reduce the effect of reverberations of sound waves.
B. increase the intensity of sound waves.
C. increase the frequency of sound waves.
D. reduce the interference effect of sound waves.

36. A sound wave moving at 340 ms^{-1} in air approaches a pool of water in which its wavelength is four times that of the wavelength in air. The speed of the wave in the water is
A. 85 ms^{-1} **B.** 170 ms^{-1} **C.** 340 ms^{-1} **D.** 1360 ms^{-1}

37. Which of the following waves are both mechanical and transverse?
A. radio **B.** sound **C.** water **D.** x-rays

38. The frequency of the beats produced when two tuning forks of frequencies 258 Hz and 270 Hz are sounded close to each other is
A. 6 Hz **B.** 12 Hz **C.** 264 Hz **D.** 528 Hz

39. One of two identical tuning forks is loaded so that 6 beats per second are heard when they are sounded together. If the natural frequency of the tuning forks is 260 Hz, the frequency of the loaded tuning fork is
A. 272 Hz **B.** 266 Hz **C.** 254 Hz **D.** 248 Hz

40. The wavelength of the fundamental note of a one-metre long guitar string is
A. 25 cm **B.** 50 cm **C.** 100 cm **D.** 200 cm

41. A stretched string has a fundamental frequency of 25 Hz. The number of overtones between 25 Hz and 120 Hz is
A. 2 **B.** 3 **C.** 4 **D.** 5

42. A string, one metre long, under tension is plucked at its centre such that a wave of velocity 250 ms^{-1} is produced. The number of vibrations made by the string in one second is
A. 2.5 **B.** 25 **C.** 125 **D.** 250

43. A piano wire which is 25 cm long has a total mass of 5 g. The fundamental frequency of the wire under a tension of 200 N is
A. 50 Hz **B.** 100 Hz **C.** 200 Hz **D.** 400 Hz

44. The frequencies of the notes produced by two strings having the same length and placed under the same tension are in the ratio 1 : 4. The corresponding ratio of the masses of the strings is
A. 16 : 1 **B.** 2 : 1 **C.** 1 : 2 **D.** 4 : 1

45. The tension in a sonometer wire is tripled. The ratio of the new frequency to the initial frequency is
A. 1/3 **B.** 3 **C.** $1/\sqrt{3}$ **D.** $\sqrt{3}$

46. A sonometer wire of length 50 cm has a fundamental frequency of 200 Hz under a tension of 30 N. The tension in the wire is now adjusted to produce a new frequency of 400 Hz, keeping the length of the wire constant. The new tension is
A. 120 N **B.** 60 N **C.** 15 N **D.** 7.5 N

47. When the tension of a vibrating sonometer wire is increased in the ratio 9:1, the velocity of the wave produced is
A. increased three times
B. increased nine times
C. decreased three times
D. decreased nine times.

48. A string of length 50 cm and mass 10^{-3} kg vibrates in 5 loops. If the tension in the string is 20 N, the frequency of vibration is
A. 500 Hz **B.** 250 Hz **C.** 100 Hz **D.** 50 Hz

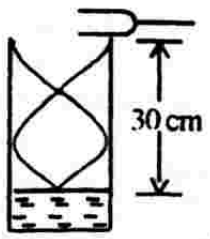
49. A vibrating sonometer wire under a tension of 20 N emits a note of frequency 250 Hz. If the tension is adjusted to 80 N, the new frequency is
A. 1000 Hz **B.** 500 Hz **C.** 125 Hz **D.** 62.5 Hz

50. The fundamental frequency of a closed pipe organ is 165 Hz. If the speed of sound in air is 330 ms^{-1}, the length of the pipe is
A. 200 cm **B.** 100 cm **C.** 75 cm **D.** 50 cm

51. If the speed of sound in air is 340 ms^{-1}, the frequency of the fundamental note of an organ pipe, 85 cm long, closed at one end is
A. 400 Hz **B.** 340 Hz **C.** 100 Hz **D.** 85 Hz

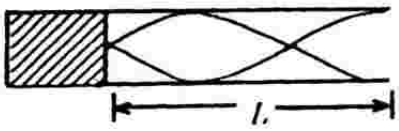
52. In a resonance tube experiment performed with a vibrating tuning fork of frequency 300 Hz, the length of the air column at first resonance is 30 cm. The velocity of sound in air is
A. 360 ms^{-1} **B.** 350 ms^{-1} **C.** 340 ms^{-1} **D.** 330 ms^{-1}

53



In a resonance tube experiment the frequency of the tuning fork is 250 Hz and the length of the air column is 30 cm (see figure). The velocity of the wave generated by the tuning fork is
A. 750 ms^{-1} **B.** 340 ms^{-1} **C.** 100 ms^{-1} **D.** 75 ms^{-1}

The figure below shows a stationary wave of wavelength 40 cm in a closed tube. Use the figure to answer questions 54 and 55.



54. The length L of the resonating air column is
A. 10 cm **B.** 20 cm **C.** 30 cm **D.** 40 cm

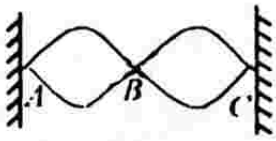
55. The distance between adjacent antinodes is
A. 20 cm **B.** 30 cm **C.** 40 cm **D.** 60 cm

56. An organ pipe open at both ends has a fundamental frequency of 400 Hz. The frequency of the second overtone is
A. 400 Hz **B.** 600 Hz **C.** 800 Hz **D.** 1200 Hz

57. A stationary wave pattern is formed by a wave of frequency 20 Hz and velocity 50 cms^{-1}. The distance between adjacent nodes is
A. 0.625 cm **B.** 1.25 cm **C.** 2.5 cm **D.** 10.0 cm

58. Transverse stationary waves of frequency 50 Hz are generated in a long, thin wire. If the distance between successive nodes on the wire is 15 cm, the speed of the waves is
A. 7.5 ms^{-1} **B.** 15 ms^{-1} **C.** 30 ms^{-1} **D.** 75 ms^{-1}

59.



The diagram shows a stationary wave set up in a string which is fixed at both ends. If the distance AB is 2.0 m and the frequency of the wave is 350 Hz, the speed of the wave is
A. 175 ms^{-1} **B.** 350 ms^{-1} **C.** 700 ms^{-1} **D.** 1400 ms^{-1}

60. A progressive wave of frequency 20 Hz and speed 60 cms^{-1} is reflected upon itself such that a stationary wave is formed. The distance between a node and an adjacent antinode is
A. 0.75 cm **B.** 1.50 cm **C.** 6.00 cm **D.** 12.00 cm

Answer Key

1. C	11. D	21. D	31. D	41. B	51. C
2. B	12. B	22. C	32. B	42. C	52. A
3. B	13. A	23. A	33. B	43. C	53. C
4. D	14. C	24. D	34. D	44. A	54. C
5. A	15. B	25. A	35. A	45. D	55. A
6. C	16. A	26. C	36. D	46. A	56. D
7. C	17. D	27. A	37. C	47. A	57. B
8. D	18. B	28. B	38. B	48. A	58. B
9. B	19. A	29. C	39. C	49. B	59. D
10.C	20. C	30. B	40. D	50. D	60. A

Solutions to Objective Questions

1. **(C)** The specified distances, except *dk*, separate successive corresponding points on the waveform.

2. **(B)** *c* and *e* are out of phase by 180°, or π.

3. **(B)** *a* and *g* are exactly in phase. Phase difference between *a* and *j* is the same as the phase difference between *g* and *j* = 90°, or $\pi/2$.

4. **(D)** $\lambda = v/f$. If the frequency is doubled while keeping the speed constant, the wavelength is halved. Note that *ej* is one-half of the wavelength of the waveform shown.

5. **(A)** Period of A = 1/60 s. Period of B = 3/2 x period of A = 3/2 x 1/60 = 1/40 s, or 0.025 s.

6. **(C)** Frequency of B = 1/0.025 = 40 Hz, i.e. 40 waves pass any given point in one second, or 200 waves in 5 s.

7. **(C)** The required distance is the wavelength $\lambda = v/f$ = (500/60) cm, or 8.33 cm.

8. **(D)** T = time to generate one flash = 60/3000 = 0.02 s.

9. **(B)** The distance AB contains 2.5 oscillations. Hence λ = length of one oscillation = AB/2.5 = 5/2.5 = 2 m. $f = v/\lambda$ = 320/2 = 160 Hz.

10. **(C)** Distance PQ contains 2.5 oscillations. Period T = time for one oscillation = $5 \times 10^{-3}/2.5 = 2 \times 10^{-3}$ s. $f = 1/T = 1/(2 \times 10^{-3}) = 500$ Hz.

11. **(D)** In a siren, sound pulses are generated by blasts of air passing through holes on a rotating disc. Frequency of the sound produced = no. of holes x no. of revs. per sec = 42 x 30 = 1260 Hz.

12. **(B)** Speed of the wave, $v = 8/4 = 2$ ms^{-1}, and $\lambda = 0.5$ m. Frequency, $f = v/\lambda = 2/0.5 = 4$ Hz.

13. **(A)** Period of the wave, $T = 5$ s, and $\lambda = 60$ m. Velocity, $v = \lambda/T = 60/5 = 12$ ms^{-1}.

14. **(C)** $\lambda = 20$ cm = 0.2 m and $v = 0.5$ ms^{-1}. $f = v/\lambda = 0.5/0.2 = 2.5$ Hz.

15. **(B)** We compare the given equation
$y = 0.20\sin[0.4\pi(x - 60t)]$
with the standard wave equation
$$y = A \sin \frac{2\pi}{\lambda}(x - vt)$$
Equating coefficients of t gives
$2\pi v/\lambda = 0.4\pi \times 60$ ..... (i)
Equating coefficients of x gives
$2\pi/\lambda = 0.4\pi$.....(ii)
Dividing (i) by (ii) gives $v = 60$ cms^{-1}

16. **(A)** $2\pi/\lambda = 0.4\pi$, or $\lambda = 2\pi/0.4\pi = 5$ cm.

17. **(D)** $f = 1/T = 1/0.02 = 50$ Hz.

18. **(B)** $\lambda = vT = (330)(10^{-3}) = 0.33$ m, or 33 cm. Distance between a rarefaction and an adjacent compression is one-half of the wavelength = 33/2 = 16.5 cm.

19. **(A)** $\lambda = 7$ cm and $v = 52.5/2.5 = 21$ cms^{-1}. $f = v/\lambda = 21/7 = 3.0$ Hz.

20. **(C)** $v = f\lambda = (200 \times 10^3)(1.5 \times 10^3) = 3 \times 10^8$ ms^{-1}.

21. **(D)** $\lambda = v/f = (3 \times 10^8)/(1.2 \times 10^6) = 250$ m.

22. **(C)** The distance between adjacent rarefactions and compressions = $\lambda/2$.
Hence $\lambda = 2(0.15) = 0.30$ m and
$f = v/\lambda = 330/0.30 = 1100$ Hz.

23. **(A)** $T = 1/f = \lambda/v = 1.70/340 = 0.005$ s.

24. **(D)** Frequency $f = 50$ vibrations per sec. = 50 Hz, $v = 20$ ms^{-1}. Hence $\lambda = v/f = 20/50 = 0.4$ m.

25. **(A)** Distance = speed of sound x time = (330)(3) = 990 m.

26. **(C)** $\lambda = v/f = (3\times10^8)/(6\times10^5) = 500$ m $= 5 \times 10^2$ cm.

27. **(A)** Time for sound to travel from ship to seabed = 1.6/2 = 0.8 s. Distance = speed of sound x time = (1500) (0.8) = 1200 m, or 1.2 km.

28. **(B)** Period of claps, T = time for sound to travel to the cliff and back = total distance/speed = 2(110) / 330 = 2/3 s.
Frequency of claps = $1/T$ = 3/2 = 1.5 Hz.

29. **(C)** $v = f\lambda = (250)(1.2) = 300$ ms^{-1}, and $t = 2 \times \frac{1}{2} = 1$ s. $d = vt = 300(1) = 300$ m.

30. **(B)** Radio waves, being electromagnetic waves, travel at the speed of light.
Time for waves to reach aircraft = 0.005/2 = 0.0025 s.
Distance = speed x time = $(3\times10^8)(0.0025)$ = 7.5×10^4 m, or 750 km.

31. **(D)** Dist. of first layer = 2000 x 1.5/2 = 1500 m
Dist. of second layer = 2000 x 1.8/2 = 1800 m
Distance between the two layers = 1800 - 1500 = 300 m.

32. **(B)** Dist. = speed x time = (3400) (0.8/2) = 136 m.

33. **(B)** Speed of sound $v = f\lambda = (200)(1.5) = 300\ ms^{-1}$.
Distance = vt = (300) (1.0/2) = 150 m.

34. **(D)** Only *transverse* waves can be polarized.

35. **(A)** Brick walls, being good reflectors of sound, reflect the sound waves back and forth across the auditorium. This is *reverberation*. The perforated pads *absorb* the sound waves, thereby reducing reverberation effects.

36. **(D)** In air $v_a = f\lambda_a$ and in water $v_w = f\lambda_w$. Hence $v_w/v_a = \lambda_w/\lambda_a = 4$, or $v_w = 4v_a = 4(340) = 1360\ ms^{-1}$.

37. **(C)** Water waves. Sound waves are mechanical but longitudinal. All components of the electromagnetic spectrum including x-rays, ultra-violet, visible light, infra-red and radio waves are *electromagnetic* and *transverse*.

38. **(B)** Frequency of beats = difference between the two frequencies = 270 - 258 = 12 Hz.

39. **(C)** A tuning fork, when loaded (e.g. by pasting a piece of plasticine on it) vibrates at a slightly lower frequency than its natural frequency. Since the number of beats per second is the difference between the frequencies of the tuning forks, the loaded tuning fork must have a frequency of 260 - 6, or 254 Hz.

40. **(D)** For the fundamental note, $\lambda = 2L = 2(100) = 200$ cm.

41. **(B)** Since the frequencies of the overtones in a vibrating string increase in the ratio 1: 2: 3: ... (see notes), the string has frequencies 25 Hz, **50 Hz, 75 Hz, 100 Hz,** 125 Hz, ... Only 3 of these (appearing in bold face) lie between 25 Hz and 120 Hz.

42. **(C)** The wire vibrates at its fundamental frequency. Hence λ = 2 x length of wire = 2 (1) = 2 m and $f = v/\lambda$ = 250/2 = 125 Hz, i.e. 125 vibrations in one second.

43. **(C)** $L = 0.25$ m, $T = 200$ N, m = mass per unit length = 0.005/0.25 = 0.02 kgm^{-1}

$$f_o = \frac{1}{2L}\sqrt{\frac{T}{m}} = \frac{1}{0.5}\sqrt{\frac{200}{0.02}} = 2\sqrt{10{,}000} = 200\ Hz$$

44. **(A)** $f \propto \frac{1}{\sqrt{m}} \Rightarrow f^2 \propto \frac{1}{m}$ or $m \propto 1/f^2$

$$\frac{m_1}{m_2} = \left(\frac{f_2}{f_1}\right)^2 = \left(\frac{4}{1}\right)^2 = 16:1$$

45. **(D)** $f \propto \sqrt{T} \Rightarrow \frac{f_2}{f_1} = \sqrt{\frac{T_2}{T_1}}$

Since $T_2 = 3T_1$, $T_2/T_1 = 3$ and $f_2/f_1 = \sqrt{3}$

46. **(A)** $f \propto \sqrt{T} \Rightarrow T \propto f^2$ or

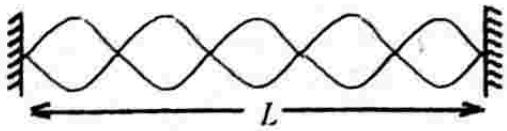
$$\frac{T_2}{T_1} = \left(\frac{f_2}{f_1}\right)^2 = \left(\frac{400}{200}\right)^2 = 4.$$

$T_2 = 4T_1 = 4 \times 30 = 120$ N

47. **(A)** $f \propto \sqrt{T}$ and $v \propto f \Rightarrow v \propto \sqrt{T}$

$$\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{9} = 3, \text{ or } v_2 = 3v_1$$

48. **(A)**



If the string vibrates in 5 loops (see figure) the frequency is 5 times that of the fundamental frequency (or the wavelength is 1/5 that of the fundamental mode). $L = 0.5$ m, $T = 20$ N. $m = 10^{-3}/0.5 = 2\times10^{-3}\ kgm^{-1}$

Hence $f_o = \frac{1}{2L}\sqrt{\frac{T}{m}} = \frac{1}{1.0}\sqrt{\frac{20}{2\times10^{-3}}} = 100$ Hz

$f = 5f_o = 5(100) = 500$ Hz.

49. **(B)** $\frac{f_2}{f_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{80}{20}} = 2$

$f_2 = 2f_1 = 2(250) = 500$ Hz.

50. **(D)** $\lambda = v/f = 330/165 = 2$ m. For a pipe closed at one end, $l = \lambda/4 = 2/4 = 0.5$ m, or 50 cm.

51. **(C)** $L = \lambda/4$ for the fundamental note.
$\lambda = 4L = 4(85) = 340$ cm = 3.4 m.
$f = v/\lambda = 340/3.4 = 100$ Hz.

52. **(A)** $\lambda = 4L$ and $v = f\lambda = 4fL = 4(300)(0.30) = 360\ ms^{-1}$

53. **(C)** $3\lambda/4 = L = 0.30$, or $\lambda = 4(0.30)/3 = 0.40$ m
$v = f\lambda = (250)(0.40) = 100\ ms^{-1}$.

54. **(C)** $L = 3\lambda/4 = 3(40)/4 = 30$ cm.

55. **(A)** Distance between adjacent antinodes = $\lambda/2$ = 20 cm.

56. **(D)** For an open pipe the frequencies of overtones are $2f_o$, $3f_o$, $4f_o$, ... The frequency of the second overtone is thus $3f_o = (3)(400) = 1200$ Hz.

overtone is thus $3f_0 = (3)(400) = 1200$ Hz.

57. **(B)** $\lambda = v/f = 50/20 = 2.5$ cm.
Distance between adjacent nodes $= \lambda/2 = 1.25$ cm.

58. **(B)** Distance between successive nodes, $d_n = \lambda/2$
Hence $\lambda = 2d_n = 2(15) = 30$ cm $= 0.3$ m.
$v = f\lambda = (50)(0.3) = 15$ ms^{-1}.

59. **(D)** $\lambda = 1.0 = 2(2) = 4$ m.
$v = f\lambda = (350)(4) = 1400$ ms^{-1}.

60. **(A)** Wavelength $\lambda = v/f = 60/20 = 3.0$ cm.
A node and an adjacent antinode are separated by $\lambda/4 = 3.0/4 = 0.75$ cm.

Revision Check-list

Under this chapter the candidate should be able to

- define *amplitude*, *wavelength*, *frequency* and *period* of a wave.
- explain *reflection*, *refraction*, *diffraction*, *interference* and *polarization*.
- distinguish between *longitudinal* and *transverse* waves.
- explain the characteristics of a *stationary wave* such as *nodes*, *antinodes* and *wavelength*.
- explain the characteristics of a sound wave in terms of the compressions and rarefactions set up in the medium.
- explain the effect of temperature, pressure and medium of propagation on the speed of sound.
- relate the *pitch*, *intensity* and *loudness* of sound to the frequency and amplitude.
- explain what is meant by *resonance*.
- classify the common musical instruments into *wind*, *stringed* and *percussion* instruments.
- distinguish between *musical sound* and *noise*.
- relate sound *quality* to the production of *overtones*.
- illustrate diagramatically the waves in a vibrating string fixed at both ends, and emitting the fundamental frequency, the first overtone, and the second overtone.
- define *octave* in relation to frequency.
- explain the production of *beats* from the interference of two sound waves.
- recall and apply the equations listed in the *revision* notes.
- describe the following experiments along with the necessary precautions:
  (1) measurement of sound velocity or unknown distances (e.g. ocean depth) using sound reflection.
  (2) measurement of sound velocity using a resonance tube.
  (3) measurement of the frequency of a source of sound.
  (4) illustrating that sound requires a material medium for its propagation.
  (5) illustrating resonance.
  (6) showing how the frequency of the note emitted by a vibrating string depends on the tension in the string.

12 Reflection of Light

12.1 Propagation of Light

- Visible light is part of the electromagnetic spectrum.
- The wavelength of light ranges from 4×10^{-7} to 7×10^{-7} m.
- It can be propagated in vacuum and through transparent materials such as glass and water.
- Light travels in vacuum at a speed of 3×10^{8} ms^{-1}. The speed is less in other material media.
- A ray of light is the path through which light is propagated.
- A beam of light is the stream of light energy being propagated.

12.2 Formation of Shadows

- Light travels in a straight line.
- An opaque material is one through which light cannot be transmitted.
- When an opaque material is situated between the source of light and a screen, its shadow is formed on the screen.
- A total shadow, called ***umbra***, of the opaque object is formed when the source of light is a point source.
- A region of partial shadow, ***penumbra***, also forms at the edges of the umbra when the source of light is extended (Fig. 12.1).

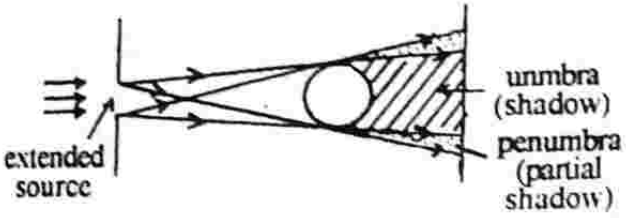


Fig. 12.1

12.3 Eclipse

- When the moon comes between the earth and the sun and the three are lined up, a shadow of the moon is cast on the earth. This is the ***eclipse of the sun***.
- Because the sun is an extended light source, some places on the earth will have ***total eclipse***, while others will have ***partial eclipse***.
- When the earth comes between the sun and the moon, the latter cannot receive light from the sun. This is the ***eclipse of the moon***.

12.4 Pinhole Camera

- A ***pinhole camera*** is made from an opaque box, one side of which is made of a translucent sheet of paper.
- A tiny hole is made opposite the translucent sheet.
- When the hole is placed near a well-lit object, the object's image is formed on the translucent sheet of paper (Fig. 12.2).
- This image is inverted and clear if the hole is sufficiently tiny.
- If the hole is too big, the image is blurred.
- The magnification m is given by

$$m = \frac{\text{height of image}}{\text{height of object}} = \frac{\text{image distance}}{\text{object distance}} \qquad (12.1)$$

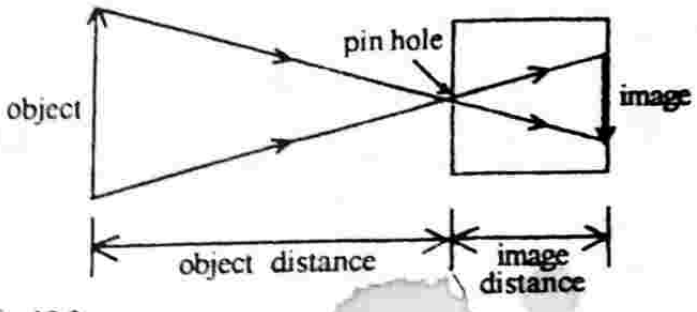


Fig. 12.2

12.5 Laws of Reflection

- When a ray of light is incident on a smooth surface such as a mirror, part or all of the ray is reflected. The laws of reflection are:
  (i) the incident ray, the reflected ray and the normal to the reflecting surface all lie on a single plane.
  (ii) the angle of incidence is equal to the angle of reflection (Fig. 12.3).

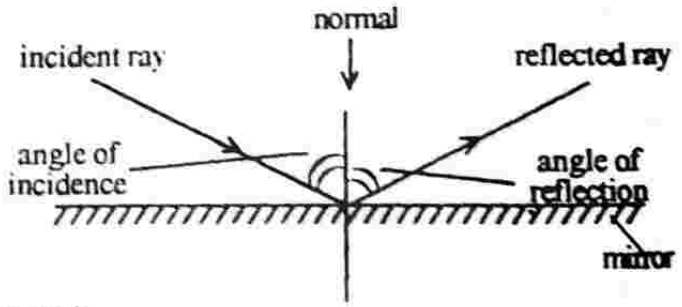


Fig. 12.3

12.6 Image Formed by a Plane Mirror

- The image formed by a plane mirror is
  (i) virtual, i.e. it cannot be captured on a screen,
  (ii) the same distance behind the mirror as the object is in front of the mirror,
  (iii) erect but laterally inverted, and
  (iv) the same size as the object.
- When two plane mirrors are inclined to each other at an angle, several images are formed. If the angle between the mirrors is θ, the number (n) of images formed is

$$n = \frac{360}{\theta} - 1 \qquad (12.2)$$

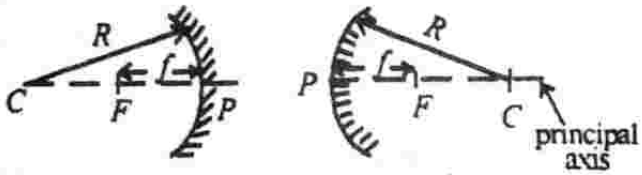
12.7 Applications of Plane Mirrors

- A *simple periscope* is made of two plane mirrors facing each other and inclined at 45° to the line joining the two.
- Rays of light from the object lying in front one of the mirrors are reflected to the second.
- The final image is formed behind the second mirror by the rays reflected to the observer.
- The periscope is used for viewing objects around obstacles.
- Plane mirrors are also used as looking glass and in *kaleidoscopes*.

12.8 Spherical Mirrors

- A spherical mirror is made from a small section of a hollow spherical glass material with one side silvered.
- A *concave mirror* is silvered on the outer surface (Fig. 12.4a).
- A *convex mirror* is silvered on the inner surface (Fig. 12.4b).
- *Centre of curvature* (C) of the mirror is the centre of the sphere of which the mirror is just a part. The centre of curvature is in front of a concave, but behind a convex, mirror.
- *Pole* (P) is the centre of the mirror.
- *Principal axis* is the line joining the centre of curvature to the pole of the mirror.
- *Radius of curvature* (R) is the distance between the centre of curvature and the pole.
- *Principal Focus* (F) is the point (on the principal axis) to which all rays initially parallel to the principal axis converge (in the case of a concave mirror) or from which they appear to diverge (convex mirror).
- The *focal length* (f) is the distance (PF) between the principal focus and the pole of the mirror. It is equal to one-half of one radius of curvature, i.e.

$$f = \frac{R}{2} \qquad (12.3)$$

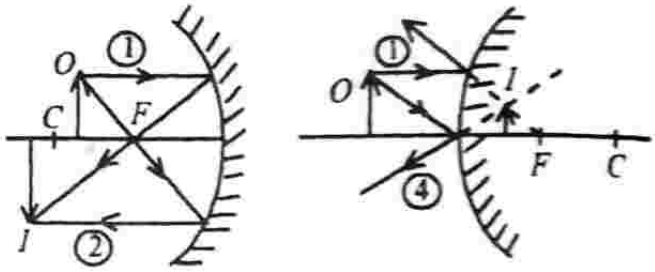


(a) concave mirror (b) convex mirror

Fig. 12.4

12.9 Reflection by Spherical Mirrors

- To determine the position and size of the image formed by a spherical mirror, the paths of incident light rays from the object to the mirror and the reflected rays from the mirror are traced out.
- A ray diagram is drawn using any two of the following rays from the tip of the object:
  (1) a ray initially parallel to the principal axis, which is reflected through the principal focus F;
  (2) a ray passing through the principal focus F and reflected parallel to the principal axis;
  (3) a ray passing through the centre of curvature C, which strikes the mirror normally and is reflected back on itself; and
  (4) a ray incident on the pole P, and is reflected such that the angle of incidence is equal to the angle of reflection.
- The point of intersection of the reflected rays is the position of the image.
- The image is *real* if it lies in front of the mirror, and *virtual* if it lies behind the mirror.
- A real image can be produced on a screen, while a virtual image cannot.
- This construction is demonstrated for both types of mirror in Fig. 12.5.
- The image shown is real for the concave mirror, but virtual for the convex mirror.
  (The candidate should try constructing ray diagrams for different positions of the object for both mirrors).



(a) concave mirror (b) convex mirror

Fig. 12.5

12.10 Nature of Images Formed by Spherical Mirrors

12.10.1 Concave Mirror

Position of Object	Position of Image	Nature of Image
Between focus and pole of mirror	Behind mirror	Magnified, erect and virtual
At focus of mirror	At infinity	—
Between focus and centre of curvature	In front of mirror and beyond centre of curvature	Magnified, inverted and real
At centre of curvature	At centre of curvature	Same size as object, real and inverted
Beyond centre of curvature	Between centre of curvature and focus	Diminished, real, and inverted
At infinity	At focus of mirror	Diminished, real, and inverted

12.10.2 Convex Mirror

- Regardless of the position of the object, the image formed by a convex mirror is ***diminished***, ***erect*** and ***virtual***.
- The image is located between the pole and the principal focus (behind the mirror).

12.11 The Mirror Equation

- If u = object distance from mirror,
  v = image distance from mirror, and
  f = focal length of mirror,
  the relationship between these quantities is

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad (12.4)$$

- In applying the mirror equation, the ***real-is-positive*** sign convention is often used:
  * u is ***positive*** for ***real*** objects (i.e. objects in front of mirror);
  * v is ***positive*** for ***real*** images (i.e. images in front of mirror);
  * v is ***negative*** for ***virtual*** images (i.e. images behind mirror);
  * f is ***positive*** for ***concave*** mirrors;
  * f is ***negative*** for ***convex*** mirrors.
- The New Cartesian sign convention is also used, but the essential point is that both sign conventions should not be mixed up.
- The magnification (m) is the ratio of the image size to the object size, i.e.

$$m = \frac{\text{height of image}}{\text{height of object}}, \text{ or}$$

$$m = \frac{\text{image distance}}{\text{object distance}} = \frac{v}{u} \qquad (12.5)$$

12.12 Applications of Curved Mirrors

- Concave mirrors are used
  (i) as shaving or dentist's mirror, where it produces erect, virtual and enlarged image;
  (ii) in searchlights and car headlamps; and
  (iii) in reflecting (astronomical) telescopes.
- Convex mirrors are used as driving mirrors, producing erect, virtual and diminished image with a wider field of view than in a plane mirrror.

True or False - Type Questions

Answer ***True*** (T) or ***False*** (F) to the following questions.

1. a. A *transparent* body is not visible because it transmits all the light that is incident on it.
   b. A *translucent* body does not allow light to pass through it.
   c. An *opaque* body is visible because of the light it reflects.
   d. A *luminous* body is visible because of the light it transmits.
   e. An *incandescent* body emits light only when heated.

2. The following phenomena are consequences of the rectilinear propagation of light:
   a. sharp shadows of opaque objects.
   b. diffraction of light.
   c. eclipse of the sun.
   d. image formation in a pinhole camera.
   e. interference patterns on a screen.

3. The image in a pinhole camera is
   a. the same size as the object.
   b. diminished and inverted.
   c. larger as the camera is moved closer to the object.
   d. virtual and inverted.
   e. real and inverted.
   f. unaffected by the distance from the pinhole to the screen.
   g. sharper as the hole becomes smaller.
   h. formed by the diffraction of light through the pinhole.

4. If the size of the hole in a pinhole camera is increased, the image
   a. is enlarged.
   b. becomes blurred.
   c. is brought to a sharper focus.
   d. becomes upright.
   e. is brighter.

5. a. Only real images can be observed on a screen.
   b. The image in a plane mirror is always virtual and laterally inverted.
   c. Multiple images observed in certain plane mirrors are due solely to multiple reflection.
   d. A convex mirror is used as a driving mirror and in supermarkets because the image formed is always erect and magnified.
   e. Real images are located on the same side of a mirror as the object, while virtual images appear to be located on the other side of the mirror.
   f. A parallel beam of light is obtained from a torch-

light when the light bulb is positioned at the centre of curvature of its concave mirror.

g. A concave mirror is used as a shaving mirror because it then forms a real and enlarged image.

h. When a concave mirror is used as a shaving mirror, the chin must be positioned between the principal focus and the pole of the mirror.

i. An eclipse of the sun by the moon occurs when the earth casts a shadow on the moon.

6. The image formed by a convex mirror
   a. can be observed on a screen, provided the object is placed at an appropriate distance from the mirror.
   b. is always virtual and never bigger than the object.
   c. is never more than one focal length from the mirror.
   d. can be inverted or erect, depending on the position of the object.
   e. is always closer to the mirror than is the object.
   f. is always positioned between the pole and the centre of curvature.
   g. is always behind the mirror and never magnified.

7. In a concave mirror
   a. the image is real if the object is placed at any distance greater than the focal length of the mirror.
   b. the image is inverted and magnified if the object is placed beyond the centre of curvature.
   c. the position of the image coincides with that of the object when the object is placed at the centre of curvature.
   d. the image can always be observed on a screen.
   e. the image is inverted whenever it can be observed on a screen.
   f. a real image of the sun can be observed at the centre of curvature.
   g. the image moves from the principal focus towards infinity as the object is moved from infinity towards the principal focus.
   h. the size of the image first decreases and then increases as the object is moved from infinity towards the principal focus.
   i. the image is located behind the mirror only when the object is positioned less than one focal length from the mirror.

Answers to True or False - Type Questions

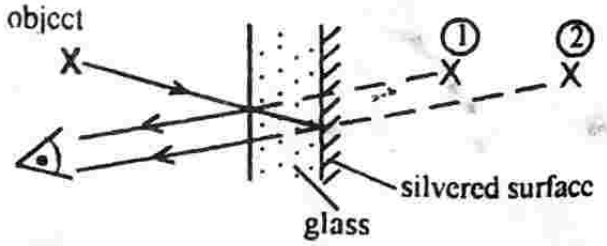
1 a **(T)** A transparent body transmits all the light incident on it and reflects no light, hence it cannot be seen.
   b **(F)** A translucent body transmits part of the light incident on it, hence one can see (though not clearly) through it.
   c **(T)** An opaque body transmits no light and is only visible because of the light it reflects.
   d **(F)** A luminous body emits its own light, even at low temperatures.
   e **(T)** An incandescent body, such as the filament of a light bulb, emits light at very high temperatures.

2. The phenomenon of light travelling in a straight line is referred to as the *rectilinear propagation of light*. The answers are
   (a) T (b) F (c) T (d) T (e) F

3. The magnification m can take on any value depending on the object and image distances (Equation 12.1). Hence the image can be smaller or bigger than the object, or the same size as the object. The image is always *inverted* and *real* (it forms on a screen). The answers are therefore
   (a) F (b) F (c) T (d) F (e) T (f) F (g) T (h) F
   Note that the distance specified in (f) is the image distance, which affects the magnification. The image formation is based on the rectilinear motion of light, and has nothing to do with diffraction as stated in (h).

4. (a) **F** (b) **T** (c) **F** (d) **F** (e) **T**
   The size and orientation of the image have nothing to do with the size of the hole. A bigger hole results in a blurred image, which, however, is brighter as more light then reaches the screen.

5. a **(T)** This is the definition of a *real* image.
   b **(T)**
   c **(F)** This happens through reflection and refraction in thick mirrors. A weak image, (1) is formed by reflection from the surface of the glass and a strong image (2) is formed by the ray refracted into the glass and subsequently reflected at the silvered surface (see figure).



   d **(F)** The image is erect, but always diminished. A convex mirror has the advantage that it has a wider field of view than either a plane or a concave mirror.
   e **(T)** This is one of the main differences between

real and virtual images.

f **(F)** The light bulb must be at the principal focus of the mirror.

g **(F)** The image is enlarged but virtual. It is also erect.

h **(T)** According to section 12.10, the type of image desired (*magnified* and *erect*) is formed only when the object lies between the principal focus and the pole of the mirror.

i **(F)** In the eclipse of the sun, the moon comes between the earth and the sun, i.e. a shadow of the moon is cast on the earth.

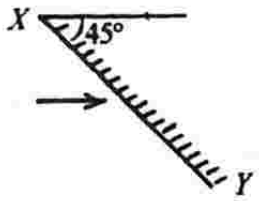
6. a **(F)** It is virtual.
   b **(T)** It is diminished.
   c **(T)** It is always located between the pole and the principal focus.
   d **(F)** It is always erect
   e **(T)** Since it is always smaller than the object, the image distance is also smaller than the object distance.
   f **(F)** See (c) above.
   g **(T)** It is behind the mirror since it is virtual.

7. The items here are re-casts of the information summarised in the table under section 12.10.
   a **(T)** The image is virtual only for objects located between the pole and the principal focus.
   b **(F)** The image is inverted but *diminished*.
   c **(T)**
   d **(F)** Only real images can be observed on a screen.
   e **(T)** Note that whenever the image is real, it is also inverted.
   f **(F)** The sun, located at an infinite distance, will have its image formed at the principal focus.
   g **(T)** This is easily deduced from the table.
   h **(F)** The image size continually *increases* as the object is moved from infinity to the principal focus.
   i **(T)** Real images only are formed for other positions of the object.

SSCE/JME - Type Objective Questions

1. An object of height 20 cm is located at a distance of 50 cm from a pinhole camera. If the distance of the pinhole from the screen is 25 cm, the height of the image is
   A. 10 cm **B.** 15 cm **C.** 20 cm **D.** 40 cm

2. The distance between the object and the pinhole of a pinhole camera is reduced by half. The size of the image of the object
   A. is halved **B.** remains the same
   C. is doubled **D.** is quadrupled.

3. 

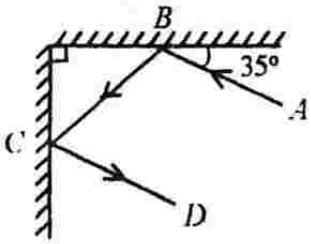
A mirror XY is inclined at 45° to the horizontal. Which of the following diagrams correctly shows the image of the horizontal arrow as reflected in the mirror?
   A. ← **B.** ↑ **C.** ↓ **D.** →

4. Which of the following diagrams correctly shows the images of the letters LF as observed through a mirror?
   A. LF FL **B.** LF **C.** LF **D.** LF

5. A ray of light strikes a plane mirror at an angle of incidence of 25°. The angle made by the reflected ray with the surface of the mirror is
   A. 25° **B.** 50° **C.** 55° **D.** 65°

6. A ray of light strikes a plane mirror at an angle of incidence θ. The angle of deviation of the ray after reflection from the mirror is
   A. θ **B.** 2θ **C.** 90 - θ **D.** 180 - 2θ

7. A man walks towards a plane mirror at a speed of 2 ms^{-1} along a direction normal to the surface of the mirror. His image moves towards him at a speed of
   A. 1 ms^{-1} **B.** 2 ms^{-1} **C.** 4 ms^{-1} **D.** 8 ms^{-1}



Two plane mirrors are inclined at 90° as shown in the diagram. A ray AB strikes the first mirror at B and emerges from the second mirror along CD.

Use the diagram to answer questions **8** and **9**.

8. The angle of reflection at the second mirror is
   A. 35° **B.** 45° **C.** 55° **D.** 65°

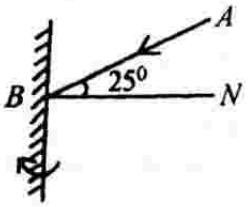
9. The deviation of the ray after reflection by the two mirrors is
   A. 210° **B.** 180° **C.** 150° **D.** 120°

10. An object is placed between two mirrors inclined at 90° to each other. The number of images observed is
    A. 5 **B.** 4 **C.** 3 **D.** 2

11. An object is placed between two mirrors inclined at 120° to each other The number of images observed is
    A. 5 **B.** 4 **C.** 3 **D.** 2

12. A boy in a barber's shop sits between two parallel mirrors. The number of images observed by him will be
A. infinite B. 10 C. 8 D. 4

13. A ray of light is incident on a plane mirror. If the plane mirror is rotated through an angle θ, the reflected ray will be rotated through
A. 3θ B. 2θ C. θ D. θ/2

14. 

A ray AB is incident at an angle of 25° on a plane mirror (see figure). If the mirror is turned through 35° in the direction indicated by the arrow, what angle will the reflected ray make with the normal *BN*?
A. 25° B. 50° C. 65° D. 95°

15. An object is placed 20 cm from a concave mirror of focal length 10 cm. The linear magnification of the image produced is
A. 0 B. 1/2 C. 1 D. 2

16. An object is placed 12 cm from a concave mirror of radius 32 cm. The image formed is
A. virtual and 48 cm behind the mirror
B. real and 48 cm in front of the mirror
C. virtual and 19.2 cm behind the mirror
D. real and 19.2 cm in front of the mirror.

17. A concave mirror positioned at a distance of 5 cm from an object gives a linear magnification of 4. If the image is upright, the radius of curvature of the mirror is
A. 4 cm B. 6.7 cm C. 8 cm D. 13.3 cm

18. An object is placed 6 cm in front of a concave mirror of focal length 9 cm. The image formed is
A. virtual and 18 cm from the mirror
B. real and 18 cm from the mirror
C. virtual and 3.6 cm from the mirror
D. real and 3.6 cm from the mirror.

19. An object of height 2.5 cm positioned 10 cm from a concave mirror produces an image 30 cm from the mirror. The height of the image is
A. 0.83 cm B. 1.25 cm C. 5.0 cm D. 7.5 cm

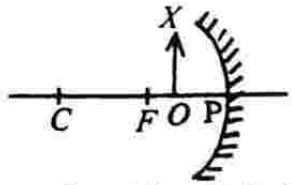
20. A concave mirror having a radius of 24 cm produces a real image four times the size of the object. The distance of the object from the mirror is
A. 7.5 cm B. 15 cm C. 24 cm D. 30 cm

21. If u and v are the object and image distances from a concave mirror of radius r, the magnification can be expressed as
A. $2u/r - 1$ B. $u/r - 1$ C. $2v/r - 1$ D. $v/r - 1$

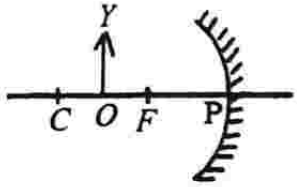
22. A pin is positioned at 21 cm from a concave mirror of radius 28 cm. The magnification of the image formed is
A. 3.0 B. 2.0 C. 1.3 D. 1.0

23. The image formed on a screen by a concave mirror of radius 30 cm is three times the size of the object. The distance of the screen from the mirror is
A. 15 cm B. 20 cm C. 30 cm D. 60 cm

24. A ray of light which passes through the centre of curvature of a concave mirror is reflected by the mirror at an angle of
A. 0° B. 45° C. 90° D. 180°

25. 

The image of the object *OX* formed by the mirror in the figure shown is
A. real, upright and diminished
B. real, inverted and magnified
C. virtual, upright and diminished
D. virtual, upright and magnified

26. 

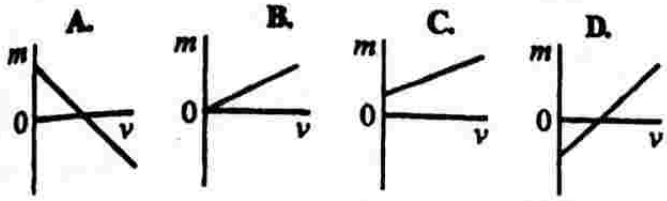
The image of the object *OY* formed by the mirror in the figure shown is located
A. between *F* and *P*
B. to the right of *P*
C. to the left of *C*
D. between *C* and *F*

27. In problem 26, the image is
A. magnified and inverted
B. magnified and erect
C. diminished and inverted
D. diminished and erect.

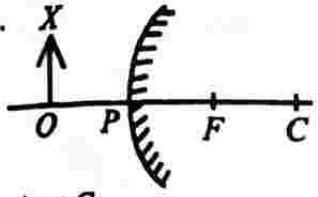
28. An object is placed half-way between the principal focus and the pole of a concave mirror. The image is located
A. at the principal focus
B. one focal length behind the mirror
C. one-half focal length behind the mirror
D. at the centre of curvature.

29. The magnification m produced by a concave mirror can be expressed in terms of the image distance

v and the focal length f of the mirror. Which of the following graphs correctly illustrates the relation between m and v?



30. A convex mirror produces an image which is one-quarter the size of an object placed in front of it. If the radius of curvature of the mirror is 32 cm, the distance between the object and its image is
A. 60 cm B. 48 cm C. 32 cm D. 12 cm

31. 

The image of the object OX formed by the convex mirror in the figure shown is
A. at C
B. between F and C
C. between P and F
D. between O and P

32. An object is placed 15 cm from a convex mirror of radius of curvature 20 cm. The image is located
A. 6 cm in front of the mirror
B. 6 cm behind the mirror
C. 30 cm in front of the mirror
D. 30 cm behind the mirror

33. An object is located at a distance of 20 cm from a concave mirror of radius of curvature 30 cm. The separation between the object and its image is
A. 20 cm B. 40 cm C. 50 cm D. 80 cm

34. An enlarged image of an object is to be produced on a screen placed in front of a concave mirror. The object must be positioned
A. at the centre of curvature
B. at the principal focus
C. beyond the centre of curvature
D. between the principal focus and the centre of curvature.

35. A real image of a candle produced by a concave mirror is located mid-way between the candle and the pole of the mirror. The candle must have been positioned
A. beyond the centre of curvature
B. at the centre of curvature
C. at the principal focus
D. between the centre of curvature and the pole

Answer Key

1. A	6. D	11. D	16. A	21. C	26. C	31. C
2. C	7. C	12. A	17. D	22. B	27. A	32. B
3. C	8. A	13. B	18. A	23. D	28. B	33. B
4. D	9. B	14. D	19. D	24. A	29. D	34. D
5. D	10. C	15. C	20 B	25. D	30. A	35. A

Solutions to Objective Questions

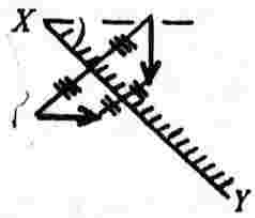
1. (A) $\frac{\text{Image height}}{\text{Object height}} = \frac{\text{image distance}}{\text{object distance}} = \frac{25}{50} = \frac{1}{2}$

Image height = object height x $\frac{1}{2} = 20 \times \frac{1}{2}$
$= 10$ cm

2. (C) Image height = object height x $\frac{\text{image distance}}{\text{object distance}}$

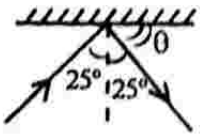
Since both the object height and the image distance remain unchanged while the object distance is halved, the image height will be doubled.

3. (C) This can be easily obtained by sketching two rays, one from each end of the arrow, impinging normally on the mirror. The distance of each of the two points from the mirror is equal to the distance of its respective image behind the mirror (see figure).



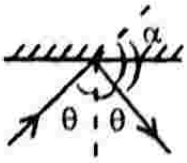
4. **(D)** Both letters are laterally inverted. i.e. turned through 180°, and the image of F is closer to the mirror.

(D)



From the diagram, the required angle is $\theta = 90° - 25° = 65°$.

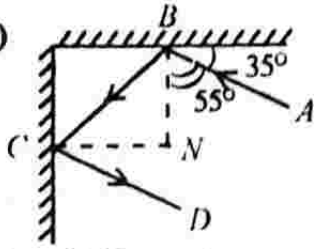
6. **(D)**



The required angle is $\alpha = 180 - 2\theta$

7. **(C)** If the man moves 1 m towards the mirror, his image also moves 1 m towards him. Hence, the distance between the man and his image is reduced by 2 m. The rate of approach of the image is thus twice the speed of the man, or 4 ms^{-1}.

8. **(A)**



BN and CN are the respective normals to each of the mirrors.
Angle of incidence at $B = NBA = 90° - 35° = 55°$
Angle of reflection at $B = NBC = 55°$
Angle of incidence at $C = BCN = 90° - 55° = 35°$
Angle of reflection at $C = NCD = 35°$

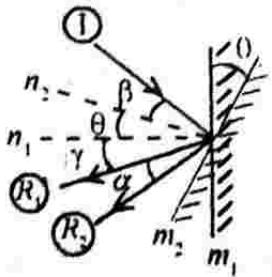
9. **(B)** Referring to the diagram in Q. 8, the angle of deviation at the first mirror is $180° - ABC = 180° - 110° = 70°$ and at the second mirror is $180° - BCD = 180° - 70° = 110°$. The total deviation is thus $110° + 70° = 180°$ [As an exercise, the candidate should verify that the ray is always deviated through 180°, regardless of the angle of incidence].

10. **(C)** From Eq. 12.2, $n = 360/\theta - 1 = 360/90 - 1 = 3$

11. **(D)** $n = 360/120 - 1 = 2$

12. **(A)** $n = 360/0 - 1 = \infty$
[The candidate should try to evaluate the number of images for other values of θ such as 10°, 15°, 30°, 45°, 60°....]

13. **(B)**



In the figure, m_1, m_2 are the initial and final positions of the mirror and n_1, n_2 are the normals at these positions. The incident ray (I) is reflected as R_1 for position m_1 and as R_2 for position m_2 of the mirror. The required angle is α.
Angle of incidence = Angle of reflection, hence for m_1:

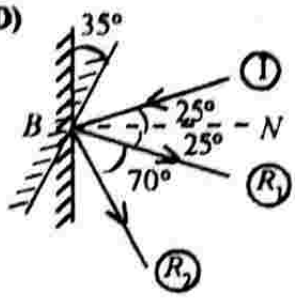
$$\beta + \theta = \gamma + \alpha \quad \text{.....(i)}$$

and for m_2:

$$\beta = \theta + \gamma \quad \text{.....(ii)}$$

Solving eqs. (i) and (ii) simultaneously gives $\alpha = 2\theta$, i.e. the reflected ray is always rotated through twice the angle of rotation of the mirror.

14. **(D)**



From Q. 13, the reflected ray is turned through 70° from position (R_1) to (R_2). The angle which (R_2) makes with BN is thus equal to 70° + 25° or 95°.

15. **(C)** $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10} - \frac{1}{20} = \frac{1}{20}$, or $v = 20$ cm
Magnification $= v/u = 20/20 = 1$

16. **(A)** $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{16} - \frac{1}{12} = -\frac{1}{48}$
[Note that $f = R/2 = 16$ cm]
or $v = -48$cm, the negative sign indicating a *virtual* image, which lies *behind* the mirror.

17. **(D)** $m = 4 = v/u \Rightarrow v = 4u = 4(5) = 20$ cm
Since the image is magnified and upright, it must be virtual, hence v is negative.

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{5} - \frac{1}{20} = \frac{3}{20}$, or $f = 20/3$ cm
$R = 2f = 40/3 = 13.3$ cm

18. **(A)** $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{9} - \frac{1}{6} = -\frac{1}{18}$, or $v = -18$ cm
The image is thus virtual and 18 cm from the mirror.

19. **(D)** $\text{Magnification} = \frac{\text{height of image}}{\text{height of object}} = \frac{\text{image distance}}{\text{object distance}} = \frac{30}{10} = 3$
Height of image = 3 x height of object = 3 (2.5) = 7.5 cm

20. **(B)** $f = R/2 = 12$ cm, $v = 4u$
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, or $\frac{1}{12} = \frac{1}{u} + \frac{1}{4u} = \frac{5}{4u}$
$u = 15$ cm.

21. **(C)** $\frac{1}{u} + \frac{1}{v} = \frac{1}{f} = \frac{2}{r}$
Multiply through by v to give $\frac{v}{u} + 1 = \frac{2v}{r}$

Magnification = $\frac{v}{u} = \frac{2v}{r} - 1$

22. **(B)** $f = 28/2 = 14$ cm

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{14} - \frac{1}{21} = \frac{1}{42}$,or $v = 42$ cm

$m = v/u = 42/21 = 2.0$

23. **(D)** $f = 30/2 = 15$ cm; magnification $= v/u = 3$, or $v = 3u$

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, or $\frac{1}{15} = \frac{1}{u} + \frac{1}{3u} = \frac{4}{3u}$

$u = 20$ cm and $v = 3 \times 20 = 60$ cm

24. **(A)** A ray which passes through the centre of curvature is incident *normally* on the mirror, i.e. the angle of incidence = 0°, which is also equal to the angle of reflection.

25. **(D)** See section 12.10 of the notes.

26. **(C)** See section 12.10 of the notes

27. **(A)** See section 12.10 of the notes

28. **(B)** $u = f/2$; $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{f} - \frac{2}{f} = -\frac{1}{f}$

or $v = -f$, i.e. the image is *virtual* and its distance is one focal length from the mirror.

29. **(D)** $\frac{1}{u} = \frac{1}{f} - \frac{1}{v}$, which on multiplying both sides of the equation by v, gives

$m = \frac{v}{u} = \frac{v}{f} - 1$.

This is the equation of a straight line with an intercept of -1 on the m axis.

30. **(A)** $f = R/2 = -16$ cm (f is negative for a convex mirror)

$m = v/u = 1/4$, or $v = -u/4$ (v is negative since a convex mirror produces a virtual image).

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, or $-\frac{1}{16} = \frac{1}{u} - \frac{4}{u} = \frac{-3}{u}$,or $u = 48$ cm

$v = -48/4 = -12$ cm.

Distance between the object and its image

$= u + |v| = 48 + 12 = 60$ cm

31. **(C)** The image in a convex mirror is *always* located between the pole and the principal focus, regardless of the position of the object.

32. **(B)** $f = -20/2 = -10$ cm, $u = 15$ cm

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = -\frac{1}{10} - \frac{1}{15} = -\frac{5}{30}$, or $v = -6$ cm

i.e. 6 cm *behind* the mirror (virtual image).

33. **(B)** $f = 30/2 = 15$ cm, $u = 20$ cm

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{15} - \frac{1}{20} = \frac{1}{60}$, or $v = 60$ cm

Since the image is real, the object and its image are on the same side of the mirror. Hence their separation $= v - u = 60 - 20 = 40$ cm.

34. **(D)** A concave mirror produces a *magnified, real* image only when the object is placed between the focus and the centre of curvature (Section 12.10 of notes).

35. **(A)** Since the image distance (v) is less than the object distance (u), and $m = v/u$, the image is diminished. A concave mirror produces a *real, diminished* image only when the object is placed beyond the centre of curvature.

Revision Check-list

Under this chapter, the student should be able to

- explain what is meant by the *rectilinear propagation* of light.
- explain what is meant by a *luminous, transparent, translucent, opaque*, or *incandescent* body.
- explain what happens during an *eclipse*.
- explain how a *pinhole camera* operates and how the image is affected by the size of the hole.
- state the *laws of reflection*.
- describe the characteristics of the image formed by a plane mirror.
- determine the number of images formed when an object is placed between two mirrors inclined at various angles to each other.
- remember that if a plane mirror on which a ray of light is incident is turned through a certain angle, the reflected ray is turned through twice the angle of rotation of the mirror.
- describe characteristics of *concave* and *convex* mirrors.
- define the *focal length* of a spherical mirror in terms of the radius of curvature.
- obtain the image formed by any spherical mirror and for any position of the object by drawing appropriate ray diagrams.
- explain the basic differences between a *real* and a

virtual image.

- state the characteristics of the image formed by a concave or convex mirror, for any position of the object.
- remember that plane and convex mirrors *never* form real images.
- explain how a real image (magnified diminished or same size) of an object can be *produced on screen* using a concave mirror.
- recall and apply *the numbered equations* in the notes, using the appropriate sign convention.
- state some *applications* of plane, concave and convex mirrors
- describe an experiment to determine the focal length of a concave mirror.

13 Refraction of Light

13.1 Laws of Refraction

- As light passes from medium 1 in which it has velocity v_1 into medium 2 where it has velocity v_2, the direction of propagation changes, i.e. the light is ***refracted***.
- The ***laws of refraction*** are (Fig. 13.1):
  - (i) the incident ray, the refracted ray and the normal to the interface at the point of incidence all lie in the same plane;
  - (ii) the ratio of the sine of the angle of incidence θ_1, to the sine of the angle of refraction θ_2, is a constant for a given pair of media. This is known as ***Snell's law***.
- The refractive index of medium 2 relative to medium 1, written as n_{12} is defined as

$$n_{12} = \frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} \qquad (13.1)$$

- The absolute refractive index (n) of a medium is

$$n = \frac{\text{velocity of light in vacuum}}{\text{velocity of light in the medium}} \qquad (13.2)$$

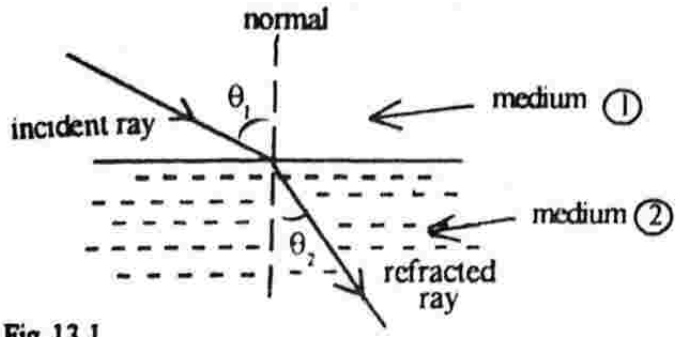


Fig. 13.1

13.2 Refraction by a Plane Surface

- A ray of light which enters a slab of glass (optically dense medium) from air (a less dense mdium) is deviated towards the normal in the glass, i.e. the ray is refracted towards the normal.
- The ray is refracted away from the normal when light goes from a denser to a less dense medium.
- ***Real and Apparent Depths:*** A stone at the bottom of a bucket filled with water appears nearer to surface than it actually is, due to the refraction of the ray as it passes from water into air. If the stone is at position B at the bottom of the bucket, the image is seen at position C (Fig. 13.2). The ratio of OB to OC is equal to the refractive index of water relative to air, i.e.

$$n_{12} = \frac{\text{real depth}}{\text{apparent depth}} \qquad (13.3)$$

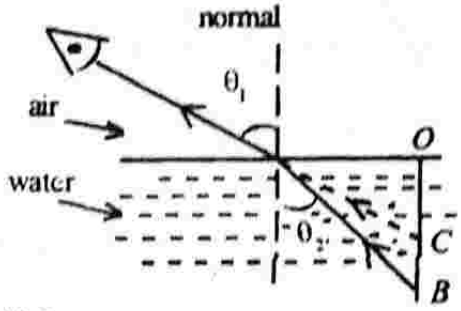


Fig. 13.2

13.3 Total Internal Reflection

- Occurs when a light ray passes from an optically dense to a less dense medium, e.g. water to air, or glass to air.
- As the angle of incidence is increased, the angle of refraction (which is greater than the angle of incidence) also increases in accordance with Eq. (13.1).
- The incident angle at which the refracted ray lies along the interface, i.e. at which the angle of refraction is 90^0, is known as the ***critical angle*** θ_c (Fig. 13.3).

