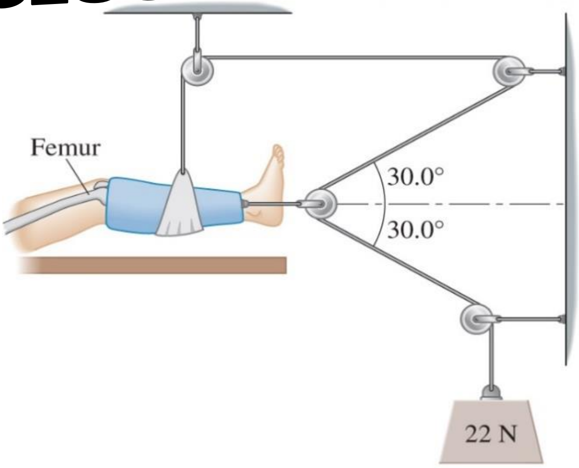
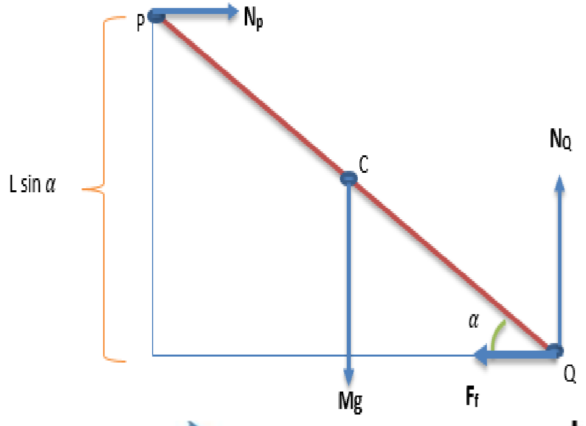
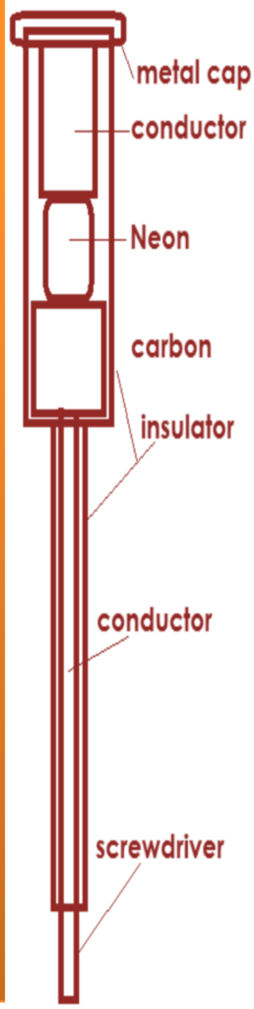
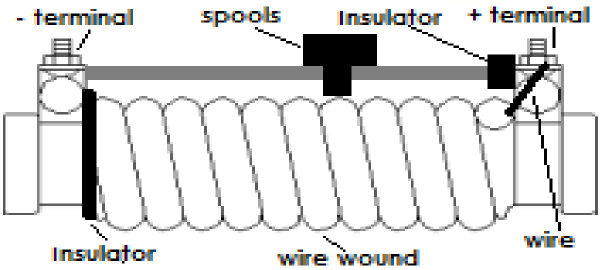
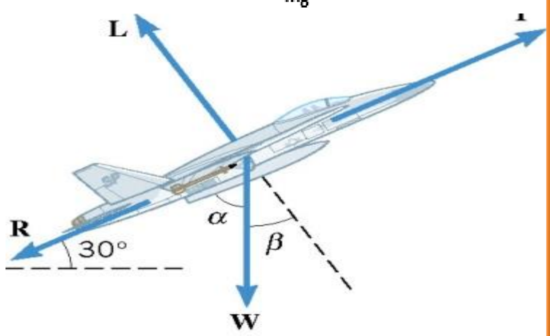
SECONDARY SCHOOL EDUCATION











COMPLETE PHYSICS FORM 3

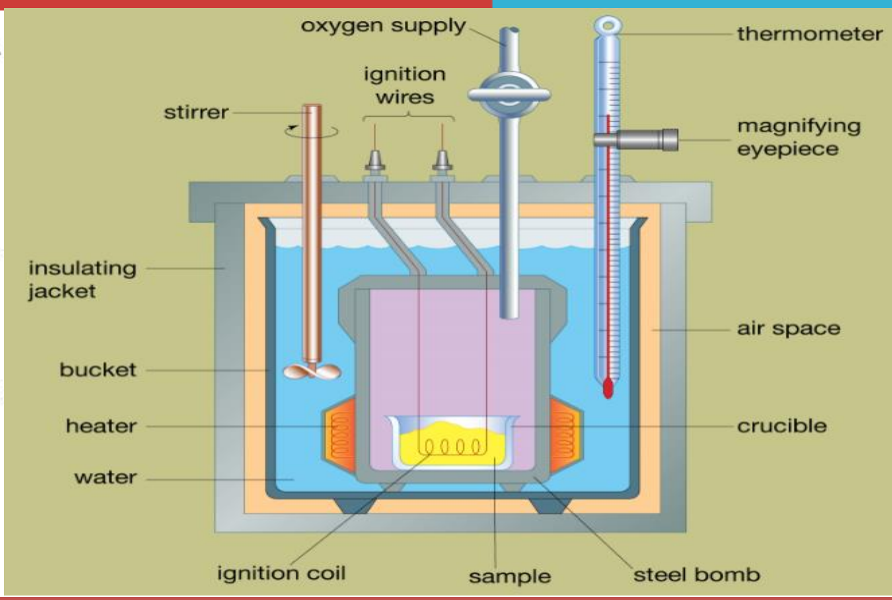
By Ben Omulangira Mutalemwa, (B.Sc. (Ed.))

$F_f = \mu_s F_n$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$F = - k x$

2016



Tegeta Nyuki, Dar es Salaam- Tanzania.

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Preface

Complete Physics notes form 3 is the third writing in the exciting series written specifically for the Form Three Secondary learners in accordance to Tanzania systems of education.

First and foremost in the minds of the author has been a desire to write a text that will support form three learners learning physics while making the subject interesting, enjoyable and meaningful.

The manuscript has been written using clear and concise language throughout, and all concepts have been fully explored first in general and then illustrated in context. Much care has been taken to use illustrative material that is fresh, varied and appealing to a wide range of students of both sexes.

The manuscript boasts many features that will help students and teachers find it easy to use. Each of the manuscript's fifteen chapters has been divided into a number of self-contained sections. At the end of each section is a set of homework-style questions that are designed to reinforce the main points.

Furthermore, demanding questions are included at the end of the chapter. These could be used for assignment or interactive tutorial works. A further set of challenging questions is included to cover each area of study. These could be used for revision. There are over 1000 questions in the manuscript and most answers are supplied.

Within each section, the concept development and worked examples occupy the main three quarters column. The remaining quarter column has been set aside for some of the diagrams and graphs. Each detailed study is a self-contained unit of work, structured to ensure efficient and effective coverage of the chosen topic.

This manuscript is a result of team work done by professional teachers from different schools in East Africa but mostly in Tanzania and experienced editors, who have worked efficiently in order to give out a better product to all learners and educators who are the main target of this manuscript.

I could see far only because I was able to stand on the shoulders of the giants. This is to thank the folks who paved the way for this manuscript to be completed. Mr. Richard Mwakyanjala, Mr. Y. Jabir, Mr. M. Luchagula for their detailed analysis of the various parts of Tanzania syllabus. Thanks are also due to Mr. H. Mdemle, Mr.Kenneth Kaunda, Mr. L. Kyarwenda and Mr. Innocent S. for advice on certain matters relating to how the book should be set.

Acknowledgement is made to my wife Magdalene for typing and again undertaking the re-type after several advises offered by my colleagues.

My children Bertha, Benson, Beatrice and Brighton are also not forgotten for offering their ample time to me so as to accomplish the task of preparing this wholesome manuscript.

01. SCALAR QUANTITIES

Scalar quantity is the any physical quantity that has magnitude only and no direction. Examples, **mass, time, length, energy, electric current, specific heat capacity, speed, area, volume, density,** etc. Requires 2 things: A value and Correct units Ex. Mass: 5kg

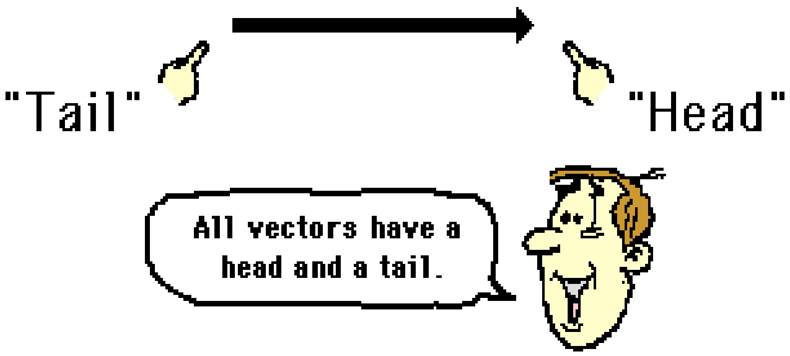
VECTOR QUANTITIES

Vector quantity is the any physical quantity that has both magnitude and direction. Example, **force**, **displacement**, **velocity**, **momentum**, **impulse, acceleration**, etc. Requires 3 things: A value, correct units and given direction Ex. Pressure: 10N/m^2

Example:- Suppose your teacher Mr. Ben tells you "A bag of gold is located outside the classroom. To find it, displace yourself 20 meters." This statement may provide you enough information to your interest; yet, the displacement required to find the bag of gold has not been fully described. On the other hand, suppose your teacher tells you "A bag of gold is located outside the classroom. To find it, displace yourself from the center of the classroom door 20 meters in a direction 30 degrees to the west of north." This statement now provides a complete description of the displacement vector - it lists both magnitude (20 meters) and direction (30 degrees to the west of north) relative to a reference or starting position (the center of the classroom door).

VECTOR ARITHMETIC

Scalar quantity can be added, multiplied, divided or subtracted. Example, if you have two liquid in different measuring cylinder let say fist one contain 25 cm^3 and a second contain 15 cm^3 if you are asked to find total volume you must add to obtain total volume of 40 cm^3.
Vector quantity can be represented on a diagram by a directed line segment. Consider the diagram below



The length of line segment represents the magnitude and the arrow represents the direction

Points to note:

(i) The direction can be represented by using compass direction
(ii) Two vector are equal if the magnitude and direction are same.
(iii) The triangle method and parallelogram method are used to adding two vectors.
(iv) The vector we get after the adding of more vectors is called resultant vector
(v) Resultant vector can be added by mathematical or graphical/drawing
(vi) Resultant vector is measured as an anticlockwise angle of rotation from due east

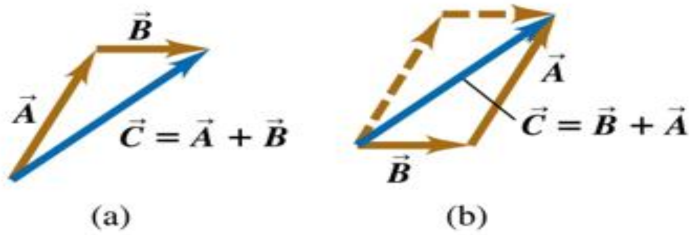
ADDING BY MATHEMATICAL METHOD

There are two methods of vector addition
(i) Graphical → represent vectors as scaled-directed line segments; attach tail to head
(ii) Analytical → resolve vectors into x and y components; add components

Adding By Graphical Method

When two given forces are neither acting in a straight line nor parallel they must be acting at a certain angle to each other.

- Vector **addition** is **commutative** (the order of vector addition doesn't matter).
- Vector **C** of a vector sum of vectors **A** and **C**. e.g: double displacement of particle.

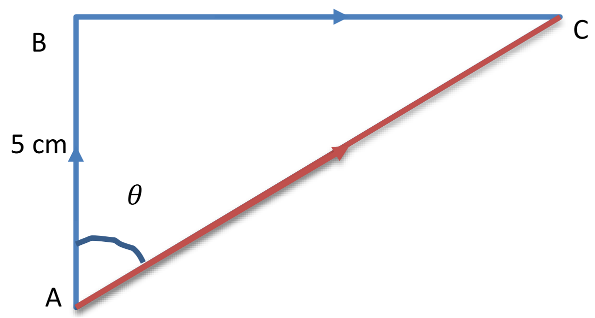


These are the steps followed when adding two or more vectors by graphical method:-

i. Choose a suitable scale and write it down on a graph paper
ii. Pick starting and draw the first vector to a proper scale and direction stated.
iii. Starting from the head of the first vector, draw the second vector to scale in the started direction until all given vectors finished
iv. Draw the line to connect tail of the first drawn vector and the head of the last vector. This is called resultant vector
v. Measure the length of the resultant vector and convert to actual unit
vi. Determine the direction of vector from where you have started to where you are

Example 01,
Suppose a lady walks starting from point A, a distance of 5m due north and then walks 12m due east. Find her new position from A
Solution

i. Using a scale of 1cm to represent 1 m. Draw a vector AB 5cm due north.
ii. From B draw BC 12cm due east.
iii. Join A and C point to this diagram



iv. Measuring the length of AC, It is found that AC = 13 cm
Changing 13cm into actual unit it becomes 13m
v. Determine the direction of vector

$$\text{Tan}\,\theta = \frac{12}{5} = 2.4$$

$$tan^{-1}\,\theta\,(2.4) = 67.38^{0}$$

Therefore position of C is represented by vector AC of magnitude 13 m at an angle of 67.38⁰ east of north

THE TRIANGLE LAW

The triangle law states that,

"If three forces are in equilibrium and that two of the forces are represented in magnitude and direction by two sides of a triangle, then, the third side of the triangle represents the resultant of the two forces"

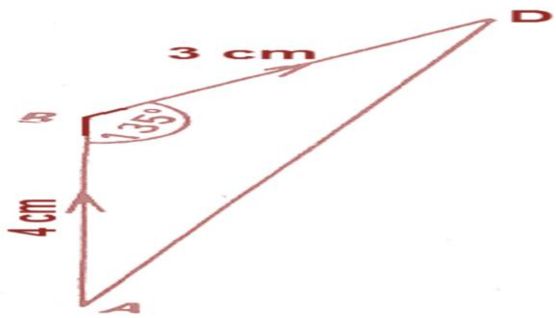
Example 02,

A brick is pulled by a force of 4N acting northward and another force of 3N acting north-east. Find the resultant of these two forces.

Solution

i. Using a scale of 1cm to represent 1 N, Draw a vector AB 4cm due north.
ii. From B draw BD 3cm at 45^0 and Join A and D point

   The resultant diagram is a triangle as shown below



iii. Measure the length of AD, You will find that AD = 6.5 cm

   Change 6.5 cm into actual unit

   1cm = 1 N

   6.5 cm =?

   Cross multiplication you get 6.5 N

   Therefore the resultant of these two forces 6.5 N

PARALLELOGRAM LAW

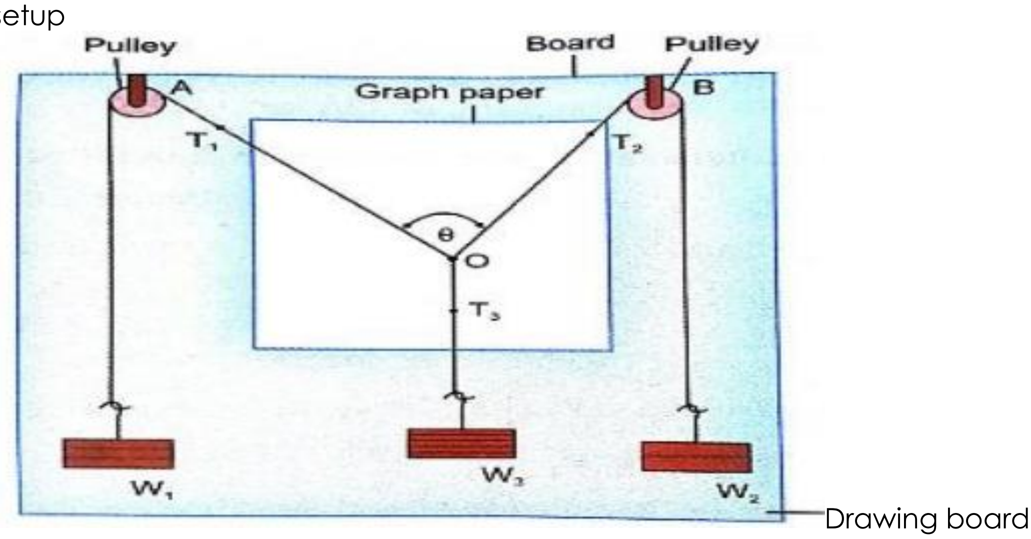
The parallelogram law of forces states that,

"If two vectors are represented by the two sides given and they include an angle between them, then the resultant of the two forces will be represented by the diagonal from their common point of a parallelogram formed by the two vectors"

Aim: To verify parallelogram of forces law.

Apparatus: Drawing board, graph paper, string, pins, pulleys, some weights, protractor

Diagram/setup



Procedure:-

1. Fix graph paper on graph board.
2. Fix two pins in graph board one at your right hand side and the other at your left hand side. Each peg should be near end of the graph board.
3. Hang one pulley in each pin fixed in graph board label the position of pulleys as A and B respectively.
4. Take string fixed with masses and hanger in its end and pass it over pulleys. Convert the units to Newton (N). Label weights as W_1 and W_2
5. Hang another weight W_3 at the middle of the thread, so that the thread forms an angle θ. Label the intersection as point O.
6. These three weights W_1, W_2 and W_3 create tension T_1, T_2 and T_3 respectively on the string. Adjust the standard weights until the system is in equilibrium.
7. Trace a string OA and OB on the graph paper fixed on the graph board.
8. Choose a suitable scale for OA and OB represent W_1 and W_2

Table of results

Force T_1 (N)	Force T_2 (N)	Angle θ°	Resultant R (N)	Equilibrium (N)

Note

The equilibrant of a system of forces is that single force which acting on the system of forces produces equilibrium. While resultant of a system of forces equals the equilibrant of the system in magnitude but acts in the opposite direction

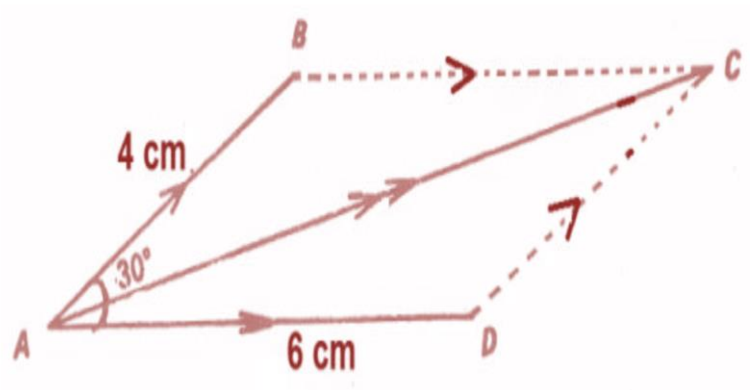
Example 03,

Two forces AB and AD of magnitude 40 N and 60 N respective are pulling a body on horizontal table. If the two forces makes an angle 30^0 between them, find the resultant force on the, body.

Solution

i. Using a scale of 1cm to represent 10 N
ii. Draw a vector AD 6 cm horizontal from point A
iii. From point A draw AB 3 cm at 30^0 from vector AD
iv. Complete the parallelogram ABCD
v. Join A and c point

   The resultant diagram is a triangle as shown below



vi. Measure the length of AC

   AC = 9.7 cm

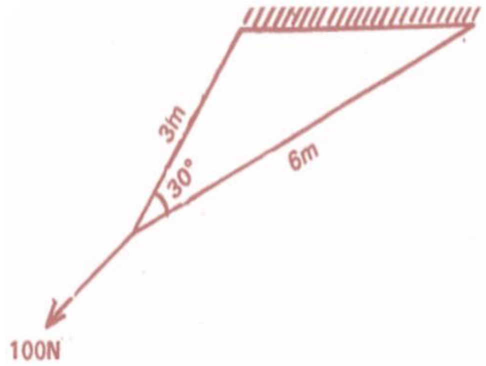
   Change to actual unit

   1cm = 10 N

   9.7 cm =?