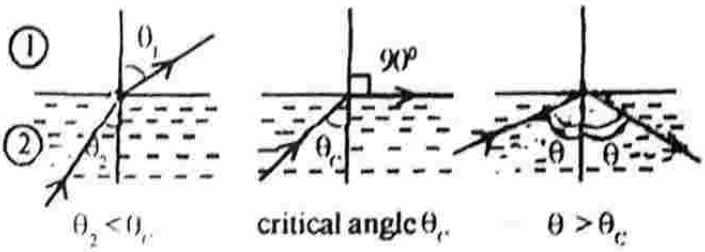


Fig. 13.3

- Beyond θ_c the ray is reflected back into the denser medium, i.e it is ***totally internally reflected***.
- Applying eq. (13.1) at the point of total internal reflection gives:

$$n_{12} = \frac{\sin 90^0}{\sin\theta_c} = \frac{1}{\sin\theta_c} \qquad (13.3)$$

- A ***mirage*** can be explained using the phenomenon of total internal reflection. On a hot day the air layer close to the ground is warm, and the warm air is optically less dense than cool air (farther from the ground). A ray of light from the sky is totally internally reflected once the critical angle is exceeded, and an image of the sky which resembles a pool of water when viewed from a distance, is produced.

13.4 Refraction by a Prism

- A triangular prism is made of glass or plastic usually with angles $60^0, 60^0, 60^0$, or $90^0, 45^0, 45^0$ (Fig. 13.4).

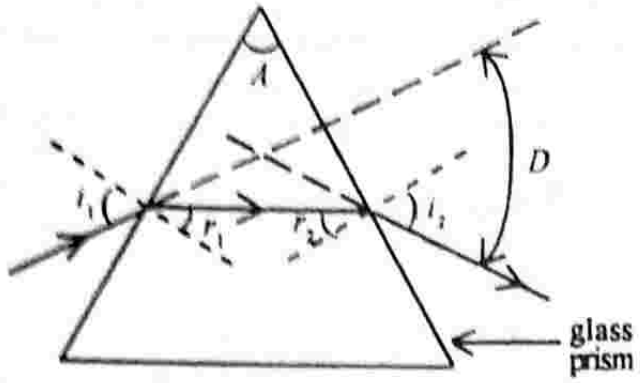


Fig. 13.4

- A ray of light incident on the first surface is refracted into the prism towards the normal.
- It emerges at the second surface refracted away from the normal.
- The ***angle of deviation*** D is the difference between the directions of the incident ray and the one emerging from the prism.
  For refraction at the left face, angle of deviation $= i_1 - r_1$, and for refraction at the right face, angle of deviation $= i_2 - r_2$. Hence $D = (i_1 - r_1) + (i_2 - r_2)$.
- Minimum deviation (D_{min}) occurs in a prism when $i_1 = i_2$ and $r_1 = r_2$. Hence

$$D_{min} = 2(i_1 - r_1) = 2(i_2 - r_2) \qquad (13.5)$$

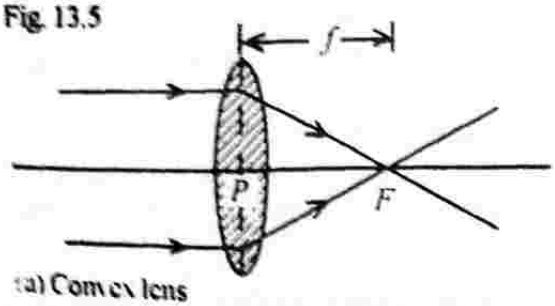
- If A is the angle of the prism, then at minimum deviation the refractive index of the prism is given by

$$n = \frac{\sin \frac{1}{2}(A + D_{min})}{\sin \frac{1}{2} A} \qquad (13.6)$$

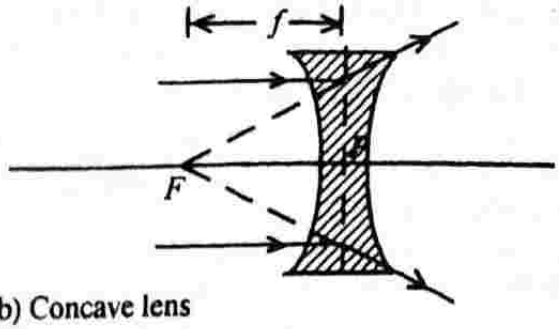
13.5 Refraction Through Lenses

- A ***lens*** is any transparent material with curved surfaces.
- A ***convex*** (or ***converging***) lens is thickest at the middle, while a ***concave*** (or ***diverging***) lens is thinnest at the middle.
- The ***optical centre***, or ***pole***, P is the centre of the lens.
- Since light can pass through a lens from either side, a lens has a principal focus (F) on each side.
- For a convex lens, rays that are initially parallel to the principal axis converge at the principal focus after refraction through the lens (Fig. 13.5a).
- For a concave lens, incident parallel rays appear to diverge from the principal focus after refraction through the lens (Fig. 13.5b).

Fig. 13.5



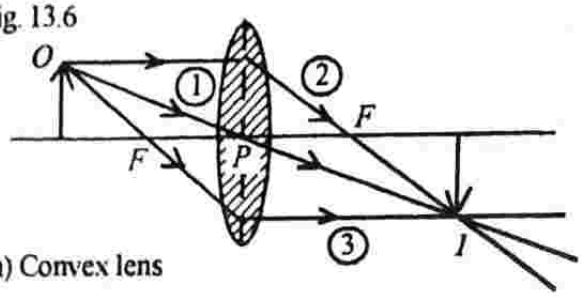
(a) Convex lens



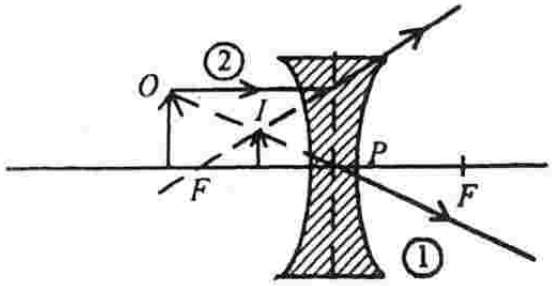
(b) Concave lens

- The position of the image formed by a lens is located using any two of the following rays (Fig. 13.6):
  (1) a ray that passes through the pole of the lens undeviated;
  (2) a ray that is initially parallel to the principal axis, which passes through the principal focus after refraction through the lens; and
  (3) a ray that passes through the principal focus and emerges parallel to the principal axis after refraction through the lens.

Fig. 13.6



(a) Convex lens



(b) Concave lens

13.6 Nature of Images Formed by Lenses

(a) Convex Lens

Position of Object	Position of Image	Nature of Image
Between P and F	Same side as object	Magnified, erect and virtual
At F	At infinity	–
Between F and $2f$	Between $2f$ and infinity	Magnified, inverted and real
At $2f$	At $2f$	Same size as object, inverted and real
Between $2f$ and infinity	Between F and $2f$	Diminished, inverted and real
At infinity	At F	Diminished, inverted and real

(b) Concave Lens

- Regardless of the position of the object, the image formed by a concave lens is:
  (i) virtual and on the same side of the lens as the object,
  (ii) erect and diminished, and
  (iii) closer to the lens than the object.

(The candidate may find it an interesting exercise to compare the nature of the images for a concave mirror with that of a convex lens, and a convex mirror with a concave lens).

13.7 The Lens Equation

- As for mirrors, the ***lens equation*** is

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad (13.7)$$

where u, v and f are the object distance, image distance and focal length, respectively.

- The ***real-is-positive*** sign convention is also applicable; f is ***positive*** for a ***convex*** lens and ***negative*** for a ***concave*** lens.

13.8 The Simple Microscope

- A ***simple microscope*** consists of a single convex lens.
- When the object is placed between the principal focus and the pole, the image formed is virtual, erect and magnified (secton 13.6).
- A slide projector makes use of a similar arrangement. In this case the object is positioned just beyond the principal focus of a convex lens, producing a real, magnified and inverted image.

13.9 The Compound Microscope

- A compound microscope consists of two lenses, arranged such that one is close to the object (***objective lens***) and the other close to the eye (***eyepiece***), Fig. 13.7
- The objective lens has a shorter focal length than the eyepiece.
- With the object (O) placed just beyond the principal focus of the objective lens, a real, inverted and magnified image (I_1) is formed.
- This image lies within, but close to, the principal focus (F_e) of the eyepiece, and serves as the object for the eyepiece which thus produces a final virtual, inverted and magnified image (I_2).

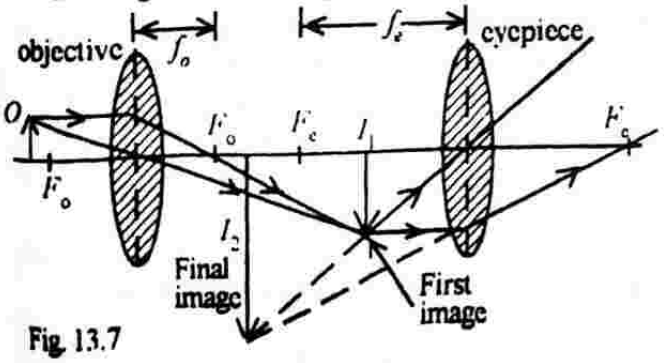


Fig. 13.7

13.10 The Telescope

- A **telescope** is used for viewing distant objects.
- It consists of an objective lens with a long focal length, f_o and an eyepiece with a short focal length, f_e.
- Under *normal adjustment*, the distance between the lenses is $f_o + f_e$ (Fig. 13.8).
- An object at infinity then forms a final, magnified image also at infinity.
- The angular magnification M of the image thus formed is

$$M = \frac{f_o}{f_e} \qquad (13.8)$$

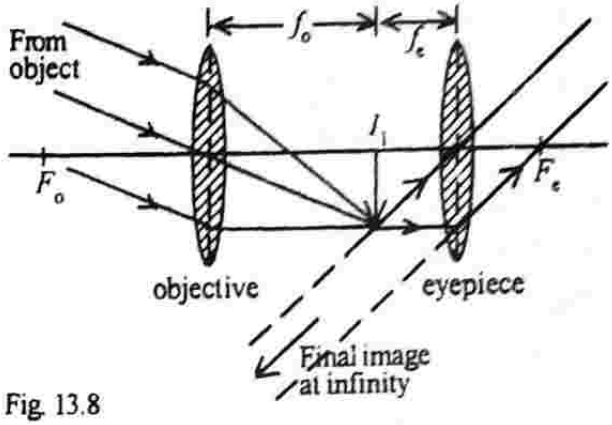


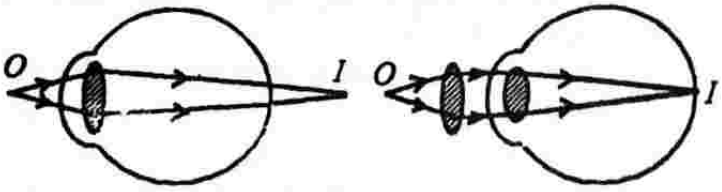
Fig. 13.8

- When adjusted to produce an image at the near point, the final image is magnified, inverted and virtual.
- In a ***terrestrial telescope*** used for viewing distant objects on the earth's surface, an extra convex lens is inserted between the objective and the eyepiece, thus producing an erect final image.

13.11 The Human Eye

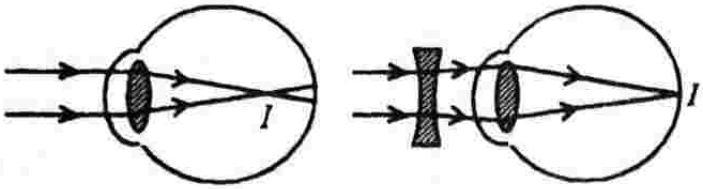
- The eye consists of a lens whose focal length can be varied by flexible ciliary muscles.
- This lens focuses the image of an object on the retina at the back of the eye.
- The ***far point*** of the eye is the furthest distance at which the eye can focus (i.e. clearly see) an object. This is ***infinity*** for a normal eye.
- The ***near point*** of the eye is the minimum distance of distinct vision. For a normal eye this is 25 cm.
- ***Accommodation*** is the ability of an eye to change its focal length and thus focus objects at various distances.
- ***Long-sightedness*** is a defect of the eye in which the image of a near object falls behind the retina. It is corrected by using a convex lens (Fig. 13.9).

- ***Short-sightedness*** is an eye defect in which the image of a distant object is focused in front of the retina. It is corrected by using a concave lens (Fig. 13.10).
- When the cornea has uneven curvature, the eye cannot see equally clearly in all directions. It is corrected by using a ***cylindrical lens***, which is one that is curved in one direction only.



(a) Long sight (b) Long sight correction

Fig. 13.9



(a) Short sight (b) Short sight correction

Fig. 13.10

13.12 The Camera

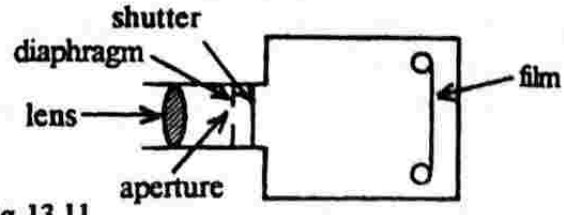


Fig. 13.11

- The ***camera*** has a convex lens which focuses a real, inverted image on a film (Fig. 13.11).
- The ***aperture*** is a hole through which light rays enter the camera, and the size of the hole is controlled by the adjustable ***diaphragm***.
- The ***shutter*** controls the length of exposure of the film to incoming light rays.
- A comparison between the human eye and the camera is provided in the table below:

Eye	Camera
* Flexible lens	Rigid lens
* Retina	Film
* Pupil	Aperture
* Iris	Diaphragm
* Real, inverted and diminished image	Real, inverted and diminished image
* Lens adjusted by ciliary muscles	Lens moved closer to or away from film.

True or False - Type Questions

Answer *True*(T) or *False* (F) to the following questions.

1. A ray of light which is incident on a rectangular glass slab which is located in air
   a. suffers no deviation upon emergence at the opposite face of the slab.
   b. suffers no displacement at the point of emergence.
   c. emerges from the slab parallel to the incident ray.
   d. is partly reflected at the point of incidence.
   e. can be totally reflected at the point of incidence, depending on the angle of incidence.
   f. suffers maximum displacement when the angle of incidence is 90°.
   g. is deviated towards the normal as it crosses the air/glass boundary.
   h. is slowed down as it crosses the glass/air boundary.
   i. travels faster in air than in glass.
   j. passes through the slab undeviated and undisplaced at zero angle of incidence.
   k. suffers an angular deviation at the air/glass interface which is equal to the angle between the refracted ray and the normal to the interface.

2. When a ray of light crosses from one medium to another, the critical angle
   a. is the angle of incidence beyond which no light is refracted.
   b. is independent of the speed of light in the media.
   c. is the maximum angle of refraction possible if the ray passes from the optically less dense medium to the denser medium.
   d. remains unchanged if one of the two media is changed.
   e. is the angle of incidence whenever total internal reflection occurs.
   f. is the angle of incidence beyond which light travelling from the optically denser medium, cannot pass through the less dense medium.
   g. is physically meaningful only when one medium is solid while the other is gas.

3. A mirage is formed
   a. through the processes of reflection, refraction and diffraction.
   b. because layers of air close to the road surface have varying refractive indices in hot weather.

c. because hot road surfaces are good reflectors of light.
d. when total internal reflection occurs at the road surface.
e. when light from the sky is reflected by air layers close to the road surface.
f. because the temperature of the air varies with distance from the road surface.

4. For a thin converging lens:
a. a ray of light that passes through the pole of the lens is undeviated.
b. a ray of light initially parallel to the principal axis emerges parallel to the principal axis after refraction
c. a real image is always inverted.
d. the image of an object is always magnified.
e. the image of an object is always located on the opposite side of the lens.
f. a real image is always obtained for an object placed beyond the principal focus.
g. it is not possible to produce an image on a screen which is exactly the same size as the object.
h. as an object is moved closer to the principal focus from infinity, the image moves away from the lens.
i. a focused image of the sun can be obtained on a screen placed at the principal focus of the lens.
j. real images are always smaller than the object.

5. In a compound microscope :
a. the objective and the eyepiece are both convex and have the same focal length.
b. both the objective and the eyepiece have short focal lengths.
c. the object is placed just beyond the objective's principal focus.
d. the distance between the objective and the eyepiece is equal to the sum of their focal lengths.
e. the intermediate image (formed by the objective) is usually located at slightly more than one focal length from the eyepiece.
f. the intermediate image is magnified and real.
g. the final image is located at infinity.
h. the final image is magnified and virtual.

6. In an astronomical telescope,
a. the objective has a longer focal length than the eyepiece.
b. the image formed by the objective is real and magnified.
c. the final image is real and inverted.
d. the final image is located at infinity with the telescope in normal adjustment.
e. the fact that the final image is virtual and diminished makes it unsuitable for viewing objects on the earth.

7. a. The iris of the eye corresponds to the shutter of a camera.
b. When the eyeball is too short and the image of a nearby object is formed behind the retina, the eye defect is short sight.
c. Long sight is the eye's inability to focus on nearby objects.
d. In a short-sighted person, parallel rays of light are focused in front of the retina.
e. *Accommodation* refers to the ability of the eye to focus objects placed at the least distance of distinct vision.
f. *Presbyopia* is the lack of power of accommodation which is mainly due to the hardening of the eye and is usually associated with old age.
g. For a long-sighted person, distant objects appear blurred.
h. To correct myopic defects in the human eye, a convex lens is needed.
i. The image of an object on the retina of a human eye is real and erect.
j. Like in the human eye, the image formed by a camera is real, inverted and diminished.

Answers to True or False - Type Questions

1. a (T) The ray emerges parallel to the incident ray.
b (F) It is displaced laterally with respect to the incident ray.
c (T) Same as (a).
d (T) Part of the incident light is always reflected at the air/glass interface while the rest is refracted.
e (F) Total internal reflection occurs only when the ray passes from an optically denser to a less dense medium.
f (T) At the grazing angle of incidence (90°), the displacement of the ray is equal to the thickness of the slab, since the emergent ray also grazes the glass/air surface.
g (T) This implies that the angle of refraction is less than the angle of incidence.
h (F) Light moves faster in air than in glass.
i (T) See (h) above.
j (T) Zero angle of incidence implies that the incident ray impinges *normally* on the glass slab, in which case it passes straight through the slab undeviated and undisplaced.
k (F) The angular deviation is the angle between the incident ray and the refracted ray.

2. a (T) Beyond the critical angle, the incident light is totally internally reflected.
   b (F) The critical angle depends on the refractive index of the denser medium relative to the other medium, which is in turn determined by the speed of light in both media.
   c (T) This is easily seen from a sketch of the refraction process.
   d (F) See (b) above.
   e (F) It is the *minimum* angle of incidence for which total internal reflection occurs. Note that total internal reflection occurs for any angle of incidence greater than the critical angle.
   f (T) The light is reflected back into the optically denser medium.
   g (F) Both media could be solid, liquid or gas, as long as the light travels from the optically denser to the less dense medium.

3. a (F) The formation of a mirage depends on the processes of reflection and refraction, but not diffraction.
   b (T) The temperature of air varies with distance from the road surface, and the refractive index varies with air temperature.
   c (F)
   d (F)
   e (T) Light from the sky, passing from cold air, (high refractive index) to warm air near the road surface (low refractive index) essentially moves from an optically denser to a less dense medium, and is totally internally reflected once the angle of incidence exceeds the critical angle.
   f (T) See (b) above.

4. a (T) See notes.
   b (F) The refracted ray must pass through the principal focus.
   c (T) See notes.
   d (F) See notes.
   e (F) Objects placed between the principal focus and the pole produce virtual images, which are on the same side of the lens as the object.
   f (T) See notes.
   g (F) An object placed at a distance of $2f$ from the lens produces a *real* image (which can be cast on a screen) of exactly the same size as the object. This image is also located at a distance of $2f$ from the lens.
   h (T) As the object is moved from infinity to the principal focus, its image moves from the principal focus to infinity.
   i (T) The sun, being located at an infinite distance, produces a real image at the principal focus of the lens.
   j (F) Converging lenses form real but magnified images when the object is placed between f and $2f$ (see notes).

5. a (F) The objective usually has a shorter focal length than the eyepiece.
   b (T) Focal lengths of 1 cm to 5 cm are typical.
   c (T) This is necessary in order to produce a *real, magnified* intermediate image (Section 13.6) which serves as the object for the eyepiece.
   d (F) The distance between the objective and the eyepiece is much larger than the sum of their focal lengths. This should *not* be confused with the arrangement in a telescope.
   e (F) The intermediate image must lie within the principal focus of the eyepiece in order to produce a magnified final image which lies on the same side of the eyepiece (*virtual* image).
   f (T)
   g (F) The final image is usually located at the near point of the eye, i.e. 25 cm from the eyepiece.
   h (T)

6. a (T) See notes.
   b (F) The intermediate image is real but *diminished*.
   c (F) The final image is virtual and inverted.
   d (T) See notes.
   e (F) The astronomical telescope is unsuitable for viewing obejcts on the earth because the final image is inverted.

7. a (F) The iris corresponds to the diaphragm of a camera.
   b (F) This is *long sight*.
   c (T)
   d (T) See notes.
   e (F) It is the eye's ability to focus objects at *various* distances, from the near point (25 cm) to infinity.
   f (T) This is the definition of *presbyopia*.
   g (F) A long-sighted person can focus distant objects clearly. However, *nearby* objects appear blurred.
   h (F) The correction of myopia (short sight) requires a concave lens (see notes).
   i (F) The image is real but *inverted*.
   j (T) See notes.

SSCE/JME - Type Objective Questions

1. The speed of light in air is 3×10^8 ms^{-1}. If the refractive index of water is 4/3, the speed of light in water is
A. 4×10^8 ms^{-1} B. 2.25×10^8 ms^{-1}
C. 4.33×10^8 ms^{-1} D. 4.56×10^8 ms^{-1}

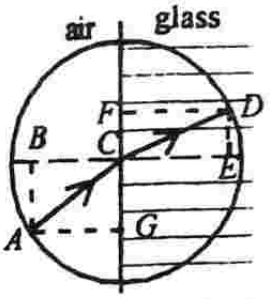
2. The speed of light in a glass medium is 1.80×10^8 ms^{-1}. If the speed of light in air is 3×10^8 ms^{-1}, the refractive index of the glass is
A. 1.67 B. 1.50 C. 1.40 D. 1.33

3. Light of wavelength 5×10^{-7}m has a speed of 3×10^8 ms^{-1} in air. Its wavelength in glass of refractive index 1.5 is
A. 7500×10^{-8} cm B. 6666×10^{-8} cm
C. 5000×10^{-8} cm D. 3333×10^{-8} cm

4. A ray of light travelling in air is incident at an angle of 30° on the surface of water of refractive index 4/3. The angle of refraction is
A. 15° B. 18° C. 22° D. 24°

5. The speeds of light in air and in glass are 3.0×10^8 ms^{-1} and 1.8×10^8 ms^{-1} respectively. If the angle of refraction of a ray of light incident on an air/glass interface is 30°, the sine of the angle of incidence is
A. 0.30 B. 0.60 C. 0.83 D. 1.00

6. A ray of light which is incident normally on an air-glass interface is, upon refraction in the glass, deviated through an angle of
A. 0° B. 45° C. 60° D. 90°

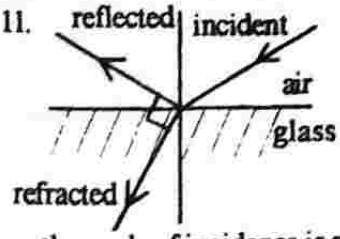
7. 

A ray of light AC travelling in air is refracted along the path CD in glass as shown in the figure. If points A and D lie on a circle centred on C, the refractive index of the glass is given by the ratio
A. $CE : BC$ B. $CF : CG$ C. $CD : AC$ D. $CG : CF$

8. The refractive index of a medium is $\sqrt{2}$. The critical angle is
A. 30° B. 45° C. 60° D. 90°

9. The critical angle for light travelling from a transparent medium to air is measured as 34°. The refractive index of the medium is
A. 0.56 B. 1.50 C. 1.79 D. 2.02

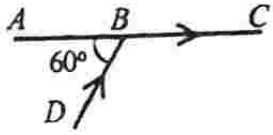
10. Two rays of light which are equally inclined to the vertical emanate from a point below the surface of a pool of water (refractive index = 4/3). If the two rays are inclined to each other at an angle of 80° in the water, the angle between the rays when they emerge into air is
A. 59° B. 105° C. 118° D. 160°

11. 

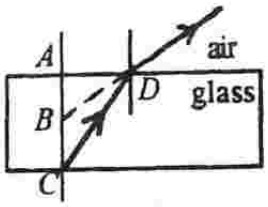
A ray of light is incident on an air/glass interface (see figure). If the reflected ray is perpendicular to the refracted ray and glass has a refractive index of 1.50, the angle of incidence is approximately
A. 42° B. 56° C. 60° D. 75°

12. A ray of light is incident on one side of a parallel-sided glass block of refractive index 1.50 and emerges from the other side after refraction through the block. If the angle of incidence is 40°, the angular deviation of the emergent ray is
A. 80° B. 40° C. 20° D. 0°

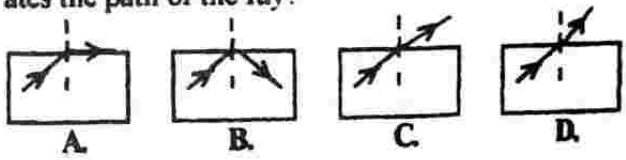
13. The refractive index for a given transparent medium is 1.4. The minimum angle required for total internal reflection to take place in the medium is
A. 46° B. 44° C. 40° D. 30°

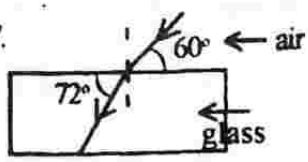
14. 

An incident ray DB is inclined at an angle of 60° to the interface AB. If the refracted ray BC lies along the surface, the refractive index of the medium is
A. 0.5 B. 1.2 C. 1.5 D. 2.0

15. 

In the figure shown, a ray of light CD moves from a glass block into air. If AC = 5 cm and BC = 2 cm, the refractive index of the glass is
A. 1.40 B. 1.50 C. 1.67 D. 1.72

16. A ray of light travelling in glass of refractive index 1.5 is incident at an angle of 45° at the glass/air boundary. Which of the following figures correctly illustrates the path of the ray?


17. 

A ray of light is incident on a glass block as shown in the figure. The refractive index of the glass is
A. 1.67 B. 1.62 C. 1.50 D. 1.10

34. An object is placed at a distance of $2f$ from a converging lens of focal length f. The image distance is
A. $2f$ B. f C. $f/2$ D. $f/4$

35. An object is placed 12 cm from a converging lens. If a virtual image is formed which is twice the size of the object, the focal length of the lens is
A. 8 cm B. 12 cm C. 18 cm D. 24 cm

36. An object placed a distance d from a converging lens of focal length 10 cm forms an image which is 20 cm from the lens and on the same side of the lens as the object. The value of d is
A. 3.3 cm B. 6.7 cm C. 10.0 cm D. 20.0 cm

37. A real image which is four times the size of the object is produced with a converging lens of focal length 16 cm. The separation between the object and its image is
A. 60cm B. 80cm C. 100 cm D. 120 cm

38. A concave lens of focal length 15 cm forms an image 1/3 the size of the object. The object distance is
A. 10 cm B. 20 cm C. 30cm D. 60 cm

39. For an object placed 6 cm from a diverging lens of focal length 18 cm, the image is
A. 4.5 cm in front of the lens
B. 4.5 cm behind the lens
C. 9.0 cm in front of the lens
D. 9.0 cm behind the lens

40. The image of an object formed by a diverging lens of focal length 12 cm is located 6 cm from the lens. The distance of the object from the lens is
A. 4 cm B. 6 cm C. 12 cm D. 24 cm

41. The image formed by a diverging lens is always
A. magnified, virtual and erect
B. diminished, real and inverted
C. diminished, virtual and inverted
D. diminished, virtual and erect.

42. The image of a real object formed by a diverging lens is always
A. inverted
B. real
C. larger than the object
D. situated between the object and the lens.

43. Of the four lenses whose focal lengths are provided below, the most suitable for use as a microscope objective is
A. -4 mm B. +4 mm C. -4 cm D. +4 cm

44. A camera lens having a focal length of 18 cm is focused on an object which is 90 cm away. To obtain a sharp image, the distance between the lens and the film must be
A. 15 cm B. 20 cm C. 22.5 cm D. 45 cm

45. A lens of focal length 10 cm which is used as a simple microscope forms an image five times the size of the object. The distance of the object from the lens is
A. 8 cm B. 10 cm C. 12 cm D. 24 cm

46. The projection lens in a slide projector has a focal length of 8 cm. The distance between the lens and the slide must be
A. less than 8 cm
B. equal to 8 cm
C. greater than 8 cm but less than 16 cm
D. greater than 16 cm

47. An exact copy of a document is to be produced using a duplicating camera. The document should be placed
A. at the optical centre of the lens of the camera
B. at the principal focus of the lens.
C. between the principal focus and a point twice the focal length of the lens
D. at a point which is twice the focal length of the lens.

48. The image in a simple microscope is
A. magnified, real and erect
B. magnified, virtual and erect
C. magnified, virtual and inverted
D. magnified, real and inverted

49. A magnifying glass produces an image which is positioned 30 cm from the lens and is five times the size of the object. The distance between the object and the magnifying glass is
A. 3.0 cm B. 4.5 cm C. 6.0 cm D. 7.5 cm

50. The image formed by the objective lens in a compound microscope is positioned at 4 cm from the eyepiece. If the final image is at 25 cm from the eyepiece, the focal length of the eyepiece is
A. 3.4 cm B. 4.8 cm C. 21.0 cm D. 29.0 cm

51. The two converging lenses of a telescope have focal lengths of 25 cm and 5 cm. The distance between the lenses in normal adjustment is
A. 0.2 cm B. 5.0 cm C. 20.0 cm D. 30.0 cm

52. Which of the following statements is not correct about long sight?
A. The image of a distant object falls behind the retina.

B. Nearby objects appear blurred.
C. It is sometimes due to the eyeball being too short.
D. It is corrected with a converging lens.

53. A long-sighted person cannot clearly see objects that are less than 75 cm away. The type and focal length of lens which will enable him to read a book at 25 cm are
A. convex, 18.8 cm B. concave, 18.8 cm
C. convex, 37.5 cm D. concave, 37.5 cm

54. A short-sighted person cannot see clearly objects which are further away than 5 m. The type and focal length of lens required to make him see distant objects clearly are
A. convex, 5 m
B. concave, 5 m
C. convex, insufficient data to determine f
D. concave, insufficient data to determine f.

Answer Key

1. B	10. C	19. A	28. C	37. C	46. C
2. A	11. B	20. A	29. B	38. C	47. D
3. D	12. D	21. C	30. D	39. A	48. B
4. C	13. A	22. D	31. B	40. C	49. C
5. C	14. D	23. B	32. D	41. D	50. B
6. A	15. C	24. A	33. A	42. D	51. D
7. D	16. B	25. C	34. A	43. B	52. A
8. B	17. B	26. B	35. D	44. C	53. C
9. C	18. D	27. A	36. B	45. A	54. B

Solutions to Objective Questions

1. (B) Refractive index of water $= \dfrac{\text{speed of light in air}}{\text{speed of light in water}}$

Speed of light in water $= \dfrac{\text{speed of light in air}}{\text{refractive index of water}}$

$= \dfrac{3 \times 10^8}{4/3} = 2.25 \times 10^8\ \text{ms}^{-1}$

2. (A) Refractive index of glass $= \dfrac{3 \times 10^8}{1.8 \times 10^8} = 1.667$

3. (D) Refractive index of glass $= \dfrac{\text{speed of light in air}}{\text{speed of light in glass}}$

$= \dfrac{\text{wavelength in air}}{\text{wavelength in glass}}$

$\Rightarrow$ wavelength in glass $= \dfrac{\text{wavelength in air}}{\text{refractive index of glass}}$

$= \dfrac{5000 \times 10^{-8}}{1.5} = 3333 \times 10^{-8}\text{cm}$

4. (C) $n = \dfrac{\sin i}{\sin r}$

$\sin r = \dfrac{\sin i}{n} = \dfrac{\sin 30^\circ}{4/3} = 0.375 \Rightarrow r = 22^\circ.$

5. (C) $n = \dfrac{3.0 \times 10^8}{1.8 \times 10^8} = 1.667$

$\dfrac{\sin i}{\sin r} = n =$

$\sin i = 1.667 \sin r = 1.667 \sin 30^\circ = 0.83$

6. (A) $n = \sin i / \sin r$

$\sin r = (1/n)\sin i = 0$ (since $i = 0$)

$r = 0$ and the angle of deviation is zero.

7. (D) $n = \dfrac{\sin i}{\sin r} = \dfrac{\sin A\hat{C}B}{\sin D\hat{C}E}$

$= \dfrac{AB/AC}{DE/CD} = \dfrac{AB}{DE} = \dfrac{CG}{CF}$

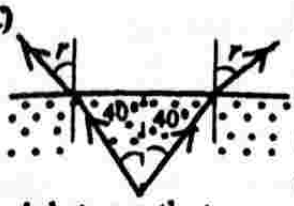
[Note that $AC = CD$, $AB = CG$ and $DE = CF$]

8. (B) $\sin c = 1/n = 1/\sqrt{2}$

$c = 45^0$

9. (C) $n = \dfrac{1}{\sin c} = \dfrac{1}{\sin 34^0} = 1.79$

10. **(C)**



From the figure

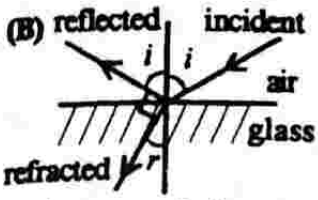
$\frac{\sin r}{\sin 40°} = \frac{4}{3}$

$\sin r = (4/3)\sin 40° = 0.857$

$r = 59°$

Angle between the two rays in air = 2 x 59° = 118°.

11. **(B)**



From the figure, the angle of incidence = angle of reflection. The angle of refraction $r = 180° - (90° + i)$
$= 90° - i$

$$n = \frac{\sin i}{\sin r} = \frac{\sin i}{\sin(90° - i)} = \frac{\sin i}{\cos i} = \tan i$$

$\Rightarrow \tan i = 1.50$, or $i = \tan^{-1} 1.50 = 56.3°$

12. **(D)** The emergent ray is parallel to the incident ray, hence the angular deviation is zero.

13. **(A)** The required angle is the critical angle, c.
$\sin c = 1/1.4 = 0.714$, or $c = 46°$.

14. **(D)** The critical angle, $c = 90° - 60° = 30°$
$n = \sin 90° / \sin c = 1/0.5 = 2$.

15. **(C)** $n = \frac{\text{real depth}}{\text{app.depth}} = \frac{AC}{AB}$

$AB = AC - BC = 5 - 2 = 3$ cm
$n = 5/3 = 1.67$.

16. **(B)** The important point to investigate here is whether or not the critical angle is exceeded.
$\sin c = 1/1.5 = 0.667$, or $c = 41.8°$.
Since the angle of incidence at the glass/air interface is greater than the critical angle, the ray is totally internally reflected.

17. **(B)** Angle of incidence, $i = 90° - 60° = 30°$
Angle of refraction, $r = 90° - 72° = 18°$
$n = \sin i / \sin r = \sin 30° / \sin 18° = 1.62$

18. **(D)** $n = \frac{\text{real depth}}{\text{app.depth}}$, or app.depth $= \frac{\text{real depth}}{n} = \frac{d}{n}$

Apparent displacement = real depth - app.depth
$= d - d/n = d(n-1)/n$

[The candidate should note the distinction between the *apparent depth* and the *apparent displacement*].

19. **(A)** $n = \frac{\text{real depth}}{\text{app.depth}}$

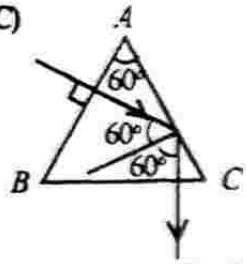
real depth = n x apparent depth
$= 4/3(1.5) = 2.0$ m

20. **(A)** Real depth = 2 m

App. depth $= \frac{\text{real depth}}{n} = \frac{2}{4/3} = 1.5$

App. displacement = 2 - 1.5 = 0.5 m

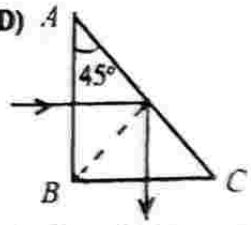
21. **(C)**



At normal incidence, the ray will pass through face AB undeflected. Angle of incidence on face $AC = 60°$.
Critical angle for the glass, $c = \sin^{-1}(1/n)$
$= \sin^{-1}(1/1.5) = 41.8°$.

Since the angle of incidence on AC exceeds the critical angle, the ray is totally internally reflected, with the angle of reflection = 60°. From the geometry of the figure, it is easy to see that the reflected ray must be normal to face BC, and it thus emerges from face BC undeflected.

22. **(D)**



A ray of light which is incident normally on face AB of the prism passes straight through AB and is incident at an angle of 45° on face AC. But the critical angle for glass is about 42° (see problem 21), hence the ray is totally internally reflected and emerges normal to the face BC.

23. **(B)** Angle of refraction, r_1 is given by

$\sin r_1 = \frac{\sin i_1}{n} = \frac{\sin 35°}{1.5} = 0.382$, or $r_1 = 22.5°$

$D_{min} = 2(i_1 - r_1) = 2(35° - 22.5°) = 25°$

24. **(A)** Angle of refraction r is given by

$\sin r = \frac{\sin i}{n} = \frac{\sin 30°}{1.5} = 0.333$, or $r = 19.5°$

Angle of deviation $= i - r = 30° - 19.5° = 10.5°$

25. **(C)** $u = 12$ cm
$m = v/u = -3.0$ (Negative sign since image is virtual)
$v = -3u = -36$ cm

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{12} - \frac{1}{36} = \frac{1}{18}$ or

$f = 18$ cm

26. **(B)** $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

At point A, $\frac{1}{u} = 0$, $\Rightarrow \frac{1}{v} = OA = \frac{1}{f}$

or $f = 1/OA$

At point B, $\frac{1}{v} = 0$, $\Rightarrow \frac{1}{u} = OB = \frac{1}{f}$

or $f = 1/OB$

27. (A) $f = 8$ cm, $v/u = 2 \Rightarrow v = 2u$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{2u} = \frac{1}{8}, \text{ or } \frac{3}{2u} = \frac{1}{8}$$

$u = 12$ cm and $v = 2(12) = 24$ cm.

28. (C) An object placed within the principal focus of a convex lens forms a magnified and virtual image. Since the image is virtual, it is on the same side of the lens. Since it is magnified, it is further from the lens than the object. [An alternative approach is to assisign a resonable value to the object distance and then estimate the image distance from the lens equation, e.g. $u = 3f/4$ gives

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{f} - \frac{4}{3f} = \frac{-1}{3f}$$

or $v = -3f$, the negative sign indicating a virtual image].

29. (B) Since the image is magnified and erect, it must be virtual (see notes). Hence $v = -3u$ and $f = 15$ cm

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}, \text{ or } \frac{1}{u} - \frac{1}{3u} = \frac{1}{15}$$

$$\frac{2}{3u} = \frac{1}{15}, \text{ or } u = 10 \text{ cm and } v = -30 \text{ cm}$$

The object and the image are on the same side of the lens. Hence the distance between them is $30 - 10 = 20$ cm.

30. (D) $u = 30$ cm, $f = 10$ cm

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10} - \frac{1}{30} = \frac{2}{30}, \text{ or } v = 15 \text{ cm}$$

Magnification $= v/u = 15/30 = 0.5$

$\Rightarrow$ Height of image $= 0.5 \times$ height of candle $= 2.5$ cm

31. (B) $f = 20$ cm, $v = 2.5u$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}, \text{ or } \frac{1}{u} + \frac{1}{2.5u} = \frac{1}{20}$$

$$\frac{3.5}{2.5u} = \frac{1}{20} \text{ or } u = \frac{70}{2.5} = 28 \text{ cm}$$

32. (D) For an object placed within the principal focus of a converging lens, the image is virtual, erect and magnified (see notes).

33. (A) $u = 18$ cm, $f = 12$ cm

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{12} - \frac{1}{18} = \frac{1}{36}, \text{ or } v = 36 \text{ cm}$$

Mag. $= v/u = 36/18 = 2.0$

Height of object $= 5/2.0 = 2.5$ cm

34. (A) $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{f} - \frac{1}{2f} = \frac{1}{2f}$, or $v = 2f$

35. (D) $u = 12$ cm, $v = -2u = -24$ cm

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{12} - \frac{1}{24} = \frac{1}{24}, \text{ or } f = 24 \text{ cm}$$

36. (B) Since the image is on the same side as the object, it is virtual. Hence $v = -20$ cm, $f = 10$ cm

$$\frac{1}{d} = \frac{1}{u} = \frac{1}{f} - \frac{1}{v} = \frac{1}{10} - \frac{1}{(-20)} = \frac{3}{20}$$

$d = 20/3 = 6.7$ cm

37. (C) $f = 16$ cm, $v = 4u$

$$\frac{1}{u} + \frac{1}{4u} = \frac{1}{16}, \text{ or } \frac{5}{4u} = \frac{1}{16}$$

$u = 20$ cm and $v = 4(20) = 80$ cm

Since the image is real, the object and the image are on opposite sides of the lens, and their separation is $20 + 80 = 100$ cm

38. (C) $f = -15$ cm, $v = -u/3$

[Note that f is negative for a concave lens and the image is always virtual, i.e. v is also negative].

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \text{ or } \frac{1}{u} - \frac{1}{u/3} = -\frac{1}{15}$$

$$\frac{-2}{u} = \frac{-1}{15}, \text{ or } u = 30 \text{ cm}$$

39. (A) $f = -18$ cm, $u = 6$ cm

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} \text{ or } -\frac{1}{18} - \frac{1}{6} = -\frac{4}{18}$$

$v = -4.5$ cm (the negative sign indicates a virtual image, i.e. the image lies in front of the lens).

40. (C) $f = -12$ cm, $v = -6$ cm

$$\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = -\frac{1}{12} - \frac{1}{(-6)} = \frac{1}{12}$$

$u = 12$ cm

41. (D) See notes.

42. (D) The image is always diminished and virtual, hence it is on the same side of the lens as the object, and it is closer to the lens than the object.

43. (B) A microscope objective must be a convex lens (positive focal length) and its focal length must be very short.

44. (C) The required distance is the image distance, v.

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{18} - \frac{1}{90} = \frac{4}{90}$$

$v = 22.5$ cm

45. (A) $f = 10$ cm (the lens must be convex)

$v = -5u$ (since mag. $= 5$ and image is virtual)

$\frac{1}{u} - \frac{1}{5u} = \frac{1}{10}$, or $\frac{4}{5u} = \frac{1}{10}$

$u = 8$ cm.

46. **(C)** The image formed by a projector is *real* and *magnified*. Thus the object (slide) distance must be between f and $2f$ (see notes).

47. **(D)** A real image which is exactly the same size as the object is produced when the object distance is $2f$.

48. **(B)** The image must be on the same side of the lens as the object, hence it is *virtual*. It is also *erect*.

49. **(C)** Mag. = v/u = 5

$u = v/5 = 30/5 = 6$ cm.

50. **(B)** $v = -25$ cm (eyepiece image is virtual)

The image formed by the objective is the object for the eyepiece, i.e. $u = 4$ cm

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{4} - \frac{1}{25} = \frac{21}{100}$

$f = 100/21 = 4.8$ cm

51. **(D)** In normal adjustment, the distance between the lenses in a telescope is equal to the sum of their focal lengths.

52. **(A)** In long sight a distant object is focused clearly while a nearby object appears blurred as its image falls behind the retina. This happens when the eyeball is too short or the lens has not got sufficient power to focus nearby objects.

53. **(C)** The lens must form an image of the object at 75 cm, and it is a virtual image since it must be on the same side of the lens as the object, hence

$v = -75$ cm, $u = 25$ cm

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{25} - \frac{1}{75} = \frac{2}{75}$

$f = 37.5$ cm, convex (since f is *positive*)

54. **(B)** The lens must form an image of a distant object ($u = \infty$) at 5 m ($v = -5$ m). Hence

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{\infty} - \frac{1}{5} = \frac{-1}{5}$

$f = -5$ m (*negative* sign indicates a *concave* lens).

Revision Check-list

Under this chapter, the candidate should be able to

- state the *laws of refraction*.
- define *refractive index* of a medium in terms of the velocity and the wavelength of light in the medium relative to the velocity and wavelength in air.
- express the refactive index of a transparent medium in terms of the real and apparent depths of an object placed in the medium.
- define *critical angle* and *total internal reflection*.
- explain the formation of a *mirage*.
- trace the path of a ray of light through a triangular glass prism, in accordance with the laws of refraction.
- remember the condition for minimum deviation for a ray of light passing through a glass prism.
- trace the paths of rays of light through a *convex* and a *concave* lens.
- remember the position and nature of the images formed by convex and concave lenses for different positions of the object.
- explain how a lens can be used to form, on a screen, an image of an object located at various distances from the lens.
- recall and apply all the equations stated in the notes.
- remember the type of lenses used in the *simple microscope*, the *compound microscope* and the *telescope*.
- remember the nature of the images produced by the optical instruments mentioned above.
- recall the relative sizes of the focal lengths, and the relative spacings of the lenses used in the compound microscope and the telescope.
- explain the basic similarities in the operations of a *camera* and the *human eye*.
- define the term *accommodation* of an eye.
- trace the paths of light rays in a short-sighted and a long-sighted eye.
- remember the types of lenses used for correcting eye defects.
- describe an experiment to determine the focal length of a converging lens.

14 Dispersion of Light

14.1 Dispersion by a Prism

- White light is a mixture of several colours-*red*, *orange*, *yellow*, *green*, *blue*, *indigo* and *violet* **(ROYGBIV)**.
- If a beam of white light is incident on a triangular glass prism, it is refracted through the prism.
- The emergent rays are split into the various colours which make up the spectrum of white light. This is known as ***dispersion*** (Fig. 14.1).
- The various components of light travel at different speeds in glass and are thus refracted along different paths.
- Red light, which has the fastest speed, is the least deviated while violet with the lowest speed is the most deviated.

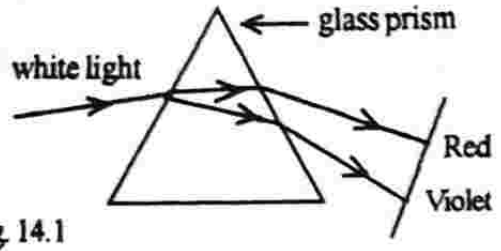


Fig. 14.1

14.2 The Electromagnetic Spectrum

- The ***electromagnetic spectrum*** is made up of ***electromagnetic waves*** of wavelengths ranging from about 10^{-14} m for ***gamma rays*** to several kilometers for long ***radio waves***.
- The following properties are common to all electromagnetic waves:
  (i) they consist of oscillating electric and magnetic fields,
  (ii) they are transverse waves, and
  (iii) they travel in vacuum with a speed of 3.0×10^8 ms^{-1}.
- White light is the visible part of the electromagnetic spectrum with wavelength ranging from 4×10^{-7} m for ***violet*** to 7×10^{-7} m for ***red*** light.
- Other properties of the electromagnetic spectrum are listed in the following table:

Type	Source	Typical Wavelength (m)
Gamma Ray	Emitted by radioactive sources.	10^{-14}
X - ray	Produced by x-ray tube; fast electrons stopped by a target.	10^{-10}
Ultraviolet	From sunlight and quartz lamps; electric discharge through gases.	10^{-8}
Visible light	From sunlight; lamps	10^{-7}
Infrared	Heat radiation emitted by hot objects.	10^{-5}
Radio Wave	Emitted by radio antenna	10^{-1} to km

- The wavelength (λ), frequency (f) and speed (v) of an electromagnetic wave are related by the equation

$$v = f\lambda \qquad (14.1)$$

14.3 Color Mixing

- If two different colours of the spectrum are superimposed, a third colour is produced.
- A white screen which is illuminated at the same time by a red and a green light will appear yellow, i.e.
  red + green ⟶ yellow
  green + blue ⟶ cyan (blue-green)
  blue + red ⟶ magenta (purple)
  red + green + blue ⟶ white
- ***Primary colours*** are colours that cannot be produced by mixing two or more other colours. These are *red*, *green* and *blue*.
- ***Secondary colours*** can be produced by mixing two or more other colours, e.g. yellow, cyan, magenta.
- In the ***colour triangle*** (Fig. 14.2) primary colours occupy the corners, secondary colours are located at the sides and white in the middle of the triangle.
- ***Complementary colours*** are two colours that will produce white when mixed together, e.g. blue + yellow ⟶ white. A pair of complementary colours consist of a primary colour plus the secondary colour at the opposite side of the colour triangle.

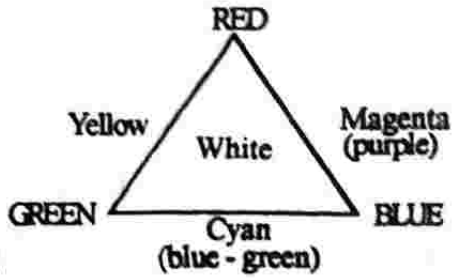


Fig. 14.2

14.4 Mixing of Pigments

- A ***colour filter*** allows light of one colour to pass through it while absorbing light of other colours.
- If white light is incident on a red filter, red is transmitted while blue and green are absorbed.
- A ***pigment*** is a substance which gives a paint its

characteristic colour.

- Pigments absorb certain colours from white light and reflect the rest.
- Paints do not usually have pure colours and the mixing of pigments therefore gives different results from the mixing of pure colours.
- Yellow paint, for instance, absorbs blue and reflects red and green while blue paint absorbs red and yellow. A mixture of yellow and blue paints thus absorbs blue, red and yellow and reflects green, i.e.
  yellow paint + blue paint ⟶ green paint
  This should be contrasted with the case of pure colours, in which yellow mixed with blue colour produces white.
- A *transparent* object is seen by the colour it *transmits*.
- An *opaque* object is seen by the colour it *reflects*.

True or False - Type Questions

1. A beam of white light can be split up into different colours by a glass prism because
   a. white light is composed of the different colours observed.
   b. the prism has all the colours of white light.
   c. different colours of light travel at different speeds in glass.
   d. white light undergoes total internal reflection in the prism.
   e. the frequency of each colour of light changes as it crosses from air into the glass prism.
   f. the refractive index of glass varies with the colour of light.
   g. different components of light have different amplitudes in glass.
   h. the angle of refraction depends on the colour of light.

2. Electromagnetic waves
   a. are all transverse waves
   b. all have the same speed and frequency in vacuum.
   c. consist of red, orange, yellow, green, blue, indigo and violet lights only.
   d. having the highest frequencies have the shortest wavelengths.
   e. all pass readily through glass.

3. A sheet of white paper viewed through a blue glass appears blue:
   a. The white paper reflects all the colours of the spectrum.
   b. The glass absorbs white light and reflects blue light.
   c. The glass reflects only blue light.
   d. The glass absorbs all colours of white light except blue which it transmits.
   e. The glass adds blue light to the paper.

4. a. Ultra-violet, infra-red and visible light are all electromagnetic waves of the same frequency.
   b. Infra-red rays produce the sensation of heat.
   c. Ultra-violet rays can be detected with a fluorescent paper.
   d. The frequency of light increases in the order ultra-violet, visible and infra-red.
   e. Infra-red rays have longer wavelengths than ultra-violet rays.
   f. In the visible spectrum, violet light has the highest frequency and red the lowest.
   g. The wavelength of blue light is longer than that of yellow light.

Answers to True or False - Type Questions

1. a (T) It is these component colours that are dispersed by the prism.
   b (F) The prism is not coloured but transparent.
   c (T) Red light is the slowest-moving and violet light the fastest - moving in glass.
   d (F)
   e (F) Frequency remains *unchanged* during refraction.
   f (T) Since the refractive index of glass is the ratio of the speed of light in air to its speed in the glass, and the latter varies with colour, the refractive index also varies with colour.
   g (F) The amplitude determines only the intensity of the light transmitted through the glass.
   h (T) This follows from (f).

2. a (T)
   b (F) They have the same speed in vacuum, but different wavelengths and frequencies.
   c (F) The listed waves are the components of the visible spectrum. Other components of electromagnetic waves include *infra - red, ultra-violet, x- rays, radio waves*, etc.
   d (T) Speed of an *EM* wave = frequency x wavelength. Since the speed of *EM* waves in air is constant while their wavelengths vary, the frequency varies

inversely with the wavelength.

e (F) Visible light passes readily through glass. Infra-red waves will penetrate glass only in the short wavelength range while ultra-violet waves are absorbed by glass.

3. a (T) Any white, opaque object reflects all the colours of the spectrum.
   b (F) The colour of a transparent object is the colour it *transmits*. The blue glass appears blue because it transmits blue light.
   c (F) The colour of an opaque object, not a transparent object, is the colour of the light it *reflects*.
   d (T) See (b) above
   e (F) Colour is *never* added to an object by the colour filter. The latter merely absorbs certain colours while the other component colours of incident light are transmitted.

4. a (F) They are all electromagnetic waves but of *different* frequencies.
   b (T)
   c (T)
   d (F) The frequency increases in the order - IR, visible, UV.
   e (T) Wavelength varies inversely with frequency.
   f (T) The frequency *increases* in the order ROYGBIV.
   g (F) The wavelength *decreases* in the order ROYGBIV.

SSCE/JME - Type Objective Questions

1. The component of the spectrum of white light having the shortest wavelength is
   A. green B. orange C. red D. violet

2. A narrow beam of white light travelling in air is incident on a triangular glass prism. The colour that experiences the greatest deviation is
   A. red B. violet C. blue D. yellow

3. Which of the following pairs of light rays are most widely separated in the spectrum of white light?
   A. blue and green B. orange and blue
   C. red and indigo D. blue and violet.

4. When a beam of white light is dispersed by a glass prism, the angular deviation of the colours of the spectrum decreases in the order
   A. blue, orange, red B. orange, red, blue
   C. red, orange, blue D. blue, red, orange

5. The arrangement which is used to attain a pure spectrum of white light is
   A. source, slit, prism, converging lens, screen
   B. source, converging lens, prism, diverging lens, screen
   C. source, slit, converging lens, prism, converging lens, screen
   D. source, slit, converging lens, prism, screen.

6. Which of the following electromagnetic waves have the lowest frequency?
   A. radio waves B. infra - red
   C. ultra -violet D. x -rays

7. The following electromagnetic waves are arranged in the order of increasing wavelength:
   A. Infra - red, radio, x- rays, gamma rays
   B. Gamma rays, x-rays, infra-red, radio
   C. Radio, x-rays, gamma rays, infra-red
   D. Gamma rays, infra-red, x-rays, radio

8. The following are not part of the electromagnetic spectrum:
   I. Alpha rays II. Beta rays
   III. Gamma rays IV. Radio waves
   A. I and II only B. III and IV only
   C. I and III only D. II and IV only

9. A spectrum of white light is not a pure spectrum when
   A. it does not contain all the colours.
   B. it is made up of only three colours.
   C. it has no red colour in it.
   D. the different colours in it overlap.

10. The electromagnetic waves which can be detected by their heating effect are
    A. x - rays B. Gamma rays
    C. infra-red rays D. ultra - violet rays.

11. Which of the following waves have the shortest wavelength?
    A. x-rays B. infra-red rays
    C. ultra-violets rays D. radio waves

12. The speed of electromagnetic waves in air is $3 \times 10^8 ms^{-1}$. The wavelength of a wave of frequency 6×10^{14} Hz is
    A. 2×10^{-7}m B. 5×10^{-7}m
    C. 2×10^{6} m D. 5×10^{6}m

13. Infra-red rays of frequency 6×10^{12}Hz have a wavelength of 5×10^{-5} m in vacuum. The wavelength of x- rays of frequency 3×10^{18} Hz is
    A. 10^{-10}m B. 3.6×10^{-10}m C. 25 m D. 10^{10} m

14. A beam of light consisting of orange and blue colours is incident on a glass prism, which of the following

statements is (are) correct?

I. Orange is more deviated than blue light
II. Blue is more deviated than orange light
III. The refractive index of glass is higher for orange than for blue light.
IV. The refractive index of glass is higher for blue than for orange light.

A. I only B. II only
C. I and III only D. II and IV only.

15. A blue flower appears blue in sunlight because it
A. transmits blue light B. refracts blue light
C. absorbs blue light D. reflects blue light

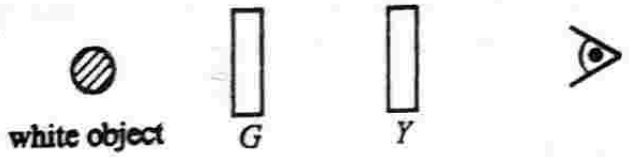
16. A red shirt when viewed in pure green light appears
A. red B. green C. black D. yellow

17. The colour(s) absorbed when white light is incident on an object which is magenta in colour is (are)
A. green only B. red only
C. red and blue D. red and green.

18. Which of the following is a primary colour of light?
A. Orange B. Yellow C. White D. Red

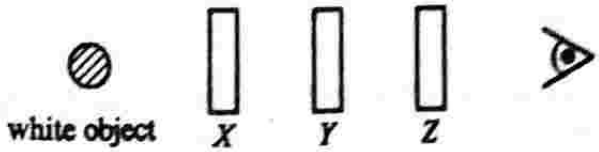
19. A yellow card observed through a blue glass would appear
A. white B. black C. green D. red

20.



In the diagram above, a white object is observed through green (G) and yellow (Y) light filters. The colour seen is
A. black B. yellow C. blue D. green

21.



In the diagram above, X, Y, Z, are yellow, red and cyan light filters respectively. A white object viewed through the filters would appear
A. black B. red C. blue D. yellow

22. A red pen is placed on a yellow table mat. In green light, the pen and the mat will appear respectively
A. red and yellow B. black and green
C. black and white D. blue and green.

23. If yellow and cyan paints are mixed, the colour of the mixture is
A. green B. blue C. white D. red

24. The colours seen in a rainbow are due to
A. polarization B. absorption
C. refraction D. interference.

25. A white screen is illuminated simultaneously by red and green light beams. The colour seen is
A. yellow B. blue C. white D. black

Answer Key

1. D	6. A	11. A	16. C	21. A
2. B	7. B	12. B	17. A	22. B
3. C	8. A	13. A	18. D	23. A
4. A	9. D	14. D	19. B	24. C
5. C	10. C	15. D	20. D	25. A

Solutions to Objective Questions

1. **(D)** The wavelength increases in the order red, orange, violet.

2. **(B)** Red is the least deviated and violet the most deviated.

3. **(C)** Red and indigo are farther apart in the spectrum (*ROYGBIV*) than any other given pair.

4. **(A)** Of the three colours, the most deviated is blue while red is the least deviated.

5. **(C)** The *slit* provides a narrow beam, which is collimalimated, i.e. made parallel by the *converging lens* before it is incident on the *prism*. After refraction in the prism, the spectrum is brought to a focus on a *screen* placed at the focal plane of the second *converging lens*.

6. **(A)** Of the four specified, radio waves have the lowest frequency while x-rays have the highest.

7. **(B)** Gamma rays have the shortest and radio waves the longest wavelengths.

8. **(A)** *Alpha* rays are positively charged helium nuclei, while *beta* rays are negatively charged electrons. Both *gamma rays* and *radio waves* are electromagnetic waves.

9. **(D)** The spectrum is said to be impure when some of the colours in the middle overlap one another.

10. **(C)** Infra-red rays are sensed as *heat*.

11. **(A)** The wavelength increases in the order x-rays, ultra-violet rays, infra-red rays and radio waves.

12. **(B)** $\lambda = v/f = (3 \times 10^8)/(6 \times 10^{14}) = 5 \times 10^{-7}$ m

13. **(A)** Speed, $v = f\lambda = (6 \times 10^{12})(5 \times 10^{-5}) = 3 \times 10^8$ ms^{-1}
Since all electromagnetic waves have the same speed, this is also the speed of the *x*-rays, i.e. wavelength of *x*-rays, $\lambda = v/f = (3 \times 10^8)/(3 \times 10^{18}) = 10^{-10}$ m

14. **(D)** Following the acronym *ROYGBIV*, blue is more deviated than orange. This means that blue travels more slowly in glass than orange, and the refractive index is correspondingly higher for blue light.

15. **(D)** An opaque object, such as the flower, is seen by the colour it reflects.

16. **(C)** A red shirt appears red in white light because it reflects only red light while absorbing all other colours. Pure green light is absorbed when incident on the red shirt and the shirt thus apears black.

17. **(A)** An object which is magenta reflects red and blue light. These are two of the three primary colours. The third colour, *green*, is absorbed.

18. **(D)** The primary colours are *red*, *green* and *blue*.

19. **(B)** Blue glass will transmit only blue light. Since a yellow card reflects yellow (i.e. mixture of red and green) light, no light is transmitted through the glass.

20. **(D)** The green filter transmits only green light. The yellow can transmit green and red. Since only green light is incident on *Y*, it is the colour seen.

21. **(A)** *X* transmits green and red, *Y* transmits only red, which is however absorbed by Z.

22. **(B)** In green light the red pen (which absorbs green) will appear black while the yellow mat (which reflects red and green) will appear green.

23. **(A)** The yellow paint absorbs blue (while reflecting red and green) and the cyan paint absorbs red. The mixture thus absorbs both red and blue, and reflects green light.

24. **(C)** Rays of sunlight are *refracted* and *totally internally reflected* by water droplets and are dispersed in the process.

25. **(A)** Red light superimposed on green light gives yellow light.

Revision Check-list

Under this chapter, the candidate should be able to

- explain how white light is split up into constituent colours.
- explain how a *rainbow* is formed.
- list the components of the visible spectrum in the order of their wavelengths or frequencies.

- describe the basic properties of *electromagnetic waves.*
- recall and apply the equation connecting the wavelength, frequency and speed of an electromagnetic wave.
- distinguish between a mechanical wave and an electromagnetic wave.
- use the colour triangle to explain the mixing of colours.
- explain the terms *primary*, *secondary* and *complementary* colours
- explain the roles of *colour filters* and *pigments.*

15 Electrostatics

15.1 Atomic Structure

- Every material substance is made up of ***atoms***.
- An atom consists of
  - (i) positively-charged ***protons*** at the nucleus,
  - (ii) electrically neutral ***neutrons*** at the nucleus, and
  - (iii) negatively charged ***electrons*** circling round the nucleus.
- The number of protons is equal to the number of electrons in an uncharged body.
- ***Conductors***: materials which contain free electrons not strongly attached to an atom and are thus free to move about from one atom to another.
  Example: metals such as silver, copper, aluminium.
- ***Insulators***: materials in which electrons are strongly bound to the atoms and hence cannot move from atom to atom. Examples: wood, plastic, glass, silk.

15.2 Charging by Friction

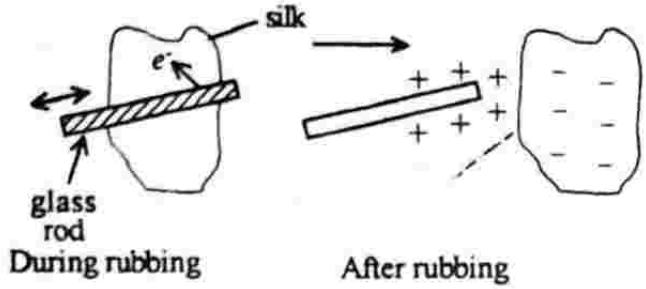


Fig. 15.1

- Two substances such as glass and silk, when rubbed together, become ***electrically charged*** (Fig. 15.1).
- During rubbing, some electrons are transferred from the glass to the silk.
- The silk acquires a net negative charge (excess electrons) while the glass acquires a net positive charge (electron deficit).
- If ebonite (hard rubber) is rubbed with fur, the ebonite is negatively-charged and the fur is positively-charged.
- A body with a positive charge attracts one with a negative charge but repels one with a positive charge, i.e. ***Like charges repel, unlike charges attract.***

15.3 Charging by Induction

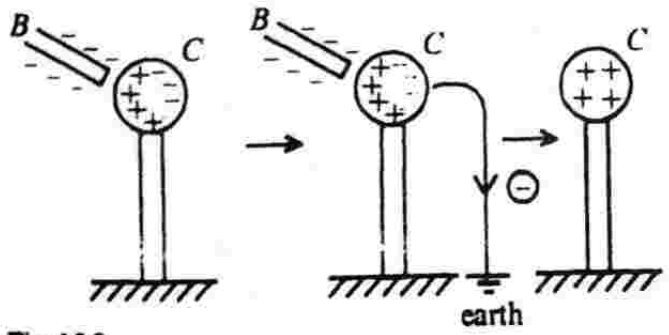


Fig. 15.2

- A conductor (C) supported on an insulating stand can be charged by ***induction*** (Fig. 15.2)
- A negatively-charged body (B) brought close to C will result in free electrons (in C) being repelled away from B.
- By connecting the conductor to the earth (e.g. by touching with a finger), the electrons flow to the earth.
- Upon removing the finger and moving B away, the conductor C is now left with a deficit of electrons, i.e. excess positive charges which will be redistributed uniformly.
- Note that C has been charged by B without actual contact between the two bodies.

15.4 The Gold-leaf Electroscope

- It is an instrument used to detect if a body carries an electric charge.
- It consists of a metal plate and rod insulated from a metal case with viewing (glass) windows. Fig. 15.3.

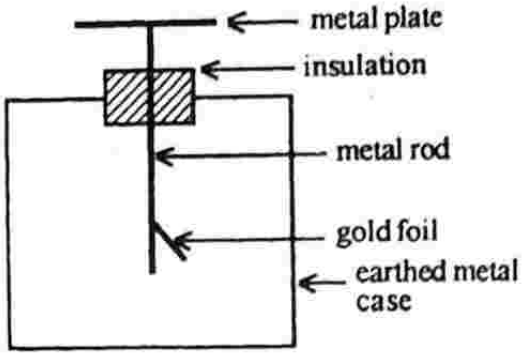


Fig. 15.3

- A thin gold foil (also called *gold-leaf*) is attached to the lower end of the rod.
- To charge the electroscope by induction:
  - (i) A charged object is brought near the metal cap.
  - (ii) With the charged object still close by, the cap is earthed temporarily.
  - (iii) After breaking the earth connection, the charged object is withdrawn.
  - (iv) Both the lower end of the rod and the gold-leaf acquire like charges opposite in sign to that on the charged object, causing the leaf to diverge (like charges repel).
- The electroscope can also be charged by direct contact.
- To determine the sign of an unknown charge on any object:
  - (i) the electroscope is first charged by induction, causing a deflection of the leaf;
  - (ii) if a charge which has the same sign as that on the electroscope is brought near the cap, the le-

af is deflected further;

(iii) the leaf collapses if a charge of opposite sign or an uncharged body is brought near the cap.

15.5 Coulomb's Law

- The force F of repulsion or attraction between two charges, q_1, q_2 is proportional to the product of the two charges and inversely proportional to the square of the distance r separating them, i.e.

$$F = \frac{kq_1q_2}{r^2} \qquad (15.1)$$

where $k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \text{Nm}^2\text{C}^{-2}$

and ε_0, the ***permittivity of free space*** is equal to $8.85 \times 10^{-12}\ \text{C}^2\text{N}^{-1}\text{m}^{-2}$ for charges located in vacuum.

- The direction of the force between two charges is along the line joining them.
- *Units*: Charge q = [coulomb] or [C], r = [m] and F = [N].
- An electron carries a charge of -1.60×10^{-19} C.

15.6 Electric Field

- The ***electric field*** of a charge q is the region of space over which the force due to the charge can be experienced.
- The ***electric field intensity***, E, at a point is the force that a unit charge will experience when placed at that point.
- A charge q placed at a point of field intensity E experiences a force (F) which is equal to the product of q and E, i.e.

$$F = qE \qquad (15.2)$$

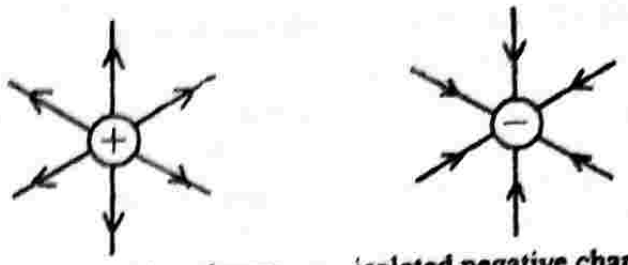
- The electric field intensity at a distance r from a point charge Q is

$$E = \frac{Q}{4\pi\varepsilon_0 r^2} \qquad (15.3)$$

- *Units*: E = [NC^{-1}] or [Volts/metre].

15.7 Electric Lines of Force

- An ***electric line of force*** indicates the direction of the force on a positive charge placed in an electric field.
- It is also the direction of the electric field intensity at that point.
- Lines of force are always directed away from a positive charge and directed to a negative charge (Fig. 15.4).



isolated positive charge isolated negative charge

Fig. 15.4

15.8 Electric Potential

- The ***electric potential*** at a point is the amount of work that will be done in bringing a unit charge from infinity to that point.
- The electric potential (V) at a distance r from a point charge q is

$$V = \frac{q}{4\pi\varepsilon_0 r} \qquad (15.4)$$

- In an electric field, positive charges move from high potential to low potential, while free electrons move in the opposite direction.
- ***Equipotential surfaces*** are surfaces having the same electric potential.
- The work done (W) in moving a charge q between two points which have a difference in potential of V is

$$W = qV \qquad (15.5)$$

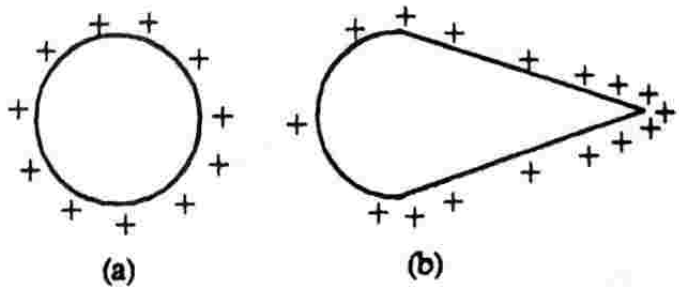
- In a uniform electric field of intensity E, the potential difference between two points distance d apart is

$$V = Ed \qquad (15.6)$$

- *Units*: V = [volts], W = [J], d = [m]

15.9 Charge Distribution on a Conductor

- Any excess electric charge on a conductor resides on the surface, not inside the conductor.
- For a uniformly curved surface such as that of a sphere, the charge is distributed uniformly on the surface (Fig. 15.5a).
- For a conductor with sharp edges (Fig. 15.5b), the charge is concentrated at the sharpest points (charge density increases with curvature).



(a) (b)

Fig. 15.5

15.10 Lightning and Lightning Conductor

- Lightning is caused by a storm cloud which is highly charged as a result of the rubbing action between the cloud and the air (charging by friction).
- The sudden flow of charge between the cloud and the earth results in a lightning flash.
- A lightning conductor consists of a copper strip with a sharply pointed end projecting above the building to be protected while the lower end is connected to a metal plate buried in the ground (Fig. 15.6)
- If a positively charged cloud passes over the building, negative electric charges are induced at the tip of the lightning conductor, thereby forming a dipole with the cloud.
- The high electric field thus set up between the cloud and the tip of the conductor results in the ionization of the atoms of the air, with negative ions drifting towards the cloud and thereeby neutralising the positive charges.

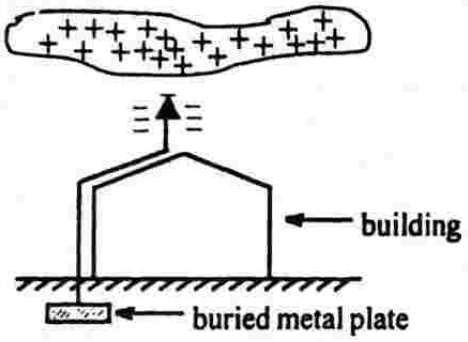


Fig. 15.6

15.11 Capacitance

- A ***capacitor*** is a device used in storing electric charge.
- It consists of two flat sheets of metal separated by an insulator which is also called a ***dielectric***.
- If a capacitor consisting of two parallel metal plates separated by air is connected to a cell, electrons flow from the negative terminal of the cell to one of the plates, which thus acquires a negative charge.
- A flow of electrons also occurs to the positive terminal of the cell from the other plate, which becomes positively charged.
- At a point, the capacitor is fully charged such that the charge is Q on one plate and $-Q$ on the other.
- ***Capacitance*** is the ability of a capacitor to store electric charge. This is defined as

$$\textit{Capacitance} = \frac{\text{charge on either plate}}{\text{p.d. across the plates}} = \frac{Q}{V} \quad (15.7)$$

- ***Units:*** Capacitance = [Farad] or [F], Q = [C] and V = [V].

15.12 Parallel Plate Capacitor

- A parallel plate capacitor consists of two parallel metal plates separated by a dielectric (Fig. 15.7).

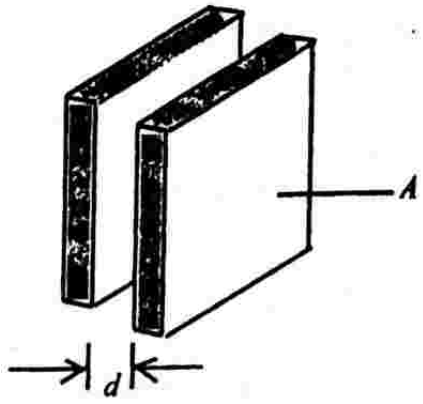


Fig. 15.7

- The capacitance of the capacitor depends on
  (i) the area of overlap (A) of the plates
  (ii) the distance (d) between the plates, and
  (iii) the nature of the dielectric separating the plates.
- The capacitance is given by

$$C = \frac{\varepsilon A}{d} \quad (15.8)$$

where ε is the ***permittivity*** of the dielectric.

- The ***relative permittivity*** (ε_r) or ***dielectric constant*** of a dielectric material is defined as

$$\varepsilon_r = \frac{\text{permitivity of the material}}{\text{permitivity of free space}} = \frac{\varepsilon}{\varepsilon_0} \quad (15.9)$$

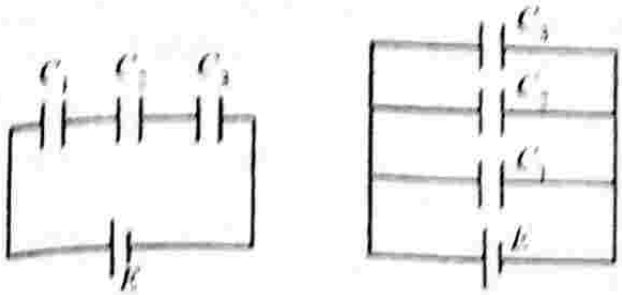
15.13 Series and Parallel Connections of Capacitors

- When capacitors C_1, C_2 and C_3 are connected in series (Fig.15.8a), the charge on each capacitor is the same and the potential drop across the three is the sum of the p.d. across each of them.
- The overall capacitance C for a *series* connection is given by

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad (15.10)$$

- When the capacitors are connected in parallel (Fig. 15.8b), the p.d.acrosss each is the same and the total charge is the sum of the charges on each capacitor.
- The overall capacitance C for a *parallel* connection is

$$C = C_1 + C_2 + C_3 \quad (15.11)$$



(a) $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ (b) $C = C_1 + C_2 + C_3$

Fig. 15.7

15.14 Energy Stored in a Capacitor

- The energy stored in a capacitor is equal to the work done in building up the charges on the plates.
- For a capacitor with capacitance C which has charge Q on the plates when the p.d. across the plates is V, the energy stored is

$$E = \frac{1}{2}\frac{Q^2}{V} = \frac{1}{2}CV^2 = \frac{1}{2}QV \qquad (15.12)$$

True or False - Type Questions

Answer ***True*** **(T)** or ***False*** **(F)** to the following questions.

1. a. Electrons and protons reside in the nucleus of an atom.
   b. In an electrically neutral atom, the total charge on the electrons is equal to the total charge on the protons.
   c. A positively-charged atom contains a deficit of electrons.
   d. A negatively-charged atom contains an excess of electrons.
   e. In the nucleus of an atom, the neutrons circle around the charged protons.
   f. The proton and the electron have approximately the same mass.
   g. The proton and the electron have numerically the same charge.
   h. The neutron carries equal numbers of positive and negative charges.
   i. Atoms of different elements differ only in the number of protons and electrons they contain.
   j. In a given element, the number of neutrons may vary from one atom to another.

2. a. When two substances are rubbed together, the one that acquires a negative charge received excess electrons from the other during the rubbing.
   b. When two substances are rubbed together, the one that acquires a positive charge received excess protons from the other during the rubbing.
   c. Glass acquires a positivecharge when rubbed with silk.
   d. Ebonite acquires a negative charge when rubbed with fur.
   e. The magnitude of the charge on a charged body may be a multiple or a fraction of the charge on an electron.
   f. When two substances are rubbed together, electrons and protons may be transferred from one substance to the other.
   g. A charged body attracts an uncharged body.
   h. All substances can be readily charged by rubbing.

3. a. The sign of the charge on a charged body can be determined with an uncharged electroscope.
   b. If the leaves of a positively-charged electroscope collapse as an object is brought close to the cap, the object must be negatively-charged.
   c. The divergence of the leaves of a positively-charged electroscope will decrease if a negatively-charged object is brought near the cap.
   d. The divergence of the leaves of a positively-charged electroscope will remain constant if an uncharged object is brought near the cap.
   e. If a negatively-charged object is brought close to (but not touching) the cap of an uncharged gold leaf electroscope, the cap acquires a negative charge while the leaves acquire a positive charge.
   f. If a strong positive charge is brought near the negatively-charged cap of a gold leaf electroscope, the leaves will collapse and then diverge.
   g. The cap and the leaves of a charged electroscope always bear opposite charges.

4. a. An electron placed in an electric field will move in the direction of the electric lines of force.
   b. If a body at a positive potential is earthed, electrons will flow from the earth to the body.
   c. If a positively-charged metal sphere is placed inside (and in contact with) a hollow metal can sitting on an insulator and then removed, the internal surface of the can will acquire a positive charge.
   d. A positve charge in an electric field will move from a point of high potential to a point of lower pot-

ential.

e. In order to move an isolated positive charge in the direction of an electric field, work must be done on the charge.

f. The electric field is stronger where lines of force are more closely spaced.

g. The electric potential is the same everywhere on the surface of a charged conductor, regardless of the shape of the conductor.

h. The strength of the electric field of a point charge is directly proportional to the square of the distance from the charge.

i. The electric potential is the same everywhere in a uniform electric field.

j. If one equipotential surface is connected with a short metallic wire to another equipotential surface of lower potential, positive charges will flow from the former to the latter.

5. The quantity of electric charge which can be stored in a parallel-plate capacitor.

a. increases as the separation of the plates increases

b. decreases if a sheet of dielectric is placed between the plates.

c. increases as the area of the plates increases.

d. increases as the voltage across the plates increases

e. increases as the capacitance decreases.

Answers to True or False - Type Questions

1. a (F) Protons and neutrons reside in the nucleus, which is orbited by electrons.

b (T)

c (T)

d (T)

e (F) See (a) above.

f (F) The proton is approximately 1,840 times as heavy as the electron. The proton, however, has roughly the same mass as the neutron.

g (T)

h (F) The neutron bears *no* electric charge.

i (F) The number of neutrons also varies from one element to another.

j (T) *Isotopes* of an element are identical in all respects, except for the number of neutrons contained in their nuclei.

2. a (T)

b (F) Only *electrons* can be transferred during rubbing.

c (T) Glass loses electrons to silk, and is therefore positively-charged.

d (T)

e (F) The magnitude of any charge must be a *whole number of multiples* of the charge on an electron.

f (F) See (b) above.

g (T) A charged body attracts a body of opposite charge, or an uncharged body.

h (F) Conductors (e.g. metals) are not readily charged by rubbing, as electrons flow through them into the earth. They can be charged by rubbing, however, if mounted on insulating stands.

3. a (F) The electroscope must be pre-charged.

b (F) The object could be negatively-charged, or uncharged.

c (T)

d (F) An uncharged object brought near the cap of a charged electroscope will result in a decrease in the divergence of the leaves, regardless of the sign of the charge on the electroscope.

e (F) Electrons are repelled from the cap (which then becomes positively charged) to the leaves (which thus acquire a negative charge).

f (T) The negatively-charged cap and leaves of the electroscope contain excess electrons. As these are attracted to the positive charge, the leaves gradually collapse. If the positive charge is sufficiently strong, the leaves become completely uncharged, and then re-charged positively as more electrons are attracted to the cap, i.e. the leaves diverge.

g (F) When the charging body is held near the cap, the leaves and the cap bear opposite charges as electrons move from one to the other. During earthing, electrons move to (or from) the earth from (or to) the cap. With the earth connection broken, excess charges are redistributed on the leaves and cap of the electroscope, which then bear similar charges.

4. a (F) A positive charge moves in the direction of the field, while an electron moves in the opposite direction.

b (T) A positive charge will move from a region of high electric potential to one of low potential. An electron will move in the opposite direction, in this case from the earth (at zero potential) to the body at a positive potential.

c (F) The can acquires a net positive charge, which will, however, reside on its *external surface*.

d (T) See (b) above.

e (F) An isolated positive charge will move by itself, in the direction of an electric field. However, work must be done to move it in the opposite direction.

f (T)

g (T) If this were not so, charges will be re-distributed betweeen regions of low and high potentials until the potentials are equalized.

h (F) The strength, or *intensity* of the electric field is inversely propotional to the square of the distance.

i (F) In a uniform electric field, the electric field intensity is constant but the potential varies. The electric potential is constant only on an *equipotential* surface.

j (F) Electrons will flow from the latter to the former. It must be emphasized again that only electrons are involved in charge transfer in a metallic conductor.

5. The questions can be answered with a knowledge of the equations $C = \varepsilon A/d$ and $Q = CV$

a (F) C decreases as d increases. Hence Q decreases.

b (F) For air, $\varepsilon = 1$, while $\varepsilon > 1$ for a dielectric. Note that C is directy proportional to ε.

c (T) C is directly proportional to A.

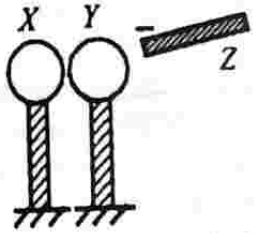
d (T) Q is directly proportional to V.

e (F) Q is directly proportional to C.

SSCE/JME - Type Objective Questions

1. Which of the following substances is not an insulator?
A. Glass B. Silver C. Plastic D. Clay

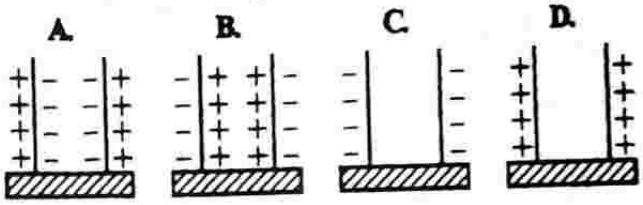
2. An electric charge can be transmitted through
A. rubber, wood and stone.
B. clay, paper and plastic.
C. the human body, water and metals.
D. acid, cloth and glass.

3. 

In the figure X and Y are insulated metal spheres which are initially in contact with each other. A negatively charged rod Z is brought close to Y, the spheres are separated and Z is then taken away. Which of the following statements is correct?
A. X has acquired a negative charge and Y a positive charge.
B. X has acquired a positive charge and Y a negative charge.
C. Both X and Y have acquired positive charges.
D. Both X and Y have acquired negative charges.

4. The leaves of a negatively charged electroscope collapse completely as an object is brought close to the cap of the electroscope. The object possesses
A. an equal quantity of negative charge.
B. an equal quantity of positive charge.
C. less quantity of negative charge.
D. less quantity of positive charge.

5. A negatively-charged sphere is suspended inside a hollow can mounted on an insulating stand. If the can is touched by hand momentarily and the charged sphere is then withdrawn, which of the following diagrams correctly represents the distribution of charge on the can after the process?



6. The magnitudes of charges on two bodies are to be compared. Which of the following instruments would be most suitable?
A. Gold leaf electroscope B. Capacitor
C. The electrophorus D. Ebonite rod

7. A short chain is usually attached to the rear side of a petrol tanker trailing behind it to ensure that
A. the heat generated in the engine is conducted to the earth.
B. the charges generated by friction in the tanker are conducted to the earth.
C. the tanker does not exceed a certain speed limit.
D. the chain vibrates in resonance with the tanker's engine.

8. A gold leaf electroscope is to be charged by induction. Which of the following indicates the correct sequence of steps to be taken?
I. Touch the cap with a finger
II. Bring a charged rod near the cap
III. Remove the charged rod
IV. Remove the finger from the cap
A. I, II, III and IV B. II, III, I and IV
C. II, I, IV and III D. II, I, III and IV

9. An electrostatic force F acts between two stationary charges. If the distance separating the charges is doubled, the new electrostatic force between them is

A. $2F$ B. $F/2$ C. $4F$ D. $F/4$

10. The force acting on an electron carrying a charge of 1.6×10^{-19} C in an electric field of intensity 5×10^{8} Vm^{-1} is

A. 3.2×10^{-29} N B. 8.0×10^{-11} N
C. 8.0×10^{-8} N D. 3.1×10^{27} N

11. An electron (charge 1.6×10^{-19} C) initially at rest is accelerated from a plate at zero volt to another plate at 60 kV. The kinetic energy acquired by the electron at the second plate is

A. 2.7×10^{-24} J B. 2.7×10^{-21} J
C. 9.6×10^{-15} J D. 3.8×10^{23} J

12. The electric potential at a distance d from a point charge q in air of permittivity ε_0 is

A. $\frac{q}{4\pi\varepsilon_0 d}$ B. $\frac{q}{4\pi\varepsilon_0 d^2}$ C. $\frac{q^2}{4\pi\varepsilon_0 d}$ D. $\frac{q^2}{4\pi\varepsilon_0 d^2}$

13. The magnitude of the electric field at a distance d from the point charge in question 12 above is

A. $\frac{q^2}{4\pi\varepsilon_0 d}$ B. $\frac{q}{4\pi\varepsilon_0 d^2}$ C. $\frac{q}{4\pi\varepsilon_0 d}$ D. $\frac{q}{4\pi\varepsilon_0 {}^2 d}$

14. The electric force between two unlike charges, each of magnitude q, separated by a distance d in air of permittivity ε_0 is

A. $\frac{q^2}{4\pi\varepsilon_0 d}$ B. $-\frac{q^2}{4\pi\varepsilon_0 d}$ C. $\frac{q^2}{4\pi\varepsilon_0 d^2}$ D. $-\frac{q^2}{4\pi\varepsilon_0 d^2}$

15. Two unequal, insulated, charged spheres carrying unlike charges are connected together with a short wire. Charges will flow from one sphere to the other until both spheres

A. carry equal charges of opposite signs.
B. carry equal charges of the same sign.
C. are at the same potential.
D. become uncharged.

16. Which of the following statements are true of an insulated positively-charged sphere?

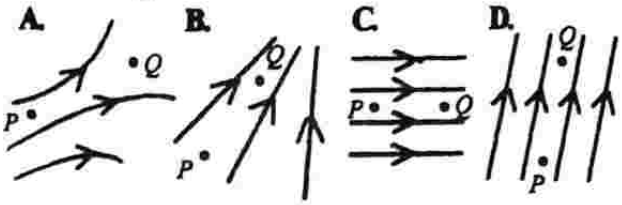
I. It contains excess positive charges
II. It has an electric field associated with it
III. It possesses potential energy
IV. It carries an electric current.

A. I and II only B. I, II and III only
C. II and III only D. I, II, III and IV.

17. A charged ball is placed in contact with the inner wall of a hollow conducting sphere. The resulting electric field is

A. inside the sphere
B. outside the sphere
C. inside and outside the sphere
D. on the surface of the ball.

18. The diagrams below show lines of force in various electric fields. In which of the diagrams would a positive test charge experience less force as it moves from P to Q?

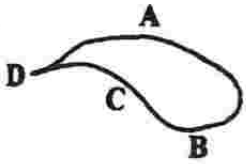


19. If 20 mJ of work is done in moving 5 μC of charge between two points in an electric field, the potential difference between the two points is

A. 4×10^{3} V B. 2.5×10^{-1} V C. 2.5×10^{-4} V D. 10^{-7} V

20. A charge of magnitude 2×10^{-4} coulomb experiences a force of 80 N in an electric field. The electric field intensity is

A. 8×10^{5} NC^{-1} B. 4×10^{5} NC^{-1}
C. 1.6×10^{-2} NC^{-1} D. 2.5×10^{-6} NC^{-1}

21. 

At which of the points on the charged conductor shown would electric charge tend to concentrate most?

22. A potential difference of 3.6 V is maintained between two plates which are 20 cm apart. The electric field intensity between the two plates is

A. 5.6×10^{-2} Vm^{-1} B. 1.8×10^{-1} Vm^{-1}
C. 7.2×10^{-1} Vm^{-1} D. 18.0 Vm^{-1}

23. 50 J of work is done is moving a charge of magnitude 10 μC through a distance of 10 cm against a uniform electric field. The electric field intensity is

A. 5×10^{5} Vm^{-1} B. 5×10^{6} Vm^{-1}
C. 5×10^{7} Vm^{-1} D. 5×10^{8} Vm^{-1}

24. The magnitude of the force experienced by a charge of 1.6×10^{-8} C in a uniform electric field of intensity 5×10^{5} NC^{-1} is

A. 3.2×10^{-14} N B. 8.0×10^{-3} N
C. 8.0×10^{3} N D. 3.1×10^{13} N

25. If $1/4\pi\varepsilon_0 = 9.0 \times 10^{9}$ Nm^2C^{-2}. the electric potential at

a distance of 10 cm from a point charge of 15 mC is
A. 1.7×10^{-11} V B. 1.35×10^{7} V
C. 1.35×10^{9} V D. 6×10^{10} V

26. Which of the following quantities is a vector?
A. Electric potential B. Electric charge
C. Electrical capacitance D. Electric field

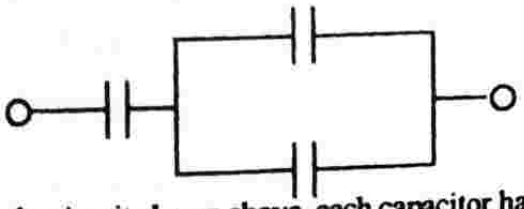
27. Which of the following is not a suitable dielectric material?
A. Brass B. Paraffin wax C. Glass D. Ebonite

28. A parallel plate capacitor of plate area 20 cm^2 in vacuum has a capacitance of 0.02 μF. If $\varepsilon_0 = 9 \times 10^{-12} Fm^{-1}$, the distance between the plates is
A. 9.0×10^{-13} m B. 9.0×10^{-7} m
C. 9.0×10^{-3} m D. 9.0×10^{-1} m

29. When the plates of a capacitor are separated by air, its capacitance is 5 μF. With a dielectric medium inserted between the plates, its capacitance is 50 μF. The relative permittivity of the medium is
A. 1/50 B. 1/10 C. 5 D. 10

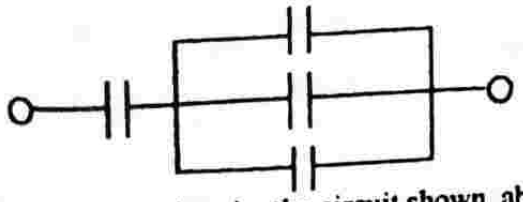
30. The plates of a 0.5 μF uncharged capacitor are connected to a 10 V battery. The charge on the capacitor after a long time is
A. 5.0 μC B. 10.0 μC C. 20.0 μC D. 50.0 μC

31.



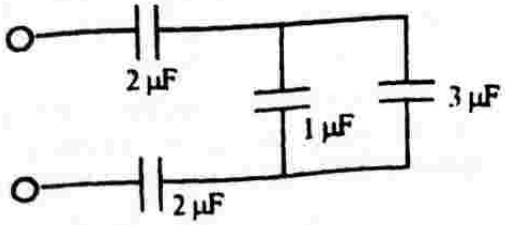
In the circuit shown above, each capacitor has a capacitance of 2 μF. The equivalent capacitance is
A. 4/3 μF B. 3/2 μF C. 3 μF D. 6 μF

32.



If each capacitor in the circuit shown above has capacitance C_1, the equivalent capacitance of the circuit is
A. $C_1/4$ B. $3C_1/4$ C. $4C_1/3$ D. $4C_1$

33.

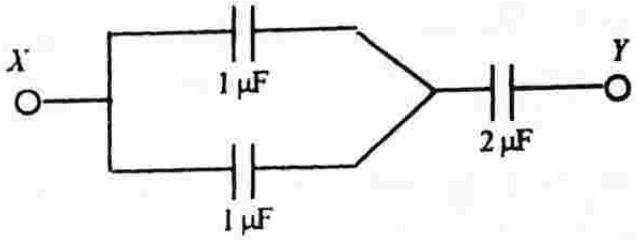


The equivalent capacitance for the circuit shown above is
A. 8.0 μF B. 4.5 μF C. 0.8 μF D. 0.5 μF

34. A 4 μF capacitor is connected in series with a 6 μF capacitor. The additional capacitance which must be connected in series with this combination to give an equivalent of 2 μF is
A. 2 μF B. 8 μF C. 12 μF D. 24 μF

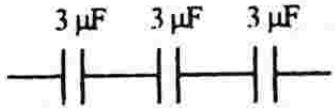
35. Three 2 μF capacitors are to be connected in such a way as to give an effective capacitance of 3 μF. This can be done by connecting
A. two parallel capacitors in series with the third capacitor.
B. two series capacitors in parallel with the third capacitor.
C. all three capacitors in series.
D. all three capacitors in parallel.

36.



The effective capacitance between the terminals X and Y in the circuit shown above is
A. 1.0 μF B. 2.5 μF C. 3.0 μF D. 4.0 μF

37.

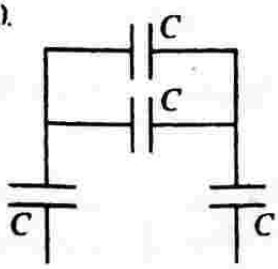


The equivalent capacitance of the three capacitors connected as shown in the diagram is
A. 9 μF B. 3 μF C. 1 μF D. 1/3 μF

38. The equivalent capacitance of three capacitors, each of capacitance C, connected in parallel is
A. $C/3$ B. C C. $3C/2$ D. $3C$

39. The equivalent capacitance of three capacitors, each of capacitance C, connected in series is
A. $C/3$ B. C C. $3C/2$ D. 3

40.

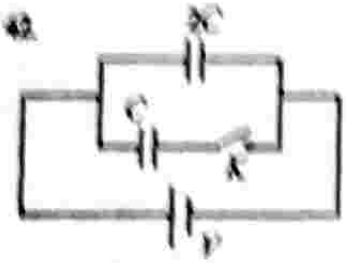


Four capacitors, each of capacitance C, are connected as shown in the diagram. The equivalent capacitance is
A. $C/4$ B. $2C/5$
C. $5C/2$ D. $4C$

41.

If the effective capacitance between terminals P and Q in the diagram shown above is 2 μF, then the value of C is

A. 0.5 μF B. 1.0 μF C. 2.0 μF D. 4.0 μF

42. 

Two capacitors, of capacitances C and $2C$, are connected across a battery of supply voltage V as shown in the diagram. With the key X open, the energy stored by the $2C$ capacitor is E. If the key is now closed and the system attains equilibrium, the total energy stored in the capacitors is

A. $2E/3$ B. E C. $3E/2$ D. $3E$

43. 25 J of energy is stored in a capacitor of capacitance 2 μF. The voltage across the capacitor's terminals is

A. 5000 V B. 250 V C. 25 V D. 5 V

44. The energy stored in a capacitor of capacitance 10 μF whose plates are maintained at a potential difference of 200 V is

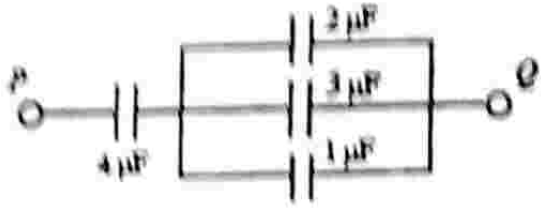
A. 1×10^{-2} J B. 2×10^{-1} J C. 1×10^{-1} J D. 2×10^{2} J

45. A capacitor is charged by connecting its plates to the terminals of a 10 V battery. When a charge of 1 μC has piled up on the plates, the energy stored in the capacitor is

A. 5×10^{-6} J B. 5×10^{-1} J C. 5 J D. 5×10^{3} J

46. 2×10^{-4} J of energy is stored in a 0.01 μF capacitor. The charge on each of the plates is

A. 2×10^{-8} μC B. 2 μC
C. 2×10^{3} μC D. 2×10^{8} μC

47. 

In the circuit shown above, the effective capacitance between P and Q is

A. 0.4 μF B. 2.4 μF C. 5.0 μF D. 10.0 μF

Answer Key

1. B	9. D	17. B	25. C	33. C	41. C
2. C	10. B	18. A	26. D	34. C	42. C
3. A	11. C	19. A	27. A	35. B	43. A
4. B	12. A	20. B	28. B	36. A	44. B
5. D	13. B	21. D	29. D	37. C	45. A
6. A	14. D	22. D	30. A	38. D	46. B
7. B	15. C	23. C	31. A	39. A	47. B
8. C	16. A	24. B	32. B	40. B	

Solutions to Objective Questions

1. **(B)** Silver, being a metal, is a conductor.

2. **(C)** All other substances mentioned in A, B and D are insulators.

3. **(A)** With X and Y in contact, electrons are repelled to the left end of X, leaving Y positive. After separation X possesses excess of electrons (i.e. negative charge) while Y possesses a deficit of electrons (positive charge).

4. **(B)** For the leaves to collapse, the objects must bear an opposite charge to that on the electroscope. If the quantity of charge on the object is less than that

on the electroscope, only a *partial* collapse of the leaves will occur.

5. **(D)** With the negatively-charged sphere suspended inside the can, electrons are repelled from the can to the earth upon touching the former. After withdrawing the sphere, the can now contains a deficit of electrons, i.e. it acquires positive charges which are distributed on its *external surface*.

6. **(A)** The relative divergence of the leaves of the electroscope is a measure of the relative magnitudes of the charges on the objects. The capacitor *stores* electric charge while the *electrophorus* is used to *separate* charges.

7. **(B)** The rubbing action between the petrol and the tank will result in the generation of electric charges, which are conducted through the chain to the earth to prevent a charge build-up on the tank.

8. **(C)** Refer to the notes.

9. **(D)** If d is the original distance separating the charges, $F = kq_1q_2/d^2$. With the separation doubled ($2d$), the new force $F_1 = kq_1q_2/(2d)^2 = kq_1q_2/4d^2 = F/4$.

10. **(B)** $F = qE = (1.6 \times 10^{-19})(5 \times 10^8) = 8.0 \times 10^{-11}$ N

11. **(C)** Change in kinetic energy of the electron = work done in moving the electron across a p.d. of 60 kV $= qV = (1.6 \times 10^{-19})(60 \times 10^3) = 9.6 \times 10^{-15}$ J.

12. **(A)** Refer to the notes.

13. **(B)** Refer to the notes.

14. **(D)** $F = \dfrac{q(-q)}{4\pi\varepsilon_o d^2} = \dfrac{-q^2}{4\pi\varepsilon_o d^2}$

15. **(C)** Charges always flow between two points of different potentials until the potentials are equalized.

16. **(A)** Any positively-charged body contains more protons than electrons. The excess charge creates an electric field. The term *potential energy* is a measure of the work that must be done to move a charge in an electric field. It is not used for an isolated charged body which is not placed in an external field.

17. **(B)** Any excess charge will reside on the external surface and the electric field inside the hollow conductor is zero.

18. **(A)** Force is directly proportional to the electric field intensity ($F = qE$). The electric field intensity is higher where the lines of force are closer together. Hence, $F_P > F_Q$ in (A), $F_P < F_Q$ in (B), $F_P = F_Q$ in (C) and in (D).

19. **(A)** $V = W/q = (20 \times 10^{-3})/(5 \times 10^{-6}) = 4 \times 10^3$ V

20. **(B)** $E = F/q = 80/(2 \times 10^{-4}) = 4 \times 10^5$ NC^{-1}

21. **(D)** Charge density is highest at the sharpest point.

22. **(D)** $E = V/d = 3.6/(20 \times 10^{-2}) = 18.0$ Vm^{-1}

23. **(C)** Potentail difference between the two points,
$V = W/q = 50/10^{-5} = 5 \times 10^6$ V.
$E = V/d = 5 \times 10^6/0.1 = 5 \times 10^7$ Vm^{-1}

24. **(B)** $F = qE = (1.6 \times 10^{-8})(5 \times 10^5) = 8.0 \times 10^{-3}$ N.

25. **(C)** $V = \dfrac{q}{4\pi\varepsilon_o r} = \left(\dfrac{1}{4\pi\varepsilon_o}\right)\left(\dfrac{q}{r}\right)$
$= (9.0 \times 10^9)(15 \times 10^{-3}/0.10) = 1.35 \times 10^9$ V

26. **(D)** Only the electric field has both *magnitude* and *direction*.

27. **(A)** A dielectric material must be an insulator. Brass is a metallic conductor.

28. **(B)** $C = \varepsilon_o A/d \Rightarrow d = \varepsilon_o A/C$
$= (9 \times 10^{-12})(20 \times 10^{-4})/(2 \times 10^{-8}) = 9 \times 10^{-7}$ m

29. **(D)** If C_a = capacitance in air and C_d = capacitance with dielectric, the relative permittivity of the dielectric, $\varepsilon_r = C_d/C_a = 50/5 = 10$.

30. **(A)** $Q = CV = (0.5 \times 10^{-6})(10) = 5.0 \times 10^{-6}$ C $= 5.0$ μC.

31. **(A)** For the two capacitors in parallel, the equivalent capacitance = 2 + 2 = 4 μF. This, in series with the 2 μF capacitor gives an equivalent capacitance C where
$\dfrac{1}{C} = \dfrac{1}{4} + \dfrac{1}{2} = \dfrac{3}{4}$, or $C = \dfrac{4}{3}$ μF

32. **(B)** The three capacitors in parallel have an equivalent capacitance of $C_1 + C_1 + C_1$, or $3C_1$. This, in series with C_1 gives an equivalent capacitance C where
$\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{3C_1} = \dfrac{4}{3C_1}$, or $C = \dfrac{3C_1}{4}$ μF

33. **(C)** The 1 μF and 3 μF capacitors in parallel have a combined capacitance of 1 + 3 = 4μF. This is now in

series with the two 2 μF capacitors, and the equivalent capacitance C_e is given by

$$\frac{1}{C_e} = \frac{1}{4} + \frac{1}{2} + \frac{1}{2} = \frac{5}{4}, \text{ or } C_e = 4/5 = 0.8\ \mu F$$

34. **(C)** If C is the additional capacitance, then for the three capacitances in series,

$$\frac{1}{2} = \frac{1}{4} + \frac{1}{6} + \frac{1}{C}, \text{ or}$$

$$\frac{1}{C} = \frac{1}{2} - \frac{1}{4} - \frac{1}{6} = \frac{1}{12} \Rightarrow C = 12\ \mu F$$

35. **(B)** If all three capacitors were to be connected in series, the effective capacitance would be less than 2 μF. It should be noted that *for any group of capacitors in series, the effective capacitance is less than the smallest individual capacitance*. If all three were to be connected in parallel, the overall capacitance would be 6 μF. Hence, options (C) and (D) are eliminated. For option (A) the two parallel capacitors have a combined capacitance of 4 μF, and this in series with a third 2 μF capacitor would give an effective capacitance which is less than 2 μF. For option (B) the two 2 μF capacitors in series have a combined capacitance of $(½ + ½)^{-1}$, or 1 μF, which in parallel with the third 2 μF capacitor gives an equivalent capacitance of 3 μF.

36. **(A)** The two 1 μF capacitors in parallel have a combined capacitance of 2 μF. This in series with the 2 μF capacitor gives an overall capacitance C where

$$\frac{1}{C} = \frac{1}{2} + \frac{1}{2} = 1 \text{ or } C = 1\ \mu F$$

37. **(C)** The three capacitors are connected in series, giving an overall capacitance C where

$$\frac{1}{C} = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1, \text{ or } C = 1\ \mu F$$

38. **(D)** For the three capacitors in parallel, the equivalent capacitance, is $C + C + C = 3C$

39. **(A)** For the three capacitors in series, the equivalent capacitance. C_e is given by

$$\frac{1}{C_e} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{3}{C}, \text{ or } C_e = C/3$$

40. **(B)** The two capacitors in parallel have a combined capacitance of $2C$. This, in series with the two other capacitors gives an overall capacitance C_e where

$$\frac{1}{C_e} = \frac{1}{2C} + \frac{1}{C} + \frac{1}{C} = \frac{5}{2C}, \text{ or } C_e = 2C/5$$

41. **(C)** The two capacitances in parallel have a combined capacitance of $2C$. This, in series with the 4 μF capacitance, gives an effective capacitance of 2 μF. Hence

$$\frac{1}{2} = \frac{1}{4} + \frac{1}{2C}, \text{ or } \frac{1}{2C} = \frac{1}{2} - \frac{1}{4} = \frac{1}{4}$$

$$\Rightarrow C = 2\ \mu F$$

42. **(C)** With the key open, $E = ½(2C)(V^2) = CV^2$
With the key closed, energy stored in the capacitor of capacitance $C = ½CV^2$. Total energy stored $= CV^2 + ½CV^2 = 3/2CV^2 = 1.5E$

43. **(A)** $E = ½CV^2 \Rightarrow V^2 = \frac{2E}{C} = \frac{2(25)}{2 \times 10^{-6}} = 25 \times 10^6$, or $V = 5 \times 10^3 = 5{,}000$ V

44. **(B)** $E = ½CV^2 = ½(10 \times 10^{-6})(200)^2 = 2 \times 10^{-1}$ J.

45. **(A)** Energy stored $= ½CV^2 = ½(Q/V)V^2 = ½QV$
$= ½(1 \times 10^{-6})(10) = 5 \times 10^{-6}$ J

46. **(B)** $E = ½CV^2 = ½C(Q/C)^2 = ½Q^2/C$
$\Rightarrow Q^2 = 2EC = 2(2 \times 10^{-4})(0.01 \times 10^{-6}) = 4 \times 10^{-12}$
or $Q = 2 \times 10^{-6}$ C, or 2 μC

47. **(B)** The three capacitors in parallel have a combined capacitance of $2 + 3 + 1 = 6$ μF. This, in series with the 4 μF capacitor gives an effective capacitance C where

$$\frac{1}{C} = \frac{1}{6} + \frac{1}{4} = \frac{5}{12}, \text{ or } C = 12/5 = 2.4\ \mu F$$

Revision Check-list

Under this chapter, the candidate should be able to

- describe the basic structure of an atom.
- explain the *transfer of electric charges* involved in the charging of a body by friction and by induction.
- identify the nature of the charges acquired by common substances when rubbed together.
- explain the use of an *electroscope* to detect electric charges.
- state and apply *Coulomb's law* of attraction and repulsion between charges and use it to solve simple problems.
- calculate the electric field around a point charge.
- explain the terms *electric line of force, electric potential and equipotential surface.*
- describe how electric charge is distributed on a conductor with even or uneven curvature.

- explain how a *lightning conductor* works.
- define the term *capacitance* and relate it to electric charge and potential difference.
- state the geometrical factors which determine the capacitance in a parallel plate capacitor.
- explain the term *relative permittivity* or *dielectric constant* of a material.
- calculate the *effective capacitance* for capacitors connected in series or in parallel.
- relate the *energy stored in a capacitor* to electric charge, capacitance and potential difference.

16 Current Electricity

16.1 Electric Current

- ***Electric current*** is the rate of flow of electric charge (electrons) around a circuit.
- If a total charge Q flows past a point in t seconds, the electric current, I, is given by

$$I = \frac{Q}{t} \qquad (16.1)$$

- Units: Q = [C], I = [Cs^{-1}] = [ampere], abbreviated to [A].

16.2 Potential Difference; Electromotive Force

- The electrical ***potential difference*** (p.d.) between two points in a circuit is the amount of work done (in joules) in transferring 1 coulomb of electric charge between the two points.
- An ***electric cell*** is a device for generating electric current.
- The ***electromotive force (emf)*** of a cell is the driving force for the current in a circuit. It is the potential difference between the terminals of a cell when no current is flowing.
- Units: *p.d.* = [joule/coulomb] = [volts], abbreviated to [V]

16.3 Electrical Resistance

- Materials vary in their ability to resist the flow of electric charge through them.
- A ***good conductor*** offers low resistance to the flow of electricity while a ***poor conductor*** (i.e. an ***insulator***) offers very high resistance.
- The ***electrical resistance*** of a piece of material is defined as the ratio of the p.d. between the terminal of the material to the electric current flowing through the material.
- The resistance of a wire or rod is directly proportional to its length L and is inversely proportional to its cross-sectional area A, i.e.

$$R = \frac{\rho l}{A} \qquad (16.2)$$

- The proportionality constant ρ is called the **resistivity of the material from which the wire is made.**
- ***Conductivity*** (σ) is the reciprocal of resistivity, i.e. $\sigma = 1/\rho$. A good conductor has a *high conductivity* but a *low resistivity*.
- The resistance of a metallic conductor generally increases with temperature. If the resistance is R_0 at 0° C and R at temperature T, then

$$R = R_0(1 + \alpha T) \qquad (16.3)$$

where α is the ***temperature coefficient of resistance.***

16.4 Ohm's Law

- ***Ohm's Law*** states that *at constant temperature the current (I) flowing through a metallic conductor is directly proportional to the p.d. (V) across it*, i.e. $I \propto V$, or

$$V = IR \qquad (16.4)$$

where the proportionality constant R is the resistance of the conductor.

16.5 Internal Resistance of a Cell

- The current which a cell drives through an external circuit must also pass through the body of the cell itself in order to complete the circuit (Fig. 16.1)

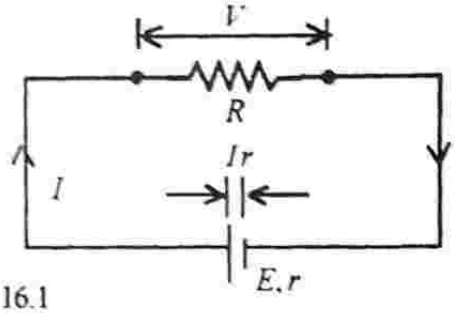


Fig. 16.1

- The body of the cell offers a resistance to the flow of current which is called its ***internal resistance*** (r).
- For a current I flowing through the circuit, the p.d. across the cell's internal resistance is equal to Ir.
- The emf (E) of the cell is equal to the sum of the p.d. (V) across the external circuit and the p.d. across its internal resistance, i.e.

$$E = V + Ir \qquad (16.5)$$

16.6 Series and Parallel Circuits

- If two or more resistors R_1, R_2, R_3 are connected in series (Fig. 16.2a), the overall resistance R is the sum of all the resistances, i.e.

$$R = R_1 + R_2 + R_3 \qquad (16.6)$$

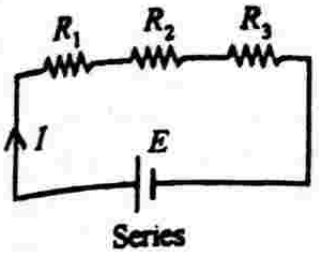


Fig. 16.2a

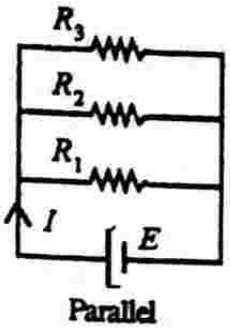


Fig. 16.2b

- For a ***parallel*** connection of resistors R_1, R_2, R_3 (Fig. 16.2b) the overall resistance R is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad (16.7)$$

- If two or more cells of emf E_1, E_2, E_3 are connected in series, the overall emf E is

$$E = E_1 + E_2 + E_3 \qquad (16.8)$$

- The p.d. across any number of cells connected in parallel is the same as the p.d. across each of them.

16.7 The Metre Bridge

- The ***metre bridge*** (or ***Wheatstone bridge***) is used to measure the resistance of a conductor.
- It consists of a standard cell connected across a metre - long wire.
- Two resistances: a known resistance R and an unknown resistance S are connected in series and the combination is connected in parallel to the wire (Fig. 16.3)
- One terminal of a sensitive zero-centre galvanometer is connected between the two resistors.

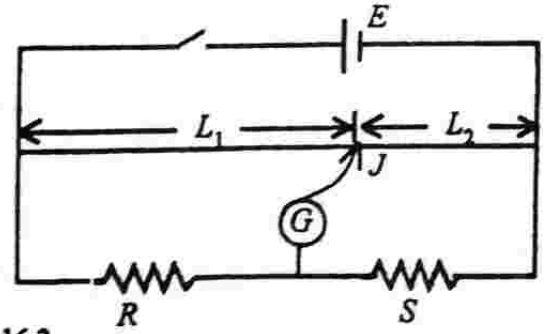


Fig. 16.3

- When the switch in series with the cell is closed, a jockey J attached to the second terminal of the galvanometer is used to find the point on the wire where no current flows through the galvanometer.
- If L_1, and L_2 are the lenghts of the two segments of the wire at the balance point,

$$\frac{R}{S} = \frac{L_1}{L_2} \qquad (16.9)$$

- Knowing R, L_1 and L_2, the unknown resistance S is calculated.

16.8 The Potentiometer

- The emf of a cell can be determined using a ***potentiometer*** which compares the unknown emf with the emf of a standard cell.
- A battery B and a standard cell of emf E are connected with a variable resistor R, a galvanometer G and a metre wire as shown in Fig. 16.4a

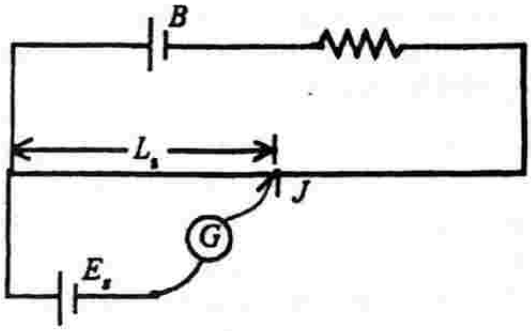


Fig. 16.4a

- A length L_s of the wire is found where the galvanometer shows no deflection.
- This length is directly proportional to the emf E_s of the standard cell.
- The standard cell is now replaced by the cell of unknown emf E and the new balance point L is found (Fig. 16.4b)

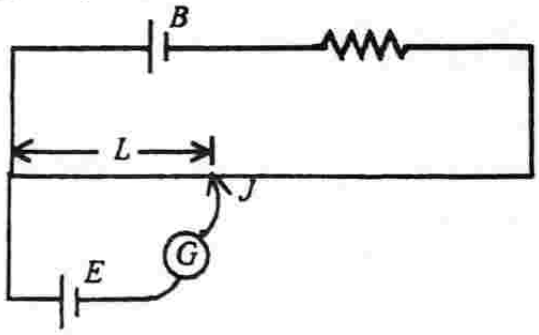


Fig. 16.4b

- Since $E \propto L$, the unknown emf is calculated from the equation

$$\frac{E}{E_s} = \frac{L}{L_s} \qquad (16.10)$$

16.9 Electrical Energy

- When an electric current flows through a resistor, electrical energy is converted to ***heat energy***, e.g. in a pressing iron, electric cooker, boiling ring, etc.
- Electrical energy can also be converted to other forms of energy, e.g. to ***electromagnetic energy*** in radio transmitters to ***sound energy*** in loudspeakers, to ***mechanical energy*** in electric motors, etc.
- If a current I flows through a resistor of resistance R at a p d. of V, the electrical energy(E) supplied to the resistor after a time t is

$$E = IVt = I^2Rt = \frac{V^2t}{R} \qquad (16.11)$$

- Units: $E = [J]$ when $I = [A]$, $V = [V]$, $t = [s]$ and $R = [\Omega]$.