   Therefore the resultant of these two forces 97 N

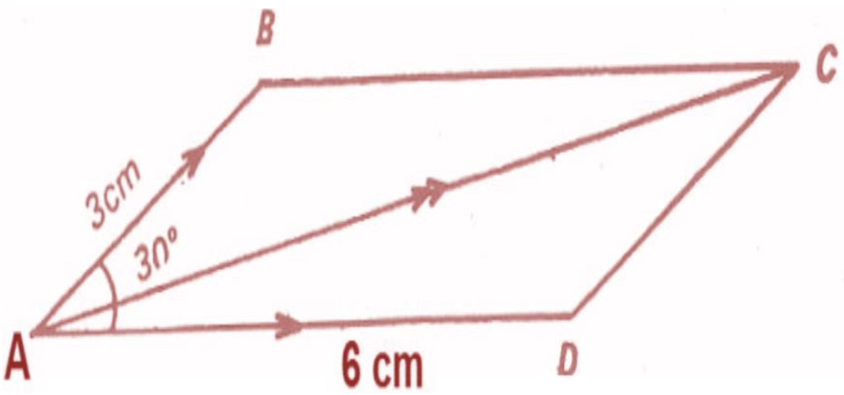
Example 04,
Two ropes of 3 m and 6 m long are tied to a ceiling and their free ends are pulled by a force of 100 N as shown in the figure below. Find the tensions in each rope if they make angle 30° between them.
Diagram:



Solution

i. Using a scale of 1cm to represent 1 m
ii. Draw a vector AD 6 cm horizontal from point A
iii. From point A draw AB 3 cm at 30^0 from vector AD
iv. Complete the parallelogram ABCD
v. Join A and c point

The resultant diagram is a triangle as shown below

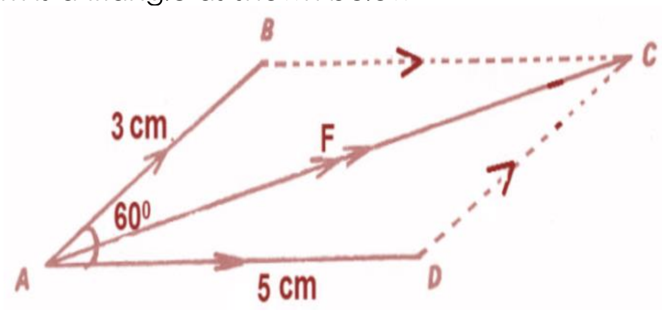


vi. Measure the length of Ac
Ac = 8.7 cm
AC is the equal to 100 N because action is equal to opposite reaction,
AC = 8.7 cm =100 N
Now: Tension at 3 cm calculated by:
8.7 cm = 100 N
3 cm =?
Cross multiplication you get 34.5 N
Therefore the Tension at 3 cm is 34.50N

Then: Tension at 6 cm calculated by:
8.7 cm = 100 N
6 cm =?
Cross multiplication you get 69 N
Therefore the Tension at 6 cm is 69 N

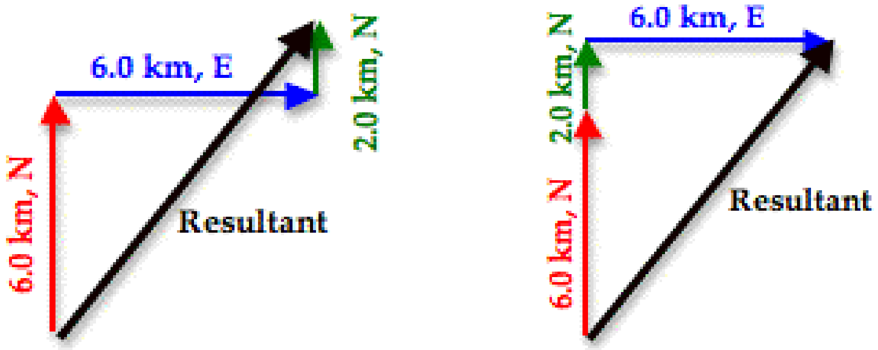
Example 05,
Find the resultant force, F, when two forces,
9 N and 15 N, act on an object with an angle of 60^0 between them.
Solution
i. Using a scale of 1cm to represent 3 N
ii. Draw a vector AD 5 cm horizontal from point A
iii. From point A draw AB 3 cm at 60^0 from vector AD
iv. Complete the parallelogram ABCD
v. Join A and c point

The resultant diagram is a triangle as shown below



vi. Measure the length of Ac
Ac = 7 cm
Change to actual unit
1cm = 3 N
7 cm = ?
Cross multiplication you get 21 N
Therefore the resultant force, F is 21 N

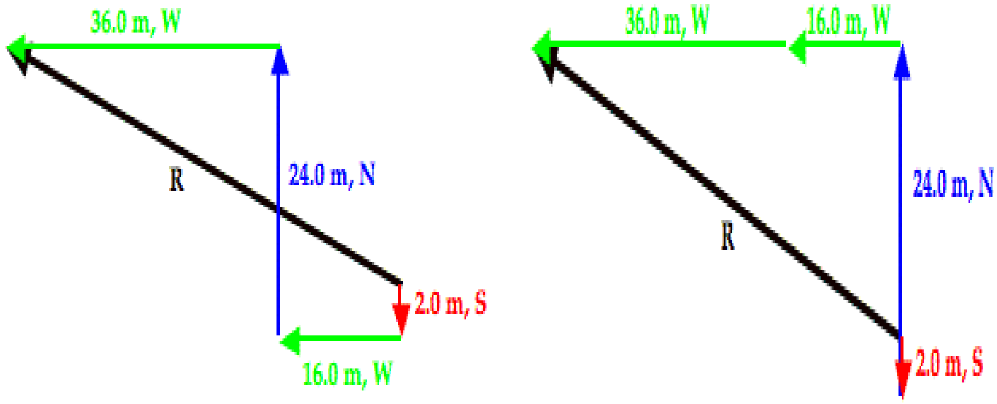
Example 06,
A student drives her car 6.0 km, north before making a right hand turn and driving 6.0 km to the East. Finally, the student makes a left hand turn and travels another 2.0 km to the north. What is the magnitude of the overall displacement of the student?
Solution



$R^2 = (8.0\ km)^2 + (6.0\ km)^2$
$R^2 = 64.0\ km^2 + 36.0\ km^2$
$R^2 = 100.0\ km^2$
R = SQRT (100.0 km2)
R = 10.0 km

Example 07,
Irene and Bridgette are doing the *Vector Walk Lab*. Starting at the door of their classroom, they walk 2.0 meters, south. They make a right hand turn and walk 16.0 meters, west. They turn right again and walk 24.0 meters, north. They then turn left and walk 36.0 meters, west. What is the magnitude of their overall displacement?

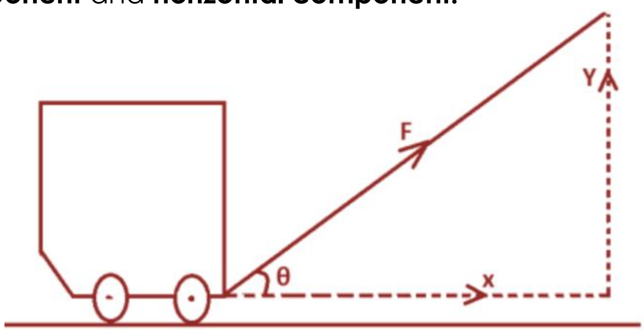
Solution



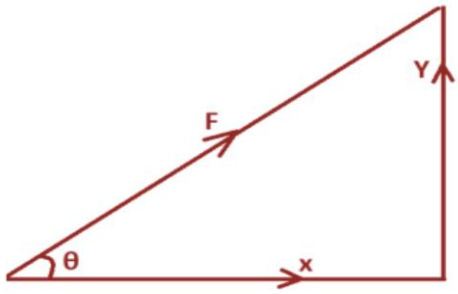
$R^2 = (22.0 \text{ m})^2 + (52.0 \text{ m})^2$
$R^2 = 484.0 \text{ m}^2 + 2704.0 \text{ m}^2$
$R^2 = 3188.0 \text{ m}^2$
$R = \text{SQRT}\ (3188.0 \text{ m}^2)$
$R = 56.5$ m

RESOLUTION OF THE VECTOR

Consider the diagram below where the toy car is pulled at a certain angle but it seems to move horizontally due to horizontal force, not only that but vertical force is formed which lowers the normal force as well as friction on the floor.
When we have values of hypotenuse and angle formed with horizontal we can split it into a **vertical component** and **horizontal component.**



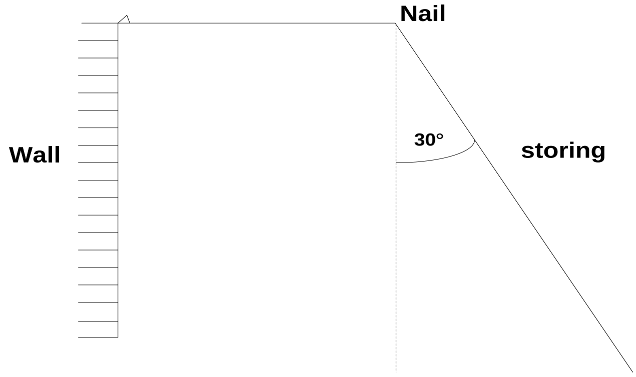
From the diagram:
Horizontal force = x and a Vertical force = y
Extracting the triangle from the above diagram



Horizontal force/vector is given by the formula
From:

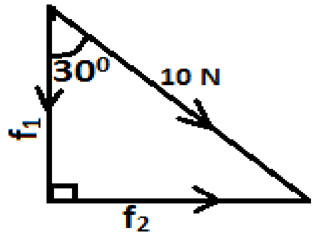
Cos θ = X/F – multiply for F both sides you get
X = FCos θ
Vertical force/vector is given by the formula
From:
Sin θ = Y/F – multiply for F both sides you get
Y = F.Sin θ

Example 08,
A nail is being pulled using a string from a wall. The string forms an angle of 60° with the normal. If the force being used is 10 N, part of the force will tend to bend the nail while the other part will try to pull it out.
Figure:



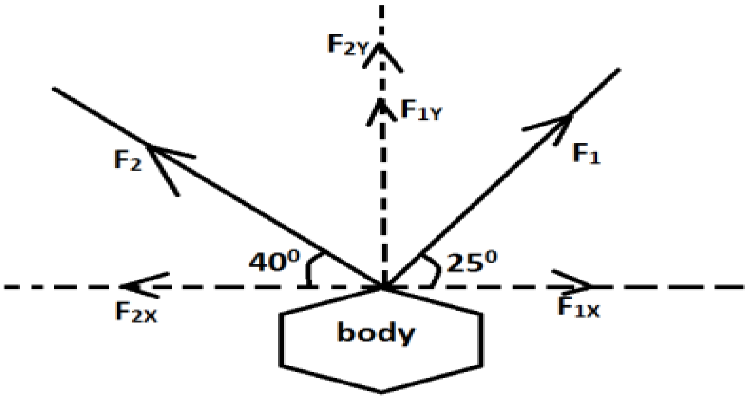
What the magnitude of the force:
a) Tend to bend the nails?
b) Tend to pull the nails out?

Solution:
Kept the information above into vector form



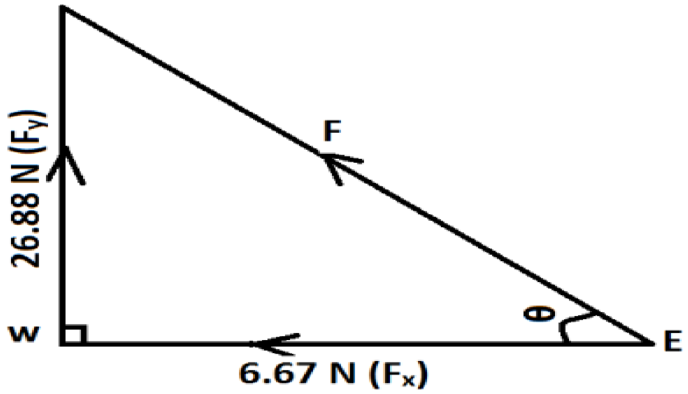
a) Force tends to bend the nails, f_1 = ?
$f_1 = 10 \times \cos 30^0$
$f_1 = 10 \times 0.866$
$f_1 = 8.66$ N
b) Force tends to pull the nails out, f_2 = ?
$f_2 = 10 \times \sin 30^0$
$f_2 = 10 \times 0.5$
$f_2 = 5.0$ N

Example 09,
A body is being acted on by two forces: F_1 = 18 N acting at an angle of 25° and F_2 = 30 N acting at 140° from due East. Find the resultant of the two forces, F, by separating the forces into x- and y- components.
Solution:
Draw the diagram first



First find F_{1X} and F_{2X}
Where:
F_1 = 18 N while F_2 = 30 N
From: X = F. Cos θ
$F_{1X} = F_1$. Cos 25
F_{1X} = 18 x Cos 25
F_{1X} = 16.31 N - toward east
Then:
$F_{2X} = F_1$. Cos 40
F_{2X} = 30 x Cos 40
F_{2X} = 22.98 N - toward west
Their net force, F_X is determined by their difference as they act in two different direction.
$F_X = F_{2X} + (- F_{1X})$
F_X = 22.98 + (-16.31)
F_X = 6.67 N - toward west

Second find F_{1y} and F_{2y}
Where:
F_1 = 18 N while F_2 = 30 N
From: Y = F. Sin θ
$F_{1Y} = F_1$. Sin 25
F_{1Y} = 18 x Sin 25
F_{1Y} = 7.6 N - toward north
Then:
$F_{2Y} = F_1$. Sin 40
F_{2Y} = 30 x Sin 40
F_{2Y} = 19.28 N - toward north
Their net force, F_Y is determined by their sum as both act towards north direction.
$F_Y = F_{1Y} + F_{2Y}$
F_Y = 7.6 + 19.28
F_Y = 7.6 + 19.28
F_Y = 26.88 N - toward north
Modify the vector diagram



Lastly find the resultant of the two forces, F = ?
By using Pythagoras' theorem,
$R^2 = 26.88^2 + (6.67^2)$
R = 27.70 N
Get the direction
Tan θ = Fy/Fx
Tan θ = 26.88/6.67
Tan θ = 4.03
θ = 76.06^0 (from the diagram above)
Therefore resultant force is 27.70 N at an angle of 13.94 North- west

WEIGHTLESSNESS

You may have experienced occasions, such as in an elevator or on a rollercoaster ride, where you seem to feel heavier or lighter than usual. This sensation is not due to your weight changing. It will remain the same value provided you don't go too far from the earth's surface.

The force that is changing is the normal force from the floor or the seat that you are using. When this normal force increases, such as when an elevator accelerates upwards, you feel a larger force acting through your feet and so feel heavier. Your apparent weight has increased because the normal force acting on you has increased.

When the elevator comes to a stop at the top of the floor, the opposite happens. The normal force decreases in size, you feel lighter and your apparent weight, decreases

RELATIVE VELOCITY

Relative velocity is the velocity of a body with respective to another moving or stationary body.

Points to note:

→ Velocity of one object let say VA respect another object let say VB is denoted by symbol VAB.

→ If all object moving to the same direction, it seems to observe low speed, therefore we minus two velocity of moving body, (-VB)
VAB = VA + (-VB)
VAB = VA – VB

→ If all object moving to the opposite direction, it seems to observe high speed, therefore we plus two velocity of moving body, (+VB)
VAB = VA + (+VB)
VAB = VA + VB

→ Relative velocity also can be calculated by triangle method and by parallelogram methods

Example 10,

Car A is moving at a velocity of 20 m/s while car B is moving at a velocity of 30 m/s. Calculate the velocity of car B relative to car A if:

a) They are moving in the same direction.
b) They are moving in the opposite directions.

Data given

Velocity of Car A, VA = 20 m/s
Velocity of Car B, VB = 30 m/s
Relative velocity, VBA = ?

Solution:

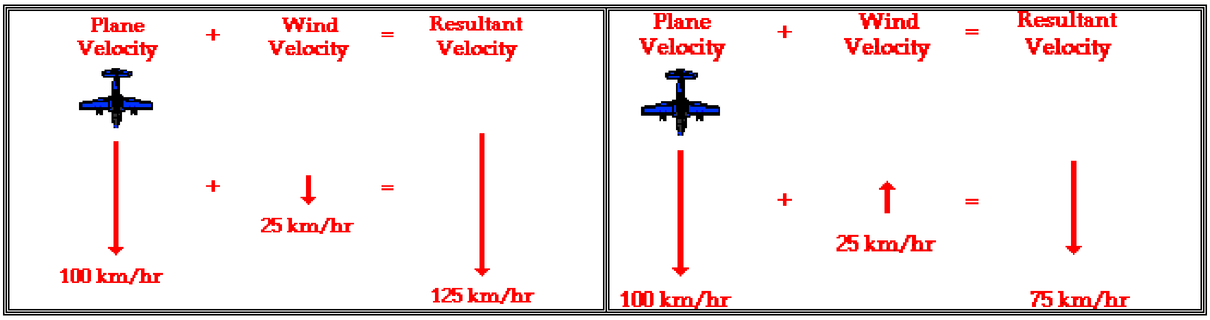
(a) they are moving in the same direction
From: VBA = VB – VA
VBA = 30 – 20
VBA = 10 m/s

(b) They are moving in the opposite directions.
From: VBA = VB + VA
VBA = 30 + 20
VBA = 50 m/s

AN AIRPLAIN'S MOTION

An airplane usually encounters a wind - air that is moving with respect to an observer on the ground below.

In such instances as this, the magnitude of the velocity of the moving object with respect to the observer on land will not be the same as the speedometer reading of the vehicle.

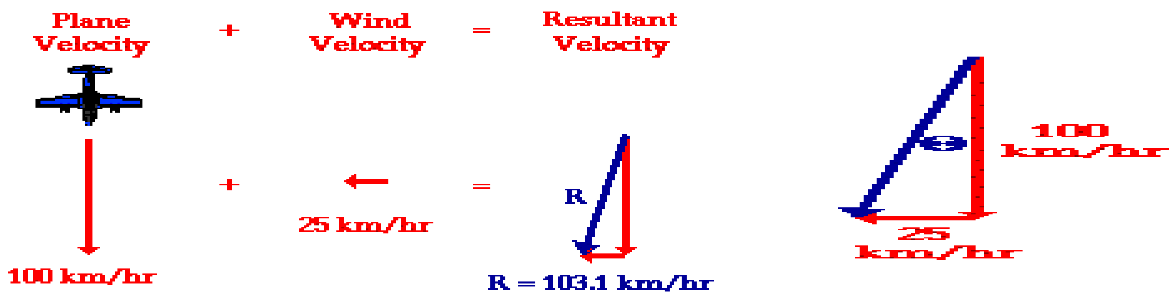


That is to say, the speedometer on the plane might read 900 km/h; yet the plane might be moving relative to the observer on the ground at a speed of 500 km/h.
A tailwind that approaches the plane from behind, increases its resulting velocity.

Suppose a plane traveling with a velocity of 100 km/h with respect to the air meets a headwind with a velocity of 25 km/h. In this case, the resultant velocity would be 75 km/h; this is the velocity of the plane relative to an observer on the ground.

Now consider a plane traveling with a velocity of 100 km/h, south that encounters a side wind of 25 km/h, west.

Since the two vectors to be added are at right angles to each other, the Pythagorean Theorem can be used. This is illustrated in the diagram below.



The magnitude of the resultant velocity is determined using Pythagorean Theorem.
The algebraic steps are as follows:

$$(100\ \text{km/h})^2 + (25\ \text{km/h})^2 = R^2$$
$$10\,000\ \text{km}^2/\text{h}^2 + 625\ \text{km}^2/\text{h}^2 = R^2$$
$$10\,625\ \text{km}^2/\text{h}^2 = R^2$$
$$\text{SQRT}\ (10\,625\ \text{km}^2/\text{h}^2) = R$$

103.1 km/h = R

The angle between the resultant vector and the southward vector can be determined using the sine, cosine, or tangent functions. The tangent function can be used; this is shown below:

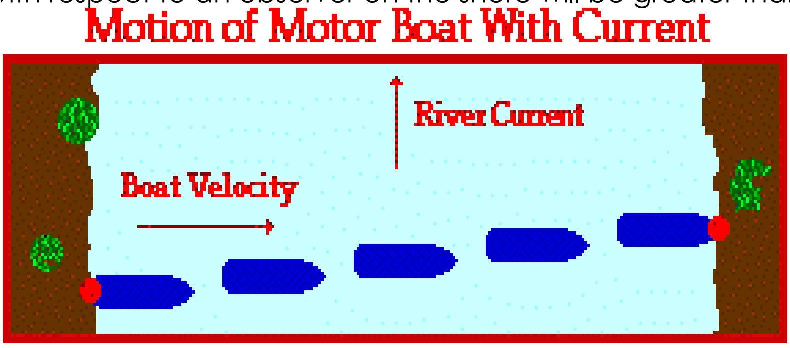
$$\boldsymbol{Tan}\ \emptyset = \frac{\boldsymbol{Opposite}}{\boldsymbol{Adjacent}} = \frac{25}{100}$$

θ = 14.0 degrees

If the resultant velocity of the plane makes a 14.0 degree angle with the southward direction, then the direction of the resultant is 256 degrees from due east.

A RIVERBOAT'S MOTION

If a motorboat were to head straight across a river, it would not reach the shore directly across it from its starting point. The river current influences the motion of the boat and carries it downstream. The motorboat may be moving with a velocity of 4 m/s directly across the river, yet the resultant velocity of the boat will be greater than 4 m/s and at an angle in the downstream direction. While the speedometer of the boat reading 4 m/s, its speed with respect to an observer on the shore will be greater than 4 m/s.

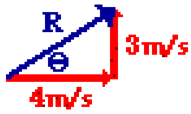


Since the boat heads straight across the river and since the current is always directed straight downstream, the two vectors are at right angles to each other. Suppose that the river was moving with a velocity of 3 m/s, North and the motorboat was moving with a velocity of 4 m/s, east. What would be the resultant velocity of the motorboat i.e., the velocity relative to an observer on the shore?