16.10 Electric Power

- ***Electric power*** is the rate at which electrical energy is consumed.
- It is the total quantity of electrical energy which passes through an appliance in one second.
- If a current I flows through an appliance of resistance R at a p.d. of V, the power (P) is

$$P = IV = I^2R = \frac{V^2}{R} \qquad (16.12)$$

- Units: $P = [Js^{-1}]$ = [watt] or [W].
- The unit of electric power consumed in the home is the ***kilowatt-hour***, which is the total energy used when 1 kilowatt (1000 W) is consumed over a period of one hour (3600 s), i.e.
  1 kilowatt-hour = 1,000 W x 3,600 s = 3.6×10^6 J

16.11 House Wiring

- Electric power is brought into the house through a meter box which monitors the amount of electrical energy consumed.
- The house and appliances are protected against possible fire that could arise from a faulty equipment drawing too much current by installing ***circuit breakers*** and ***fuses***.
- A fuse is often thin strip of wire made of a *low melting* point material such as an alloy of lead and tin.
- In most cases wall sockets installed in homes are for plugs with 13 A fuse protection. If an appliance draws more than 13 A the wire in the fuse melts as a result of overheating (i.e. the fuse blows) and breaks the circuit.
- The electric current is delivered to the house using two wires:
  (i) the ***live*** wire through which current flows in, and
  (ii) the neutral wire which forms the return path for the current.

16.12 Earthing

- Most appliances in the home are connected to the mains supply (wall socket) via a three-pin plug.
- Two of the pins are connected to the live wire (brown) and the neutral wire (blue), and the third to an earth wire (green/yellow).
- As a safety precaution, the earth wire is connected to the casing of the appliance.
- In the event of a short circuit in which the casing comes in contact with the live wire, the earth draws a current through the earth wire which is sufficiently large to blow the fuse. The circuit is thus broken and the danger of electric shock is prevented.

True or False - Type Questions

Answer ***True*** (T) or ***False*** (F) to the following questions.

1. The resistance of a wire
   a. is directly proportional to its resistivity.
   b. increases as the diameter of the wire increases.
   c. increases as the length of the wire increases.
   d. is independent of the temperature of the wire.
   e. increases as its conductivity increases.
   f. is doubled if the wire is stretched until its length doubles.
   g. is the property of the wire that causes electrical energy to be converted into thermal energy.
   h. is a measure of the ratio of the potential difference to the current intensity in the wire.

2. a. When the ends of a metallic conductor are maintained at a certain potential difference, electrons drift from the negative to the positive terminal while protons drift in the other direction.
   b. The *ampere* is the quantity of charge flowing through a unit cross-sectional area of a conductor in one second.
   The *ohm* is the resistance of a conductor through which a charge of one coulomb flows in one second when the ends of the conductor are maintained at a potential difference of one volt.
   d. The resistivity of a metallic conductor depends on the dimensions of the conductor.
   e. If a material A has a lower resistivity than a material B of identical dimensions, then more charges would flow through A per unit time when the ends of the materials are maintained at the same potential difference.
   f. If a metallic conductor whose ends are maintained at a certain potential difference is heated, the rate of charge flow through the conductor increases.
   g. If the diameter of a wire is halved while maintaining its length constant, its resistance is quadrupled.

3. The *volt* may be defined as
   a. the electric potential difference between two points in a conductor when a current of one ampere passes through the conductor.
   b. the potential difference between two points in an electric circuit when one joule of work is done in driving one coulomb of charge between the two points.

an energy of one joule that is supplied to a charge of one coulomb as it passes through an electric circuit.

d. the energy used in one second in an electric circuit to which power is being supplied at the rate of one watt.

e. the energy in joules consumed in one second in an electric circuit through which a current of one ampere flows.

4. The *electromotive force* of a cell is
   a. the electric potential difference between the terminals of the cell in an open circuit.
   b. the potential difference across an external load which is receiving electric current from the cell.
   c. the potential difference between the terminals of the cell in a closed circuit.
   d. the total chemical energy stored in the cell.
   e. the energy supplied to a unit charge as it passes through a closed electric circuit.
   f. the energy dissipated inside the cell when it is supplying current to an external load.
   g. the force which drives electric current through an electric circuit.
   h. the sum of the potential difference across the external load and the potential difference across the cell's internal resistance.

5. The *internal resistance* of a cell may be defined as
   a. the resistance to the drift of electric charges within the electrolyte of the cell.
   b. the energy dissipated inside the cell in one second when a current of one ampere passes through it.
   c. the resistance inside the cell across which a potential difference is set up which is equal to the emf of the cell.
   d. the resistance inside the cell across which a potential difference is set up which is equal to the potential difference across the external load.
   e. the resistance inside the cell across which a potential difference is set up which is equal to the difference between the emf of the cell and the potential difference across the external load.
   f. the resistance inside the cell when current is not being supplied to an external load, i.e. in an open circuit.

6. A *fuse* in an electric circuit
   a. limits the electric current which can be drawn from the mains.
   b. prevents the possibility of electric shock if a live wire is contacted.
   c. stabilizes the voltage supply.
   d. breaks as a result of the heating effect of electric current.
   e. is usually made of a low melting point metal.
   f. records the amount of electricity consumed.

7. Electrical appliances are connected in *parallel* in a domestic circuit to ensure that
   a. the voltage across the appliances is not affected by the switching of appliances.
   b. the same current can flow through the appliances.
   c. the same fuse can be used for the appliances.
   d. an appliance can be switched on or off without interfering with the supply to the other appliances.
   e. heat losses can be minimized.

8. a. In order to minimize the heat losses in an electric circuit, short, thick connecting wires are preferable to long, thin wires.
   b. For three identical resistors connected in parallel across a battery, the overall power dissipation is thrice the power dissipation in a single resistor connected across the same battery.
   c. For three identical resistors connected in series to a battery, the overall power dissipation is thrice the power dissipation in a single resistor connected to the same battery.
   d. the resistance of the filament of a 100 W bulb is twice that of a 50 W bulb.
   e. If two identical lamps are connected in parallel across a battery, the brightness of each lamp is the same as the brightness of a single lamp connected to the same battery.

Answers to True or False - Type Questions

1. a **(T)** From the equation $R = \rho L/A$, it follows that $R \propto \rho$.
   b **(F)** As the diameter increases, A increases and R decreases.
   c **(T)** This follows directly from the equation in (a) above.
   d **(F)** Resistance generally increases with increasing temperature.
   e **(F)** As the conductivity increases, resistivity decreases and R decreases.
   f **(F)** When the wire is stretched, its cross-sectional area A decreases as the length L increases. The volume of the wire remains constant and $AL = V$, or $A = V/L$. Putting this into the resistance equation gives $R = \rho L^2/V$, i.e. if the length is doubled the resistance is quadrupled.
   g **(T)** Heat energy is generated as an electric current is driven through a resistance in a circuit.
   h **(T)** This follows from *Ohm's law*: $R = V/I$

2. a **(F)** Protons do ***not*** move through the conductor

during current flow, although the free electrons move from the negative to the positive terminal.

b (F) The ampere is the quantity of charge flow (coulombs) per second through a conductor. The cross-sectional area of the conductor is not relevant.

c (T) From *Ohm's law*, $R = V/I = Vt/Q$, where Q is the charge flowing in time t. If $Q = 1$ coulomb, $t = 1$ second and $V = 1$ volt, $\Rightarrow R = 1$ Ohm.

d (F) Resistivity is a property of the material of the conductor which is independent of the dimension. Resistance, however, is determined by the dimensions.

e (T) Lower resistivity implies a lower resistance, or a larger flow of current for a given p.d.

f (F) As the temperature of the conductor rises, its resistance increases and the current flow *drops*.

g (T) $R = \rho L/A \Rightarrow R \propto 1/A \propto 1/D^2$, where D is the diameter. If D is halved, R is multiplied by four.

3. a (F) This is true only if the conductor has a resistance of 1 ohm.

b (T) 1 Volt = 1 Joule/1 coulomb (see chapter 15).

c (T) See (b) above.

d (F) See (e) below.

e (T) Voltage = Power/ current $\Rightarrow$ 1 volt $= \frac{1\ \text{J/s}}{1\ \text{A}}$

4. a (T) An open circuit is one in which no current flows. $E = V + Ir \Rightarrow E = V$ when $I = 0$.

b (F) The quantity stated is V.

c (F) This is the same as V.

d (F)

e (T) The potential difference between any two points in a circuit is the energy needed to drive a unit charge from one point to the other. The emf thus represents the energy required to move a unit charge around the whole circuit, i.e. through the external resistor and through the cell itself.

f (F) This is the work done against internal resistance, or I^2r.

g (F) See (e) above.

h (T) This is merely the equation $E = V + Ir$ restated in words.

5. a (T)

b (T) Energy dissipated inside the cell per unit time = Power dissipated = $I^2 r$. Thus r = Power/I^2, or r = Power dissipated for $I = 1$ A.

c (F) See (e) below.

d (F) See (e) below.

e (T) P.d. across the internal resistance is $Ir = E - V$.

f (F) The cell offers resistance only when there is movement of charge through the electrolyte, i.e. on closed circuit.

6. a (T) A 5 A fuse, for instance, breaks if the appliance attempts to draw more than 5 A.

b (F) The fuse has nothing to do with electric shock.

c (F) The fuse has no effect on voltage supply.

d (T) The fuse wire melts when it has been heated to its melting point.

e (T) See (d) above.

f (F) This function is performed by *electricity meter*.

7. a (T) When two or more appliances are connected in parallel, the voltage across each of them is equal to the supply voltage.

b (F) Resistors draw the same current only if connected in *series*.

c (F) Each appliance normally has its own fuse as different appliances draw different amounts of electric current.

d (T) Interfering with any or a number of resistors connected in parallel does not affect the p.d. across the others.

e. (F)

8. a (T) The heating effect increases with increasing resistance. Since $R = \rho L/A$, the resistance is lower (i.e. heating effect reduced) if L is made small (short wire) and A large (thick wire).

b (T) For a single resistor of resistance R connected to a battery of voltage V, power dissipated = V^2/R. With three identical resistors in parallel the voltage across each resistor is V and the power dissipated in each is V^2/R. Total power dissipated is thus $3V^2/R$.

c (F) The three resistors connected in series have an equivalent resistance of $3R$. Power dissipated is thus $V^2/3R$, or $^1/_3$ the power dissipation for a single resistor connected to the voltage source V.

d (F) If the voltage supply is V, then for a 100 W bulb, $R = V^2$/Power $= V^2/100$ and for a 50 W bulb, $R = V^2/50$. The resistance of a 100 W bulb is thus *half* that of a 50 W bulb.

e (T) Brightness is determined by the current drawn by the lamp. For a single lamp, current = $I = V/R$ where V is the voltage and R the resistance. For two identical lamps connected in parallel, the voltage across each lamp is still V and the current drawn by each is V/R, the same as for a single lamp connected to the voltage source.

SSCE/JME - Type Objective Questions

1. Ohm's law states that the ratio V/I is constant for
   I. Steel II. An electrolyte
   III. Silver IV. A diode
   Which of the above are correct?
   A. I and II only **B.** I and III only
   C. III and IV only **D.** I, II, III and IV.

2. A quantity of electricity is measured in the unit of
   A. the ampere **B.** the volt
   C. the coulomb **D.** the electromotive force

3. The energy needed to move a unit positive charge around a complete electric circuit is called the
   A. electromotive force
   B. electric potential difference
   C. electrical energy
   D. kinetic energy

4. A current of 180 mA passes through a conductor for 5 minutes. The quantity of electricity transported is
   A. 54 C **B.** 0.9 C
   C. 3.6×10^{-2} C **D.** 6.0×10^{-4} C

5. 60 mC of electricity passes through a conductor for 2 minutes. The current through the conductor is
   A. 7.2A **B.** 120.0 mA **C.** 30.0 mA **D.** 0.5 mA

6. Wire X has twice the diameter and twice the length of wire Y, made of the same material. The ratio of the resistance of X to Y is
   A. 1 : 4 **B.** 4 : 1 **C.** 1 : 2 **D.** 1 : 1

7. A 2 m long wire of cross-sectional area $4 \times 10^{-7} m^2$ has a resistance of 0.5 Ω. The resistivity of the wire is
   A. 4.0×10^{-8} Ωm **B.** 1.0×10^{-7} Ωm
   C. 4.0×10^{-7} Ωm **D.** 1.6×10^{-6} Ωm

8. A 0.4 Ω resistor is made from a wire of length 5 m and resistivity 2×10^{-6} Ωm. The cross-sectional area of the wire is
   A. $1.6 \times 10^{-7} m^2$ **B.** $1.6 \times 10^{-6} m^2$
   C. $4.0 \times 10^{-6} m^2$ **D.** $2.5 \times 10^{-5} m^2$

9. A standard resistor of resistance 14 Ω is to be made from a constantan wire of cross-sectional area $2\pi \times 10^{-8} m^2$ and resistivity 1.1×10^{-6} Ω.m. Taking $\pi = 22/7$. The length of wire required is
   A. 0.80 m **B.** 1.10 m **C.** 1.25 m **D.** 8.00 m

10. A 4 m long wire of cross-sectional area $2 \times 10^{-8} m^2$ has a resistance of 5 Ω. The conductivity of the wire is
   A. $2.5 \times 10^{-8} \Omega^{-1} m^{-1}$ **B.** $4.0 \times 10^{-8} \Omega^{-1} m^{-1}$
   C. $2.5 \times 10^{7} \Omega^{-1} m^{-1}$ **D.** $4.0 \times 10^{7} \Omega^{-1} m^{-1}$.

11. A cell has an open circuit voltage V_o. When the cell delivers current I, the closed circuit voltage is V_C. The internal resistance of the cell is
   A. V_C/I **B.** V_O/I
   C. $(V_O - V_C)/I$ **D.** $(V_C - V_O)/I$

12. An electric cell of internal resistance 0.5 Ω delivers a current of 2.0 A when a resistance of 3 Ω is connected across across it. The electromotive force of the cell is
   A. 1.0 V **B.** 1.5 V **C.** 2.5 V **D.** 7.0 V

The reading on a high resistance voltmeter connected across the terminals of a cell on open circuit is 5.0 V. When the cell delivers a current of 0.5 A to a lamp. the voltmeter reading falls to 4.5 V. Use this information to answer questions 13 and 14:

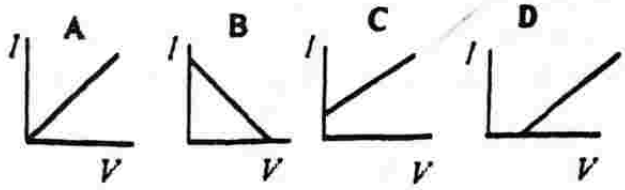
13. The resistance of the lamp is
   A. 1 Ω **B.** 9 Ω **C.** 10 Ω **D.** 19 Ω

14. The internal resistance of the cell is
   A. 0.25 Ω **B.** 0.50 Ω **C.** 1.00 Ω **D.** 9.00 Ω

15. The potential difference between the terminals of a battery is 2.8 V. With a 5 Ω resistor connected across the terminals of the cell. the p.d. is 2.5 V. The internal resistance of the cell is
   A. 0.3 Ω **B.** 0.5 Ω **C.** 0.6 Ω **D.** 5.0 Ω

16. A cell delivers a current of 0.2 A through a resistance of 10 Ω. When the resistance is changed to 6 Ω the current delivered is 0.3 A. The internal resistance of the cell is
   A. 2.0 Ω **B.** 1.5 Ω **C.** 1.0 Ω **D.** 0.7 Ω

17. Which of the following graphs correctly illustrates the relationship between the current (I) and the voltage (V) for a cell with appreciable internal resistance?



18. The efficiency of a cell of internal resistance 0.5 Ω which supplies current to a 2 Ω resistor is
A. 20% B. 25% C. 75% D. 80%

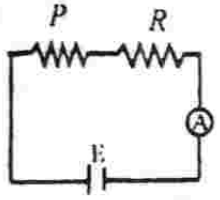
19. The voltage across the terminals of a cell drops to three-quarters of its nominal value when a resistance R is connected across the cell. The cells internal resistance is
A. $R/4$ B. $R/3$ C. $R/2$ D. R

20. A battery delivering a current of 1.0 A has a terminal potential difference of 2 V. When delivering a current of 1.5 A, the terminal p.d. is 1 V. The internal resistance of the battery is
A. 0.5 Ω B. 1.0 Ω C. 2.0 Ω D. 4.0 Ω

21. A cell of internal resistance 2 Ω and emf 12 V is connected to a resistor of 4 Ω. The terminal p.d. of the cell is
A. 12 V B. 10 V C. 8 V D. 6 V

22. A cell of emf 3 V is connected in series with a resistor of 6 Ω. A high-resistance voltmeter connected across the cell reads 2.4 V. The internal resistance of the cell is
A. 1.2 Ω B. 1.5 Ω C. 2.4 Ω D. 4.8 Ω

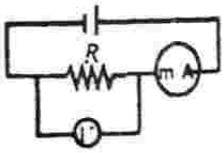
23. A cell of emf 2 V and internal resistance 0.5 Ω delivers a current of 0.4 A to an external resistance R. The value of R is
A. 0.5 Ω B. 1.0 Ω C. 4.0 Ω D. 4.5 Ω

24. 

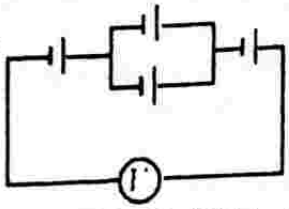
In the circuit diagram shown above, the ammeter A registers a current of 2 A when P is 6 Ω and 4 A when P is 2 Ω. The value of the resistance R is
A. 2 Ω B. 3 Ω C. 4 Ω D. 6 Ω

25. Three cells each of emf 1.1 V and internal resistance 2 Ω are connected in parallel across a 3 Ω resistor. The current in the resistor is
A. 0.12 A B. 0.30 A C. 0.39 A D. 0.90 A

26. A cell of emf 1.2 V and internal resistance 1.5 Ω is connected in series with an ammeter of resistance 0.5 Ω and a load of resistance 4 Ω. The current in the circuit is
A. 0.20 A B. 0.24 A C. 0.30 A D. 0.40 A

27. 

In the circuit shown, the voltmeter V reads 2.5 V and the milliammeter reads 125 mA. The value of R is
A. 0.02 Ω B. 0.05 Ω C. 20.00 Ω D. 50.00 Ω

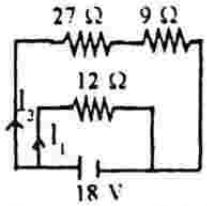
28. 

Four cells each of emf 1.5V are connected as shown in the circuit diagram. The reading on the voltmeter is
A. 1.5 V B. 3.0 V C. 4.5 V D. 6.0 V

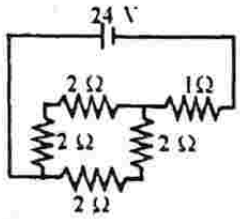
29. A 20 A car fuse operates on a 12 V battery. The resistance of the fuse wire is
A. 240.0 Ω B. 32.0 Ω C. 1.6 Ω D. 0.6 Ω

30. Two resistors R_a and R_b are connected in parallel. If $R_a < R_b$, the combined resistance is
A. less than R_a B. greater than R_b
C. $R_a + R_b$ D. greater than R_a but less than R_b

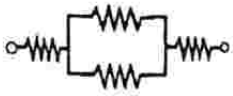
31. Three 6 Ω resistors are connected in parallel. If a potential difference of 24 V is applied across the combination, the current in each resistor is
A. 12.0 A B. 4.0 A C. 1.5 A D. 0.8 A

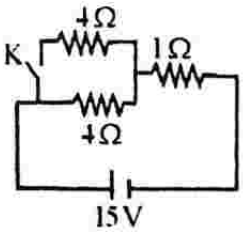
32. 

In the circuit shown, the current delivered by the battery is
A. 0.4 A B. 0.5 A C. 1.5 A D. 2.0 A

33. 

In the circuit shown, the current through the 1 Ω resistor is
A. 0.4 A B. 2.7 A C. 8.0 A D. 9.6 A

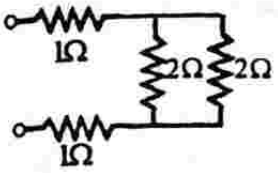
34. 
If each of the resistances in the circuit shown is 4 Ω, the total resistance is
A. 16 Ω B. 10 Ω C. 4 Ω D. 2 Ω

35. 

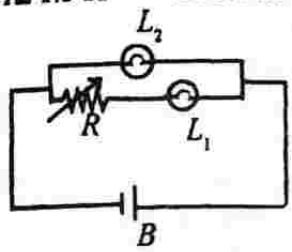
If the key in the circuit shown above is closed, the current delivered by the battery will
A. increase by 2 A B. decrease by 2 A
C. increase by 3 A D. decrease by 3 A.

36. Which of the following combinations of the three resistors 4 Ω, 6 Ω and 12 Ω will give an equivalent of 2 Ω?

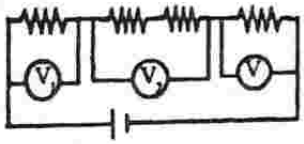
A. All three resistors in series
B. A parallel combination of the 4 Ω and the 6 Ω resistor, in series with the 12 Ω resistor.
C. A parallel combination of the 6 Ω and the 12 Ω resistor, in series with the 4 Ω resistor.
D. All three resistors in parallel.

37.


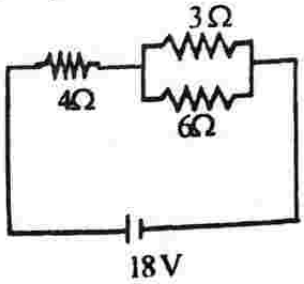
The equivalent resistance of the circuit shown in the figure above is
A. 1.3 Ω B. 3.0 Ω C. 4.0 Ω D. 6.0 Ω

38.


In the circuit shown above, R is a variable resistance while L_1 and L_2 are lamps fed by the battery B of negligible internal resistance. As the resistance R is increased
A. L_1 and L_2 become brighter
B. L_1 becomes brighter, L_2 dimmer
C. L_1 becomes brighter, L_2 unchanged
D. L_2 becomes dimmer, L_1 unchanged.

39.


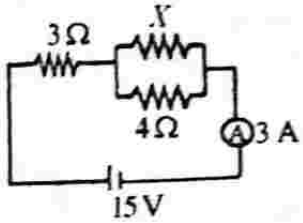
Four equal resistances are connected in series as shown in the circuit diagram above. V_1, V_2 and V_3 are voltmeters. Which of the following equations is correct?
A. $V_1 = 2V_2 = V_3$ B. $V_1 = V_3 = V_2/2$
C. $V_1 = V_2 = V_3/2$ D. $V_1 = V_2 = V_3$



Questions 40 and 41 refer to the circuit diagram shown above. Assume negligible internal resistance for the battery.

40. The current delivered by the battery is
A. 1.4 A B. 1.8 A C. 3.0 A D. 4.5 A

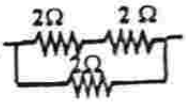
41. The current through the 6 Ω resistor is
A. 1.0 A B. 1.5 A C. 2.0 A D. 3.0 A

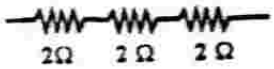
42.


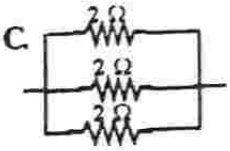
The value of the resistance X in the circuit diagram shown is
A. 1 Ω B. 2 Ω C. 3 Ω D. 4 Ω

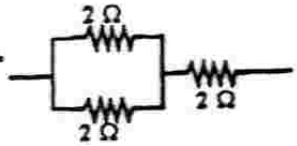
43. The potential difference across X in the circuit diagram of question 42 is
A. 6 V B. 9 V C. 12 V D. 15 V

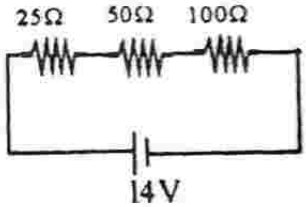
44. Which of the following combinations will give an equivalent resistance of 3 Ω from three 2 Ω resistors?

A.


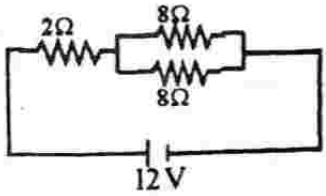
B.


C.


D.


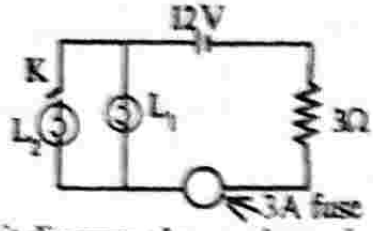
45.


In the circuit diagram shown above, the p.d. across the 25 Ω resistor is
A. 1 V B. 2 V C. 4 V D. 14 V

46.


In the circuit diagram shown above, the p.d. across the 2 Ω resistance is
A. 12 V B. 8 V C. 4 V D. 2 V

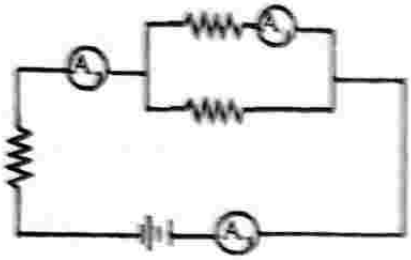
47.



In the circuit diagram shown above, L_1 and L_2 are lamps, each of resistance 1.5 Ω. The 3 A fuse will cut when

A. K is closed
B. K is opened
C. the 3 Ω resistor is doubled with K closed
D. the 3 Ω resistor is doubled with K opened

48.

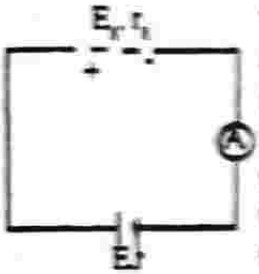


In the circuit diagram shown above, A_1, A_2 and A_3 are ammeters. Which of the following statements about the readings is (are) correct?

I. The reading of A_1 is less than that of A_3
II. The reading of A_2 is twice that of A_3
III. The readings of A_2 and A_3 are equal.
IV. The reading of A_3 is the sum of the readings of A_1 and A_2.

A. I only **B.** I and III only
C. I, II, and III only **D.** I, II, III and IV.

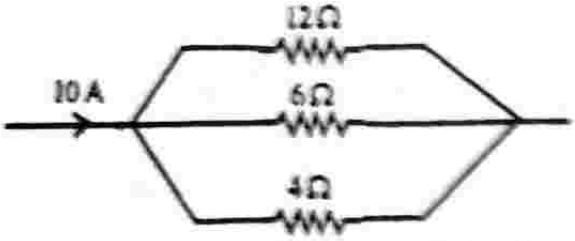
49.



The circuit shows an accumulator of emf E and internal resistance r being charged by a d. c. supply of emf E_s and internal resistance r_s. The charging current measured by the ammeter A is given by

A. $(E_s + E)/(r_s + r)$ **B.** $(E_s - E)/(r_s - r)$
C. $(E_s - E)/(r_s + r)$ **D.** $(E - E_s)/(r_s + r)$

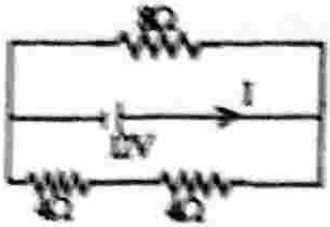
50.



The current in the 6 Ω resistor shown in the diagram above is

A. 1.7 A **B.** 2.7 A **C.** 3.3 A **D.** 60.0 A

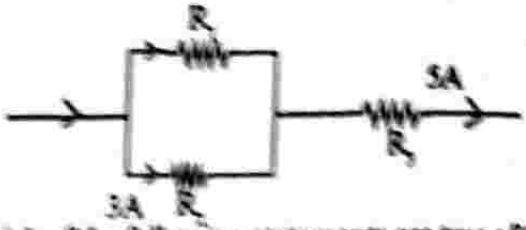
51.



The current I in the circuit shown above is

A. 12.00 A **B.** 3.00 A **C.** 1.50 A **D.** 0.75 A

52.

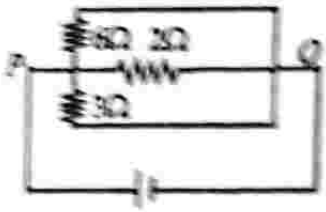


Which of the following statements are true of the diagram shown above?

I. The current in R_1 is 8 A
II. The current in R_1 is 2 A
III. Resistance R_1 is greater than R_2
IV. P.d. across R_2 = p.d. across R_3

A. I and III only **B.** II and III only
C. II and IV only **D.** II, III, and IV only.

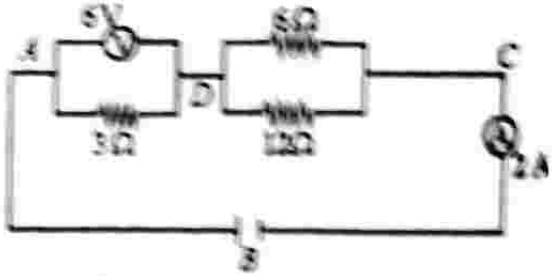
53.



The effective resistance between points P and Q in the circuit diagram shown above is

A. 1.0 Ω **B.** 2.2 Ω **C.** 2.7 Ω **D.** 11.0 Ω

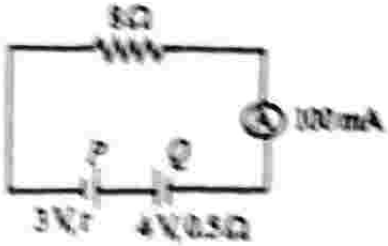
54.



In the circuit diagram shown above, the battery B has negligible internal resistance. The p.d. between D and C is

A. 2 V **B.** 4 V **C.** 6 V **D.** 8 V

55.



In the circuit shown above, cell P has an emf of 3 V and an unknown internal resistance r while cell Q has an emf of 4 V and an internal resistance

of 0.5 Ω. If the ammeter registers a current 100 mA, then r is

A. 0.5 Ω B. 1.0 Ω C. 1.5 Ω D. 2.0 Ω

56. A calibrated potentiometer can be used to measure an unknown emf E of a cell only when

I. the source of emf is greater than E

II. the cell's internal resistance is negligible

III. no current flows through the cell

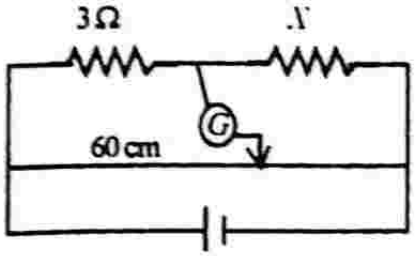
IV. the potentiometer wire has a uniform diameter

Which of the above statements are correct?

A. I and II only B. III and IV only

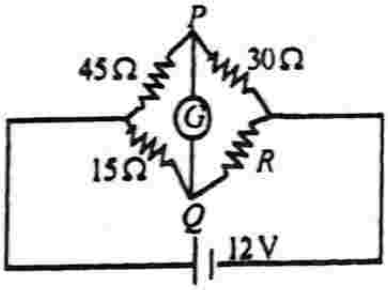
C. II, III, IV only D. I, III and IV only

57.



The diagram above shows a metre bridge in which two of the arms contain resistances 3 Ω and X. If a balance point is obtained at 60 cm from the left end, the value of X is

A. 2.0 Ω B. 2.4 Ω C. 4.5 Ω D. 6.0 Ω



In the diagram above, the galvanometer G indicates a null deflection. Use this information to answer questions 58 and 59.

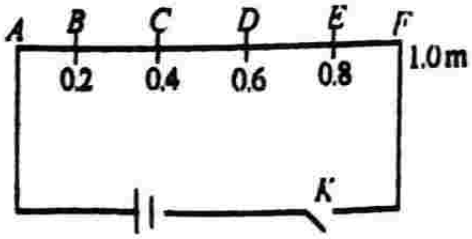
58. The value of R is

A. 5 Ω B. 10 Ω C. 15 Ω D. 22.5 Ω

59. The potential difference between P and Q is

A. 0 volt B. 2 volts C. 6 volts D. 12 volts

60.



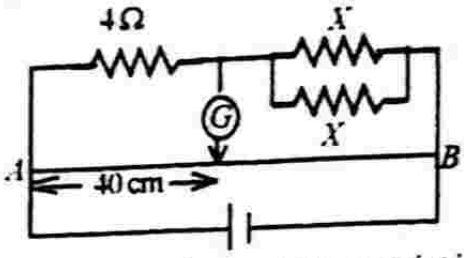
In the circuit diagram shown above, AF is a uniform resistance metre wire. If a voltmeter connected across CE with the key K closed indicates 3.0 V, the reading on a voltmeter connected across AD will be

A. 1.0 V B. 2.0 V C. 4.5 V D. 6.0 V

61. A standard cell of emf 1.6 V gives a balance point of 40 cm on a potentiometer wire. If the standard cell is now replaced by a cell emf 2.4 V, the new balance point is at

A. 26.7 cm B. 50.0 cm C. 60.0 cm D. 64.0 cm

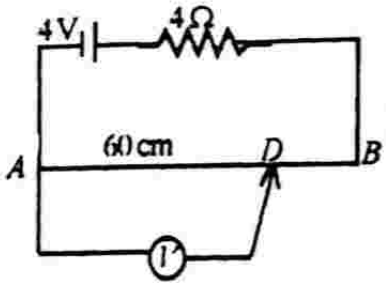
62.



In the diagram above, a balance point is obtained at 40 cm from the left end. The value of X is

A. 2 Ω B. 3 Ω C. 6 Ω D. 12 Ω

63.



In the circuit diagram shown above, AB is a uniform wire of length 1 metre and resistance 6 Ω. Neglecting the internal resistance of the cell, the reading on the voltmeter V is

A. 1.44 V B. 1.89 V C. 4.00 V D. 6.00 V

64. With a standard resistor of 6 Ω connected to the 0.0 cm end of a metre bridge, the balance point is at 75 cm. The value of the unknown resistor is

A. 1.5 Ω B. 2.0 Ω C. 4.0 Ω D. 18.0 Ω

65. If the cost of electricity is ₦1.20 per kWh, the cost of operating for 50hrs a lamp drawing 1A from a 220 V line is

A. ₦6.60 B. ₦11.00 C. ₦13.20 D. ₦26.40

66. A man has three 100 W bulbs, five 60 W bulbs and five 40 W light bulbs in his apartment. if he turns all the lights on for five hours daily and the cost o ele-ctricity is ₦1.20 per unit, his bi for 30 days is

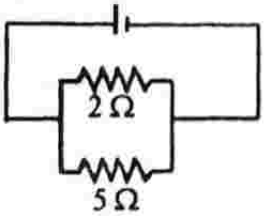
A. ₦4.80 B. ₦12.00 C. ₦28.80 D. ₦144.00

67. The resistance of a 40 W car head lamp, drawing current from a 12 V battery is
A. 0.3 Ω B. 3.3 Ω C. 3.6 Ω D. 4.8 Ω

68. A heating coil of resistance 5 Ω drawing a current of 10 A is used to evaporate 500 g of a liquid in 1 minute. Assuming 100% heating efficiency, the specific latent heat of vaporization of the liquid is
A. 1 Jg^{-1} B. 6 Jg^{-1} C. 60 Jg^{-1} D. 120 Jg^{-1}

69. An electric iron is rated at 1100 W, 220 V. The iron's resistance and the current it draws are
A. 5 Ω, 44 A B. 44 Ω, 5 A
C. 5.5 Ω, 5 A D. 5.5 Ω, 44 A

70. 3 kg of water is to be heated from 30°C to 80°C using a heating coil which draws a current of 6 A from a 200 V mains. If the specific heat capacity of water is 4200 $Jkg^{-1}K^{-1}$, the heating time required is
A. 120 s B. 360 s C. 480 s D. 525 s

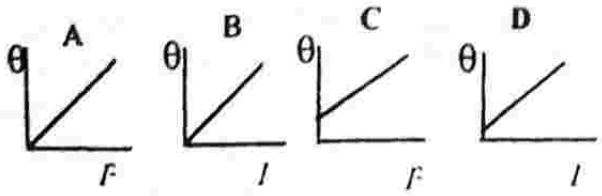
71. 

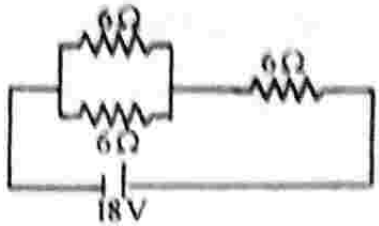
In the circuit diagram shown, if the power dissipation in the 2 Ω resistor is 50 W, then the power dissipation in the 5 Ω resistor is
A. 20 W B. 40 W C. 50 W D. 125 W

72. An electric kettle connected to a 200 V mains generates 3×10^5 J of heat energy in 2.5 minutes. The resistance of the heating element of the kettle is
A. 2 Ω B. 4 Ω C. 8 Ω D. 20 Ω

73. A resistor connected to a 12 V battery draws a current of 2 A. The energy dissipated in the resistor in 5 minutes is
A. 3,600 J B. 6,000 J C. 7,200 J D. 14,400 J

74. Which of the following graphs correctly illustrates the relationship between the temperature rise θ and the current *I* drawn for a specified period of time in an experiment to demonstrate the heating effect of electric current?



75. 

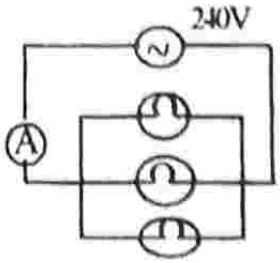
In the circuit diagram above, the total power drawn from the cell is
A. 18 W B. 36 W C. 72 W D. 162 W

76. An electric heating coil rated at 1 kW is used to heat 2 kg of water for 2 minutes. The initial water temperature is 30°C. Taking the specific heat of the water as 4,000 Jkg^{-1} and neglecting that of the container, the final water temperature is
A. 15.0°C B. 45.0°C C. 52.5°C D. 60.0°C

77. A 30 Ω resistance coil is used to melt 50 g of ice in 35 seconds. If there are no heat losses and the latent heat of fusion of ice is 336 Jg^{-1}, the current drawn by the coil is
A. 0.25 A B. 0.50 A C. 2.00 A D. 4.00 A

78. A heating coil is used to boil a certain quantity of water in 10 minutes. If heat losses are negligible and the same heating coil is to be used to boil the same quantity of water, but with the current now doubled it will take
A. 20 min B. 5 min C. 2.5 min D. 1 min

79. An electric heater of resistance 110 Ω is connected to a 220 V mains supply. The time it takes to dissipate 121 kJ of energy is
A. 275.0 s B. 137.5 s C. 55.0 s D. 27.5 s

80. 

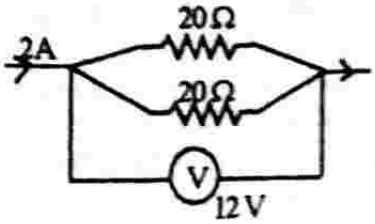
The circuit diagram shows three identical 60 W lamps connected in parallel across a 240 V mains. The reading of the ammeter is
A. 12.00 A B. 4.00 A C. 1.33 A D. 0.75 A

81. A 1.2 k W electric iron drawing from a 240 V mains is to be protected with a fuse. The most suitable fuse rating is
A. 0.2 A B. 5.0 A C. 8.0 A D. 12.0 A

82. Which of the following appliances draws the highest current?

A. 1.1 kW, 220 V B. 440 W, 110 V
C. 100 W, 200 V D. 40 W, 6 V

83. A 5760 μF capacitor is charged to a voltage V such that it stores the same energy as a fully charged 12 V, 60 Ah storage battery. The magnitude of the voltage V is
A. 30.0 kV B. 28.8 kV C. 12.0 kV D. 8.7 kV

84. 

The heat energy developed in the resistors in the above circuit in 10 minutes is
A. 14.4 kJ B. 24.0 kJ C. 28.8 kJ D. 96.0 kJ

Answer Key

1. B	15. C	29. D	43. A	57. A	71. A
2. C	16. A	30. A	44. D	58. B	72. D
3. A	17. B	31. B	45. B	59. A	73. C
4. A	18. D	32. D	46. C	60. C	74. A
5. D	19. B	33. C	47. A	61. C	75. B
6. C	20. C	34. B	48. B	62. D	76. B
7. B	21. C	35. A	49. C	63. A	77. D
8. D	22. B	36. D	50. C	64. B	78. C
9. A	23. D	37. B	51. B	65. C	79. A
10. D	24. A	38. C	52. B	66. D	80. D
11. C	25. B	39. B	53. A	67. C	81. B
12. D	26. A	40. C	54. D	68. C	82. D
13. B	27. C	41. A	55. C	69. B	83. A
14. C	28. C	42. D	56. D	70. D	84. B

Solutions to Objective Questions

1. **(B)** Ohm's law applies only to *metallic conductors.*

2. **(C)** The *ampere* and the *volt* are units of *electric current* and *voltage* respectively. Electromotive force is not a unit.

3. **(A)** The *electric potential difference* is the work done in moving a unit charge between *two points* in a circuit. The electrical energy is the total energy consumed in the circuit.

4. **(A)** Quantity of electricity = electric current x time
$= (180 \times 10^{-3}\ A)(5 \times 60\ s) = 54\ C$

5. **(D)** Current = charge/time = 60 mC/(2 x 60) s = 0.5 mA

6. **(C)** Resistance of $Y = R_y = \rho L_y/A_y$
$L_x = 2L_y$ and $D_x = 2D_y \Rightarrow A_x = 4A_y$ (Note that $A \propto D^2$)
Resistance of $X = R_x = \rho L_x/A_x = \rho(2L_y)/4A_y = \rho L_y/2A_y$
$= R_y/2$. Hence $R_x : R_y = 1 : 2$

7. **(B)** $R = \rho L/A \Rightarrow \rho = RA/L = (0.5)(4 \times 10^{-8})/2 = 10^{-7}\ \Omega.m$

8. **(D)** $A = \rho L/R = (2 \times 10^{-6})(5)/0.4 = 2.5 \times 10^{-5}\ m^2$

9. **(A)** $L = RA/\rho = (14)(2 \times 22/7 \times 10^{-8})/1.1 \times 10^{-6} = 0.80$ m.

10. **(D)** Conductivity $= 1/\rho = L/AR = 4/(2 \times 10^{-8} \times 5) = 4 \times 10^{-7}\ \Omega^{-1}\ m^{-1}$

11. **(C)** The *open circuit* voltage is the emf of the cell while the *closed circuit* voltage is the terminal potential difference. Hence $V_o = V_c + Ir$ or $r = (V_o - V_c)/I$.

12. **(D)** $E = I(R + r) = 2.0\ (3 + 0.5) = 7.0$ V

13. **(B)** The voltmeter reading when the cell is delivering a current *(I)* to an external resistance (i.e on closed circuit) is the terminal p.d. *(V)* of the cell, which is also equal to the p.d. across the external resistance. By Ohm's law the resistance of the lamp, $R = V/I = 4.5/0.5 = 9\ \Omega$.

14. **(C)** $r = (E - V)/I = (5.0 - 4.5)/0.5 = 1.00\ \Omega$

15. **(C)** Current delivered by the battery.

$I = V/R = 2.5/5 = 0.5$ A
$r = (E - V)/I = (2.8 - 2.5)/0.5 = 0.6\,\Omega$

16. **(A)** For $I = 0.2$ A and $R = 10\,\Omega$, $V = (0.2)(10) = 2\,V$
For $I = 0.3$ A and $R = 6\,\Omega$, $V = (0.3)(6) = 1.8\,V$
$E = V + I_t \Rightarrow E = 2 + 0.2r$ .....(i)
and $E = 1.8 + 0.3r$ .....(ii)
From (i) and (ii), $2 + 0.2r = 1.8 + 0.3r$, or
$0.1r = 0.2$, or $r = 2.0\,\Omega$

17. **(B)** $E = V - Ir \Rightarrow I = (E - V)/r$. The I-V relationship is a linear one with *negative* slope and with intercepts E/r and E on the I and V axes respectively.

18. **(D)** Rate of energy generation in cell $= I^2(R + r)$
Rate of energy delivery to resistor $= I^2R$

$$\text{Efficiency} = \frac{\text{energy delivered to resistor}}{\text{energy generated}}$$

$$= \frac{I^2R}{I^2(R+r)} = \frac{R}{R+r} = \frac{2}{2+0.5} = 0.8, \text{ or } 80\%$$

19. **(B)** Nominal voltage of the cell $= E$.
With an external resistance R, the terminal voltage is
$V = 3/4\,E = IR$, or $E = 4IR/3$
$E - V = 4IR/3 - IR = IR/3$
$r = (E - V)/I = R/3$

20. **(C)** Applying the equation $E - V = Ir$ gives
for $I = 1.0$ A: $E - 2 = 1.0R$ .....(i)
for $I = 1.5$ A: $E - 1 = 1.5R$ .....(ii)
Subtract (i) from (ii) : $0.5R = 1$, or $R = 2.0\,\Omega$

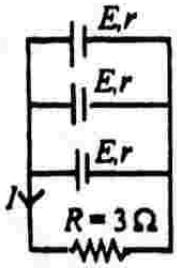
21. **(C)** $E = V + Ir = IR + Ir = I(R + r)$
$I = E/(R + r) = 12/(4 + 2) = 2$ A
$V = IR = 2\,(4) = 8\,V$

22. **(B)** $E = 3$ V, $R = 6\,\Omega$, $V = 2.4$ V
$V = IR \Rightarrow I = V/R = 2.4/6 = 0.4$ A
$r = (E - V)/I = (3 - 2.4)/0.4 = 1.5\,\Omega$

23. **(D)** $E = V + Ir = IR + Ir = I(R + r)$
$R + r = E/I = 2/0.4 = 5.0\,\Omega$
$R = 5.0 - r = 5.0 - 0.5 = 4.5\,\Omega$

24. **(A)** Assuming the cell's internal resistance is negligible,
$E = I(P + R)$
For $P = 6\,\Omega$ and $I = 2$ A, $E = 2(6 + R)$ .....(i)
For $P = 2\,\Omega$ and $I = 4$ A, $E = 4(2 + R)$ .....(ii)
From (i) and (ii) : $12 + 2R = 8 + 4R$, or $R = 2\,\Omega$

25. **(B)**



From the figure, the three cells in parallel are equivalent to a single cell of emf E and internal resistance r_t, given by
$1/r_t = 1/r + 1/r + 1/r = 3/r$ or $r_t = r/3 = 2/3\,\Omega$
$I = E/(R + r) = 1.1/(3 + 2/3) = (1.1 \times 3)/11 = 0.30$ A

26. **(A)** The total resistance of the circuit including the cell's internal resistance is $R_t = 1.5 + 0.5 + 4 = 6\,\Omega$, since the elements are in series.
$I = E/R_t = 1.2/6 = 0.20$ A

27. **(C)** The voltmeter reads the voltage V (= 2.5 V) across R while the milliammeter registers the current I (= 0.125 A) through R.
Hence $R = V/I = 2.5/0.125 = 20\,\Omega$

28. **(C)** The two cells in parallel are equivalent to a single cell of emf 1.5 V. This, in series with the two other cells, gives a total emf of 1.5 + 1.5 + 1.5, or 4.5 V

29. **(D)** $R = V/I = 12/20 = 0.6\,\Omega$

30. **(A)** The equivalent resistance R is given by

$$\frac{1}{R} = \frac{1}{R_a} + \frac{1}{R_b} = \frac{R_a + R_b}{R_aR_b}$$

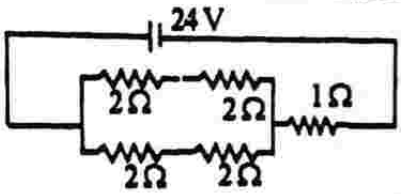
or $$R = R_a\left[\frac{R_b}{R_a + R_b}\right]$$

Since the quantity in the bracket is always less than 1, R must be less than R_a. In general, the effective resistance of any number of resistances in parallel is *always less than* the least individual resistance.

31. **(B)** The voltage V across each resistor is the same as the p.d. across the combination, i.e. $V = 24$ V.
Hence $I = V/R = 24/6 = 4$ A.

32. **(D)** Current I_1 through the 12 Ω resistor $= 18/12 = 1.5$ A.
Current I_2 through the 27 Ω and 9 Ω resistors $= 18/(27 + 9) = 0.5$ A
Current delivered by battery $= I_1 + I_2 = 2.0$ A .

33. **(C)** The circuit can be re-drawn as shown below :



The equivalent resistance of the four 2 Ω resistors is equal to $(4 \times 4)/(4 \times 4) = 2\,\Omega$
[As a rule of thumb. the equivalent resistance for

two equal resistances connected in parallel is equal to half the value of each of the individual resistances] This, in series with the 1 Ω resistor gives a combined resistance of 3 Ω. Current through the battery = 24/3 = 8.0 A.

34. **(B)** The two 4 Ω resistances in parallel give a combined resistance of (4 x 4)/(4 + 4), or 2 Ω. This, in series with two 4 Ω resistances gives a combined resistance of 2 + 4 + 4 = 10 Ω.

35. **(A)** When the key is open, current flows only through the 4 Ω and 1 Ω resistors, which are then in series. The current is I_0 = 15/(4 + 1) = 3 A.
With the key closed, the two 4 Ω resistors are now in parallel to give a combined resistance of 2 Ω. This, in series with the 1 Ω resistor gives a total resistance of 3 Ω.
Current delivered by the battery is I_f = 15/3 = 5 A.
Closing the key therefore increases the current by 5 A - 3 A, or 2 A.

36. **(D)** Only a parallel combination of the three resistors will give an equivalent resistance which is less than the smallest resistance. As a check, the equivalent resistance R is given by $\frac{1}{R} = \frac{1}{4} + \frac{1}{6} + \frac{1}{12} = \frac{6}{12}$
or R = 12/6 = 2 Ω.

37. **(B)** The two 2 Ω resistors in parallel give an equivalent resistance of 1 Ω. This is now in series with the two 1 Ω resistors to give a total resistance of 1 + 1 + 1, or 3 Ω.

38. **(C)** The brightness of each lamp increases with the current through the lamp. As R increases, the current through L_1 decreases, hence L_1 becomes dimmer. The current through L_2 is always equal to V/R_2, where V is the voltage of the battery and R_2 is the resistance of lamp L_2. Both V and R_2 remain unchanged, hence the brightness of L_2 also remains unchanged.

39. **(B)** The voltage drop across any resistor is directly proportional to the resistance (Ohm's law). $V_1 = V_3$ since they are connected across equal resistances. The resistance across which V_2 is connected is twice that of V_1 or V_3 and the voltage drop $V_2 = 2V_1 = 2V_3$, or $V_1 = V_3 = V_f/2$

40. **(C)** The 3 Ω and 6 Ω resistors in parallel give a combined resistance of (3 x 6)/(3 + 6), or 2 Ω. This, in series with the 4 Ω resistance gives a total circuit resistance of 6 Ω. Battery current = 18/6 = 3 A

41. **(A)** For any two resistances R_1 and R_2 connected in parallel, p.d. across R_1 = p. d. across R_2. If I_1 and I_2 are the currents through R_1 and R_2 respectively, then $I_1R_1 = I_2R_2$ and $I_1/I_2 = R_2/R_1$ i.e the ratio of the currents is the inverse of the ratio of the resistances. The current through the 6 Ω resistor is thus half of the current through the 3 Ω resistor. Since the total current is 3 A, the currents in the 3 Ω and 6 Ω resistors must be 2 A and 1 A respectively.

42. **(D)** The current delivered by the battery of emf 1.5 V is 3 A, hence the total circuit resistance is 15/3 = 5 Ω. X and the 4 Ω resistance in parallel must therefore give a combined resistance of 5 - 3, or 2 Ω. Hence X must be 4 Ω.

43. **(A)** P.d. across the 3 Ω resistance = current x resistance = (3) (3) = 9 V.
P.d. across the parallel combination of 4 Ω and X must be 15 - 9 = 6 V.

44. **(D)** For (A) or (C), the equivalent resistance is less than 2 Ω. For (B) it is 6 Ω and for (D), the two resistances in parallel give an equivalent resistance of 1 Ω which, in series with the 2 Ω resistance, gives a total of 3 Ω.

45. **(B)** Total circuit resistance = 25 + 50 + 100 = 175 Ω. P.d. across each resistor is directly proportional to the resistance. Hence p.d. across the 25 Ω resistor is 25/175 x 14 = 2 V

46. **(C)** The two 8 Ω parallel resistances give a combined resistance of 4 Ω. Total circuit resistance = 4 + 2 = 6 Ω.
P.d. across the 2 Ω resistance = 2/6 x 12 = 4 V.

47. **(A)** With K opened, total circuit resistance = L_1 + 3 = 1.5 + 3 = 4.5 Ω and current = 12/4.5, which is less than 3 A.
With K closed L_1 and L_2 have a combined resistance of 0.75 Ω, giving a total circuit resistance of 0.75 + 3, or 3.75 Ω. The circuit current is then 12/3.75. which is greater than 3 A.

48. **(B)** The same current passing through A_2 must pass through A_3, but it is split into two at the junction of the parallel combination. II is incorrect because the resistances are not said to be equal. However, the reading of A_1 is less than that of A_2.

49. **(C)** The supply source and the accumulator are in series, the positive pole of one being connected to the positive pole of the other. This gives a net emf of $E_s - E$. The total circuit resistance is $r_s + r$. hence $I = (E_s - E)/(r_s + r)$. Note that E_s must be greater than E in order to charge the accumulator.

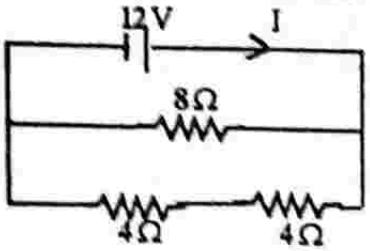
which rules out option (D).

50. **(C)** The equivalent resistance R for the parallel circuit is given by

$$\frac{1}{R} = \frac{1}{12} + \frac{1}{6} + \frac{1}{4} = \frac{6}{12} \text{ or } R = 2\ \Omega$$

P.d. across the combination = $IR = 10(2) = 20$ V
Current in the 6 Ω resistor = 20/6 = 3.3 A

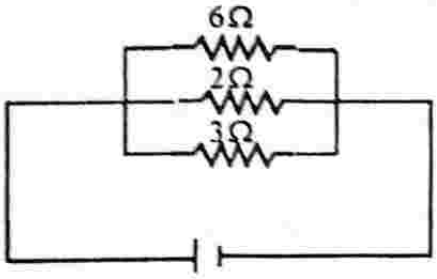
51. **(B)** The circuit can be redrawn as shown below:



The two 4 Ω resistances in series add up to 8 Ω, which, in parallel with the 8 Ω resistance, gives 4 Ω for the effective circuit resistance.
$I = 12/4 = 3$A.

52. **(B)** The sum of currents in R_1 and R_2 must be equal to the current in R_3. Hence current in $R_1 = 5 - 3 = 2$ A. Since the current in R_1 is less than the current in R_2 resistance R_1 must be greater than R_2.
P.d across R_1 = p.d. across R_2, neither of which is necessarily equal to the p.d across R_3.

53. **(A)** The circuit is equivalent to :



Clearly, all the resistances are in parallel and the effective resistance R is given by

$$\frac{1}{R} = \frac{1}{6} + \frac{1}{2} + \frac{1}{3} = \frac{6}{6} \text{ or } R = 1\ \Omega$$

54. **(D)** The 6 Ω and 12 Ω resistances have a combined resistance of $(6 \times 12)/(6 + 12) = 4\ \Omega$. This is in series with the 3 Ω resistance. Since the p.d across the 3 Ω is 6 V, the current flowing is 6/3, or 2 A. The p.d across the 4 Ω resistance (i.e between D and C) is thus 2×4, or 8 V.

55. **(C)** Since the cells are connected in opposite directions (i.e. the positive pole of one to the positive pole of the other), the net emf is $4 - 3 = 1$ V. Total circuit resistance is $8 + 0.5 + r = 8.5 + r$. Applying *Ohm's law* to the circuit gives: net emf = $I(8.5 + r)$, or $1 = 0.1(8.5 + r)$.
Hence $10 = 8.5 + r$, or $r = 1.5\ \Omega$

56. **(D)** As there is no current in the cell at the balance point it does not matter if the internal resistance is appreciable. Note that the proportionality between p.d. and the length of the wire is true only if the wire has a uniform diameter.
Thus $V = IR = I(\rho L/A) = (I\rho/A)L$.
The quantities I, ρ, and A in parenthesis must all remain constant.

57. **(A)** Since there is no current through G,
$3/60 = X/40$ (the balance point is 40 cm from the right end). Hence $X = 2\ \Omega$

58. **(B)** $45/30 = 15/R$, *or* $R = 10\ \Omega$

59. **(A)** When there is no current in G, the p.d. between P and Q is zero.

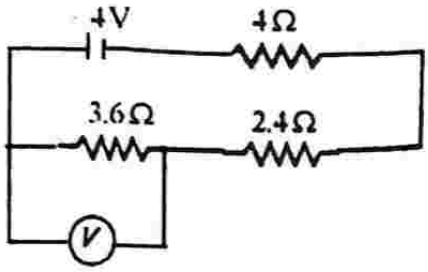
60. **(C)** Since the resistance wire is uniform, the p.d. (V) is directly proportional to the length (L) of the wire.
For CE: $L_1 = 0.4$ m and $V_1 = 3.0$ V
For AD: $L_2 = 0.6$ m
$V_2/V_1 = L_2/L_1 = 0.6/0.4 = 1.5$
Hence $V_2 = 1.5\,V_1 = 1.5(3.0) = 4.5$ V

61. **(C)** $1.6/40 = 2.4/l$ where l is the balance point for the cell of emf 2.4 V. Hence $l = 60$ cm.

62. **(D)** The equivalent resistance for the two X-Ω resistances in parallel is $X/2$. When G indicates zero:

$$\frac{4}{40} = \frac{X/2}{60} \quad \text{or } X = 12\ \Omega$$

63. **(A)** Resistance is directly proportional to the length of wire. Hence the resistance of AP is $60/100 \times 6\ \Omega$ or 3.6 Ω and that of PB is 2.4 Ω. The circuit can now be re-drawn as shown below



Since the 4 Ω, 3.6 Ω and 2.4 Ω resistances (or a total of 10 Ω) are all in series with the cell, p.d. across the 3.6 Ω resistance is $3.6/10 \times 4$ V, or 1.44 V.

64. **(B)** If X is the unknown resistance, then
$6/75 = X/25$, or $X = 2\ \Omega$.

65. **(C)** Power delivered to the lamp = IV = (1)(220)/1000 = 0.22 kW

Energy consumed = power x time = 0.22 x 50 = 11 kWh. Cost of energy = ₦1.20 x 11 = ₦13.20

66. **(D)** Total power delivered to the house = (3 x 100) W + (5 x 60) W + (5 x 40) W = 800 W
No of hours for which the lights are turned on in 30 days = 30 x 5 = 150.
Energy consumed = (800 x 150)/1000 kWh = 120 kWh,
Cost of energy = ₦1.20 x 120 = ₦144.00

67. **(C)** Power delivered to head lamp = V^2/R = 40 W
$R = V^2/40$ = (12 x 12)/40 = 3.6 Ω

68. **(C)** Power drawn by coil = I^2R = $(10)^2(5)$ = 500 W = 500 Js^{-1}. Heat generated in 1 minute = 500 x 60 = 30,000 J This must be equal to mL, where m is the mass of liquid evaporated and L is the specific latent heat of vaporization. Thus L = 30,000/500 = 60 Jg^{-1}.

69. **(B)** Power = V^2/R = 1100.
Hence $R = V^2/1100 = (220)^2/1100$ = 44 Ω
I = power/voltage = 1100/220 = 5 A.

70. **(D)** Power drawn by the coil = IV = (6)(200) = 1200 W, or 1200 Js^{-1}. Heat needed to raise water temperature = $mc\theta$ = (3)(4200)(50) = 6.3 x 10^5 J.
Time required for heating = 6.3 x 10^5/1200 = 525 s

71. **(A)** If V is the p.d. across the combination, power dissipation in the 2 Ω resistor = $V^2/2$ = 50 or V^2 = 100,
Power dissipation in the 5 Ω resistor = $V^2/5$ = 100/5 = 20 W

72. **(D)** Power delivered to kettle = heat energy/time = (3 x 10^5)/(2.5 x 60) = 2000 W
V^2/R = 500, or $R = V^2/2000 = (200)^2/2000$ = 20 Ω.

73. **(C)** Power drawn by the resistor = IV = (2)(12) = 24 W = 24 Js^{-1}. Energy dissipated = power x time = 24 x 5 x 60 = 7,200 J

74. **(A)** Heat generated in time t by a coil of resistance R = I^2Rt. If this heat is used in raising the temperature of a mass m of liquid by θ, then $I^2Rt = mc\theta$, where c is the specific heat capacity. Hence $\theta = (Rt/mc)I^2$. This is a linear relationship between θ and I^2, with the straight line passing through the origin.

75. **(B)** The two 6 Ω resistors in parallel have a combined resistance of 3 Ω, which in series with the 6 Ω resistor gives a total circuit resistance of 9 Ω.
Current drawn from cell, I = 18/9 = 2 A, and power = IV = (2)(18) = 36 W

76. **(B)** Heat supplied to the water in 2 minutes = power x time = 1,000 x 2 x 60 = 12 x 10^4 J. If the temperature rise is θ, then $mc\theta$ = 12 x 10^4, or θ = 12 x 10^4/(2 x 4000) = 15°C Final water temperature = 30 + 15 = 45°C

77. **(D)** Heat used to melt 50 g of ice = mL_f = (50)(336) J
Power drawn by coil = energy/time = 50 x 336/35 = 480 W. Hence I^2R = 480, or I^2 = 480/30 = 16, I = 4 A

78. **(C)** Heat delivered by coil is directly proportional to the square of the electric current. Doubling the current will therefore produce four times as much heat, and only *one-quarter* of the original time is now required to boil the water, i.e. 1/4 x 10 = 2.5 min.

79. **(A)** Power delivered to coil = $V^2/R = (220)^2/(110)$ = 440 W or 440 Js^{-1}. The time it takes to dissipate 121,000 J is 121,000/440 = 275 s

80. **(D)** Total power drawn from the mains = 3 x 60 = 180 W.
Current = power/voltage = 180/240 = 0.75 A

81. **(B)** Current = power/voltage = 1200/240 = 5 A. This is the maximum current which can be drawn by the iron, and a fuse of the same rating must be used.

82. **(D)** Current = power/voltage
For A, current = 1100/220 = 5 A
For B, current = 440/110 = 4 A
For C, current = 100/200 = 0.5 A
For D, current = 40/6 = 6.7 A

83. **(A)** Energy stored in capacitor = 1/2 CV^2 = 1/2 (5760 x 10^{-6}) V^2. The storage battery can deliver 60 A for 1 hr at a p.d. of 12 V. Energy stored in the battery is thus IVt = 60 x 12 x 3600
Hence 1/2 x 5760 x 10^{-6} V^2 = 60 x 12 x 3600

$$V^2 = \frac{60 \times 12 \times 3600}{2880 \times 10^{-6}} = 9 \times 10^8$$

V = 3 x 10^4 V = 30 kV

84. **(B)** Effective resistance of the two 20 Ω resistors in parallel is R = 10 Ω.
Heat generated = I^2Rt = (4)(10)(10 x 60) = 24,000 J = 24 kJ

Revision Check-list

Under this chapter, the candidate should be able to

- define the terms *electric current*, *potential difference*, *electromotive force* and *electrical resistance*.
- relate electric current to *charge flow*
- relate electrical resistance to the *resistivity* and *geometry* of a conductor.
- explain how resistance varies with *temperature*.
- state and apply *Ohm's law* to simple circuits.
- explain the source of *internal resistance* of a cell.
- determine the equivalent resistance for a number of resistors connected in series or in parallel.
- solve simple problems on *electrical energy* and *power*.
- describe experiments to determine
  (a) the resistance of a given piece of wire using a metre bridge.
  (b) the emf of a cell using a potentiometer.

17 Magnetism, Electromagnetism

17.1 Magnets

- A magnet is a material, often in the shape of a bar, which attracts pieces of iron or steel.
- When suspended or pivoted freely, a magnet always comes to rest close to the geographical *north-south* direction.
- The end which points to the north is called the north - seeking (N) pole while the end pointing to the south is the south - seeking (S) pole.
- The force with which a magnet attracts pieces of iron is concentrated at the two poles, i.e. it is stronger at the poles than at the main body of the magnet.
- The N-pole of a magnet repels the N-pole but attracts the S - pole of another magnet, i.e. *like poles repel, unlike poles attract.*

17.2 Magnetization

- A piece of steel can be made into a magnet *electrically or by stroking.*
- In the stroking method one pole of a magnet is used to stroke the steel bar several times in the same direction. The end from which the stroking action is commenced has the same polarity as the stroking pole (Fig.17.1).
- In the electrical method the steel bar is put into a solenoid to which direct electric current is applied for a few minutes. After switching off the current, the steel bar is found to behave as a magnet. If the current in the solenoid is flowing clockwise as seen from one of its ends, that end is a south pole (Fig. 17.2).
- Soft iron is more easily magnetized than steel, but it loses its magnetism more readily.

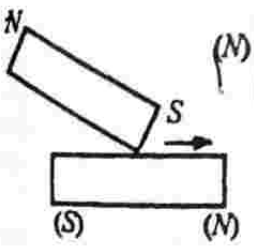


Fig. 17.1

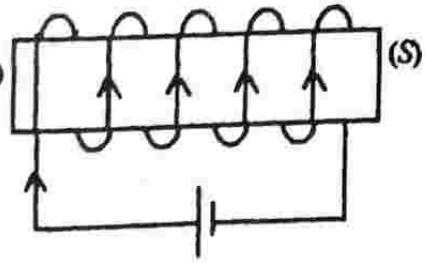


Fig. 17.2

- Soft iron is therefore used for making ***temporary magnets*** (electromagnets) used in electric bells, relays, etc. while steel is used for making ***permanent magnets.***
- Some alloys containing iron, nickel, cobalt and aluminium are used to make magnets more powerful than steel.
- ***Induced magnetism:*** an unmagnetized piece of iron which is brought near the pole of a permanent magnet is found to be magnetized. The pole *induces* an opposite pole on the iron at the end nearest to the magnet. The iron loses its magnetism if the magnet is removed.

17.3 Demagnetization

- A magnet can be made to lose its magnetism by
  (i) placing the magnet in the *E - W direction in a solenoid, passing an alternating current* through the solenoid, and then slowly withdrawing the bar from the solenoid to a long distance;
  (ii) *heating* the magnet to redness and allowing it to cool while lying in the E - W direction; and
  (iii) placing the magnet in the E - W direction and *hammering* hard on it.

17.4 Magnetic Field

- The ***magnetic field*** of a magnet is the region of space around the magnet where its magnetic effect is felt.
- The ***magnetic field strength*** or ***magnetic flux*** at a point is a measure of the force on a N - pole of a magnet placed at that point.
- A ***magnetic line of force*** at a point is the path which an imaginary free N -pole will move if placed at that point.
- Magnetic lines of force:
  (i) start from the N -pole and end at the S - pole (Fig.17.3); and
  (ii) are closest together where the magnetic field is strongest.
- The magnetic field pattern near a magnet can be plotted by sprinkling iron filings on a paper placed on the magnet or by using a plotting compass.
- When two magnets are placed with like poles facing each other, the point where the magnetic fields completely neutralize each other is the ***neutral point*** (Fig. 17.4).

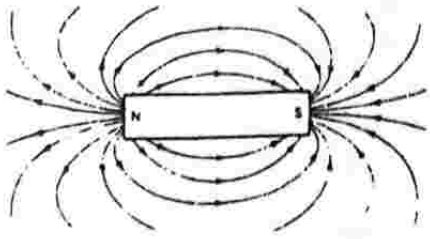


Fig. 17.3

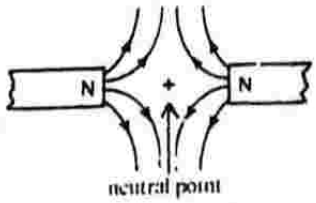


Fig. 17.4

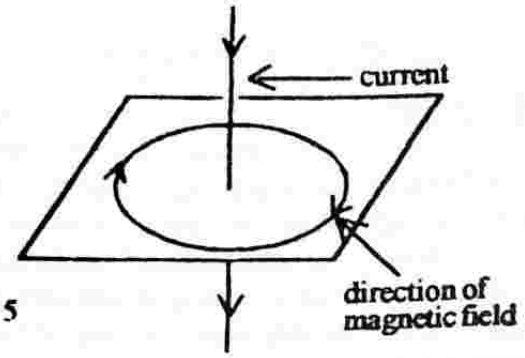


Fig. 17.5

17.5 Magnetic Field of a Current - Carrying Conductor

- A wire (conductor) carrying an electric current has a magnetic field around it, i.e. it behaves like a magnet (Fig. 17.5).
- A compass needle is deflected when placed near a current - carrying conductor. The sense of the deflection is reversed if the current direction is reversed.
- For a straight conductor the direction of the magnetic field is given by ***Maxwell's right hand screw rule*** or the ***clenched fist rule.***
  (i) ***Maxwell's right hand screw rule:*** *If a right handed screw is turned such that its point travels along the direction of the current, the direction of rotation of the screw is the direction of the magnetic field.*
  (ii) ***Clched fist rule:*** *If the wire is grasped with the right hand such that the thumb points in the direction of the current, the direction of the curled fingers is the direction of the magnetic field.*
- For a ***circular coil*** carrying a current, the face of the coil at which the current is seen to flow clockwise is a S-pole while the other face is the N-pole of the magnetic field.
- For a ***solenoid*** (i.e. a long cylindrical coil of insulated wire) carrying a current, the direction of the field is determined using any of the above rules.

17.6 Earth's Magnetic Field

- The earth behaves like a giant magnet.
- The ***magnetic meridian*** is the vertical plane through the earth which contains the magnetic N - S axis. It does not coincide exactly with the earth's geographic meridian.
- ***Angle of declination*** is the angle between the magnetic and the geographic meridians.
- A freely suspended bar magnet does not lie exactly horizontally, but rather with the north pole pointing downwards.
- ***Angle of dip*** is the angle which the axis of the magnet makes with the horizontal.

17.7 Force on Current - Carrying Conductor

- A current - carrying conductor placed in a magnetic field experiences a force.
- The force is directly proportional to
  (i) the magnetic field strength,
  (ii) the current in the conductor, and
  (iii) the length of the conductor.
- The force is largest when the direction of current is perpendicular to the magnetic field, and it is zero when the current flows in the direction of the magnetic field.
- The direction of the force can be determined using ***Fleming's left hand rule:***
  If the thumb, forefinger and the middle finger of the left hand are held mutually at right angles with the forefinger pointing in the direction of the magnetic field and the middle finger in the direction of current, the thumb will point in the direction of force.
- Using this rule, the direction of the force on the conductor in Fig. 17.6 (a) is into the paper, while that of Fig. 17.1 (b) is out of the paper.

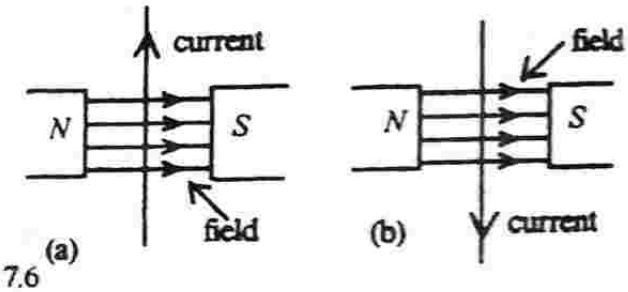


Fig. 17.6

17.8 Two Parallel Current-Carrying Conductors

- A magnetic field is set up around each of two parallel conductors which carry electric currents. The interaction of the fields results in a mutual force of attraction or repulsion between the conductors.
- The magnitude of the force is
  (i) directly proportional to the product of the currents in the conductors and to the length of the conductors, and
  (ii) inversely proportional to the distance between them.
- The force is attractive if the two currents are in the same direction, but repulsive when flowing in opposite directions (Fig. 17.7).

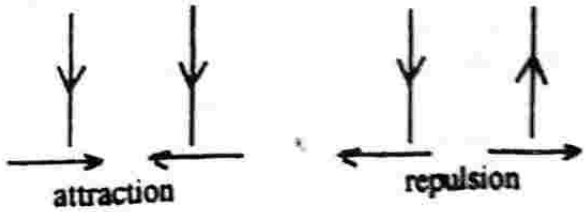


Fig. 17.7

17.9 Charged Particle Moving in a Magnetic Field

- The current flowing in a conductor is the sum total of the motions of individual charges
- Therefore the force on a current-carrying conductor is the sum total of the forces on individual charges.
- The force F on a charge q moving with velcity v in a magnetic field of strength B is

$$\mathbf{F} = q\mathbf{v}\mathbf{B}\sin\theta \qquad (17.1)$$

where θ is the angle between v and B.

- The direction of the force is obtained using Fleming's left hand rule with the middle finger pointing in the direction of a moving positive charge, but in the opposite direction to a moving negative charge.
- This force causes a charged particle initailly moving in a perpendicular direction to a magnetic field to go round in a circular or spiral path.

17.10 The Electric Motor

- An *electric motor* converts electrical energy (electric current) into mechanical energy (rotational motion).
- It consists of a rectangular coil of wire which can rotate freely between the poles of a permanent magnet (Fig. 17.8).

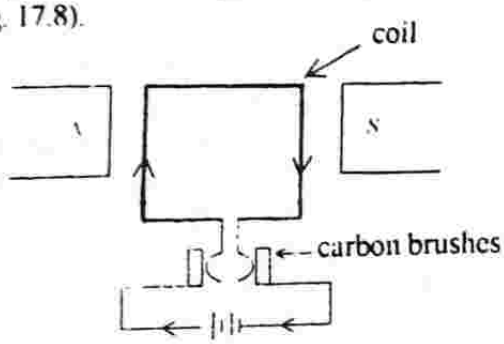


Fig. 17.8

- Electric current is supplied to the coil via a copper split-ring commutator and two carbon brushes.
- When current flows through the coil, equal and opposite forces act on the two sides of the coil, producing a torque which rotates the coil.
- As the plane of the coil passes through the vertical position, the direction of the force in each arm of the coil is reversed
- The commutator also reverses the direction of current at this instant, thus ensuring that the coil keeps rotating in the same direction.

17.11 The Electromagnet

- An *electromagnet* is made by winding wire coils in opposite directions around the two arms of a U-shape soft iron bar (Fig. 17.9).
- When current flows through the wire the ends of the soft iron become poles of a magnet: one a N-pole, and the other a S-pole

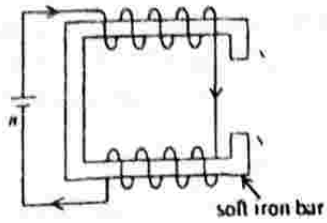


Fig. 17.9

- The magnetism lasts as long as the current flows.
- The strength of the magnet increases if
  (i) the number of turns around each arm of the U-bar is increased.
  (ii) the current is increased, and
  (iii) the poles are made closer.
- Electromagnets are used for lifting magnetic materials, and in appliances such as ***electric bells*** and ***relays***.

17.12 The Moving Coil Galvanometer

- **A galvanometer** is instrument used for measuring small electric currents (in the milliampere range).
- It consists of a rectangular coil wound on a shaft which rotates freely between the poles of a permanent magnet as current is passed through it.
- Two hair springs, one connected to each end of the shaft, produce a resisting torque to the rotation of the coil.
- The coil comes to rest at a position in which the rotation caused by the current exactly balances the resistng torque of the hair springs.
- A pointer is attached to the shaft to measure the angle of rotation of the shaft, which is directly proportional to the current.

17.13 The Ammeter

- An *ammeter* is an instrument used to measure large electric currents, of the order of amperes.
- It is connected *in series* with the part of the circuit where the current is to be measured.
- It must have very low resistance so that it does not appreciably affect the magnitude of the current flowing.
- To convert a galvanometer into an ammeter, a *low resistance* conductor, known as a ***shunt***, is connected *in parallel* to the galvanometer.
- A very small (known) fraction of the current thus passes through the galvanometer while the greater part is carrried by the shunt.

17.14 The Voltmeter

- The *voltmeter* is used to measure the potential difference across a circuit element.
- It is connected in parallel with the element across which the p.d is to be measured.
- It must have very high resistance so that it draws very little current from the circuit

- To measure p.d. of the order of volts, a galvanometer can be converted into a voltmeter by connecting the galvanometer in series with a resistor of *high resistance*, known as a *multiplier*.
- Only a small (known) fraction of the p.d. to be measured is applied across the galvanometer while a large proportion is applied across the resistor.

True or False - Type Questions

Answer *True* (T) or *False* (F) to the following questions:

1. An unmagnetized steel bar S can be distinguished from a bar magnet M in that
   a. M is attracted to another magnet while S is not.
   b. one end of M will be repelled by another magnet while both ends of S will be attracted.
   c. M will attract iron filings while S will not.
   d. when freely suspended, S will settle approxmately in the North - South direction while M will settle in any direction.
   e. a compass needle moved around S will always point in the same direction while its direction will change as it is moved around M.

2. Magnetic flux lines around a bar magnet
   a. start on the S-pole and end on the N-pole.
   b. start on the N-pole and end on the S-pole.
   c. are closer together around the poles where the magnetic field is stronger.
   d. are crowded together around a neutral point.
   e. can readily pass through a non - magnetic substance placed close to the magnet.
   f. indicate the direction along which a compass needle will settle when brought close to the magnet.
   g. are perpendicular to the direction of the magnetic field at any point.
   h. are crowded together around a small piece of soft iron placed close to the magnet.

3. a. The combined strength of a group of identical tiny magnets is greatest when they are arranged end- to- end with like poles adjacent to each other.
   b. The combined strength of a group of identical tiny magnets is greatest when they are arranged end-to-end with unlike poles adjacent to each other.
   c. A steel needle is attracted to a bar magnet because the needle is itself a magnet when placed close to the bar magnet.
   d. If a magnetized iron bar is broken into pieces, each of the fragments will lose its magnetism.
   e. A magnetized steel needle will gradually lose its magnetism if stored for a long time.
   f. Every magnet is made up of millions of microscopic magnets which are aligned along the same direction.
   g. Every magnetized material gradually loses its magnetism as it is heated, while however, still retaining a little magnetism close to the melting point.
   h. A paramagnetic substance will tend to align itself with its longest axis parallel to magnetic flux lines when placed in a magnetic field.

4. Magnetic fields
   a. are regions in which a magnetic force is experienced
   b. are scalar quantities.
   c. are zero at neutral points.
   d. are caused by moving electric charges.
   e. are of uniform strength around a bar magnet
   f. indicate the direction along which a magnetic N-pole will move if it were free.

5. Regarding the earth's magnetic field:
   a. The angle of dip is the angle which a freely suspended magnet makes with the geographic N-pole.
   b. The magnetic dip is 90° at every point on the magnetic meridian.
   c. The magnetic equator is a line connecting points of zero dip on the earth's surface.
   d. The earth's magnetic N-pole lies in the northern hemisphere.
   e. The earth's magnetic field is entirely horizontal on the magnetic equator.
   f. The earth's magnetic field is entirely vertical on the magnetic meridian.
   g. The angle of inclination is the angle which the earth's magnetic field makes with the horizontal.
   h. The magnetic declination is the angle by which a compass needle deviates from the geographic N-pole.
   i. The declination may also be defined as the angle which a freely suspended magnetized needle makes with the magnetic meridian.
   j. The declination is zero at all points on the earth's surface where a freely suspended magnetized needle points to the geographic N-pole.

6. a. An electric current always has a magnetic field associated with it.
   b. The magnetic flux lines around a straight current - carrying conductor are parallel to the conductor.
   c. Two parallel wires carrying equal currents in opposite directions are attracted to each other.
   d. When placed in a magnetic field, a current-carry-

ing conductor experiences a force due to the interaction between the magnetic field of the current and the external magnetic field.

e. The force between two parallel current-carrying wires is due to the interaction between their electric fields.

f. A magnetic field exists around a current-carrying conductor because the conductor becomes magnetized when a current passes through it.

g. A stream of fast-moving electrons has a magnetic field associated with their motion.

7. The intensity of the magnetic field due to a current-carrying coil depends on
   a. the number of turns in the coil.
   b. the diameter of the wire used for the windings.
   c. the diameter of the coil.
   d. the distance from the coil.
   e. the magnitude of the current in the windings.
   f. the material used for the windings.

8. When a plane rectangular current-carrying coil is placed in a uniform magnetic field
   a. the forces on the two parallel sides are equal and opposite.
   b. the forces produce a resultant translational motion on the coil.
   c. the torque is maximum when the plane of the coil is parallel to the direction of the field.
   d. the torque is zero when the plane of the coil is perpendicular to the direction of the field.
   e. the magnitude of the torque depends on the area of the rectangular coil.

9. A moving coil milliammeter
   a. is used to measure direct currents only.
   b. works on the principle of electromagnetic induction.
   c. has a linear scale.
   d. can be used to measure large currents by connecting a small resistance in parallel with it.
   e. can be converted to a voltmeter by connecting a small resistance in series with it.

Answers to True or False - Type Questions

1. a (F) Both M and S will be attracted by another magnet.
   b (T) *Repulsion* is the true test of magnetism. A pole will always repel the like pole of another magnet.
   c (T) An unmagnetized steel bar cannot attract iron filings.
   d (F) It is the magnet M which will settle along the earth's magnetic N-S axis.
   e (T) Around S, the compass needle will always point towards N - pole. In the case of the bar magnet M, however, the compass needle will point in the direction of M's magnetic field which varies with position around the magnet.

2. a (F) See (b) below
   b (T) Magnetic flux lines, which are also called magnetic lines of force, emerge always from the N-pole and enter into the S - pole.
   c (T) The closeness of the flux lines are directly indicative of the strength of the magnetic field.
   d (F) Flux lines are completely absent around a neutral point.
   e (F) Magnetic flux lines can pass through magnetic materials but not through non-magnetic materials.
   f (T) The compass needle always points in the direction of the magnetic field.
   g (F) The flux lines are parallel to the magnetic field
   h (T) Flux lines tend to crowd around a magnetic material while they tend to avoid a non - magnetic material. See also (e) above.

3. a (F) Adjacent like poles tend to repel one another resulting in the weakening of the magnets.
   b (T) It should be recalled that this is the way the tiny magnetic domains are arranged in a bar magnet.
   c (T) The needle becomes a magnet by induction.
   d (F) Each fragment is itself a magnet containing a N-pole and a S-pole.
   e (T) This is because the tiny magnetic domains gradually become disoriented.
   f (T) The microscopic magnets are also called *magnetic domains*.
   g (F) A magnetized material loses its magnetism as the temperature increases. However, each material completely loses its magnetism at a certain temperature, called the *Curie point*, which lies well below the melting point.
   h (T) A *diamagnetic* substance, on the other hand, tends to align itself with its shortest axis parallel to the flux lines. Ferromagnetic substances are also paramagnetic while diamagnetic materials are generally non- magnetic.

4. a (T)
   b (F) Magnetic fields are vector quantities, possessing both magnitude and direction.
   c (T) The neutral point is the point at which opposing magnetic fields neutralize each other.
   d (T) All magnetic fields can be traced to moving electric charges.
   e (F) The strength varies around a bar magnet, and it is much higher around the poles.
   f (T)

5 a **(F)** The angle of dip is the angle which a freely suspended magnet makes with the *horizontal*.
b **(F)** The magnetic dip is 90° only at the poles.
c **(T)** The earth's field is horizontal (i.e. the angle of dip is *zero*) at every point on the magnetic equator.
d **(F)** The earth's magnetic N-pole lies in the southern hemisphere while the S-pole lies in the northern hemisphere.
e **(T)** See (c) above.
f **(F)** The earth's magnetic field is entirely vertical only at the poles.
g **(T)** The angle of dip is also called the *angle of inclination*.
h **(T)** The compass needle lies in the magnetic meridian while the geographic N-pole lies in the geographic meridian.
i **(F)** A freely suspended magnetized needle lies in the magnetic meridian, i.e it makes an angle of zero with the magnetic meridian.
j **(T)** The geographic and magnetic meridians coincide at all such points.

6 a **(T)** Any flow of charges has a magnetic field associated with it. Electric current is a flow of free electrons in a metallic conductor.
b **(F)** Magnetic flux lines form a circular path around the conductor.
c **(F)** Currents in *opposite* directions give rise to a force of repulsion between the conductors
d **(T)** This force, as well as the force between two current-carrying conductors, is due to the interaction between their *magnetic fields*
e **(F)** See (d) above
f **(F)** See (a) above
g **(T)** See (a) above

7. a **(T)** The strength of the magnetic field increases as the number of turns increases.
b **(F)**
c **(T)** The intensity of the magnetic field is greater inside a small - diameter coil than inside a large - diameter one, for a given current.
d **(T)** Magnetic field intensity generally decreases with increasing distance from the source.
e **(T)** The magnetic field intensity increases with increasing current in the windings.
f **(F)**

8. a **(T)** Note that the currents are in opposite directions.
b **(F)** Rotational motion, and not translational motion, is produced.
c **(T)**
d **(T)** The torque *decreases* as the angle between the plane of the coil and the magnetic field *increases*.
e **(T)** The magnitude of the torque *increases* with the area of the coil, as well as the strength of the magnetic field, the current, and the number of turns in the coil.

9. a **(T)**
b **(F)** It works on the principle that a carrying - current coil in a magnetic field experiences a torque.
c **(T)** The torque is directly proportional to the current.
d **(T)** This is the standard procedure for converting a moving coil milliammeter into an ammeter.
e **(F)** *A large resistance* is connected in series with the milliammeter in order to convert it into a voltmeter

SSCE/JME - Type Objective Questions

1 A magnet is similar to a bi-polar charged system in the following respects:-
I. It has two opposite poles - the N and S poles.
II. The earth's magnetic N - pole is close to the geographic S - pole and the earth's magnetic S- pole is close to the geographic N-pole.
III The force of attraction or repulsion between opposite or like poles obeys a law identical in form to Coulomb's law for electric charges.
Which of the above statements is (are) true?
A. I only **B.** II only
C. I and III only **D.** I, II and III

2 Which of the following methods **cannot** be used to convert a steel bar into magnet?
I Passing of an electric current through a solenoid
II Repeated stroking of the steel bar with a magnet
III. Heating of the steel bar
IV. Hammering the steel bar in the earth's magnetic field
A. I and II only **B.** III and IV only
C. I, II and III only **D.** I, II and IV only

3.
The diagram shows the field pattern around the poles of two magnets brought close to each other. The poles are
A. N-N poles **B.** S-S poles
C. N-S poles **D.** S-N poles

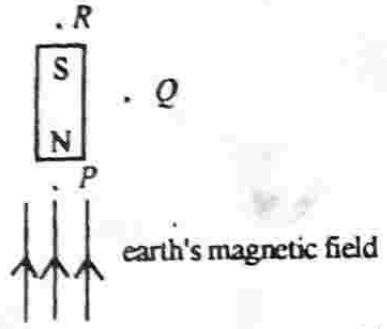
4. Soft iron is preferred to steel in electromagnets because
I. soft iron is more readily magnetized than steel
II. soft iron retains its magnetism more than steel

III. soft iron is more readily demagnetized than steel
Which of the above statements is (are) true?
A. I only B. I and II only
C. I and III only D. I, II and III.

5. The armature of an electric bell is made of soft iron because
I. soft iron can made into a permanent magnet
II. soft iron loses its magnetism readily
III. soft iron retains its magnetism for a long time
Which of the above statements is (are) correct?
A. I only B. II only
C. III only D. II and III only.

6. Which of the following methods will effectively demagnetize a bar magnet?
I. Passing an electric current through the magnet
II. Bringing its N-pole in contact with the N-pole of a strong magnet
III. Heating the magnet
A. I only B. III only
C. I and III only D. I, II and III

7.



A short bar magnet is placed in the earth's magnetic field as shown in the above diagram. Where is (are) the possible positions of the neutral point?
A. *P* only B. *R* only
C. *Q* only D. *P* and *R* only

8. Which of the following statements about magnetism is true?
A. A freely suspended bar magnet comes to rest in the geographic north-south direction.
B. Like poles attract.
C. Iron filings will concentrate mainly round the ends of a bar magnet.
D. Lodestone is a non-magnetic material.

9. Which of the following are magnetic materials?
A. Copper, steel and iron B. Iron, lead and brass
C. Steel, glass and lead D. Nickel, steel and iron

10. The angle which the earth's magnetic field makes with the horizontal is called the
A. magnetic declination B. magnetic meridian
C. angle of dip D. angle of deviation

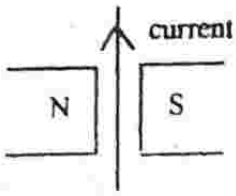
11. At a location on earth where the declination is 15°E, a compass needle indicates the direction N50°E. The true geographic bearing is
A. N65°E B. N50°E C. N35°E D. N15°E

12. The magnetic field strength at a point close to, and lying along the axis of a solenoid, will be greatest if the core of the solenoid is made of
A. brass B. iron C. copper D. steel

13. The angles which a suspended magnetic needle will make with the horizontal at the earth's magnetic poles and at a point on the magnetic equator are respectively
A. 90° and 0° B. 0° and 90°
C. 0° and 0° D. 90° and 90°

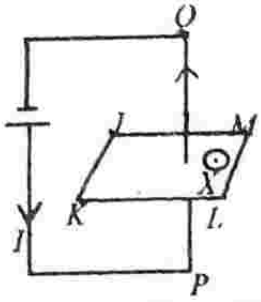
14. The angle between the geographic and the magnetic meridians at a point on the earth's surface is called the
A. angle of inclination B. angle of dip
C. angle of declination D. longitude of the point

15.



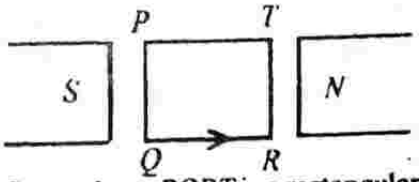
The diagram shows a current-carrying copper wire placed between the two poles of a horse - shoe magnet The wire will tend to move
A. out of the paper B. into the paper
C. towards the N-pole D. towards the S-pole

16.



The figure shows a straight vertical conductor *PQ* which carries a current *I* in the direction indicated. *X* is a compass mounted on a horizontal cardboard east of the conductor. Neglecting the earth's magnetic field, the compass needle will point
A. northward B. southward
C. eastward D. westward

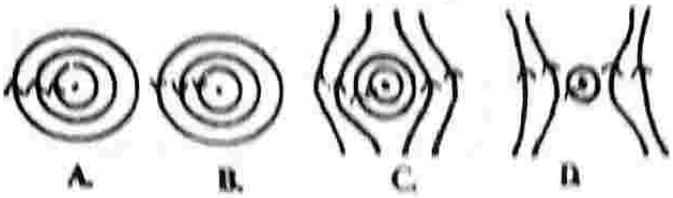
17.



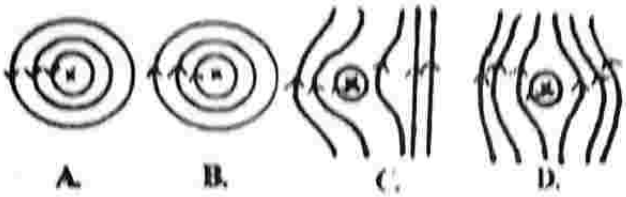
In the figure above *PQRT* is a rectangular coil situated in a magnetic field. If the current flows in the direction indicated, the side *PQ* will tend to move

A. toward the S-pole B. toward the N-pole
C. out of the paper D. into the paper.

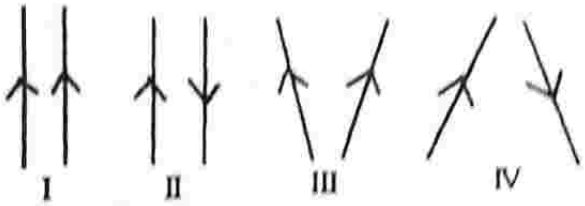
18. Which of the following diagrams correctly illustrates the magnetic field pattern around a straight conductor which carries current out of the plane of the paper if the earth's magnetic field is neglected?



19. The magnetic field around a straight wire X carrying current into the plane of the paper interacts with the horizontal components of the earth's magnetic field. Which of the following diagrams correctly illustrates the resultant magnetic filed pattern in the horizontal plane?



20. Each of the daigrams shown below reprensents two current-carrying wires placed close to each other. In which of the diagrams will the wires tend to repel each other?



A. I and II B. III and IV
C. I and III D. II and IV

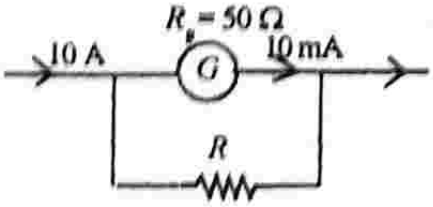
21. A particle of charge 0.5 C moves at a velocity of 2.5 ms^{-1} in a direction perpendicular to a magnetic filed of strength 0.20 T. The magnetic force experienced by the particle is
A. 0.025 N B. 0.050 N
C. 0.250 N D. 0.500 N

22. An electron of charge e moving with velocity v enters into a magnetic field of flux density B. If the electron moves in a direction parallel to the field, the force on the electron is
A. evB B. ev/B C. eB/v D. zero

23. A galvanometer can be converted into an ammeter by connecting
A. a low resistance shunt in parallel with the galvanometer.
B. a low resistance shunt in series with the galvanometer.
C. a high resistance multiplier in parallel with the galvanometer.
D. a high resistance multiplier in series with the galvanometer.

24. Which of the following connections will convert a milliammeter into a voltmeter?
A. a high series resistance
B. a high parallel resistance
C. a low series resistance
D. a low parallel resistance

25.



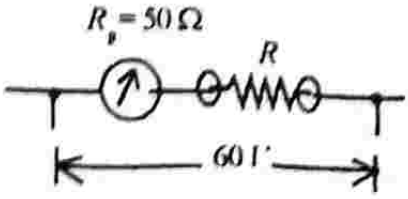
The figure above shows a galvanometer of resistance 50 Ω and full scale deflection 10 mA which is to be converted into an ammeter to measure currents up to 10 A. The value of the shunt resistance R is
A. 0.01 Ω B. 0.05 Ω C. 0.10 Ω D. 0.50 Ω

26. A 0-10 mA galvanometer of resistance 100 Ω is to be converted to a 0 - 1 A ammeter. This can be done by connecting
A. a 9.99 Ω shunt resistor
B. a 9.99 Ω series resistor
C. a 1.0 Ω shunt resistor
D. a 1.0 Ω series resistor

27. A galvanometer of resistance 38 Ω is to be connected with a shunt such that 1/20 of the current in a circuit passes through the galvanometer. The shunt resistance required is
A. 1.9 Ω B. 2.0 Ω C. 36.1 Ω D. 38.0 Ω

28. An milliammeter of resistance 10 Ω has a full scale deflection of 60 mA. The full scale deflection of the meter when a shunt of 0.20 Ω is connected across its terminals is
A. 1.00 A B. 1.06 A C. 3.00 A D. 3.06 A

29.



The above figure shows a series resistance R which is used to convert a 50 Ω galvanometer of full scale deflection of 15 mA into a voltmeter with a full scale deflection of 60 V. The value of R is

A. 950 Ω B. 1,000 Ω C. 3,950 Ω D. 4,000 Ω

30. A milliameter of resistance 100 Ω and full scale deflection of 50 mA is to be converted into a voltmeter with a full scale deflection of 100 V. The resistance required is
A. 0.05 Ω in parallel with the milliammeter
B. 0.05 Ω in series with the milliammeter
C. 1,900 Ω in parallel with the milliammeter
D. 1,900 Ω in series with the milliammeter

31. A moving-coil meter of internal resistance 20 Ω has a full scale deflection of 10 mA. A series resistance of 980 Ω is connected to the galvanometer in order to convert it into a voltmeter. The full scale deflection of the voltmeter is
A. 1 V B. 10 V C. 20 V D. 100 V

32. The operation of a moving-coil galvanometer is based on
A. electromagnetic induction
B. magnetic effect of electric current
C. force on a current-carrying conductor in a magnetic field
D. electrochemical effect.

33. A rectangular coil of wire rotating in magnetic field has its two ends connected to slip rings. Two carbon brushes make light electrical contact with the slip rings. When the brushes are connected to an external circuit with a battery and rheostat, the coil rotates. This is a description of
A. an electric motor B. an a.c. generator
C. an induction coil D. a moving - coil galvanometer

34. To convert an a.c. generator into a d.c. generator, the
A. coil is wound on a soft iron armature
B. slip rings are replaced with split rings
C. number of turns in the coil is increased
D. field magnet is made stronger

35. Which of the following is (are) not part of an a.c. generator?
I. Carbon brushes. II. Commutator
III. Slip rings IV. Field magnet
A. I only B. II only
C. I and III only D. II and IV only

36. An electric motor essentially converts
A. electrical energy into heat energy
B. mechanical energy into electrical energy
C. electrical energy into chemical energy
D. electrical energy into mechanical energy

37. A dynamo converts
A. mechanical energy into electrical energy
B. electrical energy into mechanical energy
C. heat energy into electrical energy
D. electrical energy into heat energy

38. In a simple generator, the main function of a commutator is to
A. change the direction of rotation of the armature
B. provide a uniform magnetic field around the armature
C. change the direction of current in the coil
D. increase the magnetic flux linking the coil.

39. The mouthpiece of a telephone primarily converts sound energy into
A. mechanical energy B. heat energy
C. electrical energy D. chemical energy

40. Which of the following is not a component of an electric bell?
A. Solenoid B. Contact breaker
C. Iron core D. Permanent magnet

41. Which of the following devices converts sound into electrical energy?
A. telephone earpiece B. a microphone
C. a horn D. an electric bell

42. A bar magnet is moved through a coil of wire. On which of the following factors does the induced emf depend?
I. The strength of the magnet
II. The speed of the magnet
III. The number of turns in the coil.
A. I only B. III only
C. II and III only D. I, II and III

43. A bar magnet is placed close to, and lying along the axis of a closed coil. There will be no current in the coil when
A. both the coil and the magnet are held stationary.
B. the coil is moved towards the stationary magnet
C. the coil is moved away from the stationary magnet.
D. the magnet is moved away from the stationary coil.

44. A straight conducting wire carries current into the plane of the paper. The magnetic field due to the current-carrying conductor is

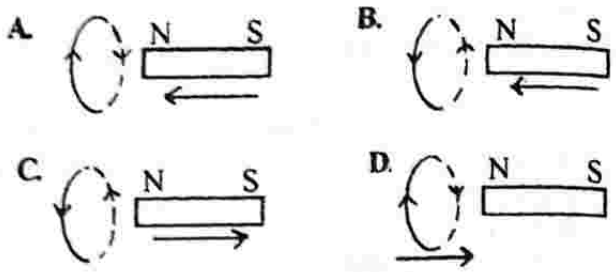
A. parallel to the conductor and directed into the plane of the paper.
B. parallel to the conductor and directed out of the plane of the paper.
C. in the clockwise direction around a circular path enclosing the wire.
D. in the counter - clockwise direction around a circular path enclosing the wire.

45.

The circular coil carries a current in the direction indicated in the diagram. The magnetic field in the space enclosed by the coil is

A. directed out of the plane of the paper
B. directed into the plane of the paper
C. in the plane of the paper, directed from left to right
D. in the plane of the paper, directed from right to left

46. A horizontal bar magnet is being moved relative to a vertical coil placed close to it. Which of the following diagrams correctly illustrates the direction of the induced current in the coil?



47. Which of the following methods can be used to increase the emf produced by a simple dynamo?
I. Increasing the speed of rotation of the coil
II. Using a longer field magnet
III. Increasing the cross-sectional area of the coil wire
IV. Increasing the number of coil windings
A. I and III only B. I and IV only
C. I, III and IV only D. I, II, III and IV

Answer Key

1.	C	9.	D	17.	D	25.	B	33.	A	41.	B
2.	B	10.	C	18.	B	26.	C	34.	B	42.	D
3.	B	11.	A	19.	C	27.	B	35.	B	43.	A
4.	C	12.	B	20.	D	28.	D	36.	D	44.	C
5.	B	13.	A	21.	C	29.	C	37.	A	45.	A
6.	B	14.	C	22.	D	30.	D	38.	C	46.	B
7.	D	15.	B	23.	A	31.	B	39.	C	47.	B
8.	C	16.	A	24.	A	32.	C	40.	D		

Solutions to Objective Questions

1. **(C)** A bipolar charged system is simply any system consisting of two neighbouring, opposite electric charges. Note that (II) is not relevant in this case.

2. **(B)** A steel bar *cannot* be magnetized by heating or hammering.

3. **(B)** They must be *like* poles as the lines of force tend to repel one another. Since the lines of force are also directed to the poles, they must be *south* poles.

4. **(C)** Electromagnets are readily magnetized by switching on the electric current in the windings and readily de-magnetized by switching off the current. Note that unlike soft iron, steel is neither readily magnetized nor de-magnetized.

5. **(B)** The armature forms the core for an electromagnet, which can be readily magnetized or de-magnetized if made of soft iron.

6. **(B)** (II) will weaken the magnet but will not effectively demagnetize it.

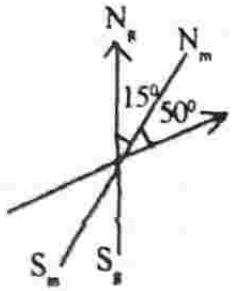
7. **(D)** Neutral points are located where the field of the bar bar magnet is exactly equal and opposite to the earth's field. The lines of force for the bar magnet are directed downwards at P close to the N-pole and at R close to the S- pole.

8. **(C)** Note that a freely suspended bar magnet comes to rest in the *magnetic* (**not** geographic) N - S direction. Lodestone is, of course, a naturally occurring *magnetic* iron ore.

9. **(D)** Copper, lead brass and glass are *non-magnetic*.

10. **(C)** Note that a freely suspended compass needle dips in the direction of the earth's magnetic field.

11. **(A)**



The direction indicated is 50°E of the magnetic meridian (N_m - S_m), which is itself 15°E of the geographic meridian (N_g - S_g) (see diagram). The true bearing (i.e. relative to the geographic meridian) is thus N65°E.

12. **(B)** The magnetic field will be strongest when the core is made of a material which is most easily magnetized. Iron is readily magnetized while steel can be magnetized but with considerable difficulty. Brass and copper cannot be magnetized.

13. **(A)** The *angle* of *dip* is 90° at each of the magnetic poles and 0° on the magnetic equator.

14. **(C)** This is the definition of *magnetic declination*

15. **(B)** This follows from Fleming's left hand rule.

16. **(A)** Using the clenched fist or the right hand screw rule, the direction of the magnetic field at X is parallel to LM, which is also the direction to which a compass needle will point. Since X lies to the east of PQ, LM is the northward direction.

17. **(D)** Fleming's *left hand rule*. It should be noted that the magnetic field is directed leftwards while current flows from P to Q.

18. **(B)** Use the *clenched fist or the right hand screw rule*.

19. **(C)** The pattern indicated in (B) is the magnetic field of the wire alone. When super-imposed on the earth's magnetic field, pattern (C) results.

20. **(D)** Currents in opposite directions result in repulsion while currents in the same direction produce a force of attraction.

21. **(C)** Force, $F = qvB\sin\theta = (0.5)(2.5)(0.20)\sin 90° = 0.250$ N.

22. **(D)** Force, $F = evB\sin\theta$, where $\theta = 0$ since the electron moves parallel to the magnetic field. Hence $F = 0$.

23. **(A)** Consult the revision notes.

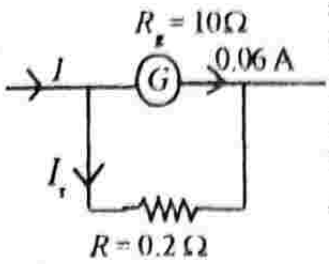
24. **(A)** Consult the revision notes.

25. **(B)** Maximum current which can pass through the galvanometer is 10 mA = 0.01 A. Hence, current through shunt resistance = 10 - 0.01 = 9.99 A.
P.d. across G = p.d. across R
$\Rightarrow (0.01)(50) = 9.99R$, or $R = 0.05\,\Omega$ (approximately).

26. **(C)** A *shunt* resistor is required to convert a galvanometer to an ammeter. Following the diagram of Q.25, the current through the galvanometer is 0.01 A while the current through the shunt resistance is 1 - 0.01, or 0.99 A.
P.d. across the galvanometer = P.d. across the shunt resistance $\Rightarrow (0.01)(100) = (0.99)R$, or $R = 1.0\,\Omega$, approx.

27. **(B)** Current through the galvanometer = $0.05I$, where I = total circuit current. Hence current through the shunt = $0.95I$. P.d. across galvanometer = P.d. across shunt $\Rightarrow (0.05I)(38) = 0.95I(R)$, or $R = 2\,\Omega$.

28. **(D)**



Referring to the above diagram, current I_r passes through the shunt such that $I_r(0.2)(0.06)(10)$, or $I_r = 3$ A. The maximum current which can now be measured with the meter is $I_r + 0.06 = 3.06$ A.

29. **(C)** Since the total current which can pass through the galvanometer is 0.015 A, the total p.d. across the galvanometer and the resistance R is $0.015(50 + R) = 60$ or $R = 3950\,\Omega$

30. **(D)** A *series* resistance R is needed to convert a milliammeter into a voltmeter (see question 29). Total p.d. across the milliammeter and the resistance is $0.05(100+R) = 100$, or $R = 1{,}900\,\Omega$.

31. **(B)** Full scale deflection of voltmeter = total p.d. across the meter and the series resistance $= 0.01\,(20 + 980) = 10$ V.

32. **(C)** See revision notes.

33. **(A)** Note that the essential difference between an electric motor and a generator is that in the *former*, the coil rotates when supplied with electric current while in the *latter*, rotation of the coil produces an electric current.

34. **(B)** See revision notes.

35. **(B)** A *commutator*, made of split rings, is used to convert alternating current into direct current.

36. **(D)** An electric motor, when supplied with electric current (electrical energy) produces a rotation of the coil (mechanical energy).

37. **(A)** In a *dynamo* or *generator*, the coil is rotated (mechanical energy) and this results in the production of electric current (electrical energy).

38. **(C)** Note that the armature always rotates in the same direction.

39. **(C)** The pressure variations from the speaker's sound waves are converted into electric signals at the telephone *mouthpiece*, while the reverse process occurs at the receiver *(earpiece)*.

40. **(D)** *Electric bells* as well as *relays*, which require rapid making and breaking of electrical contacts, are made of electromagnets, not permanent magnets.

41. **(B)** The operation of a microphone is similar in principle to that of a telephone mouthpiece (see Q. 39).

42. **(D)** The magnitude of the induced emf depends on the number of lines of force cutting across the coil per unit time and this varies with all the factors listed.

43. **(A)** An emf (and hence an electric current) is induced whenever there is *relative motion* between the coil and the magnet.

44. **(C)** This follows from the *clenched fist or right hand screw rule*.

45. **(A)** For a circular coil carrying a current, the *clenched fist rule* is also applicable with a slight modification: *If the fingers of the right hand are imagined to curve in the direction of the current, the thumb will point in the direction of the magnetic field.*

46. **(B)** *Lenz's law* states *that the current induced in the coil will be such as to produce a magnetic field which will oppose the change in magnetic flux which induced the current.* If the magnet is moved closer to the coil, the magnetic flux (directed leftwards) linking the coil will increase. The induced current will therefore produce a magnetic field which opposes the increase in magnetic flux, i.e. the field due to the coil must be directed *to the right*. Using the clenched fist rule (see Q. 45), the current has to be in the direction indicated in (B). It should be noted that situation (A) is identical to (D) since the relative motion between the coil and the magnet is the same.

47. **(B)** The emf produced by a dynamo increses with the *strength of the magnetic field* (not the length of the magnet), the *number of coil windings*, the *coil area* (not cross-sectional area of coil wire), and the *speed of rotation* of the coil.

Revision Checklist

Under this chapter the candidate should be able to

- explain the basic properties of *magnets*
- explain how a piece of steel can be made into a magnet or a *electromagnet*.
- explain how a magnet can be *demagnetized*.
- explain the terms *magnetic field, magnetic flux and magnetic lines of force*.
- sketch the magnetic lines of force around two closely-spaced magnetic poles.
- use *Maxwell's right hand screw rule* to locate the direction of the magnetic field around a currrent carrying conductor
- explain the terms *magnetic meridian, angle of declination* and *angle of dip* in connection with the earth's magnetic field.
- state and apply *Fleming's left hand rule* to current-carrying conductors and moving electric charges in a magnetic field
- explain the principles of operation of the *electric motor*, the *moving coil galvanometer*, the *ammeter*, the *voltmeter*, the *electric bell* and the *telephone earpiece*.
- state and apply *Faraday's and Lenz's laws of electromagnetic induction*.
- describe on experiment to show that a magnetic field exists around a current - carrying wire

18 Electrochemical Effects

18.1 Characteristics of Cells

- An ***electric cell*** consists of two different metal electrodes and an electrolyte.
- The electrolyte is a substance which dissociates into positive and negative ions in solution.
- The positive ions are attracted to the negative electrode where they become neutralized by acquiring electrons.
- The negative ions are attracted to the positive electrode where they combine with positive ions from the electrode.
- The flow of these ions generate current flow in the external circuit.
- There are two classes of cells: ***primary*** and ***secondary*** cells.
- In primary cells the chemical process through which electric current is generated is irreversible.
- Secondary cells (also called ***accumulators***) can be recharged after they run down by passing a current into the cell in the reverse direction.
- Examples of primary cells include the simple ***Daniell*** and ***Leclanche cells***, while the ***lead-acid cell*** is a secondary cell.
- The ***electromotive force*** (emf) of a cell is the driving force for the current in a circuit. It is the potential difference between the two electrodes when no current is flowing.

18.2 The Simple Cell

- This is a primary cell with a positive copper electrode and negative zinc electrode in a dilute sulphuric acid (H_2SO_4) electrolyte (Fig. 18.1)

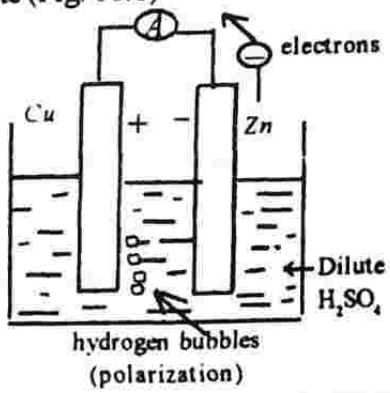


Fig. 18.1

- Sulphuric acid dissociates into positive hydrogen ion (H+) and negative sulphate ion (SO_4^{2-}).
- When a wire is connected to the two electrodes, a stream of electrons flows through the wire from the zinc to the copper electrode. (This is equivalent to a flow of current from copper to zinc).
- The zinc reacts with the acid, forming hydrogen gas bubbles which collect around the copper anode.
- ***Polarization:*** the hydrogen bubbles quickly insulate the copper electrode, thereby increasing the cell's internal resistance and setting up a back emf which eventually stops further chemical action in the cell.
- Polarization is overcome by adding a ***depolarizer*** such as manganese dioxide which oxidizes the hydrogen to form water.
- ***Local action:*** is caused by impurities of metals such as iron, which if present, form tiny local cells at the zinc surface. This results in the formation of hydrogen at the zinc electrode, and the zinc gradually dissolves.
- Local action is reduced by rubbing mercury on the surface of the zinc electrode (i.e. ***amlgamating*** the zinc), thereby shielding the impurities from the electrolyte.

18.3 The Wet Leclanche Cell

- The negative electrode is a zinc rod dipped in the electrolyte, ammonium chloride.
- A carbon rod, serving as the positive electrode and surrounded by manganese dioxide as the depolarizer, is put in a porous pot.
- The porous pot is also dipped into the electrolyte.
- The emf (of 1.5 volts) set up drives electrons from the zinc to the carbon electrode when a wire is connected to the two.
- The disadvantages of this cell are that:
  - (i) the rate of hydrogen production quickly exceeds the rate of its removal by the depolarizer, so the cell cannot be used continuously over a long period, and
  - (ii) it is bulky and inconvenient to carry around without spilling the contents.

18.4 The Dry Leclanche Cell

- In the ***dry cell***, the electrolyte of the wet Leclanche cell is replaced by a powder or jelly consisting of a mixture of starch and ammonium chloride.
- The zinc electrode is made into a can to contain the electrolyte.
- The carbon electrode is surrounded by a mixture of manganese oxide (depolarizer) and powdered carbon.
- The cell, which produces an emf of 1.5 volts, runs down after some time due to local action.
- This is the type of cell (battery) used in torch-lights and transistor radios.

18.5 Daniell Cell

- In the Daniell cell the positive copper electrode is made into a container to hold a copper sulphate solution.

- A porous pot holds the negative zinc electrode and zinc sulphate or dilute sulphuric acid electrolyte.
- The copper sulphate solution is the depolarizer.
- The cell produces an emf of 1.1 V.

18.6 Lead-Acid Accumulator

- This is a secondary cell with a negative electrode of lead, a positive electrode of lead dioxide (PbO_2) and a dilute sulphuric acid (H_2SO_4) electrolyte.
- The relative density of the acid is 1.25, and the emf is about 2.2 V when the cell is fully charged.
- As the cell discharges, the solid becomes more dilute as it reacts with the lead to form lead sulphate.
- When the relative density of the acid drops to about 1.15, the cell is recharged by passing a current through it in the reverse direction, i.e. from the negative to the positive pole.

18.7 The Alkaline Accumulator

- This is a secondary cell with a negative electrode of cadmium or iron, a positive electrode of nickel hydroxide and an electrolyte of potassium hydroxide.
- The alkaline cell develops an emf of only 1.25 V (compared to 2.2 V for the lead acid accumulator).
- It lasts much longer than the lead-acid cell.
- It can be re-charged like the lead-acid cell.

18.8 Solar Cell

- ***Solar cells*** are made of thin wafers of a semiconductor such as silicon.
- When sunlight falls on such a wafer, electrons are able to flow from one region of the semiconductor to another (current flows in the opposite direction).
- They are used in space satellites, radios, pocket calculators, etc.