Thus, the Pythagorean Theorem can be used to determine the resultant velocity as follows:

$$(4.0\ m/s)^2 + (3.0\ m/s)^2 = R^2$$
$$16\ m^2/s^2 + 9\ m^2/s^2 = R^2$$
$$25\ m^2/s^2 = R^2$$
$$\text{SQRT}\ (25\ m^2/s^2) = R$$
$$\mathbf{5.0\ m/s = R}$$

The direction of the resultant is the counter clockwise angle of rotation that the resultant vector makes with due East. This angle can be determined using a trigonometric function as shown below.



$$Tan\ \emptyset = \frac{Opposite}{Adjacent}$$

$$\tan \theta = (3/4)$$

$$\theta = \text{inv.tan}\ (3/4)$$

$$\mathbf{\theta = 36.9\ degrees}$$

Given a boat velocity of 4 m/s, East and a river velocity of 3 m/s, north, the resultant velocity of the boat will be 5 m/s at 36.9 degrees.

Motorboat problems such as these are typically accompanied by three separate questions:

(a) What is the resultant velocity (both magnitude and direction) of the boat?

(b) If the width of the river is *80* meters wide, then how much time does it take the boat to travel shore to shore?

(c) What distance downstream does the boat reach the opposite shore?

The resultant velocity of the boat can be determined using the Pythagorean Theorem (magnitude) and a trigonometric function (direction).

The second and third of these questions can be answered using the average speed equation (and a lot of logic).

$$Average\ speed = \frac{Distance}{Time}$$

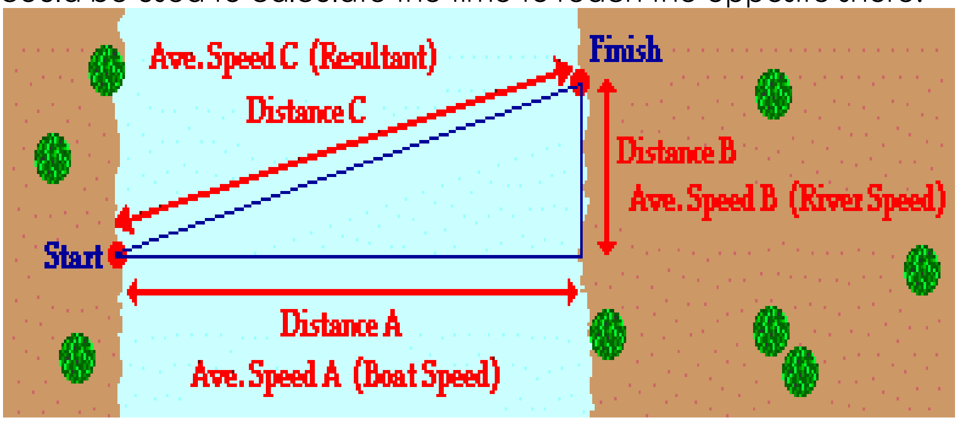
The time to cross this 80-meter wide river can be determined by rearranging and substituting into the average speed equation.

$$Time = \frac{Distance}{Average\ speed}$$

The distance of 80 m can be substituted into the numerator. But what value should be used for average speed? Should 3 m/s (the current velocity), 4 m/s (the boat velocity), or 5 m/s (the resultant velocity) be used as the average speed value for covering the 80 meters? With what average speed is the boat traversing the 80 meter wide river?

The diagonal distance across the river is not known in this case. If one knew the **distance C** in the diagram below, then the **average speed C** could be used to calculate the time to reach the opposite shore.

Similarly, if one knew the **distance B** in the diagram below, then the **average speed B** could be used to calculate the time to reach the opposite shore.
And finally, if one knew the **distance A** in the diagram below, then the **average speed A** could be used to calculate the time to reach the opposite shore.



In our problem, the 80 m corresponds to the distance A, and so the average speed of 4 m/s (average speed in the direction straight across the river) should be substituted into the equation to determine the time.

$$Time = \frac{Distance}{Average\ speed} = \frac{80m}{4m/s}$$

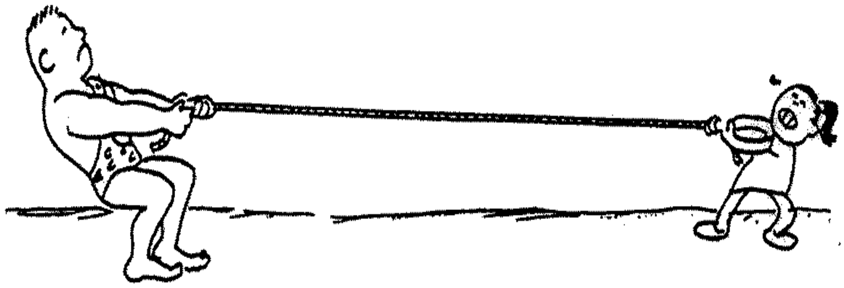
It requires 20 s for the boat to travel across the river. During this 20 s of crossing the river, the boat also drifts downstream. Part c of the problem asks "What distance downstream does the boat reach the opposite shore?" The same equation must be used to calculate this *downstream distance*.

Distance = Average speed x time = (3 m/s) x (20 s)
Distance = 60 m

The boat is carried 60 meters downstream during the 20 seconds it takes to cross the river. The motion of the riverboat can be divided into two simultaneous parts - a motion in the direction straight across the river and a motion in the downstream direction. These two parts (components) of the motion occur simultaneously for the same duration 20s.

CHECK YOUR UNDERSTANDING

1. Omulangira Strongman and Nona Small pull on opposite ends of a rope in a tug of war. The greater force exerted on the rope is by



   a) Omulangira
   b) Nona
   c) Neither (√)

2. A motorboat traveling 24 m/s, East encounters a current traveling 7.0 m/s, north. If the width of the river is 144 meters wide, then how much time does it take the boat to travel shore to shore? What distance downstream does the boat reach the opposite shore? (Ans:- t = 6sec, Downstream distance = 42m)

3. A motorboat travelling 8.0 m/s, East encounters a current travelling 6.0 m/s, north.
   (a) What is the resultant velocity of the motorboat? (Ans:- 10m/s)
   (b) If the width of the river is 96 meters wide, then how much time does it take the boat to travel shore to shore? (Ans:- 12 sec)

4. Two forces, 12N and15N, act on an object with an angle of 50^{o} between them.
   a) Find the resultant force F using triangular law of forces,
   b) Differentiate Scalar from vector giving three examples of each.

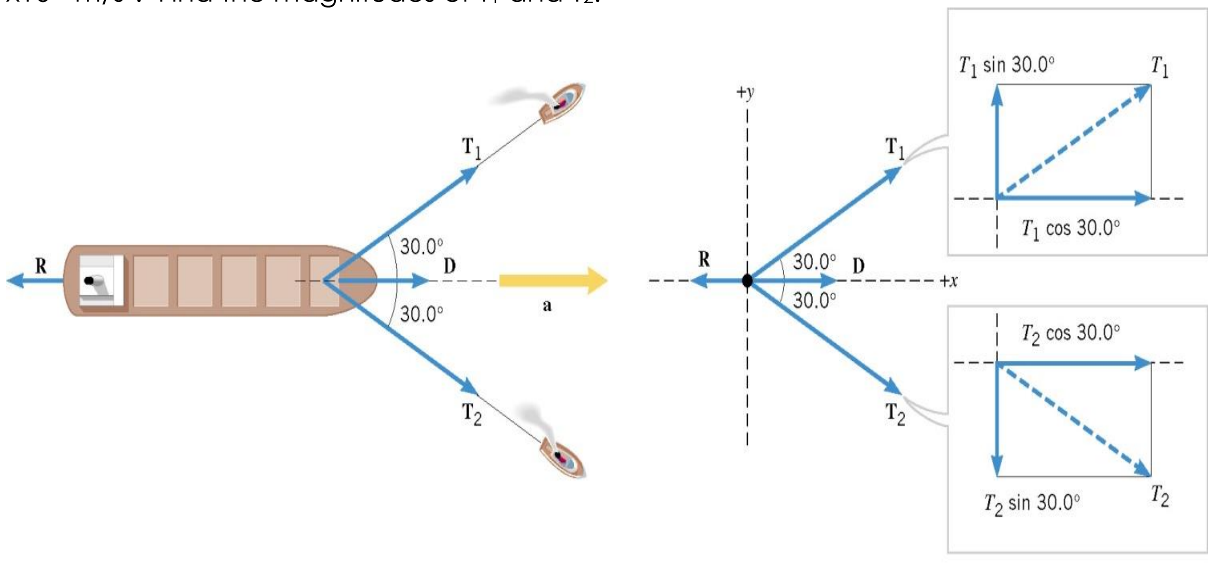
5. Two forces, one 8N and the other 6N, are acting on a body. Given that the two forces are acting perpendicularly to each other.
   a) Using parallelogram law of forces find the magnitude of the resultant force which would just counter the two forces.
   b) What do you understand by a resultant force?

6. While playing at the beach, Ronaldo and Rooney kick a stationary beach-ball simultaneously with forces of 150N south and 200N west respectively. The balls move as if it were only subjected to the net force. In what direction will it travel, and what is the magnitude of the net force on the ball?

7. A motorboat is being driven east along the Kagera River. The engine is providing a driving force of 840N towards the east. A friction force of 280N from the water and a drag force of 160N from the air are acting towards the west as the boat travels along. If an unknown force pushes it towards North with a force of 300N,
   (a) Draw a force diagram showing the horizontal forces of this situation.
   (b) Determine the resultant force acting on the motorboat and its direction.

8. A motorboat traveling 6 m/s, East encounters a current traveling 3.7 m/s, south. Calculate
   (a) The resultant velocity of the motor boat. (Ans= 6.997m/s)
   (b) The time it takes the boat to travel shore to shore If the width of the river is 120 meters wide, (Ans:- 20 sec)
   (c) The distance downstream does a boat reach the opposite shore (Ans:-72m)

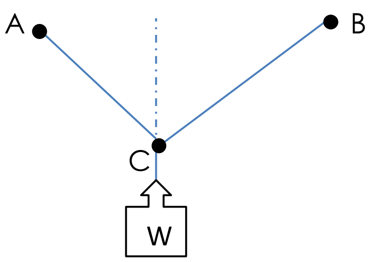
9. A supertanker of mass m = 1.50 x 10 ^{8} kg is being towed by two tugboats. The tensions in the towing cables apply the forces T_1 and T_2 at equal angles of 30.0^{o} with respect to the tanker's axis. In addition, the tanker's engines produce a forward drive force D whose magnitude is D = 75.0 x 10^{3} N. Moreover, the water applies an opposing force R, whose magnitude is R = 40.0 x 10^{3} N. The tanker moves forward with an acceleration that points along the tanker's axis and has a magnitude of 2.00 x10^{-3} m/s^{2}. Find the magnitudes of T_1 and T_2.



(a) (b) Free-body diagram for the tanker

(Use:- $\varepsilon F_x = +T_1\cos 30.0^{o} + T_2\cos 30.0^{o} + D - R = ma_x$ and $\varepsilon F_y = +T_1\sin 30.0^{o} - T_2\sin 30.0^{o} = 0$)
(Ans:- T_1 and T_2 are equal = 152,998N)

10. A string attached to two hooks A and B, supports a weight W attached at point C. CA makes an angle of 30^{0} to the vertical while CB makes an angle of 45^{0} to the vertical as shown in the figure below. If the tension in BC is 100N, find the tension in AC and the weight W (Ans:- AC= 141.42 N, W= 193.184 N)

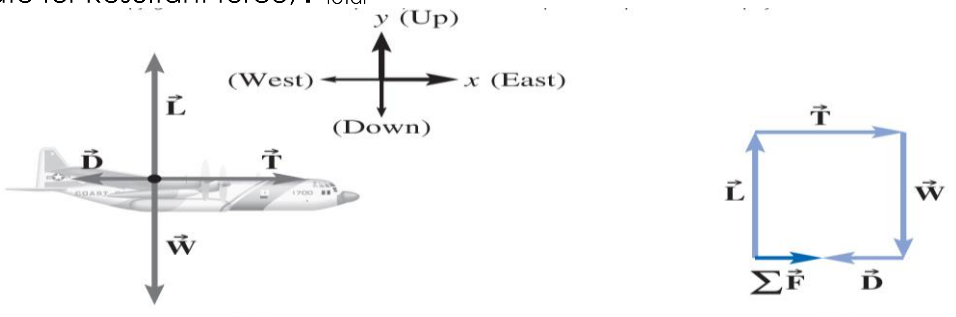


11. Car A is moving with a velocity of 120km/h while car B moving with a velocity of 80km/h. Calculate the velocity of car B relatives to car A if:
    (a) They are moving in the same direction (Ans:- -40m/s)
    (b) They are moving in opposite direction (Ans:- 200m/s)

12. A plane can travel with a speed of 80 mi/h with respect to the air. Determine the resultant velocity of the plane (magnitude only) if it encounters a
    (a) 20 mi/h headwind. (Ans:- 60mi/h)
    (b) 20 mi/h tailwind. (Ans:- 100mi/h)

13. An airplane heads East, E. The forces acting on it are:
   - Gravity 16kN down
   - Lift 16kN up
   - Thrust 1.8 kN E
   - Drag 0.8 kN W

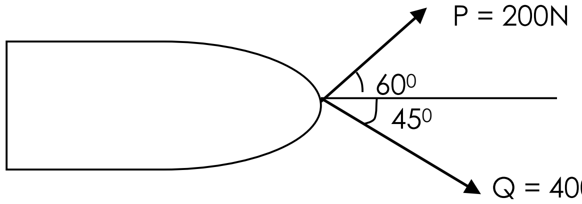
   Calculate for Resultant force, **F** $_{total}$



(a) (b)

(Answer for F_{tot} = 1.0 kN E)

14. Two forces P and Q are applied on a small boat stuck in a shallow stream as shown below.



Determine the magnitude and direction of the resultant of the two forces

15. A roller coaster moves 85 m horizontally, then travels 45 m at an angle of 30° above the horizontal. What is its displacement from its starting point?(graphical techniques) (Ans:- 126 m at 10° above the horizontal)

16. The relative velocity of Car A to that of Car B is 32 m/s when moving in opposite direction, and 7m/s when moving in the same direction. Calculate the velocity of car B. (Ans:- 7m/s)

17. A novice pilot sets a plane's controls, thinking the plane will fly at 250 km/hr to the north. If the wind blows at 75 km/hr toward the southeast, what is the plane's resultant velocity? Use graphical techniques. (Ans:- 204 km/h at 75° north of east)

18. While flying over the Grand Canyon, the pilot slows the plane's engines down to one-half the velocity of the last problem. If the wind's velocity is still 75 km/h toward the southeast, what will the plane's new resultant velocity be? (Ans:- 89 km/h at 54° north of east)

19. A motorboat is being driven west along the Kagera River. The engine is providing a driving force of 560N towards the west. A friction force of 180N from the water and a drug force of 60N from the air towards east as the boat travels along. Determine the resultant force acting on the motor boat. (Ans:- $\sum F = 320N$ due west)

02. Friction

Friction is the force which resists a body from motion.

Forms of Friction force

- Static friction
  - ✓ This exists when two surfaces try to move across each other but not enough force is applied to cause the motion
- Sliding friction
  - ✓ This exists when two surfaces slide across each other
- Rolling friction
  - ✓ This exists when one object rolls over another object
- Air friction
  - ✓ This exists when air moves around an object
- Viscous friction
  - ✓ This exists when objects move through water or other fluids

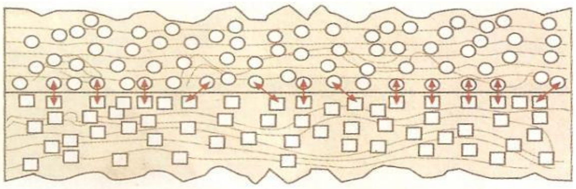
How Friction Happens

The friction force occurs due to the following

(a) Adhesive bond
(b) Mechanical bond
(c) Deformation

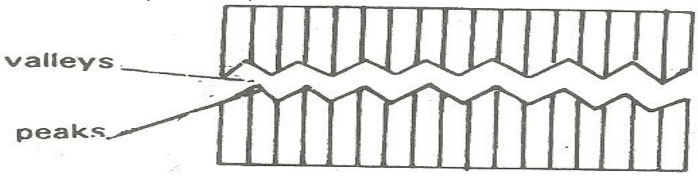
Adhesive Bond

The attraction force between two bodies can raise friction where particle from that object tend to bind each other so it is difficult to break that bond.



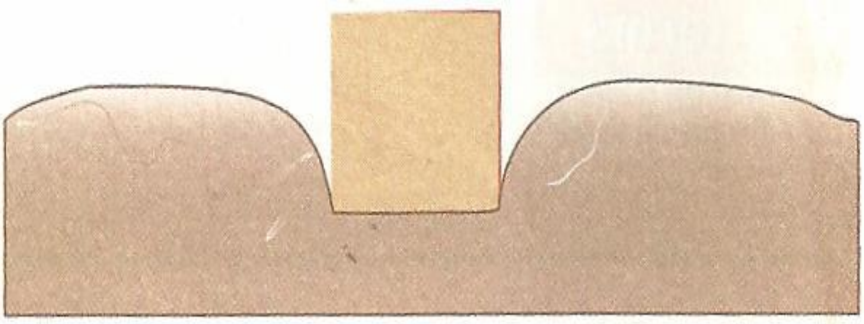
Mechanical Bond

Mechanical bond it raised due to peaks and valleys that tend to bind each other so it is difficult to break that bond. When a body becomes rough means it possesses long peaks and dip valleys.



Deformation

Sometimes deformation causes the friction, when the body deform create valley and the one which inter in that valley is peak.



Advantages of Friction

(i) It aids in walking and movement
(ii) Help moving body to stop. Brakes rely on friction between the brake drum or pads and the wheels. In a bicycle, there are brake pads which clamp onto the wheel to slow it down.
(iii) Helps in writing, drawing and erasing words using eraser
(iv) Used to wear unneeded layers of some material like during sharpening knives
(v) Cause lighting match stick
(vi) Help bottle stopper to stick on the bottle neck
(vii) Friction keeps nails and screws to sick in place.
(viii) Cleats greatly increase the friction between the sports shoe and the ground.

Ways of increasing Friction

As we saw earlier has some advantages and therefore sometimes it's necessary to increase the frictional force how?

i. By increasing the normal force between the surfaces in contact. This can be achieved by pressing the surface together.
ii. Increasing the roughness of the surfaces in touch e.g. Friction between the tyre and the road also spices on football shoes increase friction between the shoes and the football pith/ground.
iii. Scrubbing equipment is made rough to increase friction e.g. Steel wire for Scrubbing "surface"
iv. By using materials with a high coefficient of friction e.g. Rubber which used in Making car tyres has a high coefficient of friction.

Disadvantages of Friction

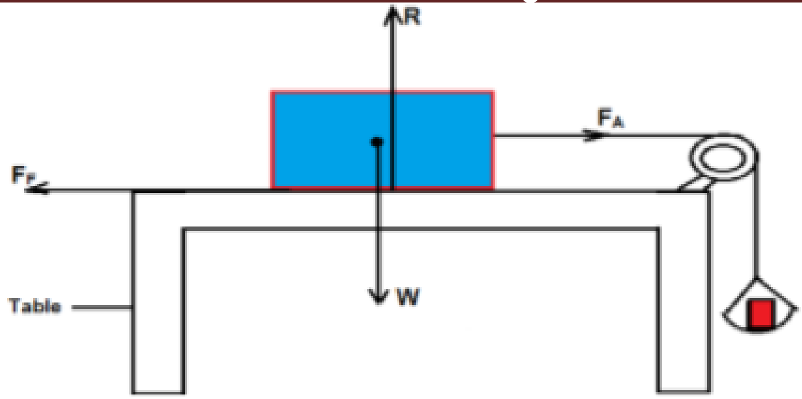
i. It causes wear and tear
ii. It causes noisy in most cases
iii. It causes loss of energy in form of heat energy
iv. It slows down motion of the body
v. It's heat can cause appliance to burn
vi. Cause wounding when skin wearing occurs especially the thighs of fat girls

Methods of Reducing Friction

- Friction cannot be completely eliminated but it can be reduced.

i. Place roller/ball bearing between the two rough surfaces which helps to convert sliding friction into a rolling friction. Rolling friction is less than sliding friction
ii. Use lubrication e.g. oil, water which provides a layer of the lubricant on which the bodies can easily slide.
iii. Speedy material which have low coefficient of friction and thus slide easily.
iv. Make surface soft by polishing which reduces irregularities of surface.
v. Streamlining. Fast cars, boats, planes etc., have a streamlined body. This allow air or water in the case of boat to easily flow by, without offering much resistance. (Flying birds have streamlined bodies)

Normal Force and Limiting Friction



Normal force	This is the equal and opposite to the weight of the body. Always it's perpendicular to the surface on which it rests
Limiting friction	This is the minimum force required to move a body over one another

Take note:-

i. From diagram: R = mg
ii. When body at rest Fr = Force applied, F
iii. When body at motion Fr ≠ F so we have to find net force, F
iv. When body is just about to start moving, static friction force is equal to limiting friction. A small force can make a body to move.
v. When body start to move kinetic friction force is not equal to minimum force applied tend to start motion
vi. If limiting friction less than force applied the body move
vii. If limiting friction greater than force applied the body cannot move

Laws of Friction Forces

The following are the laws of friction:

1. Friction depends on the nature of surface in contacts.
2. Friction does not depend on the surface area in contact.
3. Friction force is independent of the speed once a body has been set in motion.
4. Friction force is independent of the mass of the body
   - Real Life Application:- This applies to car tires in accidents. By measuring the length of skid marks, they can calculate the speed a car was going before an accident μ_k of a tire is the same for all cars since it does not depend on car mass or surface area of the tires.
5. The ration of limiting friction over normal reaction is constant for two surfaces in contact.
6. Frictional force is directly proportional to the normal force between the two surfaces in contact.
   Fr α R – remove proportionality constant
   μ = is the coefficient of frictional force
   Now:- Fr = μR
   Fr = μR – make μ subject
   Therefore $\mu = \frac{Fr}{R}$
   Coefficient of friction is the ratio of friction force to the normal reaction. Since it involve ratio of the same unit it has no SI unit.

Types of Friction

There two main types of friction includes

(a) Static friction force
(b) Dynamic friction force

Static Friction Force

- This one occurs when the bodies are trying to move relative to one another but not yet moving. A certain minimum amount of force makes an object start sliding. This force cause some materials to be stationary Example, book can kept in the top of desk without dropping down
- Note:- *Limiting friction* force (This is just a maximum static friction)

From:

$Fr = \mu_s R$

Where:

Fr = Static friction force
R = Normal reaction
μ_s = Coefficient of static friction force

Therefore:

- The *coefficient of friction* is a ratio of the strength of sliding friction between two surfaces compared to the force holding the surfaces together, called the *normal force*.
- Hence simply, this is the ratio limiting friction force to the normal reaction.
- The coefficient of friction is most often a number between zero and one.

Dynamic Friction Force

Dynamic friction force is the friction occurs when an object is already moving relative to each other. Dynamic friction force also called **kinetic friction force**.

From:

$Fr = \mu_k R$

Where:

Fr = kinetic friction force
R = normal reaction
μ_k = coefficient of kinetic friction force

Therefore:

Coefficient of kinetic friction is the ratio of kinetic friction force to the normal reaction.

- It takes more force to break two surfaces loose than it does to keep them sliding once they are already moving.

Example, 01

A block of mass 200kg is pulled along a horizontal surface. If the coefficient of kinetic friction between the block and the surface is 0.4, what is the friction force acting on the block as it slides?

Data given:

Mass of block, m = 200kg
Acceleration due to gravity, g = 9.8 m/s^2 Normal reaction, R = mg = 1960 N
Coefficient of kinetic friction, μ_k = 0.4, Kinetic Friction force, Fr = ?

Solution:

From: $Fr = \mu_k R$

$Fr = 0.4 \times 1960$

The friction force, Fr acting on the body = 784N

Example, 02

A box of mass 5kg is resting on a horizontal surface; a force of 12.25 N is required to just start the box moving. What is the coefficient of static friction between the block and the surface?

Data given:

Mass of block, m = 5kg

Acceleration due to gravity, g = 9.8 m/s2

Norma reaction, R = mg = 49 N

Static Friction force, Fr = 12.25 N

Coefficient of static friction, μ_s = ?

Solution:

From: Fr = μ_sR

$$\mu_s = \frac{Fr}{R}$$

$$\mu_s = \frac{12.25}{49}$$

The coefficient of static friction μ_s = 0.25

Example, 03

An aluminium block of mass 2.0kg rests on a steel platform. A horizontal force of 15N is applied to the block

(a) Given that coefficient of limiting friction is 0.6, will the block move?

(b) If will moves, what will be its acceleration given that coefficient of kinetic friction is 0.46

Data given:

Mass of block, m = 2.0 kg

Acceleration due to gravity, g = 9.8 m/s^2

Norma reaction, R = mg = 19.6 N and Force applied, F = 15 N

Static Friction force, Fr = 4.4 N

Coefficient of limiting friction, μ_s= 0.6

Coefficient of kinetic friction, μ_k= 0.46

Solution:

(a) Find the static friction force, Fs = ?

From: Fs = μR

Then: Fs = 0.6 x 19.6N

Fs = 11.76N

Since: F > Fs, hence the car will move

(b) Acceleration acquired, a = ?

First find the kinetic friction force, F_k= ?

From: F = μR

Then: Fr = μ_kx R

Fr = 0.46 x 19.6 = 9.016N

Fr it opposes the direction of F so the force which causes motion.

Net force is given by;

F_{net}= Fa – Fr = 15 – 9.016

F_{net}= 5.984 N = Ma

$$a = \frac{F_{net}}{m}$$

$$a = \frac{5.984}{2}$$

a = 2.992 m/s^2

Example, 04

A brick started sliding with a velocity of 8m/s across a concrete horizontal surface floor and the coefficient of friction between the two surfaces is 0.4. How far did it travel before coming to rest? (Use g = 10m/s^2)

Data given:

Initial velocity, u = 8m/s and Final velocity, v = 0m/s
Acceleration due to gravity, g = 10 m/s^2
Normal reaction, R = mg = W
Weight of the brick, W = mg = friction force, F
Coefficient of kinetic friction, μ_k = 0.4
Distance travel by brick, s = ?

Solution:

From:

F = ma - - - - - -(i) and R = mg - - - - - -(ii)

Divide equation (i) to equation (ii)

$$\frac{F}{R} = \mu = \frac{a}{g}$$

But: F/R = μ_k = 0.4

$$\text{Now: } \mu = \frac{a}{g}$$

$$0.4 = \frac{a}{10}$$

a = 4 m/s^2

From third Newton's law of motion

$V^2 = u^2 + 2as$ – making s subject

$$s = \frac{v^2 - u^2}{2a}$$

$$s = \frac{0^2 - 8^2}{2x4}$$

$$s = \frac{64}{8}$$

It travelled 8 m before coming to rest

Example, 05

A sled is traveling 4.0 m/s along a horizontal stretch of snow.
The coefficient of kinetic friction is μ_k = 0.05. How far does the sled go before stopping? (Ans:- 16.3m with an acceleration of 0.49m/s^2)

Example, 06

An aluminum block of mass 2.1kg rest on a steel platform, a horizontal force of 15N is applied on the block. Given that the coefficient of limiting friction between the two surfaces is 0.61;

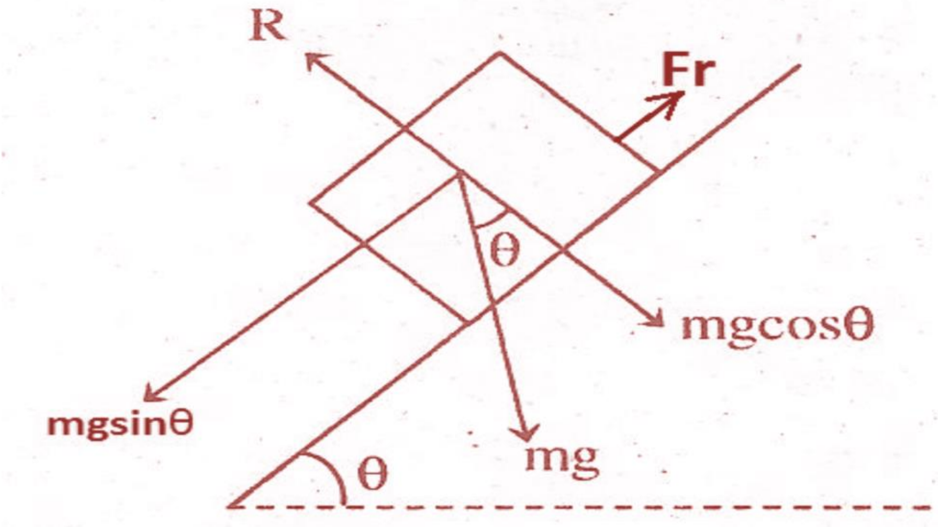
(a) Will the block move? Give reason (Ans:- it will move)
(b) If it moves, what will be its acceleration? (Ans:- acceleration > 1.165m/s^2)

Example, 07

Walk due west for 52 paces, then walk 30.0° North of West for 42 paces, and then walk due north for 25 paces. What are the magnitude and direction of the resultant, R (Ans:- 99 Paces, 28°, N of W)

Friction Force at Inclined Plane

Consider the diagram below, a mass of body sliding down the incline plane



At rest (constant speed)

Fr = Mg sin θ

R = Mg cos θ

But: Fr = μR – making μ subject

$$\mu = \frac{Fr}{R}$$

$$\mu = \frac{Mgsin\ \theta}{Mgcos\ \theta}$$

Therefore, at ***constant speed (at rest)*** coefficient of kinetic friction is given by:-

$$\boldsymbol{\mu = \tan\theta}$$

An accelerating body

When the object begins to slide (from rest) there will be kinetic friction between the object and the incline

F_{net} = Applied force, Fa – Friction force, Fr

For the above case, the force generated as an incline increases is $\mathrm{Mg}\sin\theta$

the friction force is $\mu_k\, \mathrm{Mg}\cos\theta$

$$F_{net} = \mathrm{Mg}\sin\theta - \mu_k Mg\ Cos\ \theta$$

$$F_{net} = \mathrm{Mg}\,(\sin\theta - \mu_k\ Cos\ \theta), \qquad Since\ F_{net}\ is\ not\ zero, then\ F_{net} = Ma$$

$$\mathrm{Ma} = \mathrm{Mg}\,(\sin\theta - \mu_k\ Cos\ \theta)$$

Therefore the downward acceleration can be obtained through

$$\mathbf{a = g\,(\sin\boldsymbol{\theta} - \boldsymbol{\mu_k}\ \boldsymbol{Cos\ \theta})}$$

When Fr = zero, (when the incline is frictionless) then

$$\mathbf{a = g\sin\boldsymbol{\theta}}$$

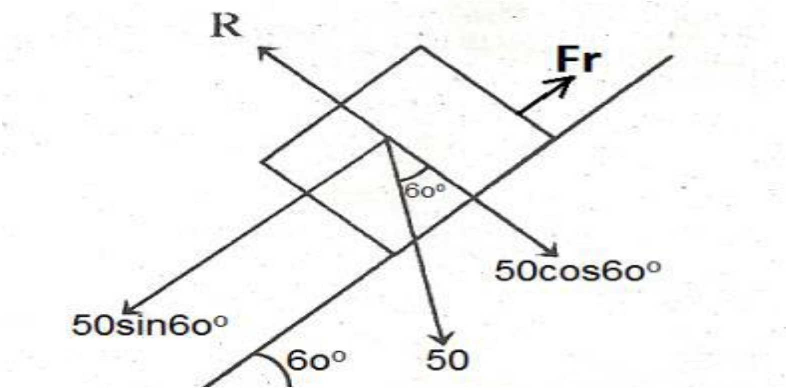
This means that the acceleration down an incline is a function of the angle of the incline alone, and not the mass of the body when friction is ignored.

Example 08,

A horizontally traveling car drives off of a cliff next to the ocean. At the same time that the car leaves the cliff a bystander drops his camera. Which hits the ocean first? (Neglect air resistance.)

(a) Car
(b) Camera
(c) They both hit at the same time (√)

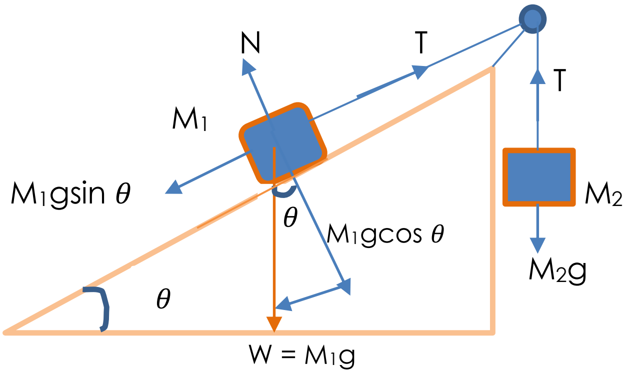
Example 09,
A skater of mass 40 kg has an initial velocity of 15 m/s. He slides on ice where the frictional force is 36 N. How far will the skater slide before she stops?
Solution
$Fr = \mu_k N$
36N = $\boldsymbol{\mu_k}$ x 392N
Fr = Ma and Fr= Mg
a = $\mu_k g$
a = 0.091837 x 9.8= 0.9m/s^2
$v^2 = u^2 + 2as$
0 = 15^2 + 2 x 0.9 x S
Answer 125 m

Example 10,
A block of wood of mass 5kg is placed on a rough plane inclined at 60^0.
Calculate its acceleration down the plane if coefficient of friction between the block and the plane when the block is moving, $\mu_k = 0.4$
Data given:
Angle of the plane, θ = 60^0 and Mass of the wood, m = 5kg
Normal reaction, R = 50cos60^0
Acceleration due to gravity, g = 10m/s^2
Coefficient of static friction, μ_s = Tan 60^0
Coefficient of dynamic friction, μ_k = 0.4
Friction force, Fr =?
Diagram:


Solution:
Net force, F = ?
F = 50sin60^0 - Fr
But: Fr = μ_k x mgcosθ
Fr = μ_k x 50cosθ
Fr = 0.4 x 50cos60^0
Now:
F = 50sin60^0 – 0.4 x 50cos60^0
F = 43.30 – 10 = 33.3N
But:-
F = ma, making a the subject
a = F/m
a = 33.3/5
The body will accelerate at 6.66m/s^2

Tension on a String and Acceleration of the system

Consider the diagram below, a mass of an object M$_1$ at an angle θ to the incline and tied to another object with mass M$_2$ with a non-extensible string. Known from experiment that there is a possibility for that system to accelerate uphill, downhill or neither at all. If the system accelerates, then μ_s becomes μ_k.



$F_{fmax} = \mu_s N$

$F_{fmax} = \mu_s M_1 g\cos\theta$

$T = M_2 g$

a) If the body is about to start accelerating uphill, then, friction is against T

T – M$_1$gsin θ – F_{fmax} = 0

M$_2$g = M$_1$gsin θ + F_{fmax}

M$_2$g = M$_1$gsin θ + μ_s M$_1$gcos θ

Now if M$_2$ is made a hair larger, the system will accelerate uphill

M$_2$g > M$_1$gsin θ + μ_s M$_1$gcos θ

b) If the body is about to start accelerating downhill, now the friction is helping T

T + F_{fmax} – M$_1$gsin θ = 0

M$_2$g = M$_1$gsin θ – F_{fmax}

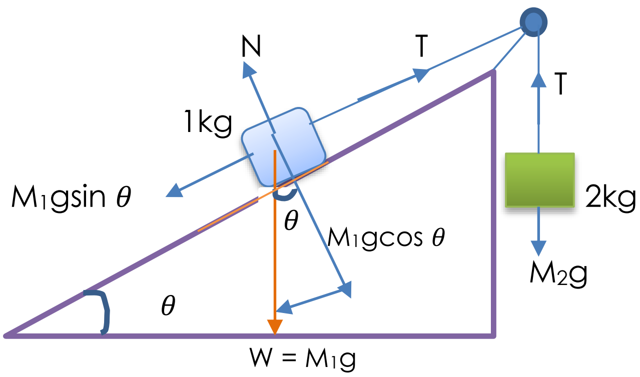
M$_2$g = M$_1$gsin θ – μ_s M$_1$gcos θ

Now if I make M$_2$ a hair less, the system will accelerate downhill

M$_2$g < M$_1$gsin θ – μ_s M$_1$gcos θ

c) If the conditions is neither a nor b then acceleration will be zero

Take an example:- M$_1$= 1kg, M$_2$= 2kg, θ =30^o, $\mu_s = 0.5$, $\mu_k = 0.4$,



Will the system accelerate uphill, downhill or neither?

Test the two equations

1. **M$_2$g > M$_1$gsin θ + μ_s M$_1$gcos θ**

   Is 19.6 > 4.9+ 4.23 ? (this is true, then it accelerates uphill)

2. **M$_2$g < M$_1$gsin θ – μ_s M$_1$gcos θ**

   Is 19.6 < 4.9 – 4.23 ?

d) Take new notes

If the system is accelerating uphill, then

$F_{fmax} = \mu_k M_1 g\cos\theta$

T – (M₁gsin θ + μk M₁gcos θ)= M₁a

T – (4.9 + 3.395)= a

T – a = 8.295 ....(Equation 1)

M_2g – T = M_2a

19.6 – T = 2a

T + 2a = 19.6 ....(Equation 2)

Solve the two equations simultaneously to get acceleration and Tension T (Acceleration = +3.768m/s^2 and Tension less than 19.6N i.e. 12.06 N)

e) Testing if it works with M_1 =1kg M_2 = 0.4kg, $\mu_s = 0.5$, which means M_2g = 3.92

$M_2g > M_1g\sin\theta + \mu_s M_1g\cos\theta$

3.92 > 4.9 + 4.24 NO

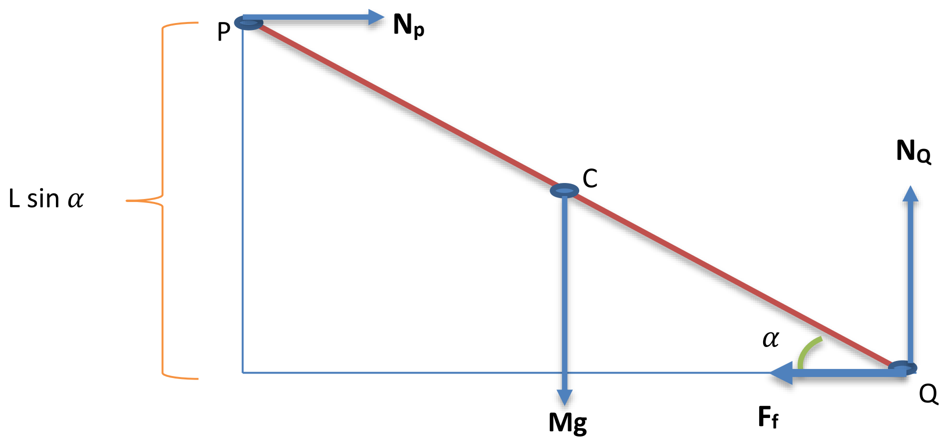
$M_2g < M_1g\sin\theta - \mu_s M_1g\cos\theta$

3.92 < 4.9 - 4.24 NO

Then if not moving T = M_2g =3.92N, $M_1g\sin\theta$ = 4.9, then F_{fmax} = 0.98N

Friction Force on a ladder

Consider the diagram below, a mass of a ladder M with a length PQ= L, C being its centre. Known from experiment that if the angle α is very small the ladder will slide. The question is, what must the angle be for the ladder not to slide? Toque



Things to note,

There are four forces, N_p, N_Q, F_f and Mg

Since the wall is smooth, there is no friction at point P, then $\mu_p = 0$

But there must be friction at point Q, which means $\mu_Q = \mu$

The sum of moments in X direction, $M_x = 0$, *i.e.* $N_p = F_f$

The sum of moments in Y direction, $M_y = 0$, *i.e.* $N_Q = Mg$

The sum of moments must be zero at any point otherwise it must be in motion

Taking the sum of moment at point Q

(This choice makes the two forces F_f and N_Q cancelled, then remains two foces)

From the principle of moment

Clockwise moment = Anticlockwise moment

Clockwise Moment at point Q, $= Np\, LSin\,\alpha$

$$Anticlockwise\ Moment\ at\ point\ Q, = Mg\ \frac{1}{2}\ L\ Cos\ \alpha$$

$$Np\ LSin\ \alpha\ \ = Mg\ \frac{1}{2}\ L\ Cos\ \alpha$$

$$Since\ it\ is\ known\ that\ N_p\ =\ F_f$$

$$F_f\ Lsin\ \alpha\ \ = Mg\ \frac{1}{2}\ L\ Cos\ \alpha$$

$$F_f\ = \frac{Mg\frac{1}{2}\ L\ Cos\ \alpha}{L\ Sin\ \alpha}$$

$$F_f\ = \frac{Mg}{2}x\ \frac{Cos\ \alpha}{Sin\ \alpha}$$

For the ladder not to slide,

$$F_f\ \ \leq F_{fmax}$$

$$We\ also\ know\ that\ \ F_f\ = \mu Mg$$

$$\frac{Mg}{2}\ x\frac{Cos\ \alpha}{Sin\ \alpha} \leq \mu Mg$$

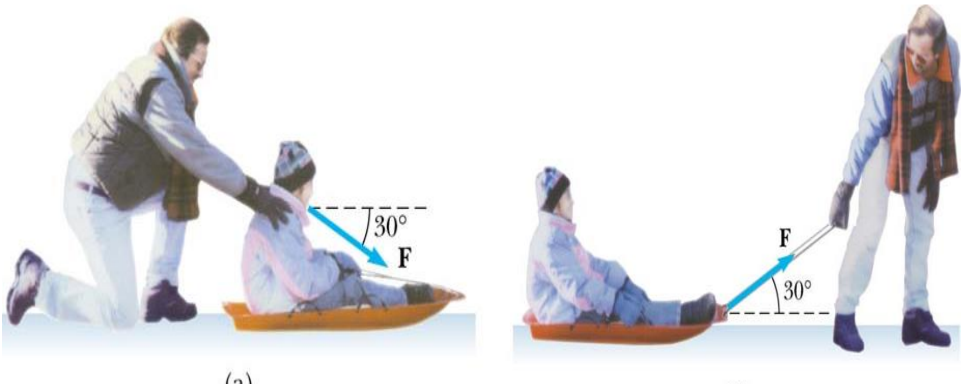
$$\frac{Cos\ \alpha}{Sin\ \alpha} \leq 2\mu$$

$$\boldsymbol{Tan\ \alpha \leq \frac{1}{2\mu}}$$

Check Your Understanding

Note:- In every question where acceleration due to gravity is needed, use 9.8m/s²

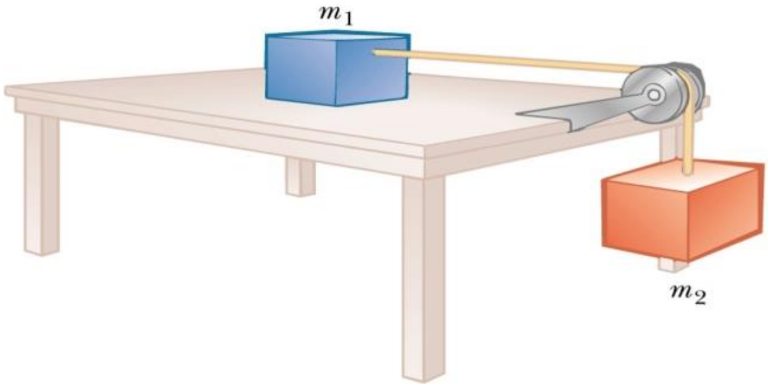
1. A 35 kg crate requires a force of 110 N to slide at an acceleration of 2 m/s². What is the coefficient of kinetic friction? **Answer** μk **= 0.117**
2. Suppose a 40 kg crate was accelerating at 0.70 m/s². Calculate the applied force. The coefficient of kinetic friction is 0.30.
   Answer F_a = 145.6N
3. A skater of mass 60 kg has an initial velocity of 12 m/s. He slides on ice where the frictional force is 36 N. How far will the skater slide before she stops? **Answer 120 m**
4. The man pushes in (a) bellow pushes while in (b) pulls with a force of 200 N. The child and sled combo has a mass of 30 kg and the coefficient of kinetic friction is 0.15. For each case: What is the frictional force opposing his efforts? What is the acceleration of the child?