18.9 Electrolysis

- ***Electrolysis*** is the process of chemical decomposition of a substance through the passage of electricity.
- Compounds which dissociate into positive and negative ions when in solution are called electrolytes, e.g. $CuSO_4 \rightarrow Cu^{2+}$ and SO_4^{2-}.
- A ***voltameter*** is a can containing an electrolyte and two electrodes.
- The positive electrode is called the ***anode*** while the negative electrode is the ***cathode***.
- When electric current is passed into a voltameter, the positive ions (***cations***) are attracted to the cathode and the negative ions (***anions***) to the anode.
- ***Example***: Electrolysis of $CuSO_4$ solution using Cu electrodes:
  - (i) The solution contains Cu^{2+} and SO_4^{2-} ions from $CuSO_4$ and H^+ and OH^- ions from water.
  - (ii) Cu^{2+} and H^+ migrate to the cathode. The Cu^{2+} ions combine with electrons to form neutral Cu atoms, i.e. $Cu^{2+} + 2e^- \rightarrow Cu$.
  - (iii) SO_4^{2-} and OH^- migrate to the anode. However copper atoms go into solution at the anode, releasing electrons, i.e. $Cu \rightarrow Cu^{2+} + 2e^-$.
  - (iv) The overall effect is that copper is lost from the anode and plated on the cathode.
- ***Faraday's First Law of Electrolysis***: *The mass (m) of a substance liberated during electrolysis is directly proportional to the quantity of electric charge (Q) which has passed through the circuit*, i.e. $m \propto Q$. Since $Q = It$, where I is the current and t the time for which it flows.

$$m = zIt \qquad (18.1)$$

where the proportionality constant z is the ***electrochemical equivalent*** of the substance.
- The electrochemical equivalent is the quantity of the substance which is liberated by 1 coulomb of electric charge.
- ***Faraday's second law of electrolysis***: *If the same quantity of charge passes through different electrolytes, the masses of the elements liberated are proportional to their chemical equivalents.*
- ***Faraday's constant*** is the quantity of charge needed to liberate the gram equivalent of an element. Its value is **96,500 coulomb/gm-at.wt.**

18.10 Electroplating

- ***Electroplating*** is the coating, through an electrolytic process, of a metal with a thin layer of a less reactive metal.
- An electroplated layer of zinc, for instance, protects steel against atmospheric corrosion in ***galvanized*** steel.
- The metal to be coated is made the cathode while the protective metal is the anode and the eletrolyte is a suitable compound of the anode material.
- As current is passed into the voltameter, the anode metal goes into solution and is deposited as a thin layer on the cathode.
- Electrolysis is also used in the extraction of metals such as aluminium, copper and sodium from their ores.

18.11 Calibration of an Ammeter

- The ammeter is connected in series with a voltameter (containing suitable electrolyte and electrodes) and a variable resistor.
- Current is passed through the circuit for a known time, t.
- If the mass (m) of the substance deposited is measured, the exact value of current (I) can be calculated from Eq. (18.1).
- By repeating this procedure for different currents, the ammeter is calibrated.

18.12 Discharge through Gases

- Suppose a long glass tube (containing a gas) is fitted with two electrodes, one at each end and the tube has a port through which the gas can be pumped out.
- Under a very high p.d. (of the order of several thousand volts) and a low pressure (a few mm of Hg), the passing of electric current through the gas causes the emission of light from the gas.
- The entire space between the electrodes is filled with a characteristic glow, the colour of which depends on the gas in the tube, e.g. sodium vapour gives yellow light, mercury vapour (bluish white), neon (red), argon (blue), etc.
- Electric dicharge is used to obtain light of different colours and is also used in spectroscopy, an experimental science that deals with the identification of unknown substances.

18.13 The Fluorescent Tube

- A fluorescent lamp consists of a tube containing mercury vapour at low pressure.
- The inside of the tube is coated with a fluorescent material.
- When current is passed through the tube, the mercury vapour emits bluish white and ultraviolet radiation.
- The ultraviolet radiation is absorbed by the fluorescent coating, and visible light is emitted.

True or False - Type Questions

Answer True (T) or *False* (F) to the following questions.

1. a. The emf of a simple cell depends on the tendency of the electrode materials to gain or lose electrons.
   b. A cell works best when the electrode materials are similar.
   c. The emf of a cell is equal to the potential difference between the two electrodes.
   d. The direction of current inside a primary cell is from the negative to the positive electrode.
   e. The emf of a cell increases if a more concentrated electrolyte is used.
   f. In the Leclanche cell, the zinc electrode is gradually consumed as the cell delivers electric current.
   g. In an accumulator, the electrons drift from the positive to the negative pole during re-charging.
   h. When a lead-acid accumulator is re-charged, the specific gravity of the acid increases.
   i. All known cells convert chemical energy into electrical energy.

2. The advantages of the dry cell over the wet Leclanche cell are that
   a. The dry cell has a higher emf than wet cell.
   b. The dry cell has a depolarizer while the wet cell does not.
   c. The dry cell is more compact than the wet cell.
   d. The contents of the dry cell are not easily spilled as those of the wet cell.
   e. The dry cell has a lower internal resistance than the wet cell.
   f. The dry cell can deliver electric current for a much longer period than the wet cell.

3. During electrolysis
   a. the electrolyte is ionised.
   b. electric charges are transported in the electrolyte by free electrons.
   c. electrons are released at the anode and consumed at the cathode.
   d. ions are discharged at the electrodes, forming solid deposits or gas bubbles.
   e. The rate of metal deposition increases with the concentration and quantity of electrolyte.
   f. The mass of metal deposited at the cathode is equal to the mass removed from the anode.
   g. The concentration of the electrolyte decreases rapidly and must be continuously replenished.

4. The following may be deduced from *Faraday's laws of electrolysis*:
   a. The rate of metal deposition is directly proportional to the electric current.
   b. The rate of metal deposition is constant under a specified electric current.
   c. The thickness of electroplating depends on the total charge flow through the electrolyte as well as the time for which it flows.
   d. If the quantity of charge passing through the electrolyte is doubled, the mass of metal deposited is quadrupled.
   e. For a given voltameter, the rate of electroplating depends only on the applied electric current.
   f. If two metals *A* and *B* have the same valence, the ratio of the masses of *A* and *B* deposited within a specified time and under the same electric current is equal to the ratio of the their atomic weights.

Answers to True or False - Type Questions

1. a **(T)** It is this tendency which determines the potential of each electrode, and hence the p.d. between them.
   b **(F)** The electrodes must be *dissimilar* to ensure that a difference of potential is established between them when dipped into the electrolyte.
   c **(T)** It is this potential difference which drives electric current round a closed circuit.
   d **(T)** Current goes from the positive to the negative electrode in the external conductor, and from the negative to the positive electrode in the electrolyte.
   e **(F)** The emf depends only on the nature of electrode materials, not on the concentration of the electrolyte.
   f **(T)** The zinc electrode acquires its negative charge as zinc is dissolved in the electrolyte, i.e. $Zn \rightarrow Zn^{++} + 2e^-$. As the zinc ions go into the solution, the electrons remain on the zinc electrode, thus giving it a negative charge.
   g **(T)** During re-charging, current moves from the negative to the positive electrode, i.e.electrons move in the opposite direction.
   h **(T)** The specific gravity of the acid decreases when the accumulator is discharging and increases as it is re-charged.
   i **(F)** The solar cell converts *light energy* into electricity.

2. a **(F)** The emf depends only on the pole materials, C and Zn, which are the same for both cells. The emf is approximately 1.5 V for both cells.
   b **(F)** Both have manganese dioxide as depolarizers.
   c **(T)** See revision notes.
   d **(T)** See revision notes.
   e **(T)** Being more compact, the electrodes in the dry cell are closer together and the internal resistance is correspondingly lower.
   f **(T)** This is because of the lower internal resistance (see (e) above) and the faster depolarizing action.

3. a **(T)** It is the ions which carry charges through the solution
   b **(F)** See (a) above.
   c **(T)** Current is directed from the cathode to the anode. This is equivalent to a flow of electrons from the anode to the cathode in the external circuit.
   d **(T)** The positive ions combine with electrons to produce metals or hydrogen gas at the cathode, while the negative ions release their electrons to form non-metals or oxygen gas at the anode.
   e **(F)** It depends only on the charge flow, and the type of metal.
   f **(T)** The overall effect in elecrolysis is to remove metal from the anode and plate it on the cathode.
   g **(F)** The concentration of the electrolyte remains unchanged.

4. a **(T)** Rate of metal deposition is $dm/dt = zI$, i.e. $dm/dt \propto I$
   b **(T)** This follows from (a) above.
   c **(F)** It depends only on the total charge flow. By varying the current, the charge flow can be held constant while varying the time.
   d **(F)** Since the mass deposited is directly proportional to the charge, doubling the charge implies that the mass deposited is also *doubled*.
   e **(T)** See (a) and (b) above.
   f **(T)** If M_a and M_b are the masses of metals A and B deposited, then according to *Faraday's second law*

$$\frac{M_a}{M_b} = \frac{A_a/v_a}{A_b/v_b}$$

   where A and v are the atomic weight and valence, respectively. If $v_a = v_b$, then $M_a/M_b = A_a/A_b$.

SSCE/JME - Type Objective Questions

1. Which of the following is not a component of a dry cell?
   A. carbon rod **B.** paste of magnesium dioxide
   C. zinc case **D.** copper rod

2. The type of energy stored by a dry Leclanche cell is
   A. electrical **B.** chemical **C.** nuclear **D.** thermal

3. In a Leclanche cell, the role of granulated carbon mixed with manganese (IV) oxide is to
   I. increase the emf of the cell
   II. prevent local action in the cell
   III. prevent polarization in the cell
   IV. reduce the internal resistance of the cell
   Which of the above is (are) correct?
   A. II only **B.** III only
   C. I and II only **D.** III and IV only

4. In a simple cell, the zinc electrode is amalgamated with mercury in order to prevent
   A. local action **B.** polarization
   C. overheating **D.** corrosion

5. The presence of hydrogen bubbles around the copper plate of a primary cell results in
   I. local action
   II. increase in the cell's internal resistance

III. production of less current by the cell
IV. polarization
Which of the above statements are true?
A. I and II only B. III and IV only
C. II. III and IV only D. I, II and III only.

6. Which of the following cells convert (s) light energy to electrical energy?
I. Leclanche cell II. photocell
III. Daniell cell IV. solar cell
A. I only B. IV only
C. I and III only D. II and IV only

7. A light bulb is connected to a simple voltaic cell. When the circuit is closed the bulb glows brightly for a short while and then becomes dim. This is because
A. hydrogen gas is produced at the cathode.
B. hydrogen bubbles accumulate on the anode
C. copper sulphate is formed in the solution
D. the filament of the bulb gradually burns out.

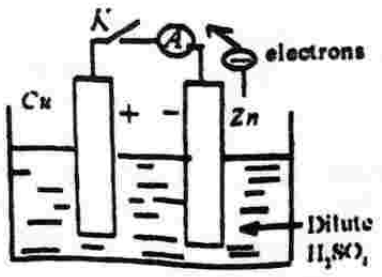
8. The container in which electrolysis takes place is called
A. a voltmeter B. an electrolyte
C. a voltameter D. a voltaic cell

9. In an electrolyte through which no current is passing
A. the ions move randomly
B. the ions remain at rest
C. positive and negative ions move in opposite directions
D. there are no ions present.

10. Which of the underlisted factors determine the emf of a voltaic cell?
I. Quality of the electrolyte
II Type of electrodes
III Dimensions of the cell
A. I only B. II only C. II and III only D. I, II and III.

11. The depolarization agent in a Leclanche cell is the
A. carbon rod B. ammonium chloride
C. manganese dioxide D. powdered carbon

12. An ammeter A and a key K are connected to the electrodes of a voltaic cell as shown in the diagram. When the key is closed:



A. the ammeter shows a maximum deflexion and then declines steadily to a certain small value.
B. the ammeter reading increases and eventually attains a certain steady value.
C. the ammeter shows no deflection at all.
D. the ammeter shows a deflection which remains constant.

13. When a storage cell is re-charged
A. chemical energy is converted into heat energy
B. heat energy is converted into chemical energy
C. chemical energy is converted into electrical energy
D. electrical energy is converted into chemical energy

14. An accumulator is rated in the unit of *ampere-hour*. This is equivalent to the unit of
A. power B. energy
C. potential difference D. charge.

15. The internal resistance of a cell depends on
I. the cell's dimensions
II. the arrangement of the electrodes
III. the quantity of the electrolyte
IV. the conductivity of the electrolyte.
Which of the above are true?
A. I and III only B. II and IV only
C. I, II and IV only D. I. II. III and IV.

16. A metal has an electrochemical equivalent of 0.12×10^{-6} kg/C. The mass of the metal that will be deposited by a current of 10 A in 1 hour is
A. 4.32 g B. 3.00 g C. 0.43 g D. 0.30 g

17. 1 g of copper is liberated by a charge flow of 10^3 C in a voltameter. In order to librate 7.2 g of copper in the same voltameter, a current of 2 A should be maintained for
A. 6 min B. 30 min C. 60 min D. 120 min

18. In an experiment to determine the electrochemical equivalent of a metal X, a cathode of mass 50 g weighs 50.3 g after a current of 5 A had been passed through the electrolyte for 20 minutes. The electrochemical equivalent of X is
A. 5×10^{-6} g/C B. 5×10^{-5} g/C
C. 3×10^{-4} g/C D. 3×10^{-3} g/C

19. Electricity is conducted through a salt - water electrolyte by
A. atoms B. free electrons
C. salt molecules D. ions

20. Silver has an electrochemical equivalent of 1.2×10^{-3} g/C. To deposit 18 g of silver in 25 minutes in a voltameter, the current required is
A. 1 A B. 5 A C. 10 A D. 100 A

21. A metal M has an electrochemical equivalent of 5×10^{-7} kg/C. To plate out 180 g of the metal, a current of 20 A must be maintained in an approriate voltameter for
A. 0.5 h B. 1.0 h C. 5.0 h D. 10.0 h

22. Copper of density 10^4 g/cm^3 and electrochemical equivalent 3.3×10^{-4} g/C is to be plated on the cathode of a voltameter. If the total surface area of the cathode is 66 cm^2 and a current of 50 A is maintained for 1 hour, the thickness of copper plated will be approximately
A. 1.80 μm B. 0.90 μm C. 0.18 μm D. 0.09 μm

23. The electrochemical equivalent of a metal Y is specified as 1.1×10^{-6} kg C^{-1}. This means that during electrolysis, 1.1×10^{-6} kg of Y will be deposited on the cathode
A. by a current of 1 A
B. in 1 s
C. by a current of 1 A passing through the electrolyte for 1 h
D. by a current of 1 A passing through the electrolyte for 1 s

24. A 60 Ah uncharged car battery is to be re-charged using a current of 12 A. The time required for the battery to acquire a full charge is
A. 5 h B. 12 h C. 60 h D. 720 h

25. Which of the following are true of a discharge tube?
I. The tube must have two electrodes, one at each end
II. The potential difference between the electrodes must be very low.
III. The pressure of the gas must be very low
IV. The gas in the tube must be air.
A. I and II only B. I and III only
C. I, II and IV only D. I, II, III and IV

26. Which of the following is not true of a discharge tube?
A. The glass tube must be very long.
B. The characteristic light produced can be used to study the structure of the atoms and molecules of the gas.
C. The gas pressure must be somewhat less than atmospheric pressure.
D. It is used to obtain light of different colours.

Answer Key

1. D	6. D	11. C	16. A	21. C	26. C
2. B	7. B	12. A	17. C	22. B	
3. D	8. C	13. D	18. B	23. D	
4. A	9. A	14. D	19. D	24. A	
5. C	10. B	15. D	20. C	25. B	

Solutions to Objective Questions

1. **(D)** The two electrodes are carbon (positive) and zinc case (negative)
2. **(B)** The *chemical* energy is converted to electrical energy during operation
3. **(D)** Hydrogen bubbles which form around the carbon electrode cause an increase in the cell's internal resistance, a phenomenon referred to as *polarization*. The MnO_2 neutralizes the hydrogen bubbles, thereby reducing the internal resistance and preventing polarization.
4. **(A)** See revision notes
5. **(C)** II and III are consequences of the formation of hydrogen bubbles around the copper electrode. The process is termed polarization.
6. **(D)** A solar cell converts sunlight into electricity. A photocell converts (any) light into electricity. Both the Leclanche and Daniell cells convert chemi-

cal into electrical energy.

7. **(B)** The accumulation of hydrogen bubbles around the copper electrode (cathode) causes a gradual increase in the cell's internal resistance and a corresponding decrease in the current passing through the bulb's filament.

8. **(C)** See revision notes. It is important for the candidate not to confuse a *voltameter* with a *voltmeter*

9. **(A)** The ions start drifting to the electrodes only when the latter acquire electric polarities, i.e.when one electrode acquires a positive charge and the other a negative charge.

10. **(B)** The emf of a voltaic cell is *independent* of the quantity of eletrolyte and the size of the container.

11. **(C)** See revision notes.

12. **(A)** The steady decrease in current is due to a build up of hydrogen bubbles around the copper electrode (polarization).

13. **(D)** In re-charging a storage cell, electricity is supplied to the cell and this results in chemical reactions (and stored chemical energy) within the cell.

14. **(D)** A one ampere-hour cell will deliver a current of one ampere for one hour. This is equivalent to a charge flow of (1 A)(3600 s), or 3,600 coulombs.

15. **(D)** The internal resistance is a measure of the resistance to the flow of ions through the electrolyte. This depends on all the four factors listed. The internal resistance is reduced, for instance, by using an electrolyte of high concentration (i.e high conductivity) or electrodes of large surface area.

16. **(A)** Mass of metal deposited $= zIt$
$= (0.12 \times 10^{-6})\ (10)\ (3600) = 4.32 \times 10^{-3}$ kg, or 4.32 g

17. **(C)** 1 g of copper is liberated by 10^3 C $\Rightarrow$ 7.2 g of copper is liberated by 7.2×10^3 C. For a current of 2 A this charge flow is accomplished in $7.2 \times 10^3 / 2 = 3.6 \times 10^3$ s, or 60 minutes.

18. **(B)** Mass of X liberated = 0.30 g. Electrochemical equivalent

$$z = \frac{m}{It} = \frac{0.30}{(5)(20 \times 60)} = 5 \times 10^{-5}\ \text{g/C}$$

19. **(D)** Electric charges are transported by the positively and negatively charged ions of the salt.

20. **(C)** Mass deposited, $m = zIt$

$$\Rightarrow I = \frac{m}{zt} = \frac{18}{(1.2 \times 10^{-3})(25 \times 60)} = 10\ \text{A}$$

21. **(C)** $t = \frac{m}{zI} = \frac{0.180}{(5 \times 10^{-7})(20)} = 1.8 \times 10^4$ s, or 5 h

22. **(B)** Mass of copper plated, $m = zIt$
$= (3.3 \times 10^{-4})(50)(3600)$ g

Volume of copper plated = mass/density
$= \frac{(3.3 \times 10^{-4})(50)(3600)\ \text{cm}^3}{10^4}$

Thickness of copper plated $= \frac{\text{volume of copper}}{\text{surface area of cathode}}$
$= \frac{(3.3 \times 10^{-4})(50)(3600)}{10^4 \times 66}$
$= 9.0 \times 10^{-5}$ cm, or 0.9 μm

23. **(D)** 1.1×10^{-6} kg of Y will be deposited by a charge of 1 C, i.e. a current of 1 A flowing for 1 s.

24. **(A)** Recharge time = 60/12 = 5 h.

25. **(B)** A high p.d. and a low a gas pressure are required. Any gas can be used.

26. **(C)** The pressure, which is of the order of a few millimeters of mecury, is *much* lower than atmospheric.

Revision Check-list

Under this chapter the candidate should be able to:

- describe the basic features of a *simple cell.*
- distinguish between *primary* and *secondary* cells.
- distinguish between the *wet and dry Leclanche cells.*
- explain the basic differences between the Leclanche cell and the Daniell cell.
- explain the terms *polarization* and *local action.*
- describe the basic features of *accumulators.*
- describe the features and basic applications of *solar cells.*
- describe the electrochemical processes of *electrolysis* and *electroplating.*
- state and apply *Faraday's laws of electrolysis.*
- describe the procedure for *calibrating an ammeter.*
- explain the basic features of electric *discharge through gases* and the operation of a *flourescent tube.*

19 Alternating Currents

19.1 Definitions

- The current supplied by a battery flows in one direction only unless the battery terminals are reversed. This is ***direct current.***
- The current supplied by an AC generator, however flows back and forth in the wire. Such a current which reverses its direction continuously is called ***alternating current.***
- ***Alternating voltage*** is the emf which gives rise to alternating current.
- The magnitude of alternating voltage or current varies with time: it increases to a positive maximum, decreases to zero, goes to a negative minimum and again increases to zero (Fig. 19.1)

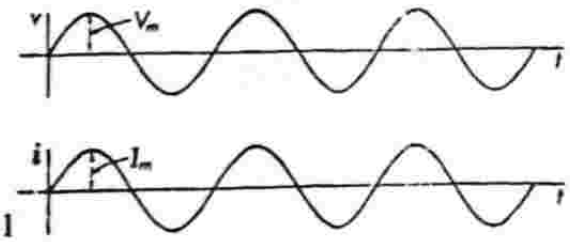


Fig. 19.1

- The simplest representation of alternating voltage or current is one in which it varies as a sine (or cosine) function of time (t):

$$v = V_m \sin(2\pi ft), \text{ and } i = I_m \sin(2\pi ft) \qquad (19.1)$$

where f = frequency or the number of times the voltage or current changes direction per second. V_m = maximum value (or amplitude) of voltage, and I_m = maximum value (or amplitude) of current.
Units: V = [V], I = [A], f = [Hz], t = [s].

19.2 Effective Values of Voltage and Current

- The ***effective*** or ***root mean square (rms)*** value of the voltage is given by

$$V_{rms} = \frac{V_m}{\sqrt{2}} \qquad (19.2)$$

- The effective or rms value of the current is

$$I_{rms} = \frac{I_m}{\sqrt{2}} \qquad (19.3)$$

19.3 Self Inductance

- When alternating current flows in a coil, a rapidly changing magnetic field is set up around the coil, which results in the generation of a self- induced emf in the coil.
- This induced emf, according to *Lenz's law*, tends to oppose the current giving rise to it.
- This effect, called ***self induction***, offers a resistance to the current build-up in an AC circuit, so that the current lags behind the imposed emf, i.e. the current and the emf are out of phase (by $\pi/2$ or 90°).
- The effective resistance due to self-induction, or the ***inductive reactance*** (X_L) is given by

$$X_L = \frac{V_m}{I_m} = 2\pi fL \qquad (19.4)$$

where L is the self-inductance of the wire.
- ***Units:*** L = [V.s.A^{-1}] = [henry], X_L = [ohm] or [Ω].

19.4 Capacitive Reactance

- A capacitor in an AC circuit offers an effective resistance called a ***capacitive reactance,*** X_C to the imposed current.
- The capacitive reactance is given by

$$X_C = \frac{V_m}{I_m} = \frac{1}{2\pi fC} \qquad (19.5)$$

where C is the capacitance.
- The capacitive reactance causes the voltage to lag behind the current by $\pi/2$ (90°).

19.5 *R-L-C* Series Circuit

- For an AC circuit which has a resistance R, an inductance L and a capacitance C (*R-L-C* circuit) in *series* (Fig. 19.2), the effective resistance, or the ***impedance*** Z is given by

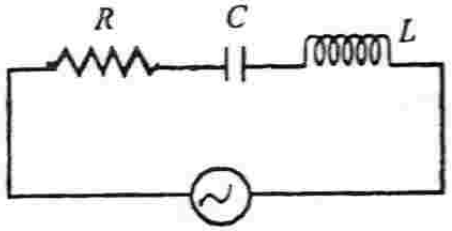


Fig. 19.2

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \qquad (19.6)$$

where X_L and X_C are defined in Eqs. (19.4) and (19.5).
- If the AC circuit has only a resistance R and an inductance L,

$$Z = \sqrt{R^2 + X_L^2} \qquad (19.7)$$

- If the AC circuit contains a resistance R and a capacitance C.

$$Z = \sqrt{R^2 + X_C^2} \qquad (19.8)$$

- *Units:* Z = [Ω].

19.6 Vector Diagrams

- In a AC circuit the voltage
  (i) ***is completely in phase*** with the current for a resistor,
  (ii) ***leads*** the current by 90° for an inductor; and
  (iii) ***lags*** the current by 90° for a capacitor.
- Since the voltages for the various elements are not all in phase, the total voltage cannot be computed by merely adding the individual voltages algebraically. It is determined ***vectorially***.
- The procedure for drawing the vector diagrams is illustrated in Fig. 19.3

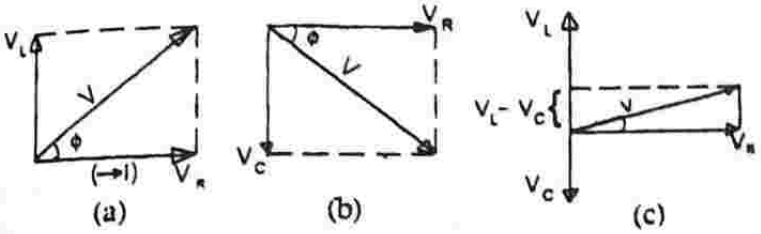


Fig. 19.3

where V_R, V_L, and V_C represent the voltages across the resistor, the inductor and the capacitor respectively, with V_R drawn parallel to the direction of current (they are in phase)

- The overall voltage V is shown in Fig. 19.3 (a) for an R-L circuit, in Fig. 19.3 (b) for an R - C circuit, and in Fig. 19.3 (c) for an R - L - C circuit.
- The angle ϕ between I and V is called the **phase angle.**

19.7 Power in an AC Circuit

- In an R - L - C circuit, power is dissipated in the resistor only.
- The power dissipated, P, is given by $P = I\,V \cos\phi$ where I, V are the effective values of current and overall voltage and ϕ is the phase angle.
- The parameter $\cos\phi$ is referred to as the ***power factor.***

19.8 The Alternating-Current (A.C.) Generator

- The ***A.C. Generator*** is a device for converting mechanical energy (rotational motion) to electrical energy (electric current) using the principle of electromagnetic induction.
- It consists of a coil of wire which is wound on a shaft and placed between the poles of a permanent magnet.
- A circular ring of copper, known as a slip ring, and a carbon brush are attached to each end of the coil.
- The coil is made to rotate between the poles of the magnet, and a current is induced in the coil.
- The carbon brushes tap the current from the coil via the slip rings.
- The direction of the current changes as the plane of the coil passes through the vertical plane, i.e. twice during a complete rotation, thus producing an ***alternating current***

19.9 The Direct-Current (DC) Generator

- The ***DC generator*** is similar to the AC generator except that the two slip rings are replaced by a ***split-ring commutator.***
- As the direction of the current in the coil changes, the commutator reverses the electrical connection between the coil and the external circuit.
- The external circuit thus continuously receives current in the same direction ***(direct current)***.

19.10 The Transformer

- The ***transformer*** consists of two coils of wire, a primary and a secondary, each wound around an arm of a continuous, laminated soft iron core (Fig. 19.4).

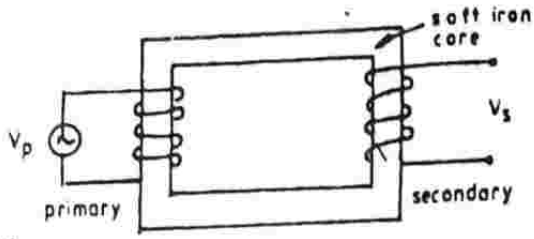


Fig. 19.4

- If the primary is connected to a source of alternating voltage, an alternating voltage is also induced in the secondary.
- The voltage induced in the secondary (V_s) depends on the voltage in the primary (V_p) and the ratio of the number of turns in the primary (N_p) to the number in the secondary (N_p). Thus

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad (19.10)$$

- It is a ***step-up*** transformer if $V_s > V_p$ and a ***step-down*** transformer if $V_s < V_p$.
- If the current in the primary and secondary coils are I_p and I_s respectively, the input power into the transformer is $I_p V_p$ and the output power from it is $I_s V_s$.
- Efficiency of the transformer is given by

$$\text{Efficiency} = \frac{I_s V_s}{I_p V_p} \times 100\% \qquad (19.11)$$

- If the efficiency is 100%, $I_s V_s = I_p V_p$ or

$$\frac{V_s}{V_p} = \frac{I_p}{I_s} \qquad (19.12)$$

- Power loss in the transformer is minimized by
  (i) laminating the core to reduce induced currents (also called ***eddy currents***) which result in heat loss in the core,
  (ii) making the coil of out a low-resistance material (copper) to reduce energy loss in the form of heat in the wire, and
  (iii) making the core of soft iron to reduce ***hysteresis*** loss.

19.11 Generation and Transmission of Electrical Energy

- In commercial electricity generation, a turbine is made to spin an *armature* (coil) placed in a strong magnetic field.
- The turbine is driven by *falling water* (hydroelectric power station), or by high pressure *steam* which is generated in a *boiler* by burning *coal, oil* or *natural gas* (gas thermal station).
- The electricity is transmitted from the power station to factories and homes through a grid system of overhead cables.
- Step-up transformers are installed at the power station to generate high voltage electricity which is transmitted in the overhead cables.
- High voltages (up to 400 kV) are used in the transmission lines because the current is then kept low. The rate of energy loss as heat, which is proportional to the square of the current, is thus minimized.
- Step-down transformers are installed at the consumer end to bring down the voltage to the required values, e.g. 220 V for domestic use.

19.12 The Induction Coil

- The *induction coil* is a transformer for stepping up *direct current*.
- The number of turns in the secondary is much larger than in the primary, both of which are wound on the same core.
- The primary voltage, for example from a 12 V battery, is interrupted by a rapid make-and-break device, so that very high voltage pulses are induced in the secondary.
- The induction coil is used in car ignition systems where the induced voltage in the secondary, which is passed on to the spark plug, is sufficiently large (up to 25, 000 V) to ionize the air and cause a spark across the gap in the spark plug.

True or False - Type Questions

Answer *True* (T) or *False* (F) to the following questions.

1. a. An alternating current of rms value 10 A will have the same heating effect as a direct current of 10 A.
   b. An alternating current which varies from zero to a peak of 20 A has an effective value of 10 A.
   c. If a coil of wire is to be connected to a source of voltage V, the current in the coil would be lower for an AC source than for a DC source.
   d. The impedance of an R-L series circuit is the algebraic sum of the resistance and the inductive reactance.
   e. In an L-C series circuit of negligible resistance, the impedance of the circuit is simply equal to the algebraic difference between the inductive and the capacitive reactances.
   f. In an R-C series circuit, the impedance increases as the capacitance increases.
   g. The impedance is never less than the resistance in an R-L-C series circuit.
   h. An R-L-C series circuit is said to be in resonance when the impedance is zero.
   i. The algebraic sum of the voltages across the various elements of an R-L-C series circuit is equal to the supply voltage.

2. In an induction coil
   a. a large secondary current is generated from a small input current.
   b. d.c. voltages are stepped up or down.
   c. the capacitor in the circuit is used to minimize the effect of induced emf in the primary coil.
   d. the coil is wound on a soft iron core.
   e. alternating current is rectified into direct current.
   f. a large secondary voltage is generated because of the alternating current supplied to the primary.

3. A transformer with more secondary windings than primary
   a. has a larger secondary current
   b. is a step-up transformer
   c. has a larger secondary voltage
   d. has a greater power output in the secondary
   e. is used for converting high-current, low-voltage supply into a low-current, high-voltage output.

4. In high tension transmission
   a. the transmitting wires are maintained under high tension.
   b. power is transmitted at low current and high voltage.
   c. heat dissipation is low.
   d. efficiency of transmission is high.
   e. the high voltage ensures a faster flow of electric power.
   f. the use of *thin* wires is made possible because of the reasonably small currents transmitted.

Answers to True or False - Type Questions

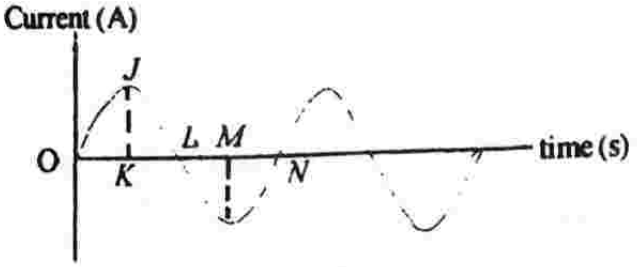
1. a **(T)** The rms value is the *effective value* of an alternating current or voltage.
   b **(F)** The effective or the rms value of current is $I_{max}/\sqrt{2} = 20/\sqrt{2} = 14.1$ A
   c **(T)** Under an AC supply the impedance Z of the coil is greater than the resistance R. For AC, $I_{AC} = V/Z$ and for DC, $I_{DC} = V/R$. Since $Z > R$, $I_{AC} < I_{DC}$
   d **(F)** The impedance $Z = \sqrt{R^2 + X_L^2}$ and not $R + X_L$
   e **(T)** $Z = \sqrt{R^2 + (X_L - X_C)^2} = X_L - X_C$ when R = zero.
   f **(F)** $X_C = 1/(2\pi f C)$. As C increases, X_C decreases and since $Z = \sqrt{R^2 + X_C^2}$, Z also decreases.
   g **(T)** The minimum value of the Z occurs when $X_L = X_C$, for which $Z = R$.
   h **(F)** it is in resonance when $X_L = X_C$, i.e. $Z = R$
   i **(F)** The supply voltage is equal to the *vectorial* sum of the voltages.

2. a **(F)** The induction coil produces a large secondary *voltage* from a low primary *voltage*. [Actually, the current in the secondary must be lower than in the primary, since IV = constant if energy losses are negligible].
   b **(F)** The induction coil is used for *stepping up DC* voltages only.
   c **(T)** The induced emf will result in the generation of unwanted sparks at the make - and - break contact points in the absence of the capacitor.
   d **(T)** This concentrates the magnetic flux inside the windings, thereby improving the efficiency.
   e **(F)** See (b) above.
   f **(F)** The large induced secondary voltage is due to the rapidly changing magnetic flux linking the coils as the circuit is closed and opened by the make -and-break device.

3. a **(F)** This is a *step-up* transformer in which the secondary *voltage* is larger than the primary. A large secondary voltage, however, implies a *small* secondary current since the power; i.e. product of current and voltage must remain constant.
   b **(T)** See (a) above
   c **(T)** See (a) above
   d **(F)** The secondary power output is less than or equal to the primary power input, depending on, the efficiency of the transformer.
   e **(T)** See (a) above.

4. a **(F)** This has nothing to do with the tension in the transmitting wires.
   b **(T)** See (c) below.
   c **(T)** Heat dissipated is directly proportional to the square of the current. Hence a low current implies a low heat loss.
   d **(T)** If heat loss is small, much of the input power is recovered at the output end of the transmission line, i.e. the efficiency is high.
   e **(F)**
   f **(T)** If the current is high, a low resistance wire (i.e. a thick wire) would be required

SSCE JME - Type Objective Questions



1. An alternating current $i = I_o \sin \omega t$ has the waveform shown in the figure above. The quantity I_o is equal to
   A. OM **B.** OL **C.** JK **D.** LN

2. The length ON in question 1 is equal to
   A. ω **B.** $\omega/2\pi$ **C.** ω/π **D.** $2\pi/\omega$

3. The rms current I_{rms} and the peak current I_o in alternating currents are related according to
   A. $I_{rms} = 1/I_o\sqrt{2}$ **B.** $I_o = 1/I_{rms}\sqrt{2}$
   C. $I_{rms} = I_o/\sqrt{2}$ **D.** $I_o = I_{rms}/\sqrt{2}$

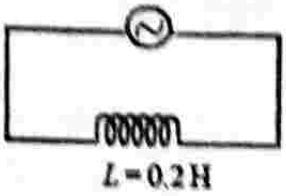
4. The peak voltage of a 110 V rms mains supply is
   A. 220 V **B.** 156 V **C.** 120 V **D.** 110 V

5. The peak value of the p.d. in an AC circuit is 240 V. The instantaneous p.d. at 1/8th of a cycle is
   A. $240\sqrt{2}$ V **B.** $120\sqrt{2}$ V **C.** 120 V **D.** 60 V

6. In question 5, the p.d. at a phase angle of 90° is
   A. 240 V **B.** 120 V **C.** 60 V **D.** 0

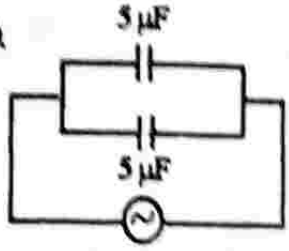
7. The units of inductance and reactance are respectively
   A. farad and henry **B.** henry and farad
   C. ohm and henry **D.** henry and ohm

8. An inductor of inductance 10 mH having negligible resistance is connected to a 1.5×10^3 Hz oscillator. The inductive reactance is
   A. 188.5 Ω B. 94.3 Ω C. 42.4 Ω D. 30.0 Ω

9. 

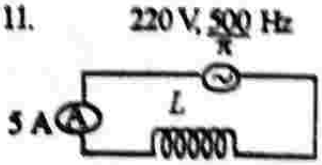
The reactance of the inductor shown in the figure above is 100 Ω. The frequency of the AC source is

A. 500/π Hz B. 250/π Hz
C. 50 Hz D. 20 Hz

10. 

The frequency of the AC supply shown in the figure is 200/π Hz. The reactance of the circuit is

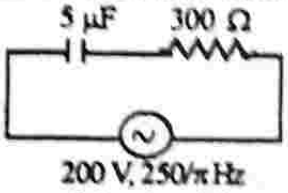
A. 1,000 Ω B. 500 Ω
C. 250 Ω D. 125 Ω

11. 

The inductance L of the coil in the AC circuit shown above is

A. 30.00 H B. 17.60 H
C. 4.40 H D. 0.04 H

Questions 12 - 15 refer to the series circuit shown below.

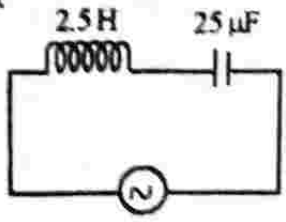


12. The impedance of the circuit is
A. 1500 Ω B. 1000 Ω C. 500 Ω D. 300 Ω

13. The current through the circuit is
A. 0.67 A B. 0.40 A C. 0.33 A D. 0.13 A

14. The voltage across the capacitor is
A. 200 V B. 160 V C. 120 V D. 100 V

15. The average power used in the circuit is
A. 48.0 W B. 80.0 W C. 133.3 W D. 160.0 W

16. 

The AC circuit illustrated in the diagram above has a frequency of 100/π Hz. The effective reactance of the circuit is

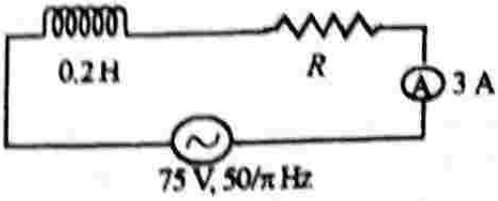
A. 700 Ω B. 500 Ω
C. 300 Ω D. 200 Ω

17. The resistance in a series R - C circuit is 15 Ω. If the impedance of the circuit is 25 Ω, the reactance of the capacitor is
A. 40 Ω B. 25 Ω C. 20 Ω D. 10 Ω

18. A coil of resistance 30 Ω is connected to a 100 V, 50/π Hz AC source. If the coil draws an rms current of 2 A, its inductance is
A. 0.40 H B. 0.60 H C. 1.25 H D. 2.50 H

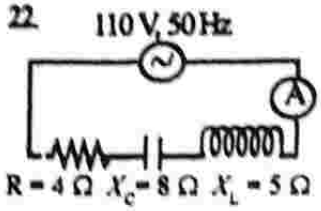
19. In a series R - L - C circuit, the current indicated by the ammeter is I. If X_L and X_C are the inductive and capacitive reactances respectively while R is the resistance, the power consumed in the circuit is
A. $I\sqrt{R^2+(X_L-X_C)^2}$ B. $I\sqrt{R^2+X_L^2-X_C^2}$
C. $I^2(R+X_L-X_C)$ D. I^2R

Questions 20 and 21 refer to the figure below



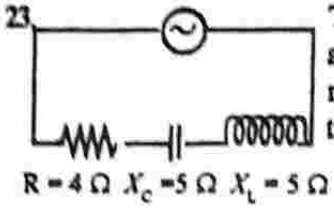
20. The inductive reactance of the circuit is
A. 20.0 Ω B. 37.5 Ω C. 40.0 Ω D. 75.0 Ω

21. The value of the resistance R is
A. 5 Ω B. 10 Ω C. 15 Ω D. 20 Ω

22. 

In the R - L - C circuit above, the current indicated by the ammeter A is

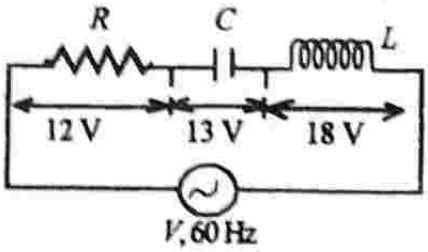
A. 22.0 A B. 15.7 A
C. 10.7 A D. 6.5 A

23. 

The diagram above shows an R - L - C circuit at resonance. The impedance of the circuit is

A. 14 Ω B. 9 Ω
C. 5 Ω D. 4 Ω

24. The inductance and capacitance are 0.25 H and 25 μF respectively in a series R - L - C circuit. The resonance frequency of the circuit is
A. 500/π Hz B. 250/π Hz
C. 200/π Hz D. 100/π Hz

25. 

The applied voltage V in the R - L - C circuit diagram shown above is
A. 43 V B. 19 V C. 17 V D. 13 V

26. The back emf induced in a current - carrying coil causes
A. resistance B. inductance
C. eddy currents D. resonance

27. The heat generated when an alternating current of peak value 10 A passes through a resistor of 4 Ω

for 30 seconds is
A. 24,000 J B. 12,000 J C. 6,000 J D. 3,000 J

28. An electric motor powered by a 110 V rms supply draws a current of 8 A. The motor is used to lift a mass of 50 kg through a vertical distance of 5.5 m in 5 s. If $g = 10\ ms^{-2}$, the efficiency of the motor is
A. 80.0% B. 62.5% C. 8.0% D. 6.3%

29. A motor whose output is 5.0 kW is used to drive a generator which delivers an rms current of 18 A at a terminal voltage of 250 V. The efficiency of the generator is
A. 22.5% B. 45.0% C. 80.0% D. 90.0%

30. The primary to secondary transformation ratio in a transformer is 2 : 5. If the voltage across the primary is 10 kV, the voltage across the secondary is
A. 4 kV B. 5 kV C. 25 kV D. 50 kV

31. If the current in the primary in question 30 is 4 A., the current in the secondary is
A. 10.0 A B. 5.0 A C. 2.5 A D. 1.6 A

32. A transformer having 500 turns in its primary coil is connected between a 200 V mains supply and a door-bell rated at 10 V. The number of turns in its secondary is
A. 25 B. 100 C. 5,000 D. 10,000

33. Which of the following is associated with alternating currents only?
A. A moving-coil galvanometer B. A transformer
C. A lead - acid accumulator D. An induction coil

Answer Key

1.	C	7.	D	13.	B	19.	D	25.	D	31.	D
2.	D	8.	B	14.	B	20.	A	26.	B	32.	A
3.	C	9.	B	15.	A	21.	C	27.	C	33.	B
4.	B	10	C	16.	C	22.	A	28.	B		
5.	B	11.	D	17.	C	23.	D	29.	D		
6.	A	12.	C	18.	A	24.	C	30.	C		

Solutions to Objective Questions

1. **(C)** I_o is the *maximum* value of current.

2. **(D)** ON is the period of the sine wave which must be equal to 2π hence $\omega t = 2\pi$ or $t = 2\pi/\omega$.

3. **(C)** See revision notes.

4. **(B)** Peak voltage. $V_0 = V_{rms}\sqrt{2} = 110\sqrt{2} = 156$ V

5. **(B)** $v = V_0 \sin \omega t$. For a full cycle, $\omega t = 2\pi$ and for 1/8th of a cycle, $\omega t = 2\pi/8 = \pi/4$.
Hence $v = V_0 \sin 45^0 = V_0/\sqrt{2} = 240/\sqrt{2} = 120\sqrt{2}$V

6. **(A)** $\omega t = 90^0 = \pi/2$ represents 1/4 of the cycle.
$v = V_0 \sin \pi/2 = V_0 = 240$ V

7. **(D)** Inductance is measured in *henrys* and reactance in *ohms*.

8. **(B)** $X_L = 2\pi fL = 2\pi(1.5 \times 10^3)(10 \times 10^{-3}) = 94.3\ \Omega$

9. **(B)** $f = X_L/(2\pi L) = 100/(2\pi \times 0.2) = 250/\pi$ Hz

10. **(C)** Effective capacitance of the two capacitors in parallel = 5 + 5 = 10 μF

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(200/\pi)(10 \times 10^{-6})} = 250\ \Omega$$

11. **(D)** Inductive reactance of the circuit, $X_L = V/I$
$= 220/5 = 44\ \Omega$
$L = X_L/(2\pi f) = 44/[2\pi \times (500/\pi)] = 0.044$ H

12. **(C)** $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(250/\pi)(5 \times 10^{-6})} = 400\ \Omega$

$Z = \sqrt{R^2 + X_C^2} = \sqrt{300^2 + 400^2} = 500\ \Omega$

13. **(B)** Current $I = V/Z = 200/500 = 0.40$ A

14. **(B)** $V_C = IX_C = (0.40)(400) = 160$ V

15. **(A)** Power consumed $= I^2R = (0.40)^2(300) = 48.0$ W

16. **(C)** For the inductor, $X_L = 2\pi fL = 2\pi(100/\pi)(2.5)$
$= 500\ \Omega$

For the capacitor:

$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(100/\pi)(2.5 \times 10^{-6})} = 200\,\Omega$

Effective reactance $= X_L - X_C = 500 - 200 = 300\,\Omega$

[Since X_L and X_C are in exactly opposite directions, thier resultant is simply given by the algebraic difference].

17. **(C)** Capacitive reactance, $X_C = \sqrt{Z^2 - R^2} = \sqrt{25^2 - 15^2} = 20\,\Omega$

18. **(A)** Impedance of the circuit, $Z = V/I = 100/2 = 50\,\Omega$
Inductive reactance, $X_L = \sqrt{Z^2 - R^2} = \sqrt{50^2 - 30^2} = 40\,\Omega$
Inductance $L = X_L/(2\pi f) = 40/(2\pi \times 50/\pi) = 0.4$ H

19. **(D)** This is equal to the power dissipated in the resistor

20. **(A)** $X_L = 2\pi fL = 2\pi(50/\pi)(0.2) = 20\,\Omega$

21. **(C)** Since the current $I = 3$ A, the impedance of the circuit is $Z = V/I = 75/3 = 25\,\Omega$.
$R = \sqrt{Z^2 - X_L^2} = \sqrt{25^2 - 20^2} = 15\,\Omega$

22. **(A)** Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{4^2 + (8-5)^2} = 5\,\Omega$

Current $I = V/Z = 110/5 = 22$ A

23. **(D)** Since $X_L = X_C$ at resonance, impedance $Z = R = 4\,\Omega$

24. **(C)** $X_L = 2\pi fL = 2\pi f(0.25) = 0.5\pi f\,\Omega$

$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi f(25 \times 10^{-6})} = \frac{10^6}{50\pi f}\ \Omega$

At resonance, $X_L = X_C \Rightarrow 0.5\pi f = \frac{10^6}{50\pi f}$

$f = 10^3/5\pi = 200/\pi$.

25. **(D)** The voltages across C and L are in opposite directions, hence their resultant is 18 - 13, or 5 V, acting at right angles to the 12 V across the resistance. The overall voltage is thus $V = \sqrt{5^2 + 12^2} = 13$ V.

26. **(B)** Eddy currents are also caused by induced back emf. However, these are set up in the *core*, such as soft iron, on which the coil is wound.

27. **(C)** Effective current = rms current = $10/\sqrt{2}$ A
Energy disspated $= I^2_{rms}(R)\,t = (10/\sqrt{2})^2(4)(30) = 6,000$ J

28. **(B)** Power delivered by motor $= IV = (110)(8) = 880$ W, or 880 J/s
Power used in lifting mass $= mgh/t = (50)(10)(5.5)/5 = 550$ J/s
Efficiency of the motor = 550/880 = 62.5%

29. **(D)** Power delivered by generator $= IV = (18)(250)$ W
Power output of motor = 5,000 W
Efficiency of generator = (18)(250)/5,000 = 0.9, or 90%.

30. **(C)** $V_S/V_P = N_S/N_P \Rightarrow V_S = V_P(N_S/N_P) = 10(5/2) = 25$ kV

31. **(D)** $I_S/I_P = V_P/V_S = N_P/N_S = 2/5$
Hence $I_s = I_p(0.4) = 4(0.4) = 1.6$ A

32. **(A)** $N_S = (V_S/V_P)\,N_P = (10/200)(500) = 25$

33. **(B)** See revision notes.

Revision Check - list

Under this chapter, the candidate should be able to

- explain the term *alternating current*.
- explain what is meant by the *root - mean square values* of current and voltage.
- explain the terms *selfinductance, capacitive reactance* and *impedance*.
- solve simple problems on *R - L - C series circuits*.
- sketch *vector diagrams* for *R - L - C* circuits.
- explain the terms *power factor* and *phase angle* and solve simple problems on power disspation in *A.C.* circuits.
- describe the basic features of *A.C.* and *D.C. generators*.
- list the factors which determine the induced emf in a generator.
- describe the basic features of a *transformer*.
- solve simple problems on transformers.
- explain how *energy loss is minimized* in transformers
- explain the basic features of *electricity generation and transmission*.
- explain the mode of operation of an *induction coil* and the roles of components such as the make-and-break device, and the capacitor.
- list the uses of an induction coil.

20 Elementary Atomic Physics

20.1 Thermionic Emission

- If a piece of metal placed in a vacuum is heated, electrons are emitted from the metal surface. This is called ***thermionic emission.***
- The piece of metal (also called a ***filament***) is heated by passing electric current through it.
- A vacuum tube containing two electrodes - a heated filament (cathode) and a positively-charged metal plate (anode) - is called a ***diode***. (Fig.20.1)

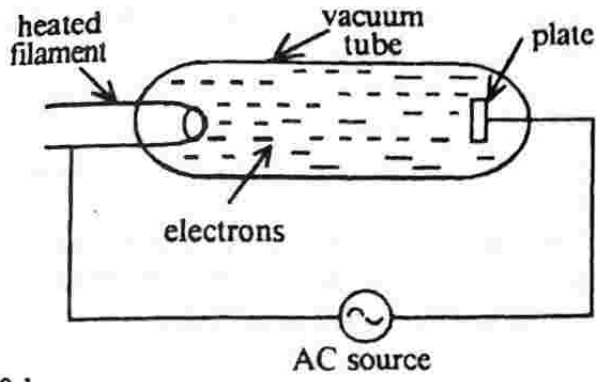


Fig. 20.1

- If alternating current is passed through the filament, electrons drift from the filament to the plate during part of the cycle in which the plate is positive with respect to the filament. In the second-half of the cycle, the plate is negative with respect to the filament and hence electrons are repelled from the plate.
- Current therefore flows in the circuit during one-half of the cycle, but not during the other half, i.e. an intermittent direct current results.
- The production of direct current from an *AC* source by a diode is known as ***rectification.***

20.2 The Photoelectric Effect

- If light of an appropriate frequency is made to fall on a suitable metal, electrons are emitted from the metal surface. This is the ***photoelectric effect.***
- Alkali metals such as sodium, potassium and caesium can be made to emit electrons by visible light. Other metals require light of higher frequency (ultraviolet).
- A ***photocell***, which makes use of the photoelectric effect, consists of a positively charged metal plate which is placed inside an evacuated enclosure. The inside of the enclosure is coated with an alkali metal such as caesium.
- When visible light falls on the coating, electrons are emitted and these are attracted to the positive plate resulting in a continuous flow of current in the external circuit.
- Photocells are used as light meters in photography, in relays, automatic door openers, burglar alarms, etc.

20.3 Quantum Theory of Light

- The photoelectric effect is explained by assuming that light is emitted in separate packets called ***quanta*** or ***photons***.
- The energy (E) carried by a quantum of radiation is proportional to its frequency (f), i.e.

$$E = hf \qquad (20.1)$$

where the proportionality constant h, called ***Planck's constant***, has the value 6.63×10^{-34} Js.

- An electron requires a certain minimum amount of energy, called the ***threshold energy***, to break loose from the surface of a metal. This energy is also called the ***work function*** of the metal.
- If an electron of mass m receives an amount of energy which is greater than the work function (W) from incident radiation of frequency f, the balance of the energy is converted into kinetic energy of the emitted electron, i.e.

Energy of incident radiation = work function + k.e. of electron, or

$$hf = W + \frac{1}{2}mv^2 \qquad (20.2)$$

where v is the velocity of the electron. Eq. (20.2) is known as ***Einstein's equation***.

20.4 Electron Energy Levels and Atomic Spectra

- Electrons in an atom are considered to occupy distinct ***energy levels***.
- An energy level can be occupied by only two electrons of opposite spins.
- An electron could shift from one energy level to another (unoccupied) energy level.
- The gaps between energy levels are forbidden, i.e. they cannot be occupied by electrons.
- An electron at the lowest energy level is said to be in the ground state. Electrons in higher energy levels are in ***excited states***.
- Vapours of different elements which are heated to incandescence emit lights of different wavelengths (and colours), e.g. sodium vapour emits yellow, potassium (violet), etc. The emitted radiation is called the ***emission spectrum*** of the substance.
- If white light is made to pass through the vapour of an element, the vapour will absorb light of certain wavelengths (and colours). The resulting spectrum, known as the ***absorption spectrum***, consists of dark

lines corresponding to the wavelength of the absorbed light.

- Both emission and absorption spectra are explained using the energy level model of the atom:
  (i) Electrons in the atoms of heated vapours are excited into higher energy levels. They emit radiations of different wavelengths (emission spectrum) as they return to their stable states.
  (ii) Electrons in the atoms of a vapour through which white light is passed are excited into higher energy levels by absorbing light of certain wavelengths (absorption spectrum).
- Emission and absorption spectra are used in *spectroscopy*.

20.5 X - rays

- X-rays are electromagnetic radiation of wavelength of the order of 10^{-10} m.
- They are produced when fast-moving electrons hit a metal target (such as tungsten) in a high-voltage vacuum tube.
- **X-rays**
  (i) can penetrate many materials of considerable thickness;
  (ii) are diffracted by crystals since their wavelength is of the same order of magnitude as atomic spacings;
  (iii) pass through electric or magnetic fields undeflected; and
  (iv) are detected by their effects on a photographic plate or a fluorescent screen.
- **X-rays are used**
  (i) in medicine for examining bones, teeth and various internal organs;
  (ii) in industry for revealing flaws in metals and welded joints; and
  (iii) for identifying the internal structure of solids.

20.6 Nature of the Atomic Nucleus

- An atom is made up of a positively-charged nucleus orbited by negatively charged electrons.
- The nucleus of an atom consists of neutrons and protons, which are also called ***nucleons***.
- The ***mass number*** (or ***nucleon number***), A, is the sum of the number of protons and neutrons in the nucleus.
- The ***atomic number***, Z is the number of protons in the nucleus. It is also equal to the number of electrons orbiting the nucleus in a neutral atom.
- The atomic nucleus of an element of chemical symbol X, represented symbolically as ${}^{A}_{Z}X$, is called a ***nuclide***, e.g. ${}^{4}_{2}He$ is a helium nucleus with $Z = 2$ and $A = 4$.
- Atoms of the same element having the same atomic number but different mass numbers are called ***isotopes***, e.g. ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$ are two isotopes of chlorine.

20.7 Radioactivity

- The nuclei of certain heavy elements, notably those with atomic number 84 (polonium) and greater, are unstable and have a natural tendency to break down into more stable nuclei while emitting certain radiations. This is known as ***radioactivity***.
- The radiations which normally accompany nuclear disintegration are called ***alpha*** (α), ***beta*** (β) and ***gamma*** (γ) radiations. They all originate from the nucleus of the radioactive atom.
- The α-radiation (or α-particle) is a helium nucleus, containing two protons and two neutrons. It is thus positively charged and is deflected by a magnetic field.
- The β-radiation (or β-particle) consists of fast-moving electrons. They are negatively-charged and are easily deflected by a magnetic field.
- The γ-radiation (or γ-ray) is an electromagnetic wave of wavelength of the order of 10^{-14}m. It is electrically neutral and hence not deflected by an electric or a magnetic field.

20.8 Radioactive Decay

- α, β, and γ radiations are represented symbolically as ${}^{4}_{2}He$, ${}^{0}_{-1}\beta$ and ${}^{0}_{0}\gamma$ respectively.
- An element of atomic and mass numbers Z and A which disintegrates by the emission of an α-particle is transformed into another element of atomic and mass numbers $Z - 2$ and $A - 4$. This reaction may or may not be accompanied by the emission of γ-radiation, e.g.

$$ {}^{232}_{90}Th \longrightarrow {}^{228}_{88}Ra + {}^{4}_{2}He + {}^{0}_{0}\gamma \qquad (20.3) $$

- If the element disintegrates with the emission of a β-particle, it is transformed into another element of atomic number $Z + 1$ while the mass number remains unchanged, e.g.

$$ {}^{228}_{88}Ra \longrightarrow {}^{228}_{89}Ac + {}^{0}_{-1}\beta \qquad (20.4) $$

- The emission of a γ-ray does not by itself, affect the atomic or mass number of a substance.
- In these types of reactions, the total number of protons as well as neutrons must be conserved.
- The nuclear disintegration of thorium (depicted in Eqs. (20.3) and (20.4)) continues until lead, with a stable nucleus ${}^{208}_{82}Pb$, is obtained.
- The number (N) of radioactive nuclei present at any time t during radioactive decay is given by

$$N = N_0 e^{-\lambda t} \qquad (20.5)$$

where N_0 is the number initially present (at $t = 0$) and λ is the decay constant for the atom. This relationship is illustrated schematically in Fig. 20.2

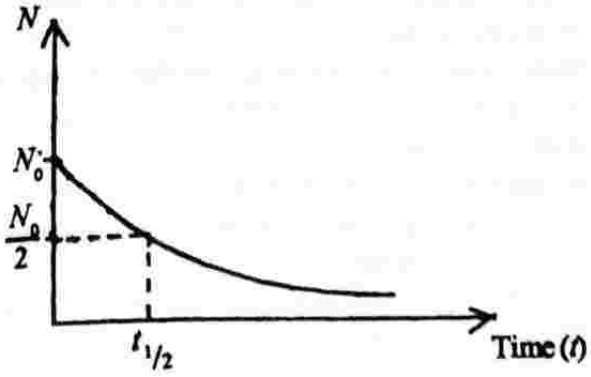


Fig. 20.2

- The ***half-life***, $t_{1/2}$ is the time it takes for a given quantity of radioactive substance to disintegrate to half of its original value. It varies from one substance to another, e.g. polonium (3 minutes), radon (4 days), and radium (1620 years).