(a) (b)

- **Answers (a) Fr =59.1 N, a = 3.8 m/s² (b) Fr =29.1 N, a = 4.8 m/s²**

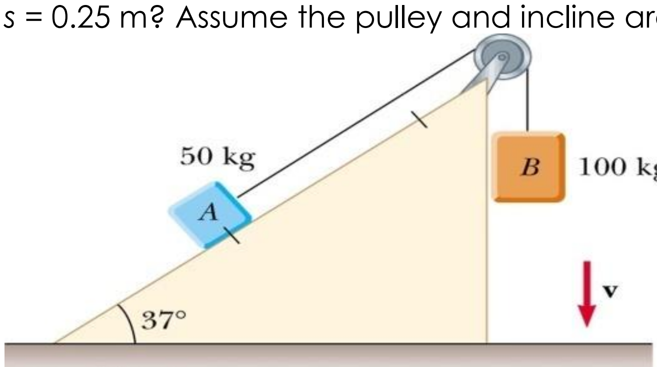
5. Given m_1 = 10 kg and m_2 = 5 kg:



(a) What value of μ_s would stop the block from sliding?
(b) If the box is sliding and μ_k = 0.2, what is the acceleration?
(c) What is the tension of the rope?

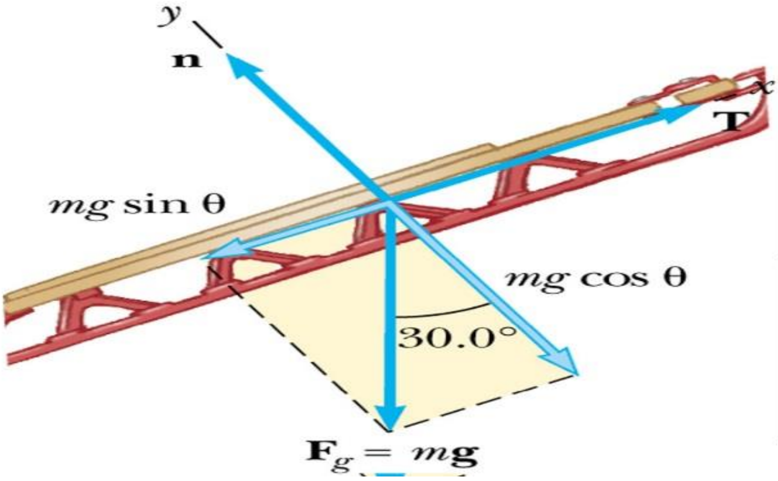
- **Answers for a)** μ_s **= 0.5 b) a = 1.96 m/s² c) 39.2 N**

6. A person pushes a 30kg shopping cart up a 10 degree incline with a force of 85 N. Calculate the coefficient of friction if the cart is pushed at a constant speed.
   - **Answer** μk **= 0.117**
7. A 10N force pushes down on a box that weighs 100 N. As the box is pushed horizontally, the coefficient of sliding friction is 0.25. Determine the force of friction resisting the motion. **Answer is 27.5 N**
8. A force of 60 N drags a 300-N block by a rope at an angle of 40^0 above the horizontal surface. If u_k = 0.2, what force P will produce constant speed? (**Answer P =67N**)
9. A 5kg block sits on a 30 degree incline. It is attached to string that is thread over a pulley mounted at the top of the incline. A 7.5kg block hangs from the string.
   (a) Calculate the tension in the string if the acceleration of the system is 1.2 m/s² (**Answer T =64.5N**)
   (b) Calculate the coefficient of kinetic friction. (**Answer** μk **= 0.8**)
10. What push P up the incline is needed to move a 230-N block up the incline at constant speed if μk = 0.3? (**Answer P =222N**)
11. Two blocks, *A* and *B* (m_A=*50 kg* and m_B=100 kg), are connected by a string as shown. If the blocks begin at rest, what will their speeds be after *A* has slid a distance *s* = 0.25 m? Assume the pulley and incline are frictionless.

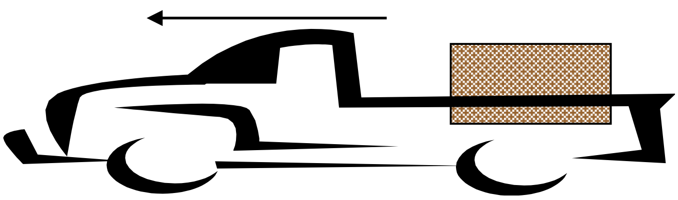


- **Answer 1.51 m/s**

12. A 925 N crate is being pulled across a level floor by a force of 325 N at an angle 25° above the horizon. The coefficient of kinetic friction between the crate and the floor is 0.25. Find the acceleration of the crate.
    - **Ans. 0.99m/s²**
13. What is the minimum μ_s required to prevent a sled from slipping down a hill of slope 30 degrees?



    - **Answer: -** μ_s **= 0.577**
14. A car, mass 500kg, is accelerated from rest along a horizontal surface. The force produced by the engine is 300N and that due to friction is 50N. What is the accelerating force and what is the acceleration produced? (**Ans:- Fa is 250 N, acceleration 0.5m/s²)**
15. A trolley of mass 5.0 kg rests on a horizontal surface
    (i) Draw a labeled sketch diagram to show the forces associated with the trolley
    (ii) When a boy pulls the trolley with a horizontal force of 24N, the trolley accelerates at 3m/s². Find the friction force acting on the trolley. **(Ans:- 9 N)**
16. Stephen Hawking is moving a 50 kg block from one side of his laboratory to the other. To accomplish this he ties a rope to the block and then ties it to his wheelchair such that the rope is pulled horizontally to the floor. If the coefficient of sliding friction is 0.38, what force must Mr. Hawking apply to the rope to move at constant speed? **(Ans:- 186.2 N)**
17. A crate having a mass of 60 kg falls horizontally off the back of a truck which is traveling at 30 m/s. Compute the coefficient of kinetic friction between the road and the crate if the crate slides 45 m on the ground with no tumbling along the road before coming to rest. Assume that the initial speed of the crate along the road is 30m/s.

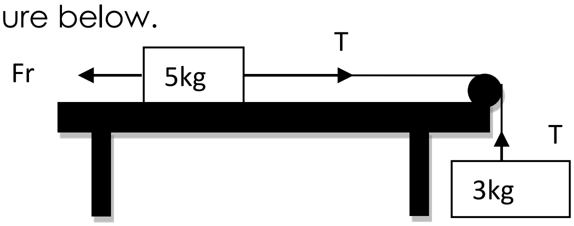


(Ans. μ **=1.02)**

18. A uniform ladder 4.0m long, of mass 25kg, rests with its upper end against a smooth vertical wall and with its lower end on rough ground. What must be the least coefficient of friction between the ground and the ladder for it to be inclined at 60° with the horizontal without slipping? **(Ans:- $\mu = 0.29$)**

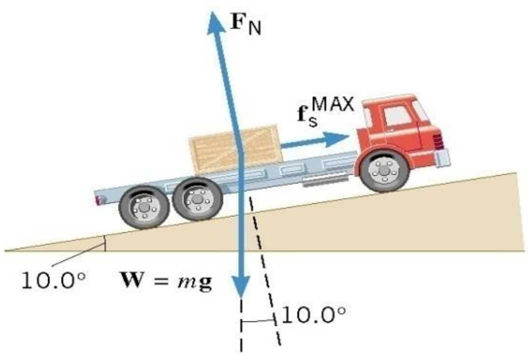
19. Old Grandma Cecilia is trying to load a wooden crate full of apples into her truck. To achieve this, she plans to slide the crate up along a board. If the crate has a mass of 50 kg and the board is at a 30° incline, what is the maximum force she must apply parallel to the board to move the crate at constant velocity into her truck if the μ is 0.25? ***(Ans:- 351.09N)***

20. A 5kg concrete block is at rest on a table where the coefficients of static and kinetic friction are 0.55 and 0.3, respectively. The block is attached to a hanging 3kg mass by a string passing over a frictionless pulley as shown in the figure below.

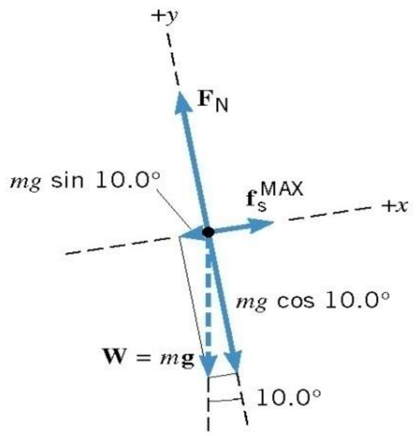


(i) Explain whether the concrete will slide or not. In case it slides, which side will it slide to and the value of T? **(Ans: to the right, T =23.8875N)**
(ii) In case it slide what will be the acceleration? **(Ans:-1.8375m/s²)**

21. A flatbed is carrying a crate up a 10.0° hill. The coefficient of static friction between the truck bed and the crate is μ_s = 0.35. Find the maximum acceleration that the truck can attain before the crate begins to slip backward relative to the track.



(a)



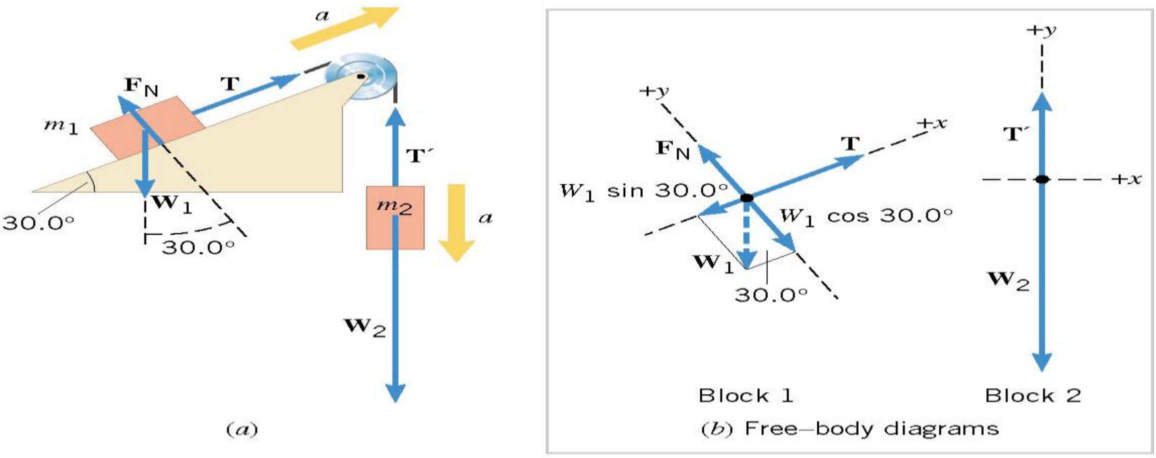
(b) Free-body diagram of the crate

(Use:- εFx = mgsin 10° - μ_sR = ma$_x$ and εFy = -mgcos10.0° + F_N = 0 **(Ans:-1.68m/s²)**

22. Driver error allows a 5 tonne truck to roll down a steep road inclined at 30° to the horizontal. As it is a high technology vehicle, there is negligible friction between the wheels of the truck and the wheel bearings. Find the acceleration of the truck if the acceleration due to gravity is taken to be 9.8m/s². **(Ans:- 4.9m/s²)**

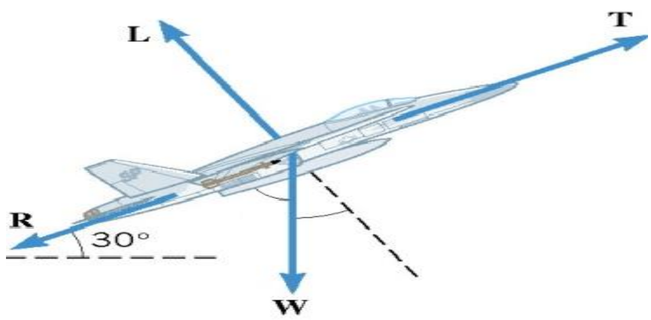
23. If the coefficient of kinetic friction between a 35-kg crate and the floor is 0.30, what horizontal force is required to move the crate to the right at a constant speed across the floor? **(F = 105 N)**

24. Mary is a 60kg skier. At the start of a ski-slope which is 20o to the horizontal, she crouches into a tuck. The surface is very icy, so there is no friction between her skis and the ice. Use g = 9.8m/s^2
    (a) Acceleration down the slope **(Ans:- 3.35m/s^2)**
    (b) If Mary starts from rest, what is her speed after travelling a distance of 80m on the ice? **(Ans:- 23m/s)**
    (c) The snow conditions change at the end of the ice patch so that Mary continues down the slope with a constant velocity. What is the force due to friction that must be acting between Mary's skis and the snow? **(Ans:- 200N up the incline)**
25. A mass of 6kg is resting on a horizontal surface. It is determined that a force of 20 N will make the object start sliding and keep it sliding with an acceleration of 0.83 m/s^2. What are the coefficients of static and kinetic friction between the mass and the surface? **(Ans:- μ_s = 0.34, μ_k = 0.255)**
26. A uniform ladder of length *l* rests against a smooth, vertical wall. The mass of the ladder is m, and the coefficient of static friction between the ladder and the ground is μ_s = 0.40. Find the minimum angle θ at which the ladder does not slip. **(Ans:- θ = 51^o)**
27. A 50g mass is placed on an inclined plane such that it can move at constant speed, when slightly tapped. If the angle of the plane makes with the horizontal plane is 45^0. Find the coefficient of kinetic friction. **(Ans: - μ_k = 1)**
28. Block 1 (mass m_1 = 8.00 kg) is moving on a frictionless 30.0^o incline. This block is connected to block 2 (mass m_2 = 22.0 kg) by a cord that passes over a massless and frictionless pulley. Find the acceleration of each block and the tension in the cord.



(Use: - $\varepsilon Fx = T - W_1 sin30.0^o = m_1 a$ and $\varepsilon Fy = W_2 - T = m_2 a$) (Ans: - T = 0, a= 10m/s^2)
29. When pushing a shopping trolley along a horizontal path, James has to continue to provide a force of 30N just to maintain his speed. If the trolley (and the shopping) has a mass of 35kg, what is the horizontal force that he will have to provide to accelerate the cart at 0.5 m/s^2? **(Ans:- 48N)**
30. A rope has a breaking tension of 120N. How can a full bucket of mass 15kg be lowed using that rope? (Ans:-To maintain the tension less than 120N in the rope, the bucket must accelerate at a greater than 1.8m/s^2 downwards. If the acceleration falls below this, the rope will snap)

31. When skiing down an incline, Omulangira found that there was a friction force of 250N acting up the incline of the mountainside due to slushy snow. The slope was at 35° to the horizontal, so if Omulangira had a mass of 70kg, what was his acceleration? (Ans:- 2.1m/s^2 down the incline)
32. Two masses, 5.0kg and 10.0kg are suspended from the ends of a rope that passes through a frictionless pulley. The masses are released and allowed to accelerate under the influence of gravity. What is the acceleration of the system and what is the tension in the rope? (Ans:- 3.3m/s^2 down, on the side of 10-kg mass, 65N)
33. A force of 120N is used to push a 20kg shopping trolley along the line of its handle at 20° down from the horizontal. This is enough to cause the trolley to travel with constant velocity to the north along a horizontal path
    (a) Determine the horizontal and vertical components of the force applied to the trolley (Ans:- 110N, 41N down)
    (b) What is the value of the friction force acting against the trolley (Ans:-110N to the south)
    (c) What is the normal force that must be supplied by the ground on which the trolley is pushed? (Ans:- 240N upwards)
    (d) Why is it often easier to pull a trolley than to push it? (Ans:- when the trolley is pulled, the vertical components of the applied force is upwards rather than downwards and so a smaller (upward) normal force is needed- helping wheels to rotate more freely)
34. A jet plane is flying with a constant speed along a straight line at an angle of 30.0° above the horizontal. The plane has a weight W whose magnitude is W=86,500 N and its engine provide a forward thrust T of magnitude T=103,000 N.



In addition, the lift force L (directed perpendicular to the wings) and the force R of air resistance (directed opposite to the motion) act on the plane. (Using $\Sigma F_x = W \cos 240^\circ + T - R = 0$ and $\Sigma F_y = -W\cos 30.0^\circ + L = 0$) Find L and R. (Ans:- R=59,800N and L = 74,900 N)

35. A brick starts sliding with 6m/s across a concrete horizontal surface floor and the coefficient of friction between the two surfaces is 0.4. How far will it travel before coming to rest? (Ans:- S = 4.5 m)
36. A 75 kg crate is to be pushed up an incline plane 5 m long that makes an angle of 20° with the horizontal. If the coefficient of static friction and kinetic friction between the crate and the inclined plane are 0.15 and 0.20 respectively how much
    (a) Force must be given to get it start up the incline? (Ans:- 389.5N)
    (b) Applied force is needed to keep it going at a constant speed up the incline? (Ans:- 355N)

03. REFLECTION OF LIGHT ON CURVED MIRRORS

In this sub topic we will study two types of curved mirror named:

(i) Convex /diverging mirror
(ii) Concave/converging mirror

CONVEX MIRROR

Convex mirror is the curved mirror of which its reflecting surface is curved inward.

Diagram:

CONCAVE MIRROR

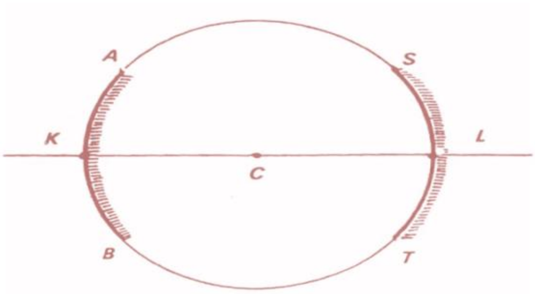
Concave mirror is the curved mirror of which its reflecting surface is curved outward.

Diagram:

Terms Used In This Topic

Consider the diagram below when two curved mirror joined

Diagram:



Where:

AB	Convex mirror
ST	Concave mirror
C	Centre of curvature
L	Pole of the Concave mirror
K	Pole of the Convex mirror
CL	Radius of curvature of the Concave mirror
CK	Radius of curvature of the Convex mirror
The principal axis extends further away from the radius of curvature.	

Centre of Curvature, C

- This is the centre of the circle of which the surface of the mirror is a part.

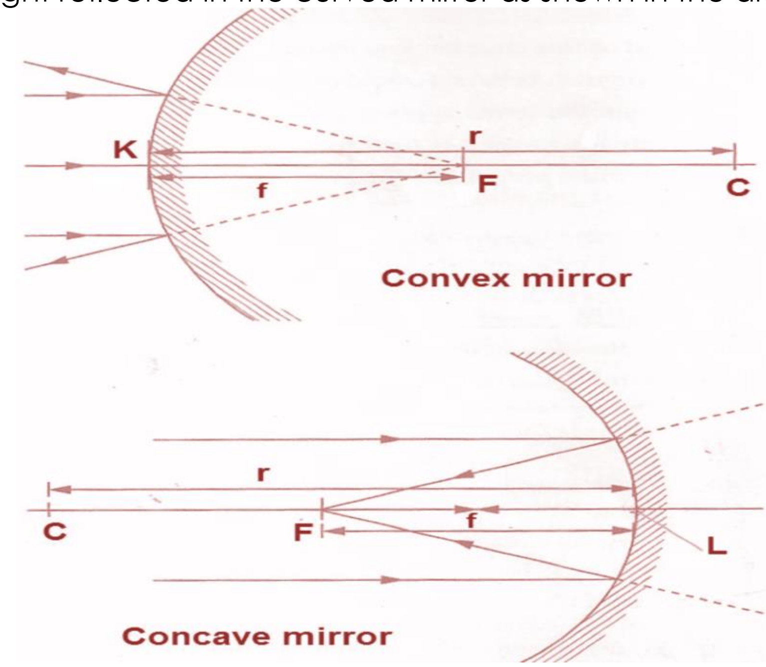
Radius of Curvature, r

- This is the distance along the principal axis between the centre of the mirror, and the centre of curvature and equal to TWICE the focal length, *f*.

Principal Axis of the Curved Mirror

- Thi is the imaginary line joining the pole of the curved mirror and the centre of curvature.

Consider the light reflected in the curved mirror as shown in the diagram below.



Principle Focus, F

- The principal focus, F is the point through which all rays travelling parallel to the principal axis before reflection pass through or appear to come from after reflection.

Focal Length, f

The focal length, *f* is the distance from the centre of the mirror, O to the principal focus, F.

NB: It was proved that focal length is equal to half of radius of curvature. **f =** $r/2$

Rules used to Locate Images in Curved Mirrors

The following is the rules used to locate image in the curved mirror.

i. A ray of light travelling to the mirror parallel to the principal axis a ray is reflected through the principal focus.
ii. A ray of light travelling to the mirror through the centre of curvature is reflected along its own path
iii. A ray of light travelling to the mirror through the principal focus is reflected parallel to the principal axis.
iv. A ray of light striking the mirror at an angle of incident θ is reflected back at an angle of reflection θ thus obeying the laws of reflection.

Note: Any two of these rays are sufficient to locate the image.

Procedure to Draw Ray Diagram

The following procedure is used to draw ray diagrams to locate the image.

i. Choose an appropriate scale so that the ray diagram fits on the available space.
ii. Draw a horizontal line to represent the principal axis of the mirror. Mark the focal point of the mirror.
iii. Using the chosen scale, draw the object in position along the principal axis. The object is drawn as a vertical line from the principal axis.
iv. Locate the position of the image by drawing rays from the object to the mirror. Use the rules for drawing ray diagrams to draw the reflected rays.
v. At the point of intersection of the reflected rays, draw the image in position

Characteristics of the image formed

Terms used to describe images formed by curved mirrors:

Position

i. **Real image** is on the same side of the mirror as the object. It is formed by actual intersection of light and can be formed on a screen.

ii. **Virtual image** is on the opposite side of the mirror compared to the object. It is formed by apparent intersection and can't be formed on a screen.

Nature

i. **Upright image** has the same orientation as the object.

ii. **Inverted image** is in an upside down position compared to the object

Size

i. **Enlarged image** is bigger than the object.

ii. **Diminished image** is smaller than the object

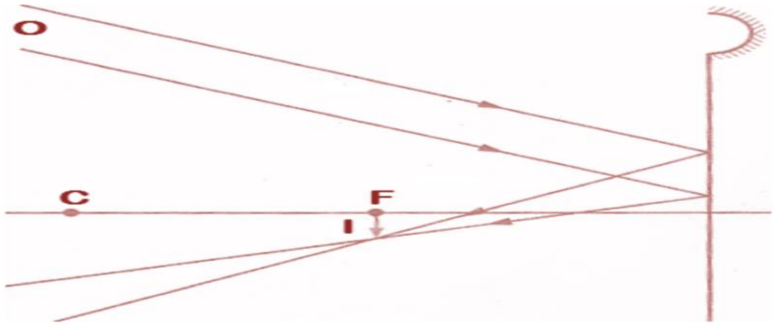
Images Formed By Concave Mirrors

The following are the characteristics of images formed when:-

(a) An object at Infinity (Very Far).

The image is formed at the focal point, F, of the mirror. It is inverted, diminished and real.

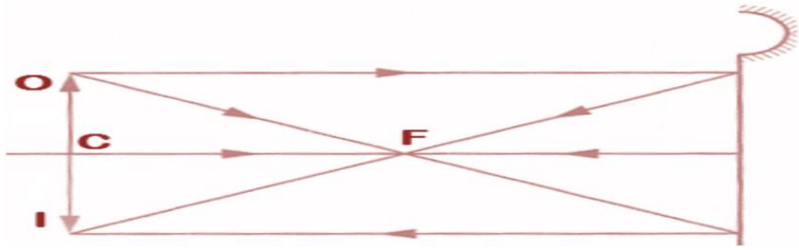
Diagram:



(b) Object at the Centre of Curvature, C

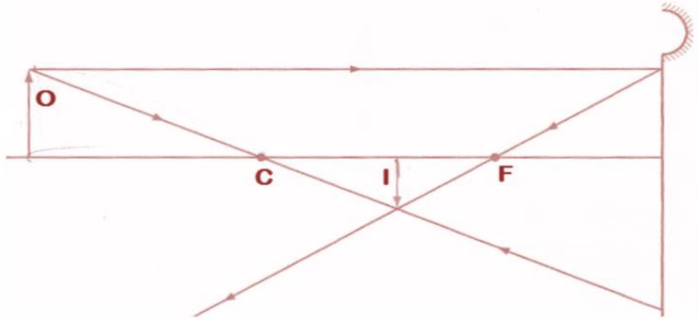
The image is formed at C. It is real, inverted and same size as the object.

Diagram:



(c) Object beyond the Centre of Curvature, C

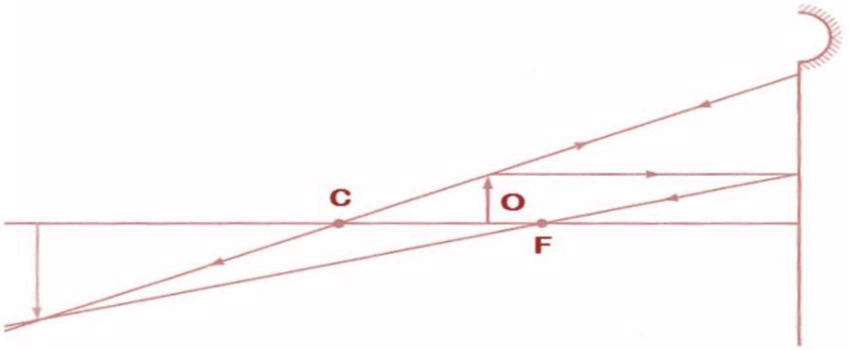
The image is formed between C and F. It is real, inverted and diminished.



(d) **Objects between F and C**

The image is formed beyond C. It is real, inverted and magnified.

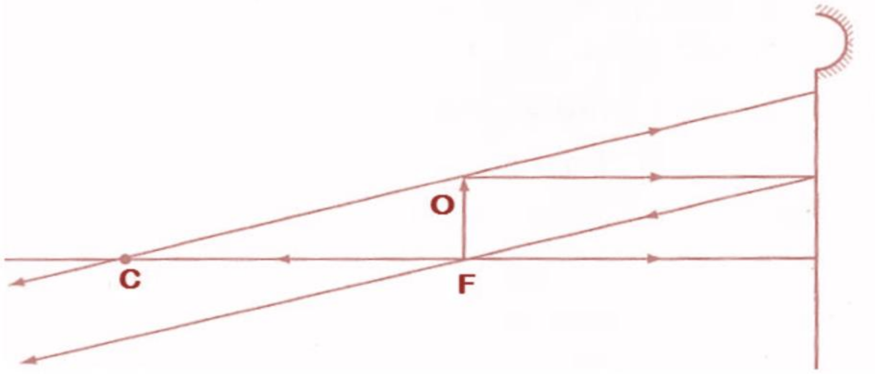
Diagram:



(e) **Object at F**

The image is formed at infinity.

Diagram:



(f) **Object between F and P**

The image is formed behind the mirror and is virtual, erect and magnified

Diagram:

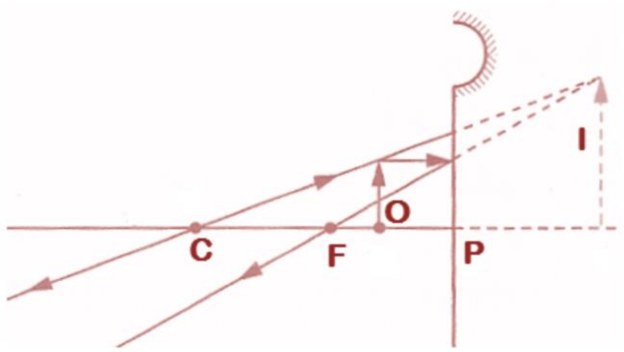
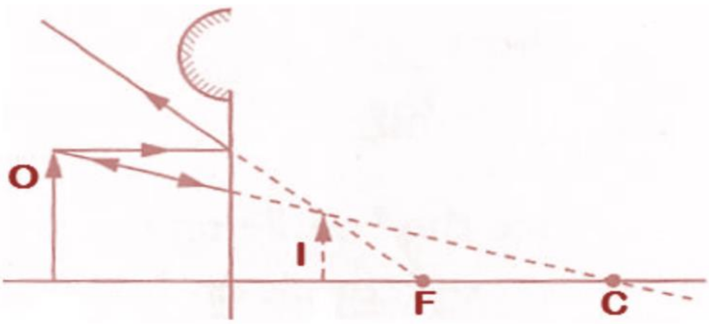


Image Formed In Convex Mirror

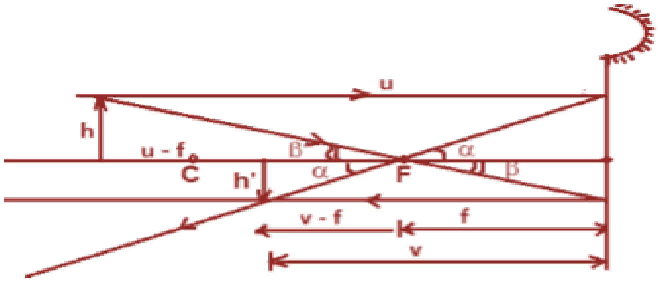
The images formed are always virtual, erect and diminished for all object positions.

Diagram:



The Mirror Formula

Consider the figure below showing an object placed beyond C in a concave mirror whose focal length is **f**, whereby the object and image distances are $\boldsymbol{u}$ and $\boldsymbol{v}$ respectively



Consider triangles which are equiangular

$$Tan\ \beta = \frac{h}{u-f} = \frac{h'}{f} \qquad \rightarrow \frac{h}{h'} = \frac{u-f}{f} \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Consider also,

$$Tan\ \alpha = \frac{h}{f} = \frac{h'}{v-f} \qquad \rightarrow \frac{h}{h'} = \frac{f}{v-f} \ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Comparing the equations (1) and (2), finally dividing by uv throughout.

$$\frac{u-f}{f} = \frac{f}{v-f}$$

$$f^2 = (u-f)(v-f)$$

$$f^2 = uv - uf - vf + f^2$$

$$uv = uf + vf = f(u+v)$$

$$\frac{uv}{f} = u + v$$

$$\frac{uv}{f} = \frac{u}{uv} + \frac{uv}{uv}$$

The mirror formula is expressed as follows:

$$\mathbf{\frac{1}{f} = \frac{1}{v} + \frac{1}{u}}$$

Points to note for both mirrors:

i. Focal length, (f) for a concave mirror is positive (+)
ii. Focal length (f) for a convex mirror it is negative (-)
iii. The image distance, (v) is negative (-) For a virtual image
iv. The image distance, (v) is positive (+) for real images

Magnification of an Image

Magnification (M) is the ratio of the image size/ height (IH) to the object size/height (OH) **or** Magnification is the ratio of the image distance (v) from the mirror to the object distance (u) from the mirror

$$Two\ formulas\ for\ \boldsymbol{M} = \frac{\boldsymbol{v}}{\boldsymbol{u}}\ and\ \boldsymbol{M} = \frac{\boldsymbol{Hi}}{\boldsymbol{Ho}}$$

Points to note:

- The image formed by a curved mirror can be larger, smaller or the same size as the object. That is, M>1, M<1 or M=1

Example, 01

An object 3 cm high is placed 30 cm away from a concave mirror of focal length 12 cm. using the mirror formula, find the position, the height and the nature of the image formed.

Data given:

Focal length, f =12cm

Image distance, v = ?

Object height, OH = 3cm

Object distance, u = 30 cm

Solution:

1st find distance of object from,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$V = \frac{uf}{u - f}$$

$$V = \frac{30\ x\ 12}{30 - 12}$$

The image distance is 20cm

2nd find the image height, IH from

$$M = \frac{Hi}{Ho}\ and\ M = \frac{V}{u}$$

$$Then\ \frac{V}{u} = \frac{Hi}{Ho}$$

$$Hi = \frac{V\ x\ Ho}{u} = \frac{3\ x\ 20}{30}$$

IH = 2 cm (The image is diminished.)

Example, 02

A concave mirror with a radius of curvature of 30 cm produces an inverted image 4 times the size of an object placed on its principal axis.

Determine the position of the object and that of the image.

Data given:

Radius of curvature, r = 30

Focal length, f = r/2 = 15cm

Magnification, M = 4

Image distance, v = ?

Object distance, u = ?

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{v}{f} = \frac{v}{u} + \frac{v}{v}$$

$$m = \frac{v}{f} + 1$$

$$v = (m - 1)f$$

$$v = (4 - 1)15$$

Answers: U = 11.25 cm and V = 45 cm (Since V = +ve, The image is virtual)

Points to note:

(i) Convex mirrors produce diminished images but have a very wide field of view compared to plane mirrors

(ii) All distances are measured from the pole of the mirror as the origin

(iii) Distance of virtual objects, virtual images and virtual lengths from the pole of the mirror are negative (-)

(iv) All distances are measured from the pole of the mirror as the origin

(v) Distances measured to the right of the mirror from the pole are positive (+)

(vi) Distances measured to the left of the mirror from the pole are negative (-)

- Now we can summarize that:-
  - (i) Focal length, (f) for a concave mirror is positive (+)
  - (ii) Focal length (f) for a convex mirror is negative (-)
  - (iii) The image distance, (v) is negative (-) for a virtual image
  - (iv) The image distance, (v) is positive (+) for real images

Uses of Convex Mirrors

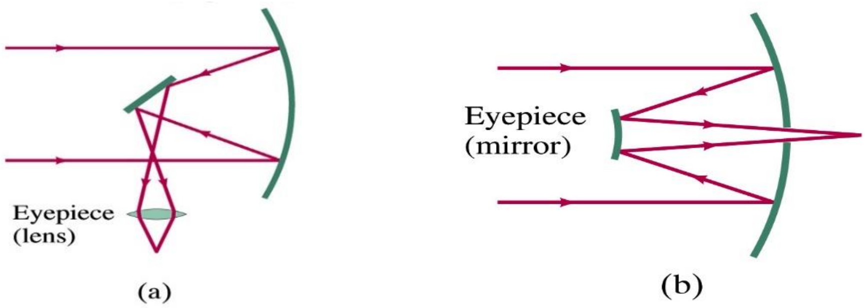
(i) Convex mirrors are used in driving due to its Wide field of view
(ii) Seeing around corners to avoid the crashing of vehicles or supermarket trolleys at the corners
(iii) Supermarket surveillance for scrutiny in business establishments and security installations

Uses of Concave Mirrors

The following are some of the areas where concave mirrors are used:

1. Reflecting telescopes

Diagram:



2. Used in solar cookers.
3. As a reflector- Concave mirror is used as a reflector in the automobile's headlights and in searchlights. This is because when source of light is placed at the principal focus of concave mirror produces a strong parallel beam of light.
4. As a shaving mirror – when an object is placed between P and F of a concave mirror, it forms a virtual and enlarged image. Thus by using this mirror we can have a proper shave, as the tiny hairs are clearly visible
5. For doctors – dentists use a concave mirror to see the back of tooth. Also, doctors use it to focus light on the internal parts of ear, nose and eye for proper examination.

Check Your Understanding

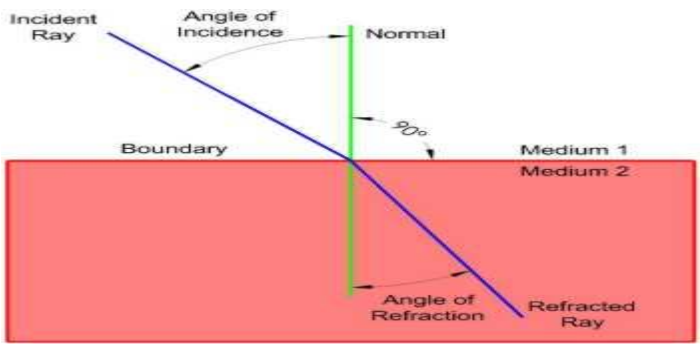
1. An object 4cm high and at right angles to the principal axis of a convex mirror, is 7.5 cm from the pole. If the radius of curvature of the mirror is 6cm, find the size of the image formed and the image distance. (Ans:- IH = 1.14cm, V = 2.14cm)
2. Determine the focal length of the concave mirror that will project the image of a lamp that is magnified 5 times, onto a screen located 9.0m from the lamp. (45m)
3. An object 12cm high and at right angles to the principal axis of a convex mirror, is 15 cm from the pole. If the radius of curvature of the mirror is 20cm, find the
   (a) distance of the image from the pole and state whether it is real or virtual
   (b) image height (Ans:- V= 6cm, virtual and IH = 4.8cm)
4. A child decided to examine a beetle by using a concave mirror of focal length 7cm. He held the mirror 14cm from the beetle and was disappointed with the image. Use the graphical ray tracing to explain:
   (a) Why he is disappointed. (Ans:- image size = object size but inverted)
   (b) Where should he hold the mirror to see an upright enlarged image?

04. REFRACTION OF LIGHT

When The Light travels in a straight line in constant speed/velocity unless there is change in medium because different media have different optical densities, this phenomenon is called **refractive**

Refraction is the process by which the direction of a ray of light changes when passes from one medium to another of different optical density.

Diagram:



Laws of Refraction

We have about three law of refraction of light which are stated as follows:

First law of refraction of light

States that

"***Incident ray, the normal and the refracted ray all lie in the same plane***"

Second law of refraction of light / Snell's Law

States that

"***For a particular material, the ratio $\frac{\sin i}{\sin r}$ is constant value called refractive index***"

Refractive Index

Refractive index can be obtained according to the angle of light formed or velocity of light from one to another medium.

Suppose light travels from air medium to glass

Let the angle of incidence be i_0 and the angle of refraction r_0. Refractive index between air and glass is given by formula

$$a\mu g = \frac{\sin i}{\sin r}$$

The refractive index is the ratio of angle of incidence to the angle of refraction.

Alternative:

Also alternative definition of refractive index may be given in terms of the velocity of light in air medium and glass medium as follows;

$$a\mu g = \frac{Va}{Vg}$$

The refractive index is the ratio of the speed of light in medium to the speed of another medium.

Points to note:

(i) Refractive index between vacuum/air to any other materials is called absolute refractive index or refractive index $a\mu g = \mu g$

(ii) Refractive index between medium to medium except vacuum is called relative refractive index. For instance if light passes from water to glass.

$$w\mu g = \frac{Vw}{Vg}$$

(iii) Any material has its own refractive index due to fact that each has a different optical density.