Taking logarithms in Eq. (20.5), $ln\frac{N}{N_0} = -\lambda t$

At $t = t_{1/2}$, $N = N_0/2$. Hence $ln\frac{1}{2} = -\lambda t_{1/2}$, or

$$t_{1/2} = \frac{ln\ 2}{\lambda}$$

- ***Artificial radioactivity*** may be induced by firing neutrons or α - particles into stable (i.e. naturally non-radioactive) nuclei, e.g.

$$^{27}_{13}Al + ^{4}_{2}He \longrightarrow ^{30}_{14}Si + ^{1}_{1}H \qquad (20.6)$$

and

$$^{10}_{5}B + ^{1}_{0}n \longrightarrow ^{7}_{3}Li + ^{4}_{2}He \qquad (20.7)$$

20.9 Nuclear Fission

- If a piece of uranium-235 is bombarded with slow-moving neutrons, the *U*-nucleus is split into two nuclei of comparable mass. The splitting of a nucleus is called ***nuclear fission***.
- Fission is often accompanied by the release of (heat) energy and the emission of neutrons.
- The newly emitted neutrons could split more uranium nuclei, thereby setting up a ***chain reaction*** resulting in the release of a large quantity of energy.
- The neutrons produced from fission are usually too fast, and must be slowed down in order to start off and maintain the chain reaction.
- The uranium rods are usually inserted in a block of ***graphite*** which slows down the neutrons and is said to act as a ***moderator***.
- Rods of cadmium or boron steel, called ***control rods***, are inserted and withdrawn intermittently to absorb some of the neutrons and thus control the rate of the nuclear reaction.
- The set-up described above is a ***nuclear reactor***, and the heat energy released is often used as a source of power generation.
- The reactor is surrounded with a shield of thick concrete wall to prevent human beings from the harmful radiation (γ-rays) produced during fission.
- The ***atomic bomb*** also operates on the principle described above, although without the elaborate control mechanisms.

20.10 Nuclear Fusion

- Nuclear Fusion is the fusing together of two or more light nuclei to form a heavier one, e.g. the fusion of two deuterium (hydrogen-2) atoms to produce one helium atom.
- Fusion is accompanied by the release of an enormous amount of heat energy, much more than is obtained with fission.
- Hydrogen fusion is believed to be responsible for the tremendous amount of heat energy released by the sun and the stars.
- The ***hydrogen bomb*** (*H*-bomb) produces energy through the fusion of hydrogen.
- The energy obtained from nuclear reactions (fission and fusion) is due to the fact that the mass of the products is always less than the mass of the reactants. The loss in mass (m) is converted to (heat) energy (E) in accordance with the *Einstein Equation*:

$$E = mc^2 \qquad (20.8)$$

where c is the velocity of light.

True or False - Type Questions

Answer ***True*** (T) or ***False*** (F) to the following questions.

1. a. Atoms of all elements are identical.
   b. Atoms of different elements have different atomic weights.
   c. An atom is made up of a nucleus and a number of electrons.
   d. The mass of an atom is concentrated in the nucleus.
   e. Mass number is the total number of protons and electrons.
   f. The nucleus of an atom is positively-charged.

g. Electrons move in orbits around the nucleus.
h. Electrons in orbits have discrete values of angular momentum.
i. Electrons emit discrete energy quanta as they move around their orbits.
j. Electrons emit discrete energy quanta as they jump from one orbit to another.
k. A large amount of energy is required to separate the particles in the nucleus of an atom.
l. The mass of a proton is approximately equal to that of an electron.

2. The isotopes of an element
a. have the same chemical properties, because they have the same number of electrons.
b. have the same number of protons.
c. can be separated physically.
d. have the same atomic number.
e. have the same nucleon number.
f. cannot be separated chemically because of their identical chemical properties.

3. a. All metallic surfaces emit the same number of photoelectrons under a given light.
b. A metallic surface emits photoelectrons only if the frequency of the incident light is higher than its own characteristic threshold frequency.
c. The energy of the emitted electron is independent of the work function of the surface.
d. The energy of the emitted electron depends on the wavelength of the incident light.
e. If the intensity of the incident light is doubled, the energy of the emitted electron is also doubled.
f. In photoelectric effect, high energy electrons impinge on a metallic surface which then emits photons.
g. The threshold frequency for photoelectric effect depends on the frequency of the incident light.
h. In thermionic emission, a metal absorbs light quanta and then emits electrons.

4. a. Natural radioactivity is a phenomenon exhibited by heavy nuclei only.
b. Both x-rays and γ-rays originate from the nucleus.
c. α, β, and γ-rays belong to the electromagnetic spectrum
d. γ-rays do not carry an electric charge.
e. The α-particle is deflected more than the β-particle in a magnetic field.
f. β-particles are much more easily absorbed than γ-rays.
g. The α-particle has approximately the same mass as the neutron.

5. a. Half-life may be defined as one-half of the life-time of a radioactive substance.
b. The activity of a radioactive substance depends on its age, purity and temperature.
c. For an α-decay, the atomic number decreases by two while the mass number remains unchanged.
d. When gamma rays are emitted from a radioactive nuclide, both the proton number and the neutron number remain unchanged.
e. In a nuclide which emits a beta particle, the proton number decreases by 1 while the neutron number remains unchanged.
f. When the nucleus of a uranium atom is split, the total mass of the products is equal to the mass of the parent nucleus.

Answers to True or False - Type Questions

1. a (F) Atoms of a given element are identical, but they are different from the atoms of any other element.
b (T)
c (T) The nucleus, which consists of protons and neutrons, is located at the centre and is orbited by electrons.
d (T) This is because the proton and the neutron are much more massive than the electron.
e (F) It is the total number of *protons* and *neutrons*. Note that the number of protons is equal to the number of electrons in a neutral atom.
f (T) Protons are positively - charged while neutrons are uncharged.
g (T)
h (T) Essentially, this means that an electron can only occupy a well-defined orbit in which its angular momentum does not change continuously.
i (F) An electron does not radiate energy as it moves round its orbit. However, energy is radiated if the electron jumps from a higher to a lower orbit.
j (T) See (i) above.
k (T) The particles in the nucleus are bound together by strong *nuclear forces*, and a large amount of energy is required to overcome these binding forces.
l (F) The proton has approximately the same mass as the *neutron* but both are much heavier than the electron.

2. a (T)
b (T) Isotopes have the same number of protons, the same number of electrons but different number of neutrons.

c. **(T)** Because isotopes have different atomic weights, they are separated using physical techniques, such as diffusion, which depend on the relative masses of the isotopes.

d. **(T)** See (b) above.

e. **(F)** Isotopes have different nucleon numbers because of the different number of neutrons contained in their nuclei.

f. **(T)**

3. a. **(F)** The number of photoelectrons emitted depends on the *work function* of the metal surface and the *intensity* of the light.

b. **(T)** The energy of the incident light ($E = hf$) must be greater than the work function ($W = hf_0$). Hence $f > f_0$

c. **(F)** Energy of the emitted electron is the difference between the energy of the incident light and the *work function*.

d. **(T)** See (c) above. Note that the energy of the incident light is hc/λ, where λ is the wavelength.

e. **(F)** Energy of the emitted electron does not depend on the intensity of the incident light.

f. **(F)** It is the impingement of photons on the metallic surface which results in the emission of electrons.

g. **(F)** The threshold frequency f_0, is a characteristic of the surface which is independent of the properties of the incident light.

h. **(F)** In thermionic emission, the emission of electrons is caused by the *heating* of the surface.

4. a. **(T)** Heavy nuclei, such as the uranium nucleus, are unstable and have a natural tendency to split into two smaller fragments.

b. **(F)** γ-rays are produced from the nucleus during radioactive disintegration but x - rays result from transitions of electrons from one energy level to another. (Note that electrons reside *outside* the nucleus).

c. **(F)** γ - rays are part of the electromagnetic spectrum but α - rays (*helium nuclei*) and β - rays (*stream of electrons*) are not.

d. **(T)**

e. **(F)** Although both particles, being charged, are deflected in a magnetic field, the α - particle is deflected *less* because of its much larger mass.

f. **(T)** γ-rays are the *most penetrating* of the radiations emerging from the nucleus.

g. **(F)** The α -particle being a helium nucleus (^4_2He) has two protons and two neutrons and is therefore approximately four times as heavy as the neutron.

5. a. **(F)** Half-life is the time taken for a radioactive substance to decay to one-half of its original quantity.

b. **(F)** The activity is the rate of disintegration and this depends on its age (which determines the amount presently in existence), its purity (which determines the actual amount of the radioactive substance present in the sample). It is independent of external parameters such as temperature.

c. **(F)** An α -decay involves the emission of ^4_2He. Hence the atomic number decreases by two while the mass number decreases by 4.

d. **(T)** This is because the gamma-ray ($^0_0\gamma$) has no protons or neutrons.

e. **(F)** Upon the emission of a beta particle ($^0_{-1}\beta$), the proton number *increases* by 1 while the nucleon number remains unchanged.

f. **(F)** The mass of the product is less than that of the parent nucleus, the difference being converted into (heat) energy.

SSCE/JME - Type Objective Questions

1. In addition to a neutron, which of the following particles also exists in the nucleus?
   A. An electron **B.** An α - particle
   C. A β - particle **D.** A proton

2. The number of neutrons in the uranium isotope $^{238}_{92}X$ is
   A. 330 **B.** 238 **C.** 146 **D.** 92

3. An atom which loses or gains a charge becomes
   A. a neutron **B.** an ion
   C. an electron **D.** a proton

4. The symbolic representation for an atom X with 33 electrons and 42 neutrons is
   A. $^{42}_{9}X$ **B.** $^{42}_{33}X$ **C.** $^{75}_{42}X$ **D.** $^{75}_{33}X$

5. The kinetic energy of a photoelectron ejected from a metal surface illuminated with radiation depends on the
   I. wavelength of the radiation.
   II. intensity of the radiation.
   III. source of the radiation.
   IV. nature of the surface.
   Which of the above statements is(are) correct?
   A. I only **B.** I and IV only
   C. II and III only **D.** I, II and IV only

6. The number of photoelectrons emitted from a metal surface depends on the

A. intensity of radiation
B. nature of the metal surface
C. source of radiation
D. duration of radiation

7. A beam of light falls on a metallic surface. The maximum kinetic energy of the photoelectrons depends on the
A. area of the metal surface
B. colour of the light
C. intensity of the light
D. duration of exposure to the light.

8. The threshold frequency for photoelectric effect depends on the
A. frequency of incident light
B. intensity of incident light
C. p.d. between the cathode and the anode
D. material of the photocathode.

9. A metal having a work function of 5.76 eV is illuminated with a radiation of 7.88 eV. The kinetic energy of the electrons emitted from the metal surface is
A. 2.12 eV B. 4.24 eV C. 6.82 eV D. 13.64 eV

10. Ultraviolet light has a wavelength of 400 nm. If the speed of light in air is 3×10^8 ms^{-1}, the frequency of ultraviolet radiation is
A. 7.5×10^{14} Hz B. 1.2×10^{11} Hz
C. 7.5×10^5 Hz D. 1.3×10^{-15} Hz

11. The energy associated with an x-ray of wavelength 9.0×10^{-10} m is [Planck's constant = 6.6×10^{-34} Js, velocity of light = 3.0×10^8 ms^{-1}]
A. 2.2×10^{-12} J B. 2.2×10^{-16} J
C. 1.1×10^{-16} J D. 2.2×10^{-24} J

12. The threshold frequency for a metal surface is 3.0×10^{14} Hz. If $h = 6.6 \times 10^{-34}$ Js, the worl function for the surface is
A. 4.54×10^{48} J B. 3.00×10^{14} J
C. 1.98×10^{-19} J D. 2.20×10^{-48} J

13. A metal has a work function of 4.4×10^{-19} J. If the speed of light in vacuum is 3.0×10^8 ms^{-1} and Planck's constant is 6.6×10^{-34} Js, the wavelength of its threshold frequency is
A. 5.0×10^{-24} m B. 4.5×10^{-7} m
C. 9.0×10^{-7} m D. 2.0×10^{23} m

14. An electron is accelerated from rest through a potential difference of 18.2 kV in vacuum. If electronic charge = 1.6×10^{-19} C and mass of electron = 9.1×10^{-31} kg, the maximum speed acquired by the electron is
A. 4.00×10^7 ms^{-1} B. 5.66×10^7 ms^{-1}
C. 8.00×10^7 ms^{-1} D. 1.13×10^8 ms^{-1}

15. In which of the following is the principle of photoelectric effect put into use ?
I. Photographic light meters
II. Activation of automatic doors
III. Setting off of burglary alarms
IV. Production of sound from film tracks
A. I and II only B. III and IV only
C. I, II and III only D. I, II, III and IV

16. Cathode rays
I. consist of tiny particles bearing negative electric charges
II. consist of fast-moving protons and are deflected in a magnetic field
III. are deflected in an electric field but not in a magnetic field
IV. can cause the emission of x- rays on hitting a metal target
Which of the above statements are correct?
A. I and II only B. III and IV only
C. I and IV only D. II and III only.

17. An atom in the *ground state* is said to be
A. grounded B. ionized
C. excited D. stable

18. Bright spectral lines obtained from atoms are due to
A. the kinetic energy of a moving atom
B. the potential energy of an electron inside the atom.
C. the drop of an electron from a higher to a lower energy level in the atom
D. the excitation of an electron from a lower to a higher energy level in the atom

19. 6.0×10^{-19} J of energy is radiated by an atom as an electron jumps from one level to another within the atom. If Planck's constant is 6.6×10^{-34} Js and the speed of light in vacuum is 3.0×10^8 ms^{-1}, the wavelength of the emitted radiation is
A. 1.65×10^{-7} m B. 3.30×10^{-7} m
C. 6.60×10^{-7} m D. 1.32×10^{-6} m

20. Of the underlisted elements, the best absorber of x-rays is
A. Lead B. Copper C. Calcium D. Hydrogen

21. X - rays cannot be used
A. to take photographs of bone structure in the body
B. to detect finger prints
C. to detect flaws in metal castings
D. to detect alterations to works of art

22. The one which is fundamentally different from the others in the following list is

A. x-rays B. γ-rays
C. infra-red rays D. cathode rays

23. The following are emitted in natural radioactivity
A. α-particles and β-rays only
B. α-particles, β-rays and x-rays
C. α-particles, β-rays and γ-rays
D. α-particles, β-rays, γ-rays and x-rays

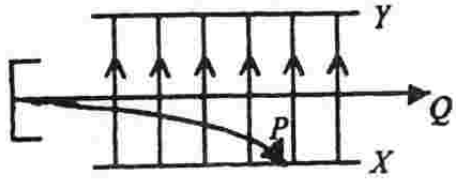
24. Of the following types of radiation, the one that does not originate from the nucleus is
A. alpha B. beta C. gamma D. x-rays

25. Which of the following radiations cannot be deflected by an electric field or a magnetic field ?
I. α-rays II. β-rays III. γ-rays IV. x-rays
A. I and II only B. III and IV only
C. I and III only D. II and IV only.

26. Of the radiations listed in question 25, the one that is *most strongly* deflected by a magnetic field is
A. I B. II C. III D. IV

27. Which of the following particles may be found in light nuclei?
I. protons II. neutrons
III. α-particles IV. β-particles
A. I and II only B. III and IV only
C. I and III only D. II and IV only.

28.



A beam of radiation passes through an electric field located between plates X and Y (see figure above). If P is deflected downwards while Q passes undeflected, then P and Q could be, respectively,
I. β-rays, γ-rays II. α-rays, γ-rays
III. β-rays, x-rays IV. α-rays, x-rays
Which of the above is (are) correct?
A. I only B. II only
C. I and III only D. II and IV only

29. Which of the following radiations will pass through a sheet of paper ?
I. Alpha rays II. Beta rays III. Gamma rays
A. I only B. II only
C. III only D. II and III only.

30. A radioactive sample initially contains n atoms. The number of atoms that would have disintegrated after four half-lives is
A. $n/16$ B. $n/8$ C. $7n/8$ D. $15n/16$

31. A radioactive sample of initial mass 80 g has a half-life of 3 years. Which of the following rows correctly gives the masses of the substance left at the times specified?

	3 yr	6 yr	9 yr
A.	40 g	20 g	10 g
B.	40 g	20 g	0 g
C.	40 g	0 g	
D.	80 g	40 g	10 g

32. An atom of $^{238}_{92}U$ undergoes eight α–decays and six β – decays. The final product has atomic and nucleon numbers of
A. 70, 206 B. 78, 222 C. 82, 206 D. 82, 222

33. A substance with a half-life of 5 minutes has a count rate of 500 after 15 minutes. The count rate at zero time was
A. 8,000 B. 4,000 C. 2,000 D. 250

34. A radioactive substance of initial mass 8 g has a half-life of 10 days. 7 g of the substance would have disintegrated after
A. 30 days B. 20 days C. 5 days D. $2^1/_2$ days

35. A radioactive material has an initial activity of 7000 counts per second and an activity of 875 counts per second after 6 hours. The half-life of the material is
A. 6 hr B. 3 hr C. 2 hr D. 1 hr

36. A sample of half-life 5 years presently weighs w newtons. Its weight in newtons 20 years ago was
A. $20w$ B. $16w$ C. $8w$ D. $4w$

37. $^{238}_{92}U$ undergoes an alpha decay to become thorium. The proton and nucleon numbers of thorium are respectively
A. 92, 237 B. 92, 235 C. 90, 238 D. 90, 234

38. A nucleus ^3_2He is formed by the decay of the nucleus ^3_1H. The decay is accompanied by the emission of
A. an alpha particle B. a beta particle
C. a gamma particle D. a neutron

39. The equation $^{140}_{54}X \longrightarrow {}^{140}_{55}Y + k$ + energy represents
A. α–decay B. β–decay
C. γ–decay D. photon emission

40. Two radioactive elements P and Q initially have the same mass. If their half-lives are 10 and 5 years, the

ratio of their masses (i.e. $P : Q$) after 20 years is
A. 4 : 1 B. 2 : 1 C. 1 : 2 D. 1 : 4

41. In the nuclear reaction $^{27}_{13}Al + ^{1}_{0}n \longrightarrow ^{24}_{11}Na + X$ the product denoted by X is
A. a proton B. a neutron
C. an alpha particle D. a gamma ray

42. An element X of atomic number 92 and nucleon number 238 emits an α–particle, a β–particle and γ–rays. The respective proton and nucleon numbers of the new element formed are
A. 92, 234 B. 91, 234 C. 90, 234 D. 89, 232

43. A radioactive element of decay constant λ has a half-life of
A. $\frac{ln\,2}{\lambda^2}$ B. $\frac{-ln\,2}{\lambda^2}$ C. $\frac{ln\,2}{\lambda}$ D. $\frac{2ln\,2}{\lambda^2}$

44. A radioactive substance with a half-life of 5 s has a decay constant of
A. 0.693 s^{-1} B. 0.347 s^{-1} C. 0.218 s^{-1} D. 0.139 s^{-1}

45. A deuterium ($^{2}_{1}H$) nucleus fuses with a tritium ($^{3}_{1}H$) nucleus to produce an α–particle and a second product X which is
A. a proton B. an electron
C. a neutron D. a gamma ray

46. What type of reaction is represented by the equation $^{2}_{1}X + ^{2}_{1}X \longrightarrow ^{3}_{2}Y + ^{1}_{0}n$ + energy ?
A. Fusion B. Fission C. Chain D. Ionization

47. If four protons each of mass M_p are fused to produce a nucleus X of mass M_X in a nuclear fision process, then
A. $M_p = M_X$ B. $4M_p > M_X$
C. $4M_p < M_X$ D. $4M_p = M_X$

48. The process by which protons are converted into helium atoms with a tremendous release of energy is called
A. thermionic emission B. nuclear fission
C. thermonuclear fusion D. photoelectric emission

49. Which of the following is not a product of nuclear fission?
A. x-ray B. γ-ray C. α-particle D. neutron

50. A uranium nucleus splits into two fragments of nearly equal masses. The total mass of the fragments is less than the mass of the original uranium nucleus. The difference in masses is accounted for by the
A. potential energy lost
B. kinetic energy lost
C. nuclear energy released
D. experimental error in the measurement of the masses

51. Which of the following is used to slow down fast-moving neutrons in a nuclear reactor ?
A. Concrete shield B. Carbon dioxide gas
C. Boron rods D. Graphite block

52. Which of the following is used to shield radiation fallouts?
A. Lead B. Wood C. Plastic D. Aluminium

53. In the radioactive series
$^{235}_{92}W \longrightarrow ^{235}_{93}X \longrightarrow ^{231}_{91}Y \longrightarrow ^{231}_{92}Z$
the particles emitted are respectively
A. α, α, β B. α, β, α C. β, β, α D. β, α, β

Answer Key

1. D	10. A	19. B	28. C	37. D	46. A
2. C	11. B	20. A	29. D	38. B	47. B
3. B	12. C	21. B	30. D	39. B	48. C
4. D	13. B	22. D	31. A	40. A	49. A
5. B	14. C	23. C	32. C	41. C	50. C
6. A	15. D	24. D	33. B	42. B	51. D
7. B	16. C	25. B	34. A	43. C	52. A
8. D	17. D	26. B	35. C	44. D	53. D
9. A	18. C	27. A	36. B	45. C	

Solutions to Objective Questions

1. **(D)** The electron moves in an orbit around the nucleus. Both α and β - particles are formed during nuclear disintegration.

2. **(C)** In the notation ${}^{A}_{Z}X$, the number of neutrons is $A - Z$.

3. **(B)**

4. **(D)** In the notation ${}^{A}_{Z}X$,
A = number of protons + number of neutrons
= number of electrons + number of neutrons.

5. **(B)** Kinetic energy of the photoelectrons is the *difference* between the *energy of the incident radiation* (which varies inversely with the wavelength) and the *work function* (which depends on the nature of the metal surface).

6. **(A)** The number of photoelectrons *increases* with radiation intensity.

7. **(B)** The *colour* of the light depends on its *frequency*, which determines the energy of the incident radiation.

8. **(D)** The threshold frequency f_o, is a characteristic of the emitting surface (photocathode) which determines the work function ($W = hf_o$)

9. **(A)** Kinetic energy = Energy of incident radiation – Work function = 7.88 – 5.76 = 2.12 eV

10. **(A)** Frequency $f = c/\lambda = (3 \times 10^8) / (400 \times 10^{-9})$
$= 7.5 \times 10^{14}$ Hz.

11. **(B)** Energy, $E = hc/\lambda$
$= (6.6 \times 10^{-34})(3.0 \times 10^8) / (9.0 \times 10^{-10}) = 2.2 \times 10^{-16}$ J

12. **(C)** Work function, $W = hf_o = (6.6 \times 10^{-34})(3.0 \times 10^{14})$
$= 1.98 \times 10^{-19}$ J

13. **(B)** $W = hf_o = hc/\lambda_o$
$\lambda_o = hc/W = (6.6 \times 10^{-34})(3 \times 10^8)/(4.4 \times 10^{-19})$
$= 4.5 \times 10^{-7}$m

14. **(C)** K.E. of electron = work done on the electron
$\Longrightarrow \frac{1}{2}mv^2$ = charge x p.d = $(1.6 \times 10^{-19})(18.2 \times 10^3)$ J
$v^2 = \frac{2(1.6 \times 10^{-19})(18.2 \times 10^3)}{(9.1 \times 10^{-31})} = 64 \times 10^{14}$,
or $v = 8 \times 10^7 \text{ms}^{-1}$

15. **(D)** All the devices listed make use of the *photocell*, which depends on the principle of photoelectric effect.

16. **(C)** Cathode rays, being fast-moving electrons, are deflected by magnetic, as well as electric fields.

17. **(D)** In the excited state, an electron in the atom is at a higher energy level above the ground state.

18. **(C)** The excitation of electrons from lower to higher energy levels will result in *dark* spectral lines as energy is *absorbed*.

19. **(B)** Energy of emitted radiation, $E = hc/\lambda$
$\lambda = hc/E = (6.6 \times 10^{-34})(3.0 \times 10^8) / (6.0 \times 10^{-19})$
$= 3.3 \times 10^{-7}$m

20. **(A)** Lead, being the *densest*, is the best absorber of x-rays.

21. **(B)** Finger prints are transparent to x-rays.

22. **(D)** All, except cathode rays are *electromagnetic waves*.

23. **(C)** X-rays are not produced during natural radioactive decay.

24. **(D)** α, β and γ rays are produced during the disintegration of the nucleus. However, x-rays result from electron movements from higher to lower energy levels in metals. (Note that electrons do **not** reside inside the nucleus).

25. **(B)** γ-rays and x-rays, being uncharged, *cannot* be deflected by electric or magnetic fields.

26. **(B)** β-rays, being much lighter than α-rays, are more easily deflected by electric or magnetic fields.

27. **(A)** Protons and neutrons are found in all nuclei except hydrogen, which contains only a proton. α- and β - particles are produced during the disintegration of certain heavy nuclei.

28. **(C)** Since the electric field is directed upwards from plate X to Y, then X must be positive and Y negative. Hence P must be negatively-charged (β -rays) while Q is uncharged (γ - rays or x - rays)

29. **(D)** Beta rays will penetrate a few *millimetres of alu-*

minium while gamma rays will penetrate a few *centimetres of lead*. The order of penetrating power is gamma (most penetrating), beta and alpha (least penetrating).

30. **(D)** We can write $n \longrightarrow n/2 \longrightarrow n/4 \longrightarrow n/8 \longrightarrow n/16$, where each arrow represents one half-life. After four half-lives, $n/16$ atoms would be left $\Longrightarrow 15n/16$ atoms would have decayed.

31. **(A)** The mass of the sample reduces by half after every 3 years. Hence it is 40 g after 3 years, 20 g after a further 3 years and 10 g after the third 3 years.

32. **(C)** We can write ${}^{238}_{92}U \longrightarrow 8({}^{4}_{2}He) + 6({}^{0}_{-1}\beta) + {}^{b}_{a}X$
For nucleons: $238 = (8 \times 4) + 0 + b$, or $b = 206$
For protons: $92 = (8 \times 2) + (6 \times -1) + a$, or $a = 82$

33. **(B)** After 15 min, count rate is 500
After 10 min, count rate was 1,000
After 5 min, count rate was 2,000
At zero time, count rate was 4,000

34. **(A)** From 8 g $\longrightarrow$ 4 g $\longrightarrow$ 2 g $\longrightarrow$ 1 g, it will take three half-lives, or 30 days, to reduce the mass of the substance to 1 g, i.e. for 7 g to have decayed.

35. **(C)** $7000 \longrightarrow 3500 \longrightarrow 1750 \longrightarrow 875$. It takes 3 half-lives or 6 hours for the count rate to decrease from 7,000 to 875. Hence one half-life is 6/3, or 2 hours.

36. **(B)** 5 years ago the weight was $2w$
10 years ago the weight was $4w$
15 years ago the weight was $8w$
20 years ago the weight was $16w$

37. **(D)** During an alpha decay, the nucleon number decreases by 4 and the proton number by 2. The new element is thus ${}^{234}_{90}Th$ with proton and nucleon numbers 90 and 234 respectively.

38. **(B)** ${}^{3}_{1}H \longrightarrow {}^{3}_{2}H + {}^{b}_{a}X$
From the equation, $b = 0$ and $a = -1$
$\Longrightarrow X$ is ${}^{0}_{-1}\beta$, or a beta particle.

39. **(B)** We can write the equation as
${}^{140}_{54}X \longrightarrow {}^{140}_{55}Y + {}^{b}_{a}Z$ + energy.
Hence $b = 0$ and $a = -1$, i.e. Z is ${}^{0}_{-1}\beta$

40. **(A)** If m = initial mass of P and Q,
After 20 years, we have for $P : m \longrightarrow m/2 \longrightarrow m/4$
and for $Q : m \longrightarrow m/2 \longrightarrow m/4 \longrightarrow m/8 \longrightarrow m/16$
Ratio of the masses of P to Q is $m/4 : m/16$, or $4 : 1$.

41. **(C)** ${}^{27}_{13}Al + {}^{1}_{0}n \longrightarrow {}^{24}_{11}Na + {}^{b}_{a}X$
$\Longrightarrow 27 + 1 = 24 + b$, or $b = 4$
and $13 + 0 = 11 + a$, or $a = 2$
Hence X is an alpha particle, ${}^{4}_{2}He$.

42. **(B)** ${}^{238}_{92}X \longrightarrow {}^{4}_{2}He + {}^{0}_{-1}\beta + {}^{0}_{0}\gamma + {}^{b}_{a}Y$
The element Y has $a = 91$ and $b = 234$

43. **(C)** See revision notes.

44. **(D)** $\lambda = \dfrac{\ln 2}{t_{1/2}} = \dfrac{0.693}{5} = 0.139\ s^{-1}$

45. **(C)** ${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{b}_{a}X$
$2 + 3 = 4 + b$, or $b = 1$
$1 + 1 = 2 + a$, or $a = 0$
$\Longrightarrow X$ is ${}^{1}_{0}n$, a neutron.

46. **(A)** The equation represents the *fusion* of two nuclei (${}^{2}_{1}X$) to form a new nucleus (${}^{3}_{2}Y$) and a neutron. Energy is released in the process.

47. **(B)** Mass of the product (M_χ) is less than the total mass of the reactants ($4M_p$), the balance being converted into energy.

48. **(C)** This is represented by the equation
${}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{4}_{2}He$ + energy

49. **(A)** X-rays are not produced during nuclear fission.

50. **(C)** The difference between the masses of the parent nucleus and the products represents the nuclear energy released in the form of heat.

51. **(D)** The graphite acts as a *moderator* (see revision notes).

52. **(A)** Lead, because of its ability to absorb the highly-penetrating gamma radiation.

53. **(D)** From W to X, the atomic number increases by 1, hence a β-particle is emitted. From X to Y, the atomic number decreases by 2 and the mass number decreases by 4 $\Rightarrow$ an α-particle is emitted. From Y to Z, the atomic number increases by 1 $\Rightarrow$ a β-particle is emitted.

Revision Check-list

At the end of this chapter, the candidate should be able to

- describe the structure of an atom.
- explain the phenomenon of *thermionic emission*.
- explain the various methods of producing a beam of electrons.
- explain the *photoelectric effect* and its applications.
- define the terms *threshold energy* and *work function* of a metal.
- apply *Einstein's photoelectric equation* to simple numerical problems on the photoelectric effect.
- explain the sources of *emission and absorption spectra* in atoms.
- explain the production of *x-rays*.
- list the energy transformations occurring during the operation of an x-ray tube.
- state the properties and uses of x-rays.
- define *atomic number*, *nucleon number* and *isotope*.
- explain the nature of *alpha*, *beta* and *gamma* radiations.
- write balanced equations involving simple types of radioactive decay.
- explain the terms *half-life*, *decay constant* and *isotope*.
- list the uses of *radioisotopes*.
- explain the phenomena of a *nuclear fission* and *fusion* and state their relative merits and demerits.
- explain the operation of a *nuclear reactor*.
- list common radiation hazards and their prevention methods.

Model Matriculation Examination 1

1. The expression $M^a L^b T^c$, when $a = 1$, $b = 2$ and $c = -2$ is the dimension of
   A. Force B. Energy C. Acceleration D. Power

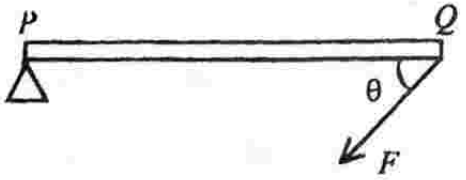
2. The most suitable instrument for measuring the diameter of a thin wire accurately is
   A. a metre rule
   B. a pair of vernier callipers
   C. a micrometer screw gauge
   D. a ruler

3. A body accelerated uniformly from rest covers a distance of 8 m in 2 seconds. The distance covered in the third second is
   A. 18 m B. 12 m C. 10 m D. 4 m

4. A stone P of mass 20 g is projected horizontally from the top of a tall building. At the same instant, a second stone Q of mass 40 g is dropped from the same position so that it falls freely under gravity. Neglecting air resistance,
   A. P will reach the ground first because it has a smaller mass
   B. Q will reach the ground first because it has a bigger mass
   C. Q will reach the ground first because it has no horizontal component of motion
   D. Both P and Q will reach the ground at the same instant.

5. A crate which is pulled up a smooth inclined plane with a force F moves up the plane with an acceleration of a. If F is doubled, the acceleration
   A. is doubled B. remains the same
   C. is more than doubled D. is less than doubled.

6. A simple pendulum makes 90 oscillations in one minute on the earth's surface. The number of oscillations per minute which the same pendulum will execute at an altitude where the acceleration due to gravity is 81 percent of its value on earth is
   A. 73 B. 81 C. 100 D. 111

7. 

   A force is applied at the end Q to a bar PQ pivoted at P (see diagram). The torque produced by the force F about the pivot is greatest when θ is
   A. zero B. 45° C. 90° D. 180°

8. A horizontal force of 12 N is applied to a body of mass 10 kg which rests on a horizontal surface of coefficient of friction 0.1. The body will
   A. accelerate
   B. remain at rest
   C. move with uniform speed
   D. first accelerate, and then move with uniform speed.

9. A lift of weight 30 kN moves upwards through height of 20 m. If 25% of the work done on the lift is used in overcoming friction, the work done is
   A. 4.5×10^5 J B. 6.0×10^5 J
   C. 7.5×10^5 J D. 8.0×10^5 J

10. Two masses separated by a distance d attract each other with a gravitational force of 12 N. If the separation between the masses is reduced to $d/2$, the gravitational force will
    A. increase to 48 N B. increase to 24 N
    C. decrease to 6 N D. decrease to 3 N

11. A weight of 500 N is pushed up a platform inclined at 30° to the horizontal. If the efficiency of the plane is 60%, the effort needed to push the weight up the platform is
    A. 300 N B. 417 N C. 833 N D. 1,667 N

12. A metal rod of diameter 7 mm and length 100 mm is made from steel of Young's modulus 2×10^{11} Nm^{-2}. The force constant for the rod is
    A. 7.7×10^7 Nm^{-1} B. 3.5×10^7 Nm^{-1}
    C. 2.8×10^7 Nm-1 D. 7.7×10^6 Nm^{-1}

13. The pressure on a diver is 1.5×10^7 Nm^{-1}. Taking the density of water as 10^3 kgm^{-3}, the depth of the diver below the water surface is
    A. 150 m B. 200 m C. 1,500 m D. 15,000 m

14. An object floats in water with 90% of its volume submerged and in a liquid L with 60% of its volume submerged. The relative density of L is
    A. 0.54 B. 0.67 C. 1.20 D. 1.50

15. The net downward force on a metal ball falling through a liquid at the terminal velocity is
    A. zero B. its weight
    C. the viscous force D. the upthrust

16. A change in temperature of 45°C is equivalent to a change in temperature on the Kelvin scale of
    A. 25 K B. 45 K C. 81 K D. 318 K

17. One advantage of alcohol over mercury as a thermome-

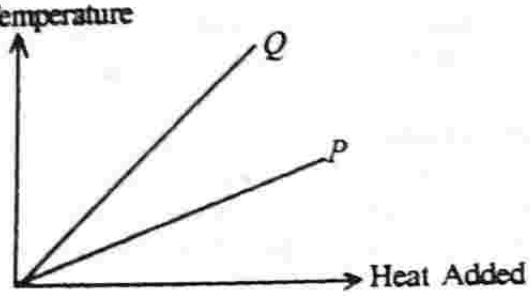
metric fluid is that alcohol
A. expands more uniformly than mercury
B. is a better conductor of heat than mercury
C. has a lower freezing point than mercury
D. has a lower specific heat capacity than mercury

18. As water is cooled from 10° C to 2° C, its density
A. increases
B. decreases
C. first decreases and then increases
D. first increases and then decreases

19. A metal ring of diameter 2.0000 cm is to be fitted on a rod of diameter 2.0002 cm by heating the ring through a temperature rise of θ. If the coefficient of linear expansion of the metal is 1.25×10^{-5} K^{-1}, the minimum value of θ is
A. 4°C B. 8°C C. 16°C D. 25°C

20. Ice at 0° C is added to 10 kg of water at 50 °C. If the final temperature of the water is 30° C, the mass of the ice added is
A. 1.8 kg B. 2.7 kg C. 4.5 kg D. 6.7 kg
[Specific heat capacity of water = 4,200 Jkg^{-1} $°C^{-1}$ and specific latent heat of fusion of ice = 336,000 Jkg^{-1}]

21. Temperature



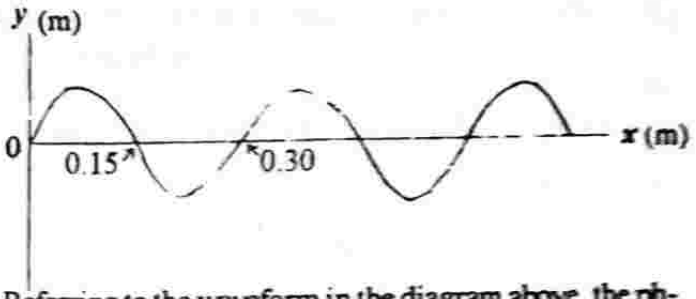
The changes in temperature as heat is added to equal masses of two substances *P* and *Q* are indicated in the diagram above. From the diagram, it can be deduced that the
I. specific heat of *Q* is greater than that of *P*
II. specific heat of *P* is greater than that of *Q*
III. thermal capacity of *P* is greater than that of *Q*
IV. latent heat of fusion of *Q* is greater than that of *P*
Which of the above statements is(are) correct?
A. I only B. II only
C. II and III only D. I and IV only

22. When water condenses on the surface of a cup of cold water placed on a table, the temperature of the surrounding air
A. decreases slightly
B. increases slightly
C. remains unchanged
D. first decreases and then increases.

23. Which of the following emit(s) radiant heat energy?
I. A forest fire II. The human body
III. Ice cubes placed on a table IV. The walls of a room
A. I only B. I and II only
C. I, II and IV only D. I, II, III and IV.

24. A fixed mass of gas is compressed isothermally until its volume is appreciably reduced. Which of the following statements is (are) correct about the gas?
I. The average kinetic energy of its molecules is increased
II. The rate of molecular collisions is increased.
III. The average inter-molecular spacing is reduced
A. II only B. I and II only
C. II and III only D. I, II and III

25.



Referring to the waveform in the diagram above the phase difference between any two points which are 1.20 m apart is
A. zero B. π/2 C. π D. 3π/2

26. A wave is represented by the equation $y = 0.10\sin(5\pi x - 300t)$, where *x* and *y* are in m, and *t* is in s. The frequency of the wave is
A. 30/π Hz B. 60/π Hz C. 150/π Hz D. 300/π Hz

27. A student attempts to estimate the speed of sound in air by dropping a stone into an 80 m deep well. He heard the sound of the stone's splash in the water 4.25 s after its release. If $g = 10$ ms^{-2}, the estimated speed of sound in air in ms^{-1} is
A. 320 B. 330 C. 335 D. 340

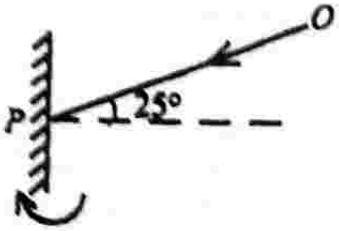
28. The speed of sound is *independent* of the
I. temperature II. pressure III. transmitting medium
Which of the above is(are) correct ?
A. I only B. II only
C. I and III only D. II and III only

29. A closed organ pipe and an open organ pipe emit notes of the same pitch. The ratio of the length of the air column in the closed pipe to that of the open pipe is
A. 1 : 4 B. 1 : 2 C. 1 : 1 D. 2 : 1

30. Beats of frequency 6 Hz are produced by two tuning forks sounded close together. If one of the forks has a frequency of 500 Hz, which of the following could be the frequency of the other fork?

I. 3,000 Hz II. 494 Hz III. 506 Hz
A. I only B. II only C. III only D. II and III only

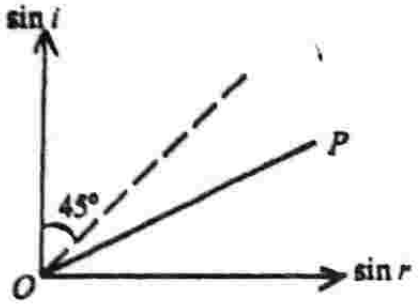
31.



A ray OP is incident at an angle of 25° on a plane mirror as shown in the diagram above. If the mirror is turned through 40° in the direction indicated, the angle between the incident ray and the new reflected ray is
A. 50° B. 80° C. 105° D. 130°

32. An object is placed at a distance of 15 cm from a concave mirror of focal length 10 cm. The distance between the object and its image is
A. 15 cm B. 30 cm C. 45 cm D. infinite

33.



The diagram above shows the plot (line OP) of the sine of the angle of incidence (i) against the sine of the angle of refraction (r) for a ray of light which passes from a medium X to a medium Y. If water and glass have refractive indices of 1.33 and 1.50 respectively, which of the following statements could be true?
I. X is air and Y is glass
II. X is glass and Y is water
III. X is water and Y is air
IV. X is water and Y is glass
A. I and IV only B. II and III only
C. I, III and IV only D. II, III and IV only

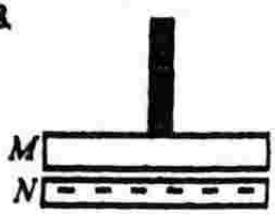
34. A converging lens of focal length 25 cm is used to produce an image of a candle on a screen. If the height of the image is five times that of the candle, the distance between the lens and the screen is
A. 30 cm B. 120 cm C. 150 cm D. 180 cm

35. Which of the following may produce a virtual image?
I. Convex mirror II. Concave mirror
III. Convex lens IV. Concave lens
A. I and IV only B. I and III only
C. I, II and IV only D. I, II, III and IV.

36. Light waves of different frequencies will have different
A. speeds B. amplitudes C. colours D. intensities

37. When light from air crosses into a transparent medium, its speed decreases by 40%. The refractive index of the medium is
A. 1.40 B. 1.50 C. 1.67 D. 2.50

38.



A metal disk M with an insulating handle is brought very close to a negatively charged flat disk N (see diagram). If M is momentarily earthed and then moved away from N,
A. M becomes positively charged
B. M becomes negatively charged
C. The net charge on M is zero
D. The negative charge on N is completely transferred to M

39. Two point charges which are spaced a distance d apart, repel each other with a force of 8×10^{-5} N. If the distance between the two charges is increased to $2d$, the force of repulsion between them is
A. 3.2×10^{-4} N B. 1.6×10^{-4} N
C. 4.0×10^{-5} N D. 2.0×10^{-5} N

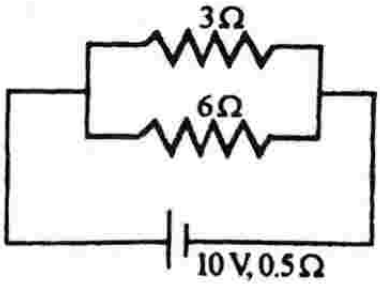
40. Which of the following capacitances cannot be obtained frsom a combination of three 2 μF capacitors?
A. 6 μF B. 3 μF C. $1\frac{1}{3}$ μF D. 1 μF

41. For a wire of a specified material, which of the following will give the lowest resistance in a circuit?
A. A short, thin wire B. A long, thin wire
C. A short, thick wire D. A long, thick wire

42. If Ohm's law is written as $I = kV$, the proportionality constant k is the
A. resistance B. conductance
C. resistivity D. conductivity

43. A lamp X is connected across a battery. If a second (identical) lamp Y is now connected in parallel with X,
A. X will become brighter
B. X will become dimmer
C. the brightness of X will remain unchanged
D. the lamps will not glow due to a short circuit

44.



The power dissipated in the 6 Ω resistor in the circuit diagram above is
A. 10.7 W B. 13.3 W C. 21.3 W D. 96.0 W

45. The horizontal component of the earth's magnetic field is
I. zero at the magnetic equator
II. zero at the magnetic poles
III. maximum at the magnetic equator
IV. maximum at the magnetic poles
Which of the above statements is (are) correct?
A. I only B. II only
C. II and III only D. I and IV only

46. During electrolysis, electric charge is transported through the electrolyte by
A. positive ions B. free electrons
C. negative ions D. positive and negative ions

47. An A.C. supply whose voltage is represented by the equation $V = 50 \sin 100\pi t$ is connected to a circuit of impedance 12.5 Ω. An ammeter connected to the supply will indicate a current of
A. 2.0 A B. 2.8 A C. 4.0 A D. 5.6 A

48. A coil of resistance 3 Ω has an inductive reactance of 4 Ω. The power dissipated in the coil when connected to an AC supply of 50 V rms is
A. 300 W B. 400 W C. 500 W D. 633 W

49. A metallic surface exposed to radiation of certain frequency f emits photoelectrons. If the surface is exposed to radiation of frequency $2f$, the maximum kinetic energy of the photoelectrons emitted will
A. be doubled B. be halved
C. remain unchanged D. increase but not exactly doubled

50. The following radiations are electrically neutral EXCEPT
A. α-rays B. γ-rays C. x-rays D. neutrons

Answer Key

1. B	10. A	19. B	28. B	37. C	46. D
2. C	11. B	20. A	29. B	38. A	47. B
3. C	12. A	21. C	30. D	39. D	48. A
4. D	13. C	22. B	31. D	40. D	49. D
5. C	14. D	23. D	32. A	41. C	50. A
6. B	15. A	24. C	33. B	42. B	
7. C	16. B	25. A	34. C	43. C	
8. A	17. C	26. C	35. D	44. A	
9. D	18. D	27. A	36. C	45. C	

Solutions To Model Matriculation Examination 1

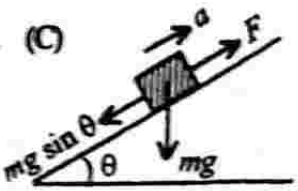
1. (B) $ML^2T^{-2} = [M][LT^{-2}][L]$ = [Mass x Acceleration x Distance] = [Force x Distance] = [Work] or [Energy].

2. (C) Since the wire is *thin*, a micrometer screw gauge which is capable of measurements to the nearest 0.001cm is most suitable.

3. (C) $s = \frac{1}{2}at^2$. At $t = 2$ s, $s = 8$ m
$8 = \frac{1}{2}a(2)^2$, or $a = 4$ ms^{-2}
At $t = 3$ s, $s = \frac{1}{2}(4)(3)^2 = 18$ m
Distance covered in the third second = 18 m - 8 m = 10 m.

4. (D) The stone (P) projected horizontally has a vertical component of motion which is equivalent to free fall under gravity, or the same vertical motion as stone (Q). Since they were released at the same height (h) and $h = \frac{1}{2}gt^2$, the time to reach the ground is the same and is independent of the mass of each stone.

5. (C)



Applying Newton's second law to the crate (see diagram) $F - mg\sin\theta = ma_1$, or $a_1 = \frac{F - mg\sin\theta}{m}$

If F is doubled, the new acceleration is

$$a_2 = \frac{2F - mg\sin\theta}{m}$$

$$\frac{a_2}{a_1} = \frac{2F - mg\sin\theta}{F - mg\sin\theta} = \frac{2(F - mg\sin\theta)}{F - mg\sin\theta} + \frac{mg\sin\theta}{F - mg\sin\theta}$$

$$= 2 + \frac{mg\sin\theta}{F - mg\sin\theta}. \quad \text{Hence } a_2 > 2a_1$$

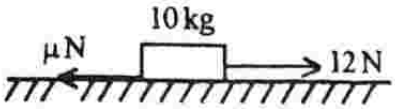
6. **(B)** $f_1 = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$ on the earth's surface.

$f_2 = \frac{1}{2\pi}\sqrt{\frac{0.81g}{L}} = 0.9 f_1$ at the altitude.

Hence $f_2 = 0.9 \times 90 = 81$ oscillations per minute.

7. **(C)** If L = length of PQ
Torque about $P = L(F\sin\theta) = FL\sin\theta$
This is maximum when $\sin\theta = 1$, or $\theta = 90°$.

8. **(A)**



Limiting frictional force $= \mu mg = 0.1(10)(10) = 10$ N
Under an applied force of 12 N, a net force of 2 N acts on the body and causes it to accelerate. [If the applied force is less than 10 N, the body will remain at rest].

9. **(D)** Work done in moving lift = weight x height moved
$= (30 \times 10^3)(20) = 6 \times 10^5$ J
The work represents 75% of the total work done on the lift. Hence work done $= 6 \times 10^5 / 0.75 = 8 \times 10^5$ J.

10. **(A)** $F_g = Gm_1m_2/d^2 = 12$ N. With the distance between the bodies reduced to $d/2$, the new gravitational force of attraction $= \frac{Gm_1m_2}{(d/2)^2} = \frac{4Gm_1m_2}{d^2} = 4F_g$
$= 4 \times 12 = 48$ N

11. **(B)** V.R. $= L/h = 1/\sin 30° = 2$
M.A. = Efficiency x V.R. $= 0.60 \times 2 = 1.20$
Effort = Load/ M.A. $= 500/1.2 = 417$ N.

12. **(A)** $\frac{F}{A} = \frac{Ex}{L}$, or $F = \frac{EA}{L}x = kx$
Hence $k = EA/L$
$A = \frac{\pi d^2}{4} = \frac{22(7 \times 10^{-3})^2}{7 \times 4} = \frac{77 \times 10^{-6}\ \text{m}^2}{2}$
$k = (2 \times 10^{11})(77/2 \times 10^{-6})/0.10 = 7.7 \times 10^7\ \text{Nm}^{-1}$.

13. **(C)** Pressure $= hdg$
$1.5 \times 10^7 = h(10^3)(10)$, or $h = 1.5 \times 10^3$ m.

14. **(D)** Let V = volume of object, and d_w, d_L = densities of water and liquid L respectively.
Mass of water displaced $= 0.9V \times d_w$ = mass of object
Mass of L displaced $= 0.6V \times d_L$ = mass of object
Hence $0.9Vd_w = 0.6Vd_L$, or $d_L/d_w = 0.9/0.6 = 1.50$.

15. **(A)** There is no net force on the ball, since it falls with a *constant* (terminal) velocity.

16. **(B)** A division on the Celsius scale (1 Celsius degree) is equal to a division on the Kelvin scale (1 Kelvin degree).

17. **(C)** Alcohol freezes at -115° C and mercury at -39° C. Hence the alcohol thermometer can be used for measuring temperatures lower than -39° C. Note that mercury actually expands more uniformly and is a better conductor of heat than alcohol. Furthermore, mercury has a lower specific heat capacity than alcohol.

18. **(D)** Water has its maximum density at 4° C. As it is cooled from 10° C its density *increases* until the temperature drops to 4° C. Cooling past 4° C results in a *decrease* in density.

19. **(B)** The diameter of the metal ring must increase to 2.0002 cm for it to fit on the rod. Change in diameter is
0.0002 = Original dia. x α x θ,
or $\theta = \frac{0.0002}{2(1.25 \times 10^{-5})} = 8°$C

20. **(A)** Heat gained by the ice $= m_iL_f + m_ic_i(30 - 0)$
$= 336{,}000m_i + (4{,}200 \times 30)m_i = 462{,}000\,m_i$ (J)
Heat lost by water $= 10(4200)(50 - 30) = 840{,}000$ J
$462{,}000m_i = 840{,}000$, or $m_i = 1.8$ kg

21. **(C)** Heat added = mass x specific heat x temp. change
Temp. change $= \frac{\text{Heat added}}{\text{mass x specific heat}} = \frac{\text{Heat added}}{\text{thermal capacity}}$
For any given value of heat added (see figure), P shows a lower temperature change and therefore has higher specific heat and higher thermal capacity.

22. **(B)** As the water condenses, heat of vaporization is *evolved*, which warms the surrounding air. Note that this is the exact opposite of the process of evaporation resulting in the cooling of the surroundings.

23. **(D)** All surfaces with temperature greater than *absolute zero* emit radiant heat.

24. **(C)** Since the gas is compressed *isothermally* (i.e. at constant temperature) the average k.e. of its molecules remains constant. However, the molecules are packed into a smaller space after compression, hence both the average spacing between molecules and the number of molecular collisions per unit time increase.

25. **(A)** Wavelength, $\lambda = 0.30$ m. The phase difference required is zero since 1.20 m is an integral number of wavelengths (1.20/0.30 = 4)

26. **(C)** $y = 0.10\sin[5\pi x - 300t] = A\sin\left[\frac{2\pi x}{\lambda} - \frac{2\pi vt}{\lambda}\right]$
$2\pi v/\lambda = 300$, $f = v/\lambda = 300/2\pi = 150/\pi$ Hz

27. **(A)** Using the equation of motion $s = \frac{1}{2}gt^2$, the time taken for the stone to reach the water is $\sqrt{2s/g} = 160/10 = 4$ s. Hence it takes 0.25 s for the sound to travel back to the student. Speed of sound = distance/time = 80/0.25 = 320 ms^{-1}.

28. **(B)** Speed of sound *increases* with temperature and also varies from one medium (i.e. water) to another (e.g. air).

29. **(B)** $L_c = \lambda/4$ for closed pipe, and $L_o = \lambda/2$ for open pipe. $\lambda = 4L_c = 2L_o$ (same pitch means same frequency and wavelength) $\Longrightarrow L_c/L_o = 2/4 = 1/2$.

30. **(D)** Frequency of beats = difference between the two frequencies. Beats of frequency 6 Hz will be produced if the other tuning fork has a frequency of 494 Hz or 506 Hz.

31. **(D)** As the mirror is rotated through 40° in the direction indicated, the new angle of incidence is 25° + 40° = 65° = new angle of reflection. Angle between incident and reflected rays = 65°+ 65°= 130°

32. **(A)** $u = 15$ cm, $f = +10$ cm
$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} \Rightarrow \frac{1}{10} - \frac{1}{15} = \frac{1}{30}$, or $v = 30$ cm
Since v is positive, the image is located at 30 cm *in front of* the mirror. Distance between the object and its image is 30 - 15, or 15 cm.

33. **(B)** From the diagram $\sin i/\sin r$ is less than 1 since the line *OP* is inclined at *less than* 45° to the horizontal. Hence the light ray must be passing from a denser to a rarer medium, e.g. glass to water or water to air.

34. **(C)** For a magnification of 5, $v = 5u$
$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{5u} + \frac{1}{u} = \frac{1}{25}$
$6/5u = 1/25$, or $u = 30$ cm
$v = 5u = 150$ cm

35. **(D)** A virtual image may be produced by any of the mirrors or lenses depending on the position of the object. However real images can be produced only by a concave mirror or a convex lens.

36. **(C)** All electromagnetic waves travel with the same speed. The amplitude and intensity have nothing to do with the frequency.

37. **(C)** Refractive index $= \frac{\text{velocity of light in air}}{\text{velocity of light in the medium}}$
$= \frac{v}{0.6v} = 1.67$

38. **(A)** As the disk *M* is brought close to the negatively-charged disk *N*, electrons are repelled to the upper surface of *M* while its lower surface becomes positively-charged. Upon earthing, the electrons flow to the earth, resulting in a net positive charge on M. This is the principle of the *electrophorus*.

39. **(D)** $F_1 = Kq_1q_2/d^2$
$F_2 = kq_1q_2/(2d)^2 = kq_1q_2/4d^2 = F_1/4$
$= 8 \times 10^{-4}/4 = 2 \times 10^{-4}$ N

40. **(D)** The effective capacitance is 6 μF if all three capacitors are connected in parallel, $1^1/_3$ μF if two parallel capacitors are connected in series with the third capacitor. If all three capacitors are connected in series, the equivalent capacitance is $^2/_3$ μF.

41. **(C)** From the equation $R = \rho L/A$, the resistance decreases as L decreases (short wire) or as A increases (thick wire).

42. **(B)** Ohm's law is $V = IR$, or $I = V/R$
Hence $k = 1/R$ = conductance.

43. **(C)** The brightness of each lamp depends on the current drawn. The current drawn by *X* is equal to battery voltage/lamp resistance, which is the same before and after connecting *Y*. [What happens if the lamps are connected in series?]

44. **(A)** Effective resistance of the 3 Ω and 6 Ω resistors in parallel is (6 x 3)(6 + 3) = 2 Ω. Current delivered by the battery, $I = E/(R + r) = 10/(2 + 0.5) = 4$ A. This current is partitioned in the ratio 1: 2 in the 6 Ω and 3 Ω resistors. Current through the 6 Ω resistor = 1/3 x 4 = 4/3 A. Power dissipated in 6 Ω resistor = $(4/3)^2(6) = 10.7$ W

45. **(C)** The earth's magnetic field is completely horizontal on the magnetic equator and completely vertical at the magnetic poles.

46. **(D)** Electric charge is transported by ions in the electrolyte, and by free electrons in the external circuit.

47. **(B)** $V_{rms} = 50/\sqrt{2}$ V. The current indicated by the ammeter is the *rms* current = *rms* voltage/impedance
$= \frac{50/\sqrt{2}}{12.5} = 4/\sqrt{2} = 2\sqrt{2} = 2.8$ A

48. **(A)** Coil impedance, $Z = \sqrt{R^2 + X^2} = \sqrt{3^2 + 4^2} = 5\,\Omega$
$I = V/Z = 50/5 = 10$ A
Power dissipated $= I^2R = 100\,(3) = 300$ W
[Note that power is dissipated *only* in the resistor in an R - L - C circuit].
[Alternatively: $\cos\phi = R/Z = 3/5$
Power $= IV\cos\phi = (10)(5)(3/5) = 300$ W.]