Refractive Index of Different Medium

Medium	Refractive Index
Diamond	2.417
Glass/crown	1.520
Water(20^0C)	1.333
Air (at stp)	1.00029

1. Derivation

Given: The refractive index of light from water to grass given as:

$$w\mu g = \frac{Vw}{Vg} \ldots\ldots\ldots\ldots 1$$

Given: The refractive index of light from glass to water given as:

$$g\mu w = \frac{Vg}{Vw} \ldots\ldots\ldots\ldots 2$$

Then: find Reciprocal equation (2)

$$(g\mu w)^{-1} = \frac{Vw}{Vg} \ldots\ldots\ldots\ldots 3$$

But: Comparing equations, it is seen that equation 1 = equation 3

Then:

$$\frac{1}{(g\mu w)} = w\mu g$$

2. Derivation

Given: The absolute refractive index of water to given as:

$$\mu w = \frac{Va}{Vw}$$

Given: The absolute refractive index of glass given as:

$$\mu g = \frac{Va}{Vg}$$

Since: va is equal, so equation (1) = equation (2)

Divide by v_w and μ_w both sides

$$\frac{Vw}{Vg} = \frac{\mu g}{\mu w}$$

Where:

v_w= velocity of light in the water medium

μ_w= absolute refractive index of water

v_g= velocity of light in the glass medium

μ_g= absolute refractive index of glass

Since: $w\mu g = \frac{Vw}{Vg}$

Finally: $_w\mu_g = \mu_g/\mu_w$

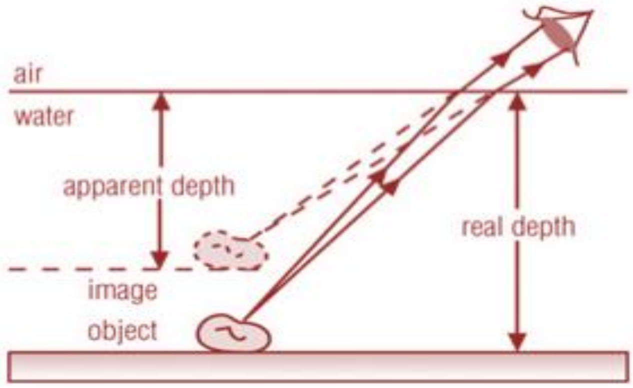
$$w\mu g = \frac{\mu g}{\mu w}$$

3. Derivation

$$a\mu g = \frac{\sin i}{\mathrm{Sin}\ r} = \frac{1}{g\mu a} = \frac{\sin r}{\sin i}$$

$$a\mu g = \frac{1}{g\mu a}$$

Alternative:
Another way of determining the refractive index of a material is by **real-and-apparent depth method**.
Diagram:



When one looks at a stick placed inside a beaker of water, the stick immersed in water point raised from its real position due to refractive index of water
Where:

$$a\mu w = \frac{H}{h}$$

H = real depth/height
h = apparent depth/height

The refractive index is the ratio of the real/actual depth/height to the apparent depth/height of water/liquid

Example, 03
When a ray of light is travel from one air to glass, the angle of is 30^0. If the refractive index of the glass is 1.5. Determine the angle of refraction, r.
Data given:
Angle of incidence, i = 30^0, Angle of refracted = ?
Refractive index of the glass, $a\mu g$= 1.5
Solution:
From

$$a\mu g = \frac{\sin i}{\sin r}$$

$$\sin r = \frac{\sin 30}{1.5}$$

r^o= 19.47^0

Example, 04
A coin at the bottom of a jar of glycerine appears to be 16.5 cm below the surface of the glycerine. Calculate the height of the column of glycerine in the jar given that the refractive index of glycerine is 1.46.
Data given:
Real depth, H = ?, Apparent depth, h = 16.5 cm
Refractive index of the glass, $a\mu g$= 1.46
Solution:
From:

$$a\mu w = \frac{H}{h} \text{ making H the subject}$$

H = $a\mu g \times h$
H = 1.46 x 16.5cm
The real depth is 24.09 cm

Example, 05

Water is poured into a beaker to a depth of 24 cm. To an eye looking vertically down through the water, the bottom of the beaker appears to be raised 6 cm from the bottom of the beaker. Determine the refractive index of the water.

Data given:

Real depth, H = 24 cm

Apparent depth, h = (24 - 6) cm = 18 cm

Refractive index of the glass, aμg= ?

Solution:

From:

$$a\mu w = \frac{H}{h}$$

$$a\mu w = \frac{24}{18}$$

The refractive index of the water is 1.33

Example, 06

The refractive index of water is $\frac{4}{3}$ and that of glass$\frac{3}{2}$. Calculate the refractive index of a glass with respect to the water

Solution

$$w\mu g = a\mu g \div a\mu w$$

$$w\mu g = a\mu g \text{ x } w\mu a$$

$$w\mu g = \frac{3}{2} \text{ x } \frac{3}{4}$$

$$w\mu g = \frac{9}{8} = 1.125$$

The refractive index of a glass with respect to the water is 1.125

Applications of Refractive Index

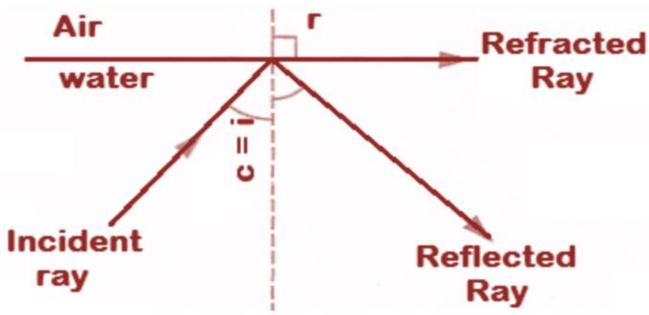
(i) The refractive index of a material is very important in optical systems. It is used to calculate the focusing power of lenses

(ii) Refractive index is also used to identify a substance or confirm its purity. This is because pure substances have definite refractive indices

Critical Angle

This is a unique angle of incidence for which the angle of refraction is 90°.

Diagram:



Where:

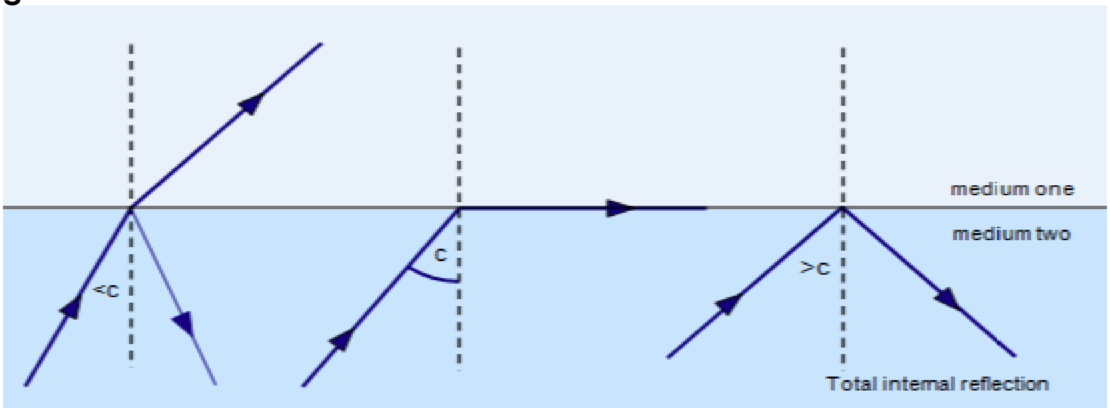
c = critical angle

r = refracted angle = 90°

Total Internal Reflection

This is a phenomenon that occurs when a ray of light strikes a medium boundary at an angle larger than a critical angle with respect to the normal on the surface

Diagram:



Conditions for Total Internal Reflection to occur:

(i) Light must be travelling from a denser medium to a less dense medium.

(ii) The critical angle must be exceeded

Relation between Critical Angle and Refractive Index

Consider the equation below;

$$w\mu a = \frac{\sin i}{\sin r}$$

When: $r^o = 90^0$ then $i^0 = c$

$$w\mu a = \frac{\sin C}{\sin 90}$$

But: $\sin 90^0 = 1$

$w\mu a = \sin C$

Then: $\sin c = 1 \times w\mu a$

But:

$$w\mu a = \frac{1}{a\mu w} = \frac{1}{1.5} = \frac{2}{3}$$

Therefore:

$$\sin C = \frac{1}{\mu w}$$

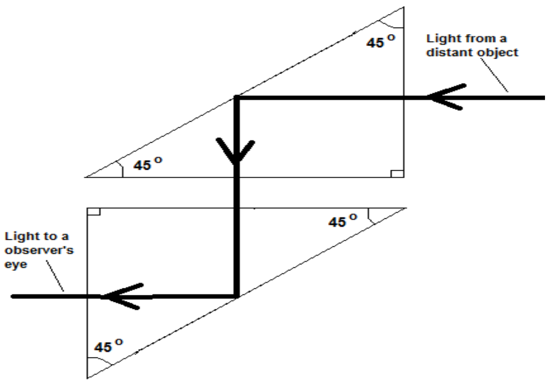
This is true for all material media where, water, w represent material media.

Applications of Total Internal Reflection

1. **Prism periscope**

A prism periscope consists of two 45° - 90°

Diagram:

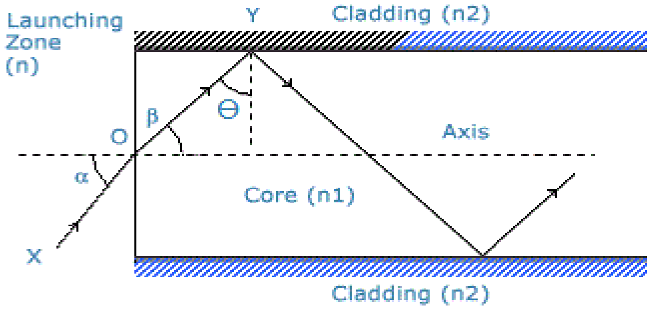


2. **Optical fibres**

An optical fibre is a thin rod of high-quality glass designed to guide light along its length by total internal reflection.

Light inside these fibres hits the sides at an angle greater than the critical angle and is transmitted by being repeatedly totally internally reflected.

Diagram:



Some uses of optical fibres

(i) Used as a medium for telecommunications and networking.

(ii) They are also used as light guides in medical and other applications

(iii) Optical fibres are also used in imaging optics. A bundle of fibres along with lenses are used to make a long imaging device called an **endoscope**.

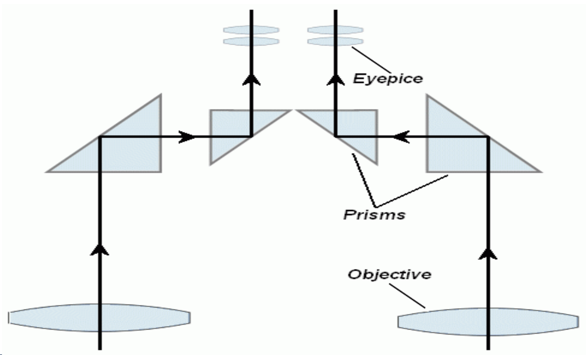
NB:

(i) Medical endoscopes are used in minimally invasive surgical procedures.

(ii) Industrial endoscopes are used for inspecting machine parts

3. **Binoculars and telescopes**

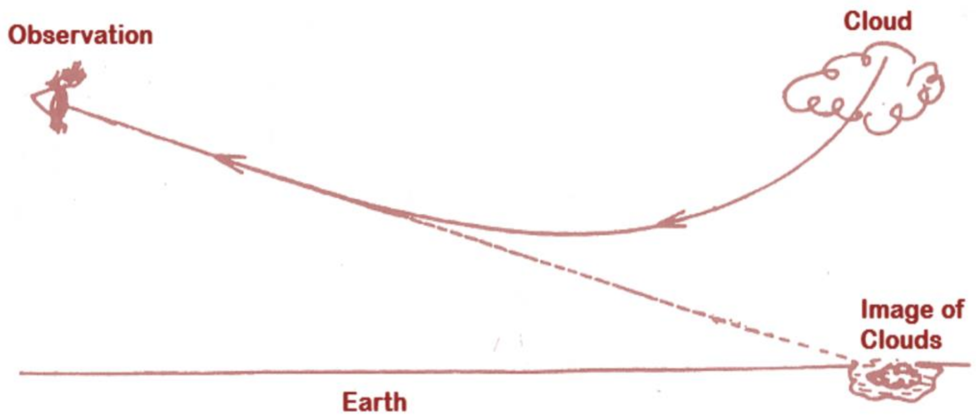
Diagram:



Mirages

A mirage is an optical phenomenon in the atmosphere that makes an object appears to be displaced from its true position.

Diagram:



Mirage occurs as a result of continuous bending (refraction) of light rays as they pass through layers of air having a large temperature gradient. The most common mirage is one in which an observer sees non – existent pools of water on hot desert sands or roads
On a hot day, the air above the ground is hot and hence less dense than the air above it.
When light pass from cold sky air (optical dense) to earth surface of hot air layer (optical less dense) continuously light bends (refraction), away from the normal where incidence exceeds the critical angle.
All the light is reflected upwards (total internal reflection). This looks like reflection produced by 'a pool of water'. In deserts, mirages can mislead caravans to think they are approaching oasis

Refraction through Prism

Prism is a solid piece of glass or transparent material that has a least two planes inclined toward each other through which light is refracted.

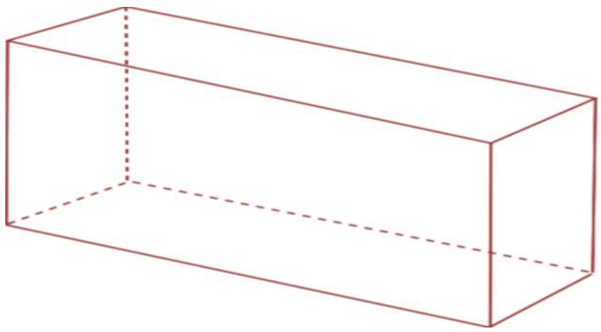
Types of prism

(i) Rectangular prism
(ii) Triangular prism

Rectangular prism

Rectangular prisms are commonly called glass blocks, which already discussed in previous topic

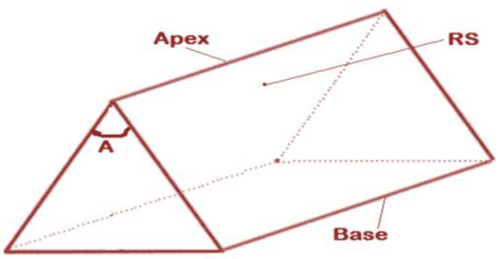
Diagram:



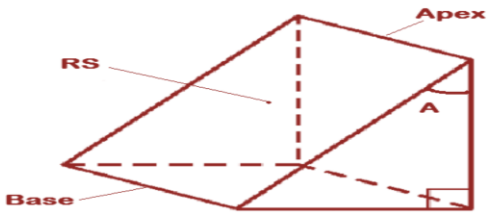
Triangular prism

Triangular prism is a wedge-shaped piece of glass material or any other transparent material.The straight line where the two refracting surfaces **RS** of the prism meet is called the **refracting edge** or the **apex** of the prism. The angle between the refracting surfaces is known as the **apical angle** (A) of the prism. The surface of the prism that lies parallel to the apex is called the base of the prism.

Diagram:



Equilateral prisms (60°-60°-60°)

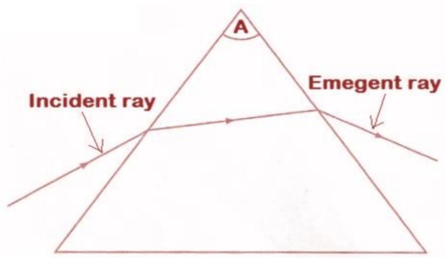


Right angle prisms (45°-90°-45°)

Points to note:-

i. The most common triangular glass prisms are Equilateral prisms and Right angle prisms
ii. Triangular prism has two refracting surfaces.
iii. Light travels slower in glass than in air.
iv. Light rays are bent towards the normal on entering the prism.
v. Light rays are bent away from the normal on leaving the prism is called emergent ray
vi. rays leaving the prism is called **emergent ray**
vii. rays entering the prism is called **incident ray**

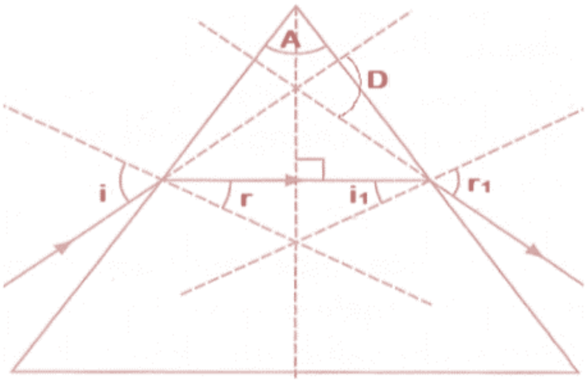
Diagram:



Angle of Deviation, D

Angle of deviation is the angle formed by the intersection of the incident ray directions and the emergent ray directions.

Consider this diagram below



From Snell's Law

$$\eta_g = \frac{\sin i}{\sin r} \ldots\ldots\ldots\ldots 1 \qquad and \qquad \eta_a = \frac{\sin r}{\sin a} \ldots\ldots\ldots\ldots 2$$

But:

i = α + r……………………3

$r_1 = \beta + i_1$……………………4

Therefore:

α = i - r……………………5

$\beta = r_1 - i_1$……………………6

Since: exterior angle of triangle = sum of the two opposite interior angle

D = $\alpha + \beta$ ……………………7

Then: Substitute equation 5 and 6 into equation 7

D = (i – r) + ($r_1 - i_1$) ……………………8

Since: A and A' is supplementary to each other

A + A' = 180°. ……………………9

But: r + i_1 + A' = 180°……………………10

Then: r + i_1 + (180°-A) = 180° - make r subject

r = A - i_1 ……………………11

Then: Substitute equation 11 into equation 8

$D = (i - (A - i_1)) + (r_1 - i_1)$

$D = (i - A + i_1) + (r_1 - i_1)$

$D = i - A + i_1 + r_1 - i_1$

$D = i - A + r_1$

$\mathbf{D = i + r_1 - A}$

The angle of deviation depends on

(i) the apical angle of the prism, A

(ii) the angle of incidence, i

(iii) The refractive index of the glass prism.

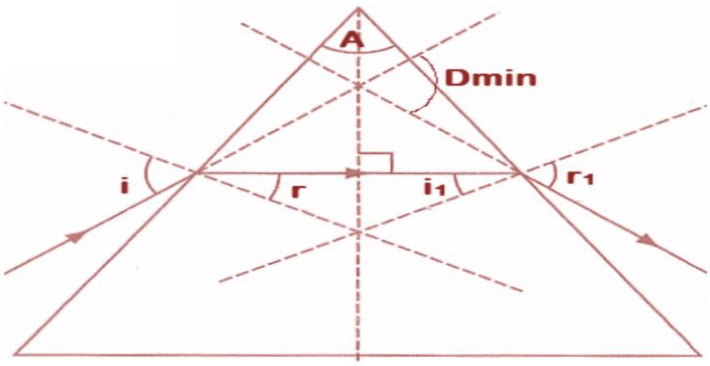
Point note:

Angle of deviation decreases with an increase in the angle of incidence and vice versa

Minimum Angle of Deviation, D_{min}

- Minimum angle of deviation is the deviation angle occurs when the emergent ray is refracted at an angle equal to the angle of incidence
- At the angle of minimum deviation, the refracted ray from the first surface travels through the prism perpendicular to the bisector of the apical angle

Diagram:-



Since: $r = i_1$ and $i = r_1$, $D = D_{min}$

Substitute: $r = i_1$ and $i = r_1$,

Also: $A = r + i_1$

$A = r + r = 2r$

But: $D_{min} = i + r_1 - A$, substituting $A = r + i_1$

Then: $D_{min} = i + r_1 - (r + i_1)$

$D_{min} = i + i - (r + r)$

$D_{min} = 2i - 2r$

$D_{min} = 2(i - r)$, making i the subject

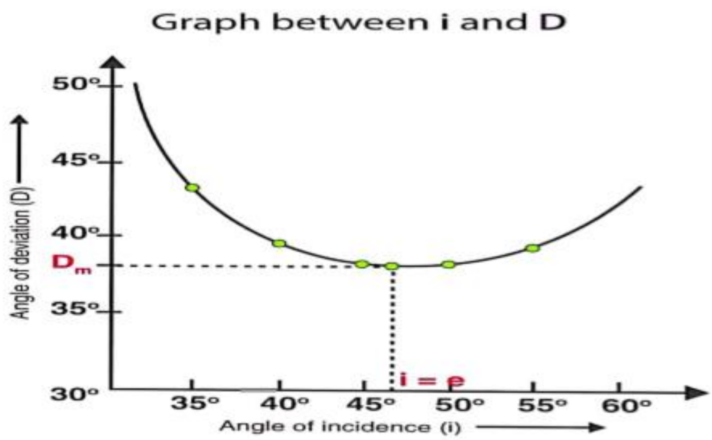
$$i^o = \frac{D_{min}}{2} + r^0$$

$$But\ since\ r = \frac{A}{2}\quad Then\quad i^o = \frac{D_{min}}{2} + \frac{A}{2}$$

From: Snell's law

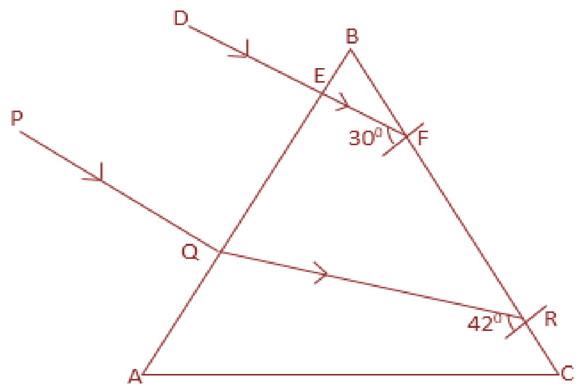
$$a\mu g = \frac{\sin i}{\sin r} = \frac{sin\left(\frac{D_{min}}{2} + \frac{A}{2}\right)}{sin\frac{A}{2}}$$

$$\boldsymbol{a\mu g} = \frac{\boldsymbol{sin\left(\frac{D_{min} + A}{2}\right)}}{\boldsymbol{sin\frac{A}{2}}}$$



Check Your Understanding

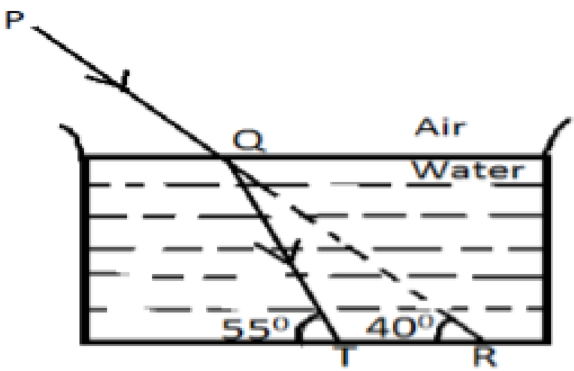
1. The figure below shows two rays of light one entering the prism along the normal DE and the second along PQ



   (a) Why a ray DEF cannot change the direction although it passes through different media?
   (b) The refractive index of the glass of the prism is 1.49. The ray EF is refracted at F. Use the information from figure above to calculate the angle of refraction at F then draw the refracted ray starting from F.
      (i) State how the refraction starting at F would be different if the ray was replaced by a ray of white light.
      (ii) The critical angle for the glass of the prism is just over 42^0. State the approximate angle of refraction for the ray striking BC at R.
      (iii) Another ray not shown in figure above passes through the prism and strikes BC at an angle of incidence of 50^0. State what happens to this ray at the point where it strikes BC?
2. A coin at the bottom of a jar of glycerin appears to be 13.2 cm below the surface of the glycerin. Calculate the height of the column of glycerin in the jar given that the refractive index of glycerin is 1.47. **(**Ans:-19.4 cm)
3. The refractive index of water is 4/3. Find the speed of light in water given that the speed of light in air is 3.0×10^8 m/s (Ans:- 2.25×10^8 m/s)
4. Water is poured into a beaker to a depth of 24 cm. To an eye looking vertically down through the water, the bottom of the beaker appears to be raised 6 cm from the bottom of the beaker. Determine the refractive index of the water. (Ans: $_a\mu_g$ = 1.33)
5. If a ray of light is travelling from air to glass, with an angle of refraction 30^0. If the refractive index of the glass is 1.5. Determine the angle of incidence(Ans:- 48.6^0)

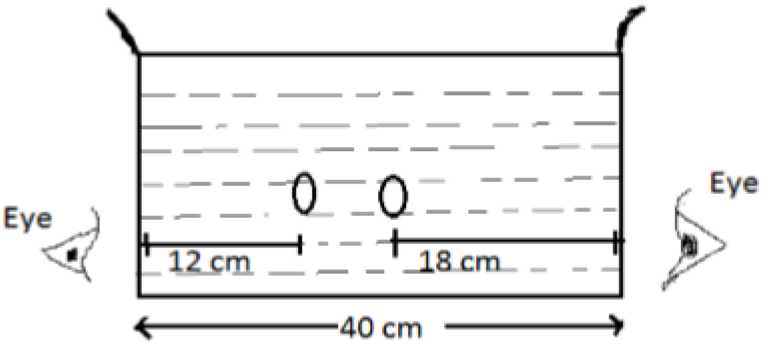
6. The figure of a graph below is of the angle of deviation against the angle of incidence for the prism with a refracting edge of 60^0 Determine the critical angle.