49. **(D)** K.E. of the photoelectrons under a radiation of frequency f is $E_1 = hf - W$
Under a radiation of frequency $2f$
$E_2 = 2hf - W = 2(hf - W) + W = 2E_1 + W$
i.e. E_2 is more than twice E_1

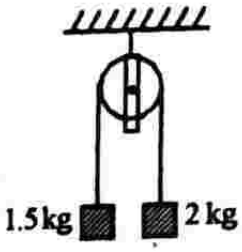
50. **(A)** α- rays are *positively - charged* helium nuclei. All the others bear no electric charge.

Model Matriculation Examination 2

1. A spring balance measures
   I. the mass of the body hung on it
   II. the earth's gravitational pull on the body hung on it
   III. the weight of the body hung on it.
   Which of the above statements is (are) correct?
   A. I only B. III only
   C. II and III only D. I, II and III

2. An aircraft travelled from a point X to a point Y 100 km away in the N 45° E direction. It then travelled westwards to a point Z which is N 45° W from X. The distance of the aircraft from X is
   A. 50 km B. $100/\sqrt{2}$ km C. 100 km D. $100\sqrt{2}$ km

3. A body initially at rest falls freely under gravity. If $g = 10\ ms^{-2}$, the distance covered by the body in the fourth second of fall is
   A. 35 m B. 40 m C. 45 m D. 80 m

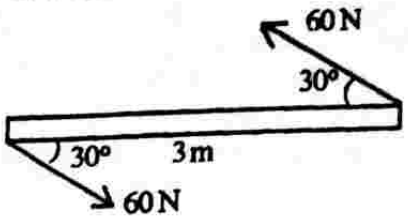
4. 

   Two masses 2 kg and 1.5 kg are tied to the ends of a light inextensible string which passes over a smooth light pulley which is fixed to the ceiling as shown in the diagram. The acceleration of the 2 kg mass is ($g = 10\ ms^{-2}$)
   A. $10.00\ ms^{-2}$ B. $5.71\ ms^{-2}$ C. $4.29\ ms^{-2}$ D. $1.43\ ms^{-2}$

5. An automobile travelling at a speed of $20\ ms^{-1}$ is brought uniformly to a halt in 10 seconds when a braking force of 5 kN is applied. The mass of the automobile is
   A. 1,000 kg B. 1,500 kg C. 2,000 kg D. 2,500 kg

6. The centripetal acceleration of an object moving at constant speed around a circular path is
   I. directly proportional to the speed of the object
   II. directly proportional to the mass of the object
   III. directly proportional to the square of the speed of the object
   IV. inversely proportional to the radius of the circular path.
   Which of the above statements are correct?
   A. I and II only B. II, III and IV only
   C. III and IV only D. II and III only

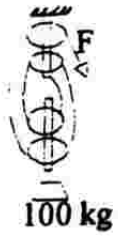
7. A box is pulled along a horizontal surface with the aid of a rope of length 80 cm. One end of the rope is attached to the box while the other end is held 48 cm above the ground. If the horizontal component of force on the box is 80 N, the tension in the rope is
   A. 64 N B. 80 N C. 100 N D. 133.3 N

8. 

   A bar of length 3 m is subjected to two parallel but opposite forces of 60 N at its ends as shown in the diagram above. The couple on the bar is
   A. 90 Nm B. $90\sqrt{3}$ Nm C. 180 Nm D. 360 Nm

9. An object of mass 10 kg initially at rest on a horizontal surface is subjected to a horizontal force of 40 N. The body moves in the direction of the applied force with an acceleration of $3\ ms^{-2}$. The work done against friction after moving the object for two seconds is
   A. 240 J B. 180 J C. 120 J D. 60 J

10. The escape velocity of an object from the gravitational field of a planet
    I. increases with the mass of the object
    II. increases with the mass of the planet
    III. is smaller on the moon than on the earth.
    Which of the above statements is(are) correct?
    A. I only B. I and II only
    C. II and III only D. I, II and III

11. 

    The diagram shows a pulley system which is used to raise a 100 kg load. If the effort F needed to raise the load is 750 N, the efficiency of the machine is
    A. 20% B. $33\frac{1}{3}$% C. 50% D. 75%

12. The load supported by a spring is increased from 50 N to 90 N. If the force constant for the spring is $2000\ Nm^{-1}$, the additional energy stored in the spring due to the increase in load is
    A. 1.40 J B. 0.90 J C. 0.50 J D. 0.40 J

13. Two objects P and Q have the same weight W in air. When completely immersed in a liquid, the apparent weight of P is $3W/4$ while that of Q is $W/2$. It can be concluded that the
    I. volume of P is twice the volume of Q
    II. volume of Q is twice the volume of P
    III. density of P is twice the density of Q
    IV. density of Q is twice the density of P
    Which of the above conclusions is (are) valid?
    A. I only B. II only C. I and IV only D. II and III only

14. The ratio of the diameter of the large piston to that of the small piston in a hydraulic press is 3:1. To move a load of 180 N on the large piston, the effort applied to the small piston must be
A. 20 N B. 60 N C. 540 N D. 1,620 N

15. A change in temperature of 90° C is equivalent to a change in temperature on the Fahrenheit scale of
A. 50°F B. 90°F C. 162°F D. 194°F

16. The volume of a bubble is doubled as it rises from the bottom to the top of a lake. If the atmospheric pressure is equivalent to 10.3m of water, the depth of the lake is
A. 5.15 m B. 10.3 m C. 20.6 m D. 30.9 m

17. At which of the following temperatures will a given mass of water occupy the greatest volume?
A. 0°C B. 4°C C. 80°C D. 100°C

18. A fixed mass of gas is heated at constant volume so that its Celsius temperature is doubled. The pressure of the gas
A. is halved
B. is doubled
C. is more than doubled
D. increases but is less than doubled.

19. The specific heat capacity of water is 4.2 kJ kg^{-1} $°C^{-1}$. This statement means that 4.2 kJ of heat will
A. change 1 kg of ice to water at 0° C
B. vaporize 1 kg of water at 100° C
C. raise the temperature of 1 kg of water from 70°C to 71°C
D. raise the temperature of a given mass of water by 1°C.

20. The effect of increased pressure on the transformation temperatures of water is that the
I. melting point is reduced
II. melting point is increased
III. boiling point is reduced
IV. boiling point is increased
Which of the above statements are correct?
A. I and III only. B. II and IV only
C. II and III only D. I and IV only.

21. A 2 kW immersion heater is used to heat 1 kg of water initially at a temperature of 20° C. How much water will boil away in 3 minutes? [specific heat capacity of water = 4.2 kJkg^{-1} $°C^{-1}$; specific latent heat of vaporization of water = 2.4 x 10^3 kJkg^{-1}]
A. 10 g B. 100 g C. 140 g D. 150 g

22. A person in a room feels cooler under a rotating fan because the fan
A. lowers the room temperature
B. increases the rate of evaporation from the skin
C. reduces the relative humidity in the room
D. blows cooler air to the skin.

23. On a hot and sunny day, the inside of a car with the glass windows rolled up is hotter if the upholstery is black than if it is made of a bright and shiny material because a
A. bright and shiny surface is a better reflector of heat
B. bright and shiny surface is a better radiator of heat
C. black surface is a better conductor of heat
D. black surface has a lower thermal capacity.

24. In a perfectly still liquid, the molecules
A. are perfectly at rest
B. undergo translational motion
C. undergo only vibrational motion
D. exert no intermolecular forces on one another.

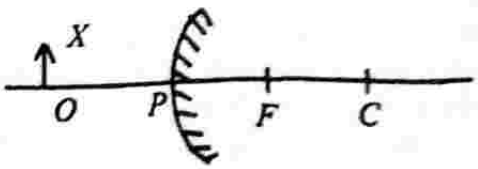
25. The vibrator which is used to generate ripples in a pool of water produces 300 ripples in one minute. If the ripples are spaced 5 cm apart, their speed is
A. 1,500 cms^{-1} B. 300 cms^{-1} C. 60 cms^{-1} D. 25 cms^{-1}

26. Which of the following statements is (are) not correct?
I. The pitch of a note emitted by a vibrating string depends on its length.
II. Two identical strings may emit notes of the same pitch and intensity but different quality.
III. The loudness of a note emitted by a vibrating string depends on the number of overtones
A. I only B. II only C. III only D. II and III only

27. A pipe organ X produces a note whose pitch is twice that of the note produced by a second pipe organ Y. If the speed of the wave in X is v, then the speed of the wave in Y is
A. $v/2$ B. v C. $2v$ D. $4v$

28. A boy standing between two cliffs which are 850 m apart claps his hands and receives the echo from the nearer cliff after 2 s. If the speed of sound in air is 340 ms^{-1}, he will receive the echo from the second cliff after
A. 1.5 s B. 2.5 s C. 2.8 s D. 3.0 s

29. A vibrating string of length 50 cm produces a note of frequency 250 Hz. In order to produce a note which is an octave higher, the length of the string required is
A. 25 cm B. $25\sqrt{2}$ cm C. $50\sqrt{2}$ cm D. 100 cm

30.


The diagram above shows an object OX placed in front of a convex mirror. As the object is moved towards P, its image, which is located between P and F

A. moves to the right and becomes smaller
B. moves to the right and becomes larger
C. moves to the left and becomes smaller
D. moves to the left and becomes larger

31. A candle placed 12 cm from a spherical mirror produces an image on a screen placed 36 cm from the mirror. The separation between the candle and its image is

A. 12 cm **B.** 24 cm **C.** 36 cm **D.** 48 cm

32. A beam of light is incident normally on an air/glass interface. Upon passing into the glass, which of the following properties of the light beam will change?

I. Frequency II. Speed
III. Direction IV. Amplitude

A. I and III only **B.** II and IV only
C. I, II and IV only **D.** None of the above

33. A beam of white light passes through a glass prism. The widest separation in the refracted beam occurs between the colours

A. red and violet **B.** white and black
C. blue and yellow **D.** green and orange

34. A convex lens of focal length 0.1 m is used in a camera. When focusing on a distant object, the distance from the lens to the film is approximately

A. 5 cm **B.** 10 cm **C.** 20 cm **D.** 100 cm

35. A yellow liquid in a green, transparent bottle will appear

A. red **B.** yellow **C.** green **D.** black

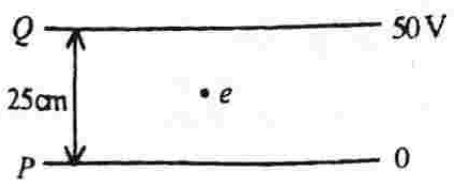
36. Electromagnetic waves which are usually associated with heat are called

A. γ- rays **B.** x-rays **C.** microwaves **D.** infra - red rays

37. The divergence of the leaves of a negatively-charged electroscope increases as an object is brought close to its cap. The object is

A. a glass rod **B.** a silk cloth
C. negatively-charged **D.** positively-charged.

38.



Two parallel plates P and Q are spaced 25 cm apart in air. The plates are maintained at potentials of 0 V and 50 V respectively. An electron (of charge 1.6×10^{-19} C) placed between the plates will experience a force of

A. 3.2×10^{-17} N, towards plate P
B. 3.2×10^{-17} N, towards plate Q
C. 2.0×10^{-17} N, towards plate P
D. 2.0×10^{-17} N, towards plate Q

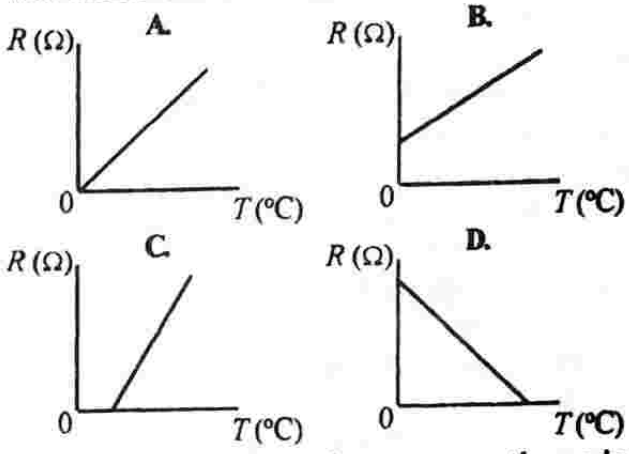
39. The plates of a parallel-plate capacitor with air separating the plates are connected to a battery so that the potential difference between the plates is constant. If the separation between the plates is decreased

I. the capacitance of the capacitor decreases
II. the capacitance of the capacitor increases
III. the charge on each plate decreases
IV. the charge on each plate increases

Which of the above statements are correct?

A. I and IV only **B.** II and III only
C. I and III only **D.** II and IV only

40. Which of the following diagrams correctly illustrates the variation of resistance with temperature for a metallic wire resistor over a moderate temperature range?



41. Which of the following resistances *cannot* be produced from a combination of three 6 Ω resistors?

A. 2 Ω **B.** 4 Ω **C.** 9 Ω **D.** 12 Ω

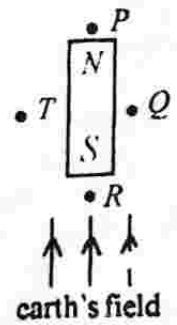
42. A 12 V battery of internal resistance 0.1 Ω is connected across a lamp of resistance R. If a current of 10 A flows through the circuit, the value of R is

A. 0.9 Ω **B.** 1.0 Ω **C.** 1.1 Ω **D.** 1.2 Ω

43. Two resistors P and Q are connected in parallel across a D.C. voltage supply. The resistance of P is three times that of Q. The ratio of the power dissipated in P to the power dissipated in Q is

A. 1 : 3 **B.** 3 : 1 **C.** 1 : 9 **D.** 9 : 1

44.



The diagram shows a short bar magnet placed in the earth's magnetic field. The neutral points will likely occur at

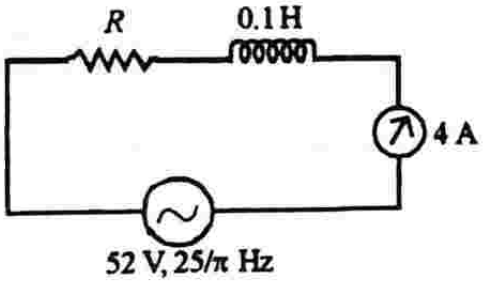
A. P and R only
B. Q and T only
C. P only
D. R only

45. A particle bearing a charge of 0.2 C moves parallel to a magnetic field of 0.05 T. If the velocity of the particle is 40 ms^{-1}, the force experienced by the particle is
A. 4.0 N B. 2.0 N C. 0.4 N D. 0.0 N

46. A voltmeter is connected to a simple cell of emf 1.1 V. When the circuit is closed,
A. the voltmeter gives no deflection at all
B. the voltmeter gives an initial deflection of 1.1 V which steadily decreases to a small value.
C. the voltmeter reading increases steadily to a value of 1.1 V and remains constant at this value.
D. the voltmeter gives a deflection of 1.1 V which remains constant for a long period of time.

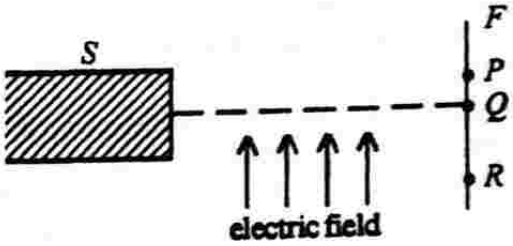
47. An alternating current with *rms* voltage of 50 V has a frequency of 60 Hz. The A.C. can be represented by the equation
A. $v = 50 \sin 60\pi t$ B. $v = 50 \sin 120\pi t$
C. $v = 70.7 \sin 60\pi t$ D. $v = 70.7 \sin 120\pi t$

48.



In the R-L series circuit shown in the diagram above, the ammeter indicates a current of 4 A. The value of the resistance R is
A. 5 Ω B. 10 Ω C. 12 Ω D. 13 Ω

49.



A flourescent screen F is positioned (in vacuum) close to a radioactive source S placed in an electric field as shown in the diagram above. After some exposure, bright spots are absorbed at P, Q and R. The spots P, Q and R correspond respectively to
A. α, γ and β rays B. β, γ and α rays
C. α, β and γ rays D. β, α and γ rays

50. A certain radioactive element of initial mass 160 g has a half-life of 20 years. After a period of T years, only 5 g of the element is left undecayed. The value of T is
A. 8 B. 40 C. 80 D. 100

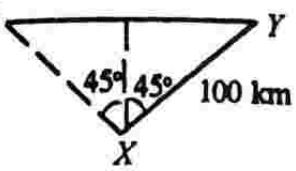
Answer Key

1. C	10. C	19. C	28. D	37. C	46. B
2. C	11. B	20. D	29. A	38. B	47. D
3. A	12. A	21. A	30. D	39. D	48. C
4. D	13. D	22. B	31. B	40. B	49. A
5. D	14. A	23. A	32. B	41. D	50. D
6. C	15. C	24. B	33. A	42. C	
7. C	16. B	25. D	34. B	43. A	
8. A	17. D	26. C	35. C	44. B	
9. D	18. D	27. B	36. D	45. D	

Solutions To Model Matriculation Examination 2

1. **(C)** A spring balance indicates the extension in a spring due to the *weight*(or *gravitational pull*) of a body hung on it. [The reading on a spring balance will vary, for instance with altitude even though the mass of the body is constant].

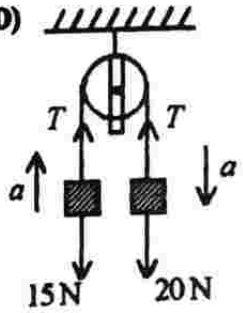
2. **(C)**



From the geometry of the figure, XYZ is an isosceles triangle with $XZ = XY = 100$ km

3. **(A)** In 3 s, the distance covered by the body is
$h = \frac{1}{2}gt^2 = \frac{1}{2}(10)(3)^2 = 45$ m
In 4 s, $h = \frac{1}{2}(10)(4)^2 = 80$ m
Distance covered in the *fourth* second = 80 - 45 = 35 m

4. **(D)**

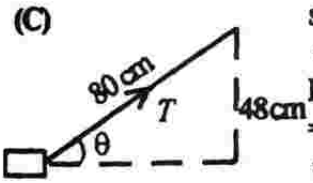


Let T = tension in the string. Applying Newton's second law to the 2 kg mass;
$20 - T = 2a$ ..... (i)
and to the 1.5 kg mass
$T - 15 = 1.5a$ ..... (ii)
Adding (i) and (ii) gives
$3.5a = 5$ or $a = 1.43$ ms^{-2}

5. **(D)** Acceleration, $a = (v - u)/t = (0 - 20)/10 = -2$ ms^{-2}
$m = F/a = 5000/2 = 2{,}500$ kg

6. **(C)** Centripetal acceleration = v^2/r, which is independent of the mass of the object. [The centripetal *force*, however, increases linearly with the mass].

7. **(C)**



$\sin\theta = 48/80 = 3/5$
$\Rightarrow \cos\theta = 4/5$
Horizontal component of force $= T\cos\theta$
$\Rightarrow T(4/5) = 80$, or $T = 100$ N.

8. **(A)** The component of each force in the normal direction to the bar is 60sin 30°. Couple = (60sin 30°)(3) = 90 Nm

9. **(D)** The applied force of 40 N is used in overcoming friction and in giving the object an acceleration.
Force accelerating the object = $ma = 10(3) = 30$ N
$\Rightarrow$Frictional force = 40 - 30 = 10 N
After 2 s, the object is moved through distance
$s = \frac{1}{2}at^2 = \frac{1}{2}(3)(2)^2 = 6$ m
Work done against friction = frictional force x distance
= 10 x 6 = 60 J

10. **(C)** Escape velocity, $v = \sqrt{2Gm_p/r_p} = \sqrt{2g_pr_p}$,
where m_p, r_p and g_p are the mass, radius of the planet and acceleration due to gravity on the planet respectively. Note that v is independent of the mass of the object. Also, since g_p and r_p are smaller for the moon, v is smaller on the moon.

11. **(B)** V.R. = 4, since there are 4 pulleys
M.A. = Load / Effort = 1000 / 750 = 4/3
Efficiency = M.A./V.R. = 4/3 x 1/4 = 4/12 = $33\frac{1}{3}$%

12. **(A)** Additional energy stored in the spring
= Work done in increasing the load from 50 N to 90 N
= Average force x additional extension
Average force = (50 + 90)/2 = 70 N
Additional extension = (90 - 50)/2000 = 0.02 m
Additional energy stored = 70 x 0.02 = 1.4 J

13. **(D)** Upthrust on $P = W - 3W/4 = W/4$
Upthrust on $Q = W - W/2 = W/2$
Upthrust on Q = 2 x Upthrust on P
$\Rightarrow$Volume of liquid displaced by Q
= 2 x volume of liquid displaced by P
This is true if volume of Q = 2 x volume of P, or since P and Q have the same true mass, if density of P = 2 x density of Q.

14. **(A)** $\frac{\text{Effort}}{\text{Load}} = \frac{\text{Area of small piston}}{\text{Area of large piston}} = \frac{d^2}{D^2}$,
where D and d are the diameters of the large and the small pistons, respectively.
Effort = Load x $(d/D)^2 = 180(\frac{1}{3})^2 = 20$ N

15. **(C)** A division on the Celsius scale is 9/5 times the size of a division on the Fahrenheit scale. Hence a change in temperature of 90°C is equivalent to $\frac{9}{5}(90) = 162$°F.

16. **(B)** The (air) bubble increases in size as it rises through the lake because of the decreasing pressure (PV = constant). The pressure at the surface must be one - half of the pressure at the bottom of the lake. Hence pressure at the bottom of the lake = 2 x 10.3 = 20.6 m = atmospheric + 10.3 m . This is the pressure at a depth of 10.3 m of water.

17. **(D)** The volume of a given mass of water is smallest at 4°C, but the volume thereafter increases with temperature until the boiling point (100°C) is reached.

18. **(D)** The pressure is directly proportional to the *absolute*, not the Celsius temperature. Thus

$$\frac{P_1}{T_1 + 273} = \frac{P_2}{2T_1 + 273}$$

$$\frac{P_2}{P_1} = \frac{2T_1 + 273}{T_1 + 273} = \frac{2(T_1 + 273)}{T_1 + 273} - \frac{273}{T_1 + 273}$$
$$= 2 - \frac{273}{T_1 + 273}$$

Hence P_2/P_1 is greater than one but less than 2

19. **(C)** Specific heat capacity is the heat needed to raise the temperature of 1 kg of water by 1°C. [It does not matter if the temperature increases from 0°C to 1°C or from 70°C to 71°C].

20. **(D)** See revision notes.

21. **(A)** Heat needed to raise the temp. of water from 20° C to 100° C = $mc\theta$ = 1(4.2)(80) = 336 kJ
Heat supplied by the 2 kW heater in 3 min.
= 2 (kJ/s) x 3 x 60 (s) = 360 kJ
The difference, 360 - 336 = 24 kJ is used in boiling off m kg of water.
Hence $24 = mL_v$, or $m = 24/(2.4 \times 10^5) = 10^{-2}$ kg, or 10 g.

22. **(B)** The skin feels cooler as the rate of evaporation from its surface increases. The room temperature and relative humidity do not change appreciably, and the blown air is at room temperature.

23. **(A)** The bright and shiny surface is a *poor absorber* and thus a *good reflector* of radiant heat.

24. **(B)** The molecules of a liquid are constantly in motion even though the bulk of the liquid appears to be perfectly still.

25. **(D)** Frequency, f = 300/60 = 5 Hz
Wavelength, λ = 5 cm; $v = f\lambda = 5 \times 5 = 25$ cms^{-1}

26. **(C)** Pitch depends on frequency which also depends on the length of the string. Two identical strings may emit notes of different quality depending on the number of *overtones* in each string. Loudness depends only on the *amplitude* of the waveform, and not on the number of overtones.

27. **(B)** The speed of sound in the air column of an organ pipe is a constant, i.e. it does not vary from one organ pipe to another.

28. **(D)** The boy's distance from the nearer cliff is
$d_1 = vt_1$ = 340 (1) = 340 m
Hence his distance from the second cliff is
d_2 = 850 - 340 = 510 m, and the time for sound to travel from the boy to the second cliff = 510 / 340 = 1.5 s.
The echo reaches him after 1.5 x 2 = 3.0 s

29. **(A)** The frequency of the new note is 500 Hz. Since $f \propto 1/l$, the length of the string must be halved, i.e. the new length is 50/2 = 25 cm

30. **(D)** This question is easily solved by assigning arbitrary values to u and evaluating v from the mirror equation
$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$
Thus if $u = 2f$,
$$\frac{1}{v} = -\frac{1}{f} - \frac{1}{2f}, \quad \text{or } v = -2f/3$$
$$\text{Mag.} = \left|\frac{v}{u}\right| = \frac{2f/3}{2f} = \frac{1}{3}$$
After the object is moved to $u = f$, for instance,
$$\frac{1}{v} = -\frac{1}{f} - \frac{1}{f} = -\frac{2}{f}, \quad \text{or } v = -f/2$$
(i.e. the image is now *closer* to the mirror)
$$\text{Mag.} = \frac{f/2}{f} = \frac{1}{2} \text{ (image is now } larger\text{)}.$$
[The question can also be answered correctly by sketching the ray diagrams for two positions of the object].

31. **(B)** Since the image is real, the mirror is concave and the image is located 36 cm *in front of* the mirror. Separation between the candle and its image = 36 - 12 = 24 cm

32. **(B)** The angle of incidence is zero. Part of the beam is reflected while the rest is transmitted undeviated through the glass. Frequency and direction are therefore unchanged. The speed of light in glass is less than in water, and, since part of the light is reflected, the intensity(and hence amplitude) of the transmitted light is reduced.

33. **(A)** Red is the least deviated and violet the most deviated.

34. **(B)** $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{f} - \frac{1}{\infty} = \frac{1}{f}$, or
$v = f = 0.1$ m, or 10 cm

35. **(C)** The green bottle absorbs all colours except green. Yellow is composed of red and green. Hence the bottle absorbs the red and transmits green.

36. **(D)** See revision notes

37. **(C)** If the divergence of the leaves of a charged electroscope increases as an object is brought close to the cap of the electroscope, the charge on the object has the same sign as that on the electroscope.

38. **(B)** $$\text{Electric field} = \frac{\text{potential difference}}{\text{separation between plates}}$$
$$= 50/25 = 2 \text{ Vcm}^{-1} = 200 \text{ Vm}^{-1}$$
Force = charge x electric field = $1.6 \times 10^{-19} \times 200$

$= 3.2 \times 10^{-17}$ N.
[The electron, being negatively-charged, is attracted to the positively-charged plate, Q].

39. **(D)** Capacitance is inversely proportional to the separation of the plates, hence C increases as d decreases. Since $Q = CV$ and V is held constant, Q also increases.

40. **(B)** $R = R_0(1 + \alpha T) = R_0 + R_0\alpha T$
The plot of R versus T is linear with a positive slope $(R_0\alpha)$ and with $R = R_0$ at $T = 0°$ C.

41. **(D)** All three resistors connected in parallel give an effective resistance of 2 Ω. Two series resistors in parallel with the third resistor give 4 Ω. Two parallel resistors in series with the third resistor give 9 Ω.

42. **(C)** $I = \dfrac{E}{(R + r)}$, or $R = \dfrac{E}{I} - r = \dfrac{12}{10} - 0.1 = 1.1\ \Omega$

43. **(A)** If V = voltage of the battery, I = current delievered and R = resistance of Q, $3R$ = resistance of P.
Current through Q $= I_q = V/R$
Power consumed by Q $= I_q^2R = (V/R)^2R = V^2/R$
Current through P, I_p $= V/3R$
Power consumed by P $= (V/3R)^2(3R) = V^2/3R$
Required ratio $= V^2/3R : V^2/R = 1 : 3$

44. **(B)** The field due to the magnet is exactly opposite in direction to the earth's field at points Q and T only. The magnetic field is in the same direction as the earth's field at P and R.

45. **(D)** $F = qvB \sin\theta$, where θ = angle between v (direction of motion of charge) and B(magnetic field). In this case, $\theta = 0°$ and $F = 0$.

46. **(B)** The voltmeter indicates 1.1 V initially, which decreases with time due to the *polarization* of the cell.

47. **(D)** The equation for alternating voltage is of the form $v = v_m \sin 2\pi ft$, where v_m = maximum voltage $= v\sqrt{2}$ $= 50\sqrt{2} = 70.7$ V and $2\pi f = 2\pi(60) = 120\pi$.

48. **(C)** Inductive reactance, $X_L = 2\pi fL = 2\pi(25/\pi)(0.1) = 5\ \Omega$
Circuit impedance, Z = voltage/current = 52/4 = 13 Ω.
$R^2 = Z^2 - X_L^2 = 13^2 - 5^2 = 12^2$, or $R = 12\ \Omega$.

49. **(A)** Q must be due to a neutral radiation (γ) which goes through the electric field undeflected. P corresponds to a positively - charged particle (α) which is deflected towards the negative polarity of the electric field and R to a negatively - charged particle (β) which is deflected towards the positive polarity.

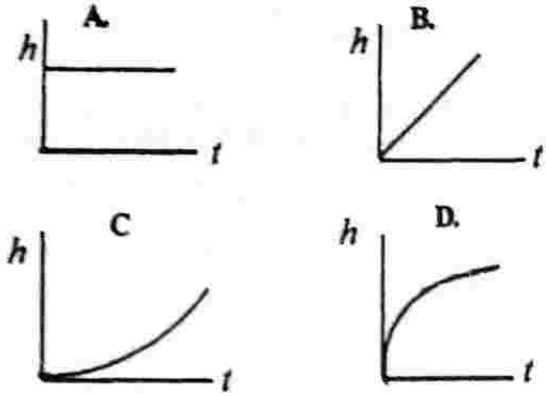
50. **(D)**
$$160\text{ g} \xrightarrow{(20)} 80\text{ g} \xrightarrow{(20)} 40\text{ g} \xrightarrow{(20)} 20\text{ g} \xrightarrow{(20)} 10\text{ g} \xrightarrow{(20)} 5\text{ g}$$

From the illustration above, the disintegration from 160 g to 5 g takes five half - lives, or 20 x 5 = 100 years.

Model Matriculation Examination 3

1. The unit *cycles per second* is the same as
   A. watt B. metres per second
   C. hertz D. radians per second

2. A body initially at rest falls freely under gravity. The graph of the distance (h) covered as a function of time(t) is given by



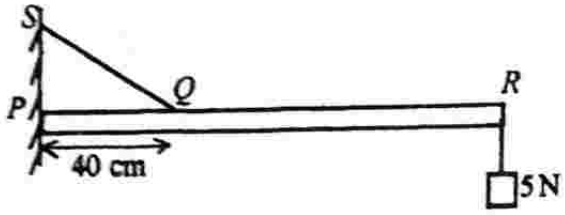
3. A stone of mass 50 g tied to the end of a string of length 0.5 m is whirled around in a horizontal circle of radius 0.5 m at a constant speed of 20 ms^{-1}. The tension in the string is
   A. 100 N B. 40 N C. 10 N D. 4 N

4. Two stones P and Q are projected with same speed at angles of 30° and 60° respectively to the horizontal. The ratio of the horizontal distance covered by P to that of Q after a given time is
   A. $\sqrt{3}$ B. $1/\sqrt{3}$ C. 2 D. 1

5. A man stands on a scale in a lift which descends with an acceleration of $g/5$, where g is the acceleration due to gravity. If the man's true weight is W, the reading on the scale is
   A. $1.2W$ B. W C. $0.9W$ D. $0.8W$

6. If the length of a simple pendulum is halved, its frequency is
   A. increased by a factor of 2
   B. decreased by a factor of 2
   C. increased by a factor of $\sqrt{2}$
   D. decreased by a factor of $\sqrt{2}$

7.

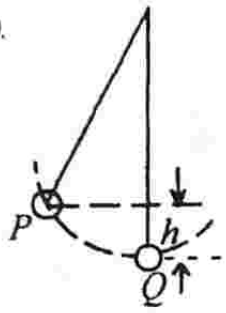


A light, horizontal metre rule PQR has the end P fixed to a vertical wall while a weight of 5 N is suspended from the end R (see diagram). A light string QS of length 50 cm fixed to the wall at S is used to maintain the metre rule in equilibruim. If PQ = 40 cm, the tension in the string is
   A. 20.8 N B. 15.6 N C. 12.5 N D. 2.0 N

8. A box of mass 10 kg rests on a plane inclined at an angle of 30° to the horizontal. The coefficient of friction between the surface and the box is 0.2. If a force of 60 N is applied parallel to the plane in an attempt to slide the box up the plane, the box will
   A. accelerate up the plane
   B. accelerate down the plane
   C. remain at rest
   D. slide down the plane at a uniform speed.

9. A body accelerates uniformly from rest for a time t. The kinetic energy of the body at t
   (I) is directly proportional to the displacement
   (II) is directiy proportional to the square of the instantaneous velocity
   (III) is directly proportional to t^2
   (IV) depends on the value of the acceleration
   Which of the above statements is (are) correct ?
   A. II only B. I and II only
   C. I, II and III only D. I, II, III and IV.

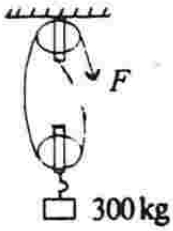
10.



The bob of a simple pendulum initially at rest at P is released so that the bob passes the point Q with a speed of 50 cms^{-1}. The height h is [g = 10 ms^{-2}]
   A. 1.25 cm B. 2.5 cm
   C. 3.0 cm D. 5.0 cm

11. A screw of pitch 3 mm is turned with the aid of a spanner of length 15 cm. If the efficiency of the screw is 70 percent, the effort required to lift a load of 660 kg with the screw is
   A. 3 N B. 30 N C. 300 N D. 330 N

12.



A two-pulley block and tackle system is used to lift a load of 300 kg (see diagram). The force exerted on the ceiling is
   A. 1,500 N B. 3,000 N C. 4,500 N D. 6,000 N

13. A steel specimen and a plastic specimen of identical dimensions are subjected to the same tensile force. The plastic specimen shows a greater extension because
   I. plastic has a higher modulus of elasticity than steel.

II. steel has higher modulus of elasticity than plastic.
III. steel has higher force constant than plastic .
IV. steel has higher density than plastic.
Which of the above statements is (are) correct?
A. I only. **B.** II only.
C. I and IV only **D.** II and (III) only

14. An object of volume 200 cm^3 and relative d suspended from a spring balance while full in water of density 10^3 kgm^{-3}. The reading balance is
A. 10 N **B.** 8 N **C.** 5 N **D.**

15. A fine steel wire mesh can be made to float on wate can be explained by
A. Archimedes' principle.
B. Pascal's principle.
C. The concept of suface tension.
D. The principle of flotation.

16. The readings on the Celsius and the Fahrenheit scales are numerically equal at a temperature of
A. - 80° **B.** - 40° **C.** 0° **D.** 40°

17. A glass flask has a capacity of 500 cm^3 at 100 °C. If the coefficient of linear expansion of glass is 3.2×10^{-6} °C^{-1}, the capacity of the flask at 30 °C is
A. 500.336 cm^3 **B.** 500.112 cm^3
C. 499.888 cm^3 **D.** 499.664 cm^3

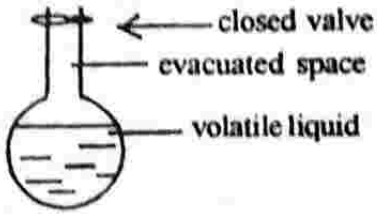
18. A fixed mass of gas at a temperature of 27 °C is heated at constant volume until the pressure is doubled. The final temperature of the gas is
A. 327 °C **B.** 163.5 °C **C.** 54 °C **D.** 13.5 °C

19. A glass bottle is filled with water, corked, and kept in a freezer. After all the water is frozen, the bottle is found to have cracked. This is because
A. glass becomes weaker as the temperature decreases.
B. glass is a poor conductor of heat.
C. of the uneven contraction of the walls of the glass.
D. the density of ice is less than that of water.

20. The following data is provided for water:
Specific heat capacity = 4.2 $kJkg^{-1}$ °C^{-1}
Specific latent heat of fusion = 335 $kJkg^{-1}$
Specific latent heat of vaporization = 2260 $kJkg^{-1}$
The heat required to change one kilogram of ice at 0°C to steam at 100 °C is
A. 3015 kJ **B.** 2599.2 kJ **C.** 755 kJ **D.** 420 kJ

21. A room which measures 3 m x 4 m x 5 m is cooled from 30°C to 25°C. If the density and specific heat capacity of air are 1.3 kgm^{-3} and 1.0 $kJkg^{-1}$ °C^{-1} respectively, the amount of heat removed from the room is
A. 300 kJ **B.** 390 kJ **C.** 600 kJ **D.** 780 kJ

22. The rate of evaporation of water from a lake will be high on a day when the
A. temperature and relative humidity are high
B. temperature is low but the relative humidity is high
C. relative humidity is high
D. relative humidity is low



A flask containing a volatile liquid at room temperature has the space above the liquid evacuated of all air and the valve closed (see diagram above). If the flask is now placed in a jar containing an ice-water mixture, the level of the liquid in the flask
A. decreases
B. increases
C. remains the same
D. first increases and then decreases.

24. Some ice crystals are held down at the bottom of a glass tube with a metal wire gauze. The tube is now filled with water and heated near the top. The water boils while the ice remains unmelted because
I. water is a poor conductor of heat
II. glass is a poor conductor of heat
III. cold water is denser than hot water
IV. metal wire is a good insulator.
Which of the above statements are correct?
A. I and II only **B.** I and III only
C. II and IV only **D.** I, II, and III only

25. Heat reaches the food which is being cooked in a saucepan chiefly by
A. conduction and convection
B. conduction and radiation
C. convection and radiation
D. conduction and diffusion

26. A tuning fork attached to a vibrating diaphragm is placed close to the open end of a horizontal tube containing a small quantity of fine powder. A steady vibration is generated in the tube (whose other end is closed) such that the powder piles up at regular distances 2 cm apart in the tube. If the velocity of sound in air is 340 ms^{-1}, the frequency of the sound wave is
A. 85 Hz **B.** 170 Hz **C.** 8,500 Hz **D.** 17,000 Hz

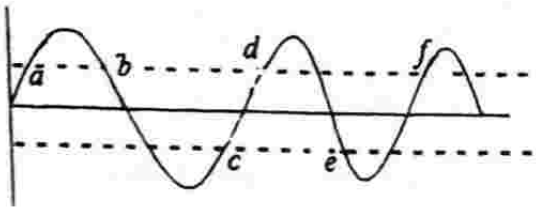
27. Two sound waves have the same wavelength in air.

Which of the following characteristics must also be common to both waves?

I. Pitch II. Intensity III. Amplitude IV. Frequency

A. I only **B.** II and III only
C. I and IV only **D.** I, II and IV only.

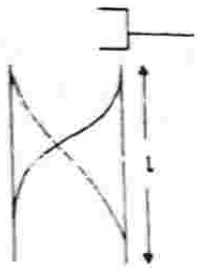
28.



Which of the points on the waveform shown in the figure is (are) exactly in phase with point *a*?

A. *b* and *c* only **B.** *d* and *f* only
C. *d* and *e* only **D.** *b*, *d* and *f* only.

29.



An air column of length *L* in an open pipe is in resonance with a vibrating tuning fork (see diagram). In the time it takes for the wave to move the distance *L* in the air column, the tuning fork makes

A. two complete vibrations **B.** one complete vibration
C. one-half of a vibration **D.** one-quarter of a vibration.

30. An echo sounder uses sound signals generated on a boat at the surface to determine the depth of water. The echo from one such signal directed toward the seabed is received 5seconds later. If the speed of sound in water is 1400 ms^{-1} the depth of water is

A. 7,000 m **B.** 3,500 m **C.** 1,700 m **D.** 850 m

31. Which of the following waves cannot be polarized?

A. infra-red **B.** yellow light **C.** x-rays **D.** sound

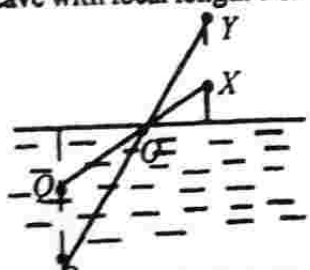
32. A plane mirror is moved towards a stationary girl at a speed of 10 cms^{-1}. The image moves towards the girl at a speed of

A. 40 cms^{-1} **B.** 30 cms^{-1} **C.** 20 cms^{-1} **D.** 10 cms^{-1}

33. An object placed 15 cm from a spherical mirror forms an image 10 cm behind the mirror. The mirror is

A. convex with focal length 30 cm
B. concave with focal length 30 cm
C. convex with focal length 6 cm
D. concave with focal length 6 cm

34.



A girl stands with her eyes at level *X* above a pool of water. A fish is located at level *P* in the pool. If *POY* and *QOX* are straight lines, which of the following statements is (are) correct?

I. The girl sees the fish at *P*
II. The girl sees the fish at *Q*
III. The fish sees the girl's eyes at *X*
IV. The fish sees the girl's eyes at *Y*

A. I only **B.** II only
C. I and III only **D.** II and IV only

35. A slide of width 2.5 cm is positioned 5.0 cm from the lens of a projector. If the width of the image is 100 cm, the distance from the lens to the screen is

A. 40 cm **B.** 200 cm **C.** 250 cm **D.** 500 cm

36. A ray of light is incident at an angle of 48.6° on one face of a rectangular glass block of refractive index 1.5. The angular deviation of the ray as it crosses the air/glass interface is [sin 48.6° = 0.75]

A. 0° **B.** 18.6° **C.** 30.0° **D.** 78.6°

37. A rainbow is viewed through a blue sheet of glass. The rainbow will appear

A. white **B.** yellow **C.** blue **D.** black

38. A positive point charge *B* is placed near a positively charged metal sphere. As the charge *B* is moved closer to the sphere

I its electric potential energy increases
II. its electric potential energy decreases
III. work is done by the point charge *B*
IV. work is done on the point charge *B*

Which of the above statements is(are) correct?

A. I and IV only **B.** II and III only
C. I and III only **D.** II and IV only

39. The unit *newton per coulomb* is also equivalent to the

A. farad **B.** volt **C.** joule **D.** volt per metre

40. A parallel plate capacitor has its plates maintained at a potential difference *V*. Introducing a dielectric material between the plates will efffectively

A. decrease the charge on each plate
B. increase the charge on each plate
C. leave the charge on each plate unchanged
D. decrease the capacitance of the capacitor.

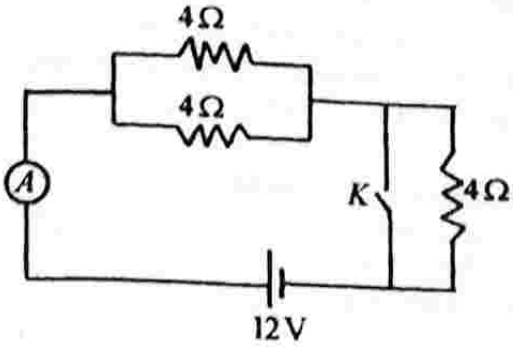
41. A lamp is connected across a battery. A piece of low conductivity wire is now connected in series with it. The lamp will

A. glow brighter **B.** glow dimmer
C. remain unaffected **D.** quickly burn out.

42. Upon starting a car. a current of 125 A is drawn from

the 12 V battery and the p.d. across its terminals drops to 8 V. The internal resistance of the battery is
A. 0.096 Ω B. 0.064 Ω C. 0.032 Ω D. 0.016 Ω

43.



In the circuit diagram above, the key K is initially open. When the key is closed, the reading on the ammeter (A)
A. remains unaffected
B. decreases to zero because of the short circuit
C. decreses to one-third of its initial value
D. increases to thrice its initial value.

44. A 1.2 kW immersion heater is connected to a voltage supply of 240 V. The resistance of the heater element and the current drawn by the heater are, respectively
A. 5 Ω, 48 A B. 1200 Ω, 0.2 A
C. 48 Ω, 5 A D. 0.2 Ω, 1200 A

45. A freely suspended magnetic needle makes an angle of 0° with the horizontal at a location X on the earth's surface. Which of the following statements is (are) correct about X?
I. X is located on the magnetic equator
II. X is located on a magnetic pole
III. The declination at X is zero
IV. The geographic and the magnetic meridians coincide at point X

A. I only B. II only
C. I and III only D. I, III and IV only

46. One advantage of connecting electric cells in parallel is that the effective
A. emf is increased
B. internal resistance is decreased
C. emf is decreased
D. internal resistance is increased

47. The maximum current in a series R-L-C circuit is obtained when the
A. impedance is zero
B. impedance is equal to the resistance
C. impedance is maximum
D. inductive reactance is zero

48. In a series R-L-C circuit connected to an A.C. supply of 130 V(rms), the voltages across the inductor and the capacitor are 80 V and 30 V respectively. The voltage across the resistor is
A. 20 V B. 50 V C. 100 V D. 120 V

49. A metallic surface is exposed in turn to green, red and violet lights. The maximum kinetic energy of photoelectrons ejected from the surface increases in the order
A. green, red, violet B. violet, green, red
C. red, green, violet D. violet, red, green

50. A nucleus of $^{3}_{1}H$ decays to form a nucleus of $^{3}_{2}He$. This is an example of
A. an alpha decay B. a beta decay
C. a gamma decay D. a neutron decay

Answer Key

1. C	10. A	19. D	28. B	37. C	46. B
2. C	11. B	20. A	29. C	38. A	47. B
3. B	12. C	21. B	30. B	39. D	48. D
4. A	13. D	22. D	31. D	40. C	49. C
5. D	14. B	23. B	32. C	41. B	50. B
6. C	15. C	24. D	33. A	42. C	
7. A	16. B	25. A	34. D	43. D	
8. C	17. D	26. C	35. B	44. C	
9. D	18. A	27. C	36. B	45. A	

Solutions to Model Examination 3

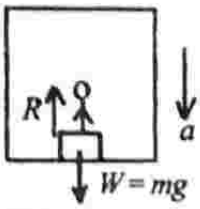
1. **(C)** This is the unit of *frequency*

2. **(C)** $h = \frac{1}{2}gt^2$, which is a parabola of the type shown in (C)

3. **(B)** Tension in the string = centripetal force
$= mv^2/r = 0.05(20)^2/0.5 = 40$ N

4. **(A)** Horizontal distance covered is directly proportional to the horizontal component of velocity. Hence
for $P : d_p \propto V\cos 30°$, and
for $Q : d_q \propto V\cos 60°$
$d_p : d_q = \cos 30° : \cos 60° = \sqrt{3}/2 : 1/2 = \sqrt{3} : 1$

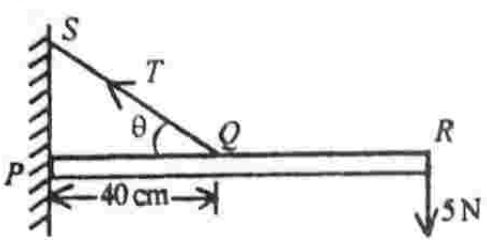
5. **(D)**



The reading on the scale is the reaction R. Newton's second law: $mg - R = ma$
$R = m(g - a) = m(g - g/5)$
$= 0.8mg$, or $0.8W$

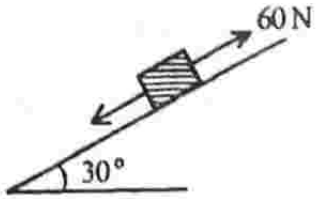
6. **(C)** For a pendulum of length L, frequency
$$f_1 = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$$
For a pendulum of length $L/2$,
$$f_1 = \frac{1}{2\pi}\sqrt{\frac{g}{L/2}} = \sqrt{2}\left[\frac{1}{2\pi}\sqrt{\frac{g}{L}}\right] = \sqrt{2}f_1$$

7. **(A)**



From the diagram, $PQ = 40$ cm and $QS = 50$ cm
$\Rightarrow PS = 30$ cm (3 - 4 - 5 right-angled triangle)
$\sin\theta = PS/QS = 30/50 = 0.6$
Taking moments about P gives
$5(100) = T\sin\theta\,(40) = T(0.6)(40)$, or $T = 20.8$ N

8. **(C)**



The two forces acting down the plane are the resolved component of the box's weight $= W\sin 30° = 100\sin 30°$
$= 50$ N, and
the limiting frictional force $= \mu W\cos 30°$
$= 0.2(100)\cos 30° = 17.3$ N.
The combined downward force (67.3 N) is greater than the upward force, hence the box remains stationary. [As an exercise, the candidate may show that the box will accelerate *down* the plane, if the applied effort is less than 32.7 N].

9. **(D)** Since $v^2 = 2as$ and $v = at$, we can write
K.E. $= \frac{1}{2}mv^2 = \frac{1}{2}m(2as) = \frac{1}{2}m(at)^2 = \frac{1}{2}ma^2t^2$
i.e. the K.E is directly proportional to s, and to t^2 and it also depends on the acceleration a.

10. **(A)** P.E at P = K.E at Q
If m = mass of the bob, $mgh = \frac{1}{2}mv^2$, or $h = v^2/2g$
$= (0.5)^2/20 = 1.25 \times 10^{-2}$ m, or 1.25 cm.

11. **(B)** For one complete turn of the spanner, the effort moves through a distance of $2\pi(15) = 30\pi$ cm while the load moves a distance equal to the pitch, or 0.3cm
V.R. $= 30\pi/0.3 = 100\pi$
M.A. = Efficiency x V.R. = 0.7 x 100(22/7) = 220
Effort = Load / M.A. = 6,600/220 = 30 N.

12. **(C)** The tension in each segment of the string is 3,000/2 = 1,500 N = F. Force pulling on the ceiling is the sum of the load and the effort $F = 3{,}000 + 1{,}500 = 4{,}500$ N.

13. **(D)** $$\text{Extension} = \frac{\text{Tensile force}}{\text{Force constant}}$$
Plastic which shows a greater extension must have a smaller force constant and a lower elastic modulus.
[$E = FL/Ax = (F/x)(L/A]$ = Force const. x L/A].

14. **(B)** True mass of the object = density x volume
$= (5 \times 10^3\ \text{kgm}^{-3})(200 \times 10^{-6}\ \text{m}^3) = 1.0$ kg
Volume of water displaced $= 200 \times 10^{-6}\ \text{m}^3$
Mass of water displaced $= (200 \times 10^{-3})(10^3) = 0.2$ kg
Upthrust $= (1.0 - 0.2) \times g = 0.8 \times 10 = 8$ N.

15. **(C)** Steel is denser than water. However, a sufficiently light steel wire mesh can be made to float on the surface of water because the surface acts like an elastic membrane(*surface tension*).

16. **(B)** $T_c/100 = (T_f - 32)/180$
When $T_c = T_f = T$, $T/100 = (T - 32)/180$
$4T = -160$, or $T = -40°$
(i.e. $-40°$ C = $-40°$ F).

17. **(D)** Coefficient of cubical expansion of glass
$= 3.2 \times 10^{-6} \times 3 = 9.6 \times 10^{-6}\,°\text{C}^{-1}$.
In reducing the temperature from 100° C to 30°C, the vo-

lume of the flask *decreases* by an amount
$V_0\gamma\theta = 500(9.6 \times 10^{-6})(100 - 30) = 0.336\ cm^3$
Volume at 30°C = 500 - 0.336 = 499.664 cm^3.

18.(A) $T_1 = 27 + 273 = 300$ K
$T_2/T_1 = P_2/P_1 = 2$
$T_2 = 2T_1 = 2 \times 300 = 600$ K = 327°C

19.(D) As the water changes to ice of lower density, its volume tends to increase. Because the bottle is corked and ice is not compressible, a stress is set up on the wall of the bottle, which then cracks.

20.(A) Heat to melt 1 kg of ice at 0°C
$= mL_f = (1)(335) = 335$ kJ
Heat to raise the temperature from 0°C to 100°C
$= mc\theta = (1)(4.2)(100) = 420$ kJ
Heat to vaporize 1 kg of water at 100°C
$= mL_v = (1)(2{,}260) = 2{,}260$ kJ
Total heat required = 335 + 420 + 2,260 = 3,015 kJ.

21.(B) Volume of the air = 3 x 4 x 5 = 60 m^3
Mass of the air, m = volume x density = 60 x 1.3 = 78 kg
Heat removed from the room = $mc\theta$ = (78)(1)(30 - 25)
= 390 kJ.

22.(D) When the relative humidity is low, the water content of air is low and water will evaporate faster from the lake.

23.(B) The space above the volatile liquid is filled with its vapour after the valve is closed. As the flask is placed in an ice-water mixture, the *SVP* of the liquid decreases, causing some vapour to condense and raise the level of liquid in the flask.

24.(D) Heat cannot flow readily from the top to the bottom of the tube, since both the glass and the water are poor conductors. Also the heated water remains at the top because it is less dense than cold water.

25.(A) Heat flows in through the wall of the saucepan by *conduction* and to the different parts of the food by *convection*, involving the circulation of water and steam.

26.(C) A standing wave is set up in which the powder piles up at the nodes (which are stationary). Distance between successive nodes = $\lambda/2$ = 2 cm, or λ = 4 cm
Frequency of sound, $f = v/\lambda$ = 340/0.04 = 8,500 Hz.

27.(C) Since $v = f\lambda$, two waves of the same wavelength must have the same frequency and thus also the same pitch. Intensity and amplitude have nothing to do with the wavelength.

28. (B) Points d and f are located at corresponding points (just before the crest) as point a. Thus $ad = df$ = wavelength of the wave.

29.(C) For an open pipe the length L of the pipe is one-half of a wavelength. Hence it takes *half-a-period* for the wave to travel this length, i.e. the vibrating tuning fork makes *one-half* of a vibration.

30.(B) It takes the sound signal 2.5 s to reach the sea-bed. Depth = speed x time = 1,400 x 2.5 = 3,500 m.

31.(D) Sound, being a *longitudinal* wave, cannot be polarized. All the others are transverse waves, which can be polarized.

32.(C) If the mirror is moved by x cm closer to the girl, her image also moves x cm closer to the mirror. The distance between the girl and her image is thus reduced by 2x cm, i.e. it decreases at double the rate at which the mirror is moved towards the girl.

33.(A) The image is *virtual* since it is formed behind the mirror, hence v = - 10 cm
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{15} - \frac{1}{10} = -\frac{1}{30}$, or
f = -30 cm (the negative sign indicates a *convex* mirror)

34.(D) To the girl's eyes located at X, rays of light from the fish appear to come from Q, since QOX is a straight line. Also, the rays of light from the girl's eyes appear to the fish to come from Y, since YOP is a straight line.

35.(B) Magnification, m = 100/2.5 = 40
Distance from the lens to the screen is
$v = mu$ = 40(5) = 200 cm.

36.(B) $\sin i/\sin r = n = 1.5$
$\sin r = \sin 48.6°/1.5 = 0.75/1.5 = 0.5$, or $r = 30°$
Angular deviation = $i - r$ = 48.6° - 30° = 18.6°.

37.(C) The blue glass absorbs all the colours except blue.

38.(A) As B is moved closer to the sphere, it is *repelled* (i.e its P.E. *increases*) and because of the repulsion, external force must be done to move B closer to the sphere. [This is somewhat analogous to the gravitational problem of raising a load from the ground level: the gravitational P.E. increases and work must be done to raise the load].

39.(D) The NC^{-1} is the unit of electric field intensity, which is also equal to Vm^{-1}.

40.(C) As a dielectric material is inserted between the plates, the capacitance increases, the p.d. decreases but the charge remains constant ($Q = CV$).

41.**(B)** The low conductivity wire has a high resistance. Since this is connected in series with the lamp, current through the circuit is reduced ($I = V/R$) and the lamp glows dimmer. [What happens if the wire is connected in parallel with the lamp?]

42.**(C)** $E - V = Ir$
$r = (E - V)/I = (12 - 8)/125 = 0.032\ \Omega$.

43.**(D)** The two 4 Ω resistors in parallel have an effective resistance of 2 Ω. With the key open, the total resistance of the circuit is 2 + 4 = 6 Ω and $I = V/R = 12/6 = 2$ A. With the key closed, the single 4 Ω resistor is effectively shunted out and the circuit has an effective resistance of 2 Ω. Thus $I = 12/2 = 6$ A = 3 x original current.

44.**(C)** Power = $V^2/R = IV$
$R = V^2/\text{power} = 240^2/1{,}200 = 48\ \Omega$
$I = \text{power}/V = 1{,}200/240 = 5$ A.

45.**(A)** The angle of dip is zero on the magnetic equator and 90° at the magnetic poles. [This has nothing to do with the declination which is the angle between the magnetic and geographic meridians].

46.**(B)** The effective emf of n identical cells connected in parallel is equal to the emf of any one of them. However, the effective internal resistance is r/n, where r is the internal resistance of each cell.

47.**(B)** Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2}$
Current, $I = V/Z$ is maximum when Z is minimum, i.e. when $X_L = X_C$ and $Z = R$. [Note that the impedance can not be zero once there is a resistance in the circuit].

48.**(D)** The voltages across the inductor (V_L) and capacitor (V_c) are 180° out of phase. The net voltage across the two elements is thus 80 V - 30 V = 50 V. This is 90° out of phase with the voltage across the resistor (V_R). Hence net voltage = 130 V = $\sqrt{50^2 + V_R^2}$, or $V_R = 120$ V.

49.**(C)** $E = hf - \phi$, hence the highest frequency radiation gives the most energetic photoelectrons. In the light spectrum (*ROYGBIV*), red has the lowest frequency and violet the highest. The maximum K.E. of photoelectrons thus increases in the order red, green and violet.

50.**(B)** It is a *beta decay* since the atomic number of the product is one higher than that of the reactant, i.e

$$^{3}_{1}H \longrightarrow {}^{3}_{2}He + {}^{0}_{-1}\beta$$

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