7. A coin is placed at the bottom of a tall gas jar. When the jar is filled with paraffin to a depth of 32.4 cm, the coin is apparently seen displaced 9.9 cm from the bottom. What is the refractive index of paraffin? (Ans:-1.44)
8. A fish appears to be 0.9 m below the surface of water of refractive index 4/3 when viewed directly from above. What is the true depth the fish is?(Ans:-1.2m)
9. A beaker of height 10 cm is filled with water. How far does an optical pin at the bottom appear when viewed from the surface of water, if the refractive index of water is 4/3? (Ans: 7.5 cm)
10. Refractive index of glass is 1.5 .If the speed of light in vacuum is 3 x 108 m/s, find the velocity in medium (Ans: 2 x 10^8 m/s)
11. The refractive index for a ray of light travelling from air to oil (ano) is 5/3, while that for a ray travelling from air to glass is 3/2. What is the refractive index for a ray travelling from glass to oil? (Answer: 10/9)
12. A ray of light is passing from air into water along PQ. The ray strikes the bottom surface at T instead of R as shown in the figure below calculate
    (a) the angle of incidence (b) the angle of refraction (c) the refractive index

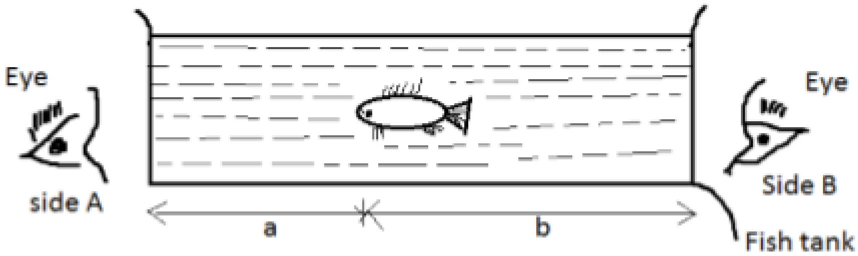


13. Sunlight making an angle of 60^0 with the horizontal enters a pool which is 50 cm deep. Determine the distance travelled by the sunlight in the water (Refractive index of water = 1.33)

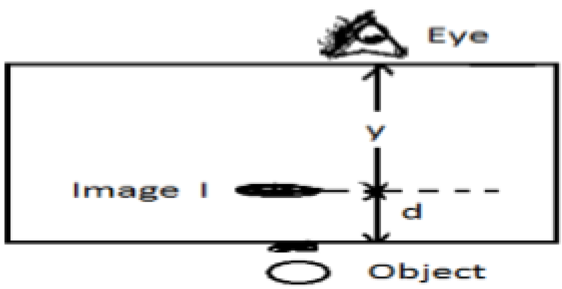
14. A person spear fishing from a boat sees a fish located 3 m from the boat at an apparent depth of 1 m. To spear the fish, should the person aim
    (a) at,
    (b) Above, or
    (c) Below the image of the fish?
15. In a transparent liquid container, an air bubble appears to be 12 cm when viewed from one side and 18 cm when viewed from the other side (see the figure below).Where exactly is the air bubble, if the length of the tank is 40 cm?



16. In a fish aquarium (as shown in the figure below) the image of a fish seems to be 30 cm when seen from side A and 42 cm when seen from side B. Calculate the length of the fish tank , if the refractive index of water is 1.33.



17. In an attempt to determine the refractive index of a glass block , a student finds the displacement produced due to refraction by glass as d and apparent thickness of the block as y as shown in the figure below. Show that the refractive index of glass may be expressed as $\boldsymbol{\eta = 1 + \frac{d}{y}}$



18. An observer looks into a water tank half filled with water .If the height of the tank is 180 cm. A solid that is 80 cm beneath the water surface is seen to be 60 cm below the water surface. Determine
    (a) The Refractive Index of water
    (b) the vertical displacement of the solid
19. A ray of light passing from air into oil at an angle of incidence 30^0. Calculate the angle of refraction in oil if the velocity of light in air is 3.0×10^8 m/s and that in a transparent oil is 2.2×10^8 m/s

20. The light ray passing from glass to air is monochromatic and has a frequency of 4×10^{14} Hz and a wavelength of 5×10^{-7} m in glass. Calculate
    (a) The velocity of light in glass
    (b) The velocity of light in air (refractive index of glass is 1.50)
21. A glass prism has three sides of angle 60^0. A ray of light falls on one of the faces and the angle of incidence is 48^0 .The ray is refracted and now travels parallel to the second face. When it reaches the third face it is again refracted and emerges from the prism. Find
    (a) The refractive index of the glass prism
    (b) The angle between the ray entering the prism and the ray leaving the prism
22. A glass prism has two parallel sides which are 6 cm apart. A ray strikes one of the two parallel sides at an angle of incidence of 50^0 .Find by drawing the perpendicular distance between the ray entering the prism and the ray leaving the prism
23. A rectangular glass block 5 cm thick is placed on top of the page of a book. If the refractive index of the glass block is 1.53, calculate apparent depth of the letters on the book
24. A ray of light is incident at an angle of 60^0 on a block of glass of refractive index 1.5. Determine the angle of refraction of the ray
25. A small coin was placed at the bottom of a tall glass containing some water and viewed from above .The real and apparent depths of the coin were then measured. By varying the depth of the water in the jar ,the following readings were obtained

Real depth (cm)	8.1	12.0	16.0	20.0
Apparent depth (cm)	5.9	9.0	12.0	15.1

    By plotting an appropriate graph from the results, determine the refractive index of the water
26. Calculate the critical angle for air and water medium if the refractive index of water is 4⁄3. (Ans:- The critical angle is 48^0 38')
27. Given that the refractive index of glass is 1.5, what is the value of the critical angle? (Ans:- The critical angle is $41^0 49'$)
28. Given that the refractive index of ethyl alcohol is 1.36. Find the apparent depth in the beaker if the real depth of the optical pin is 52cm. (Ans:- h = 38.23 cm)
29. A fish is located 10m deep in the liquid when viewed from the top. The depth of the fish is 8m. Find the refractive index of the liquid. (Ans:- 1.25)
30. The apparent depth of a certain point at the bottom of water pond is 25cm. find the real depth of this point given that the refractive index is 4⁄3 (Ans:- H = 33. cm)
31. If the light has a velocity of 3×10^8 and has a velocity 1.97×10^8 m/s in the glass.
    (a) What is the refractive index of the glass? (Ans:- 1.52)
    (b) Calculate the refractive index for light traveling from glass to air. (Ans:- 0.6458)
32. Taking the refractive index of glass is 3/2, what is the critical angle?
33. A glass prism has two parallel sides which are 6 cm apart. A ray strikes one of the two parallel sides at an angle of incidence of 50^0. Find by drawing the perpendicular distance between the ray entering the prism and the ray leaving the prism

Color Theory

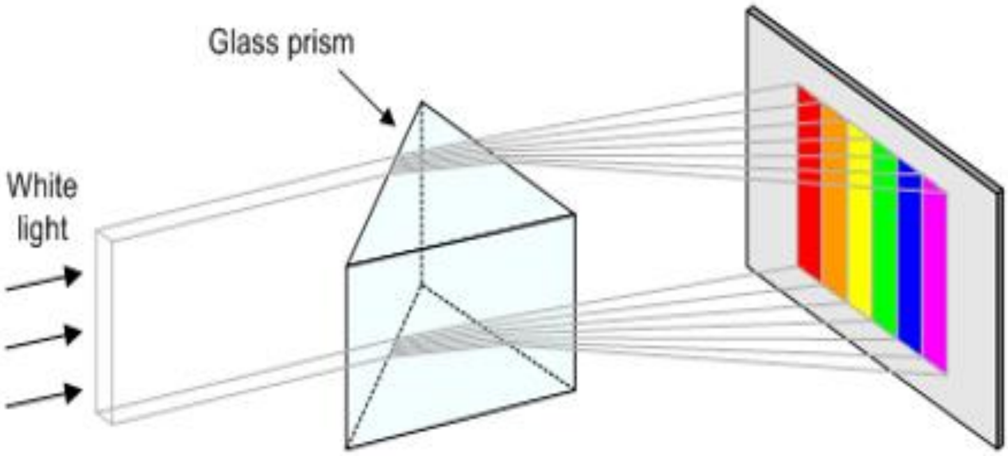
Color is the perceptual quality of light.

- Colour is the property of light that reaches our eyes
- The human eye can distinguish almost ten million colors.

Dispersion of White Light

Dispersion of white light is the process of splitting the white light beam into its component colours.

The band of colours produced in splitting like here below is called **Spectrum**.



Polychromatic Light

Polychromatic light is the white colour where consists more than one colour. Example, sunlight

Monochromatic Light

Monochromatic light is the one with only one colour. Example, red colour

Wavelengths of the Colors of White Light

S/N	Colour	Wavelength(nm)
1	Red	625 - 740
2	Orange	590 - 625
3	Yellow	565 - 590
4	Green	520 - 565
5	Blue	440 - 520
6	Indigo	420 - 440
7	Violet	380 - 420

Point note:

(i) Spectrum of colour is red, orange, yellow, green, blue, indigo and violet.
(ii) Each of these colours has a different wavelength.
(iii) These coloured lights are refracted differently on passing through the prism.
(iv) The velocity of light in a medium (refractive index) depends on the wavelength of incident light. As a result different wavelengths are refracted by differently.

$$a\mu g = \frac{Speed\ of\ light\ in\ vacuum}{Speed\ of\ light\ in\ a\ material}$$

(v) White colour split due to difference in wave length
(vi) Shorter wavelengths have higher refractive indices and get bent more than longer wavelengths

Types of Spectra

There are two types of spectra:
(i) Pure spectra
(ii) Impure spectra

Pure Spectra
Pure spectrum is the one in which the colours are clearly separated from each other

Impure Spectra
Impure spectrum is the one in which the colours not clearly separated from each other, hence the colours overlap.

Recombining Colours of Light
Spectrum comes from white light can recombine to form white colour. The recombination of the colours of the white light spectrum may also be shown by the use of Newton's colour disc. The disc consists of sectors painted with the colours of the spectrum or using spectrum.

Rainbow

The rainbow is a natural phenomenon of dispersion of sunlight by raindrop.

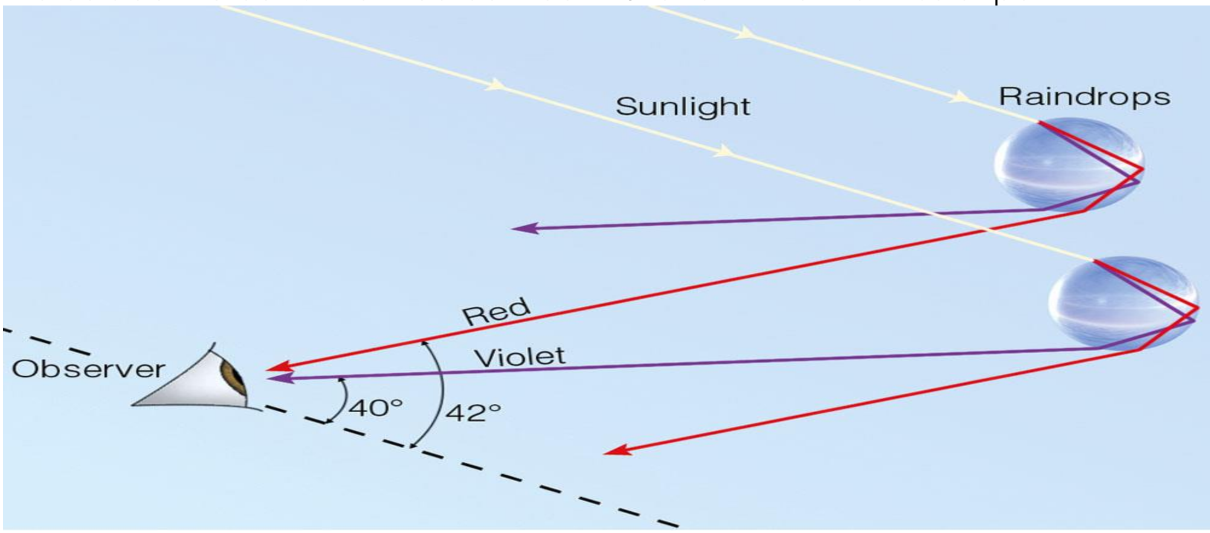
Formation of a Rainbow

It formed by dispersion of sunlight by drops of rain. Since water is denser than air the dispersion of sunlight on a drop of water is the same as when it falls on a glass prism.
The light is first refracted as it enters the surface of the raindrop, reflected off the back of the drop and again refracted as it leaves the drop.

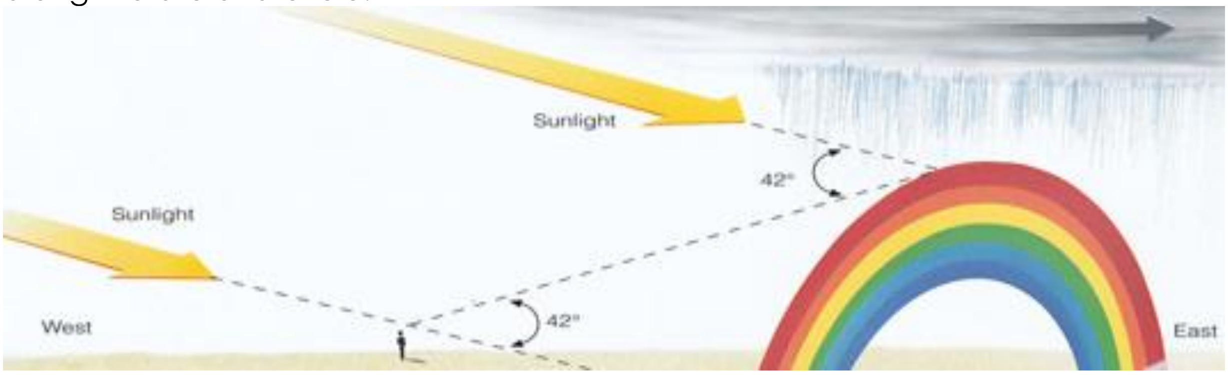
Types of Rainbow
(i) Primary rainbow
(ii) secondary rainbow

Primary Rainbow

It is formed when light undergoes one total internal reflection (refracted twice but reflected once) in the water drops. The violet colour is inside and the red in the outside the bow. It formed between 40^0 and 42^0 from anti-solar point



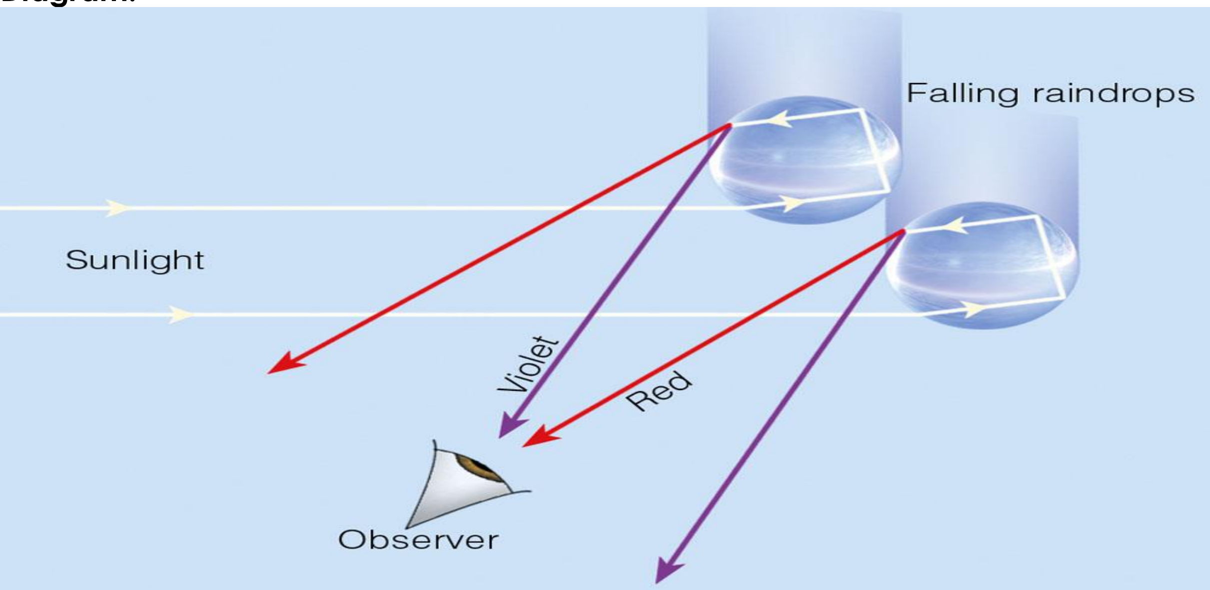
Anti-solar point is a point that lies directly opposite the sun from the observer, that is, on the line from the sun through the observer. This angle is maintained along the arc of a circle.



Secondary Rainbows

It is formed when light undergoes two total internal reflections in the water drops. The violet colour is outside and the red in the inside the bow.

Diagram:



Colour

Colour is the property of light that reaches our eyes.

Appearance of coloured objects under while light

The object seems to have kind of colour due to the fact that it absorbs all colours and reflect the colour that the object has.

Example:-

(i) Yellow flower is yellow because it absorbs all the other colours in the light and reflects only the yellow colour.

(ii) Blue object absorbs the entire colour in white light except blue.

Appearance of white objects under coloured light

When a coloured object is viewed under a coloured light, it takes the colour of that light. Example, the object will appear blue in blue light and red in red light. A colour filter is work on this principle.

Colour filters are materials made of glass or celluloid that let through light of certain colours only.

Example:-

Green filters allow green colour to pass through.

The colour of an object depends on the colour of the light falling on it and the colour(s) it absorbs or reflects.

White object	coloured light	Colour of object
White object	Red filters	Red colour
White object	Yellow filters	Yellow colour
White object	Green filter	Green colour
White object	Blue filter	Blue colour

Types of Colour

(i) Primary colour

(ii) Secondary colour

Primary colour

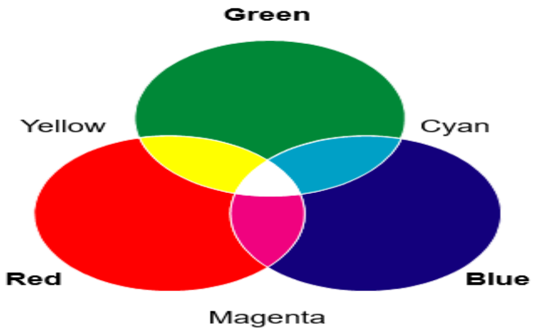
Primary colour is a colour that cannot be created by mixing other colours. Example, red, Blue and Green

Secondary colour

Secondary colour is a colour created by mixing other colours. Example, cyan, magenta and yellow

Complementary Colour

Complementary Colour is the colour that when mixed in a definite ratio produce white (required) colour.



Points to note:

(i) We are only concerned with colours of light and not with coloured substances (pigments)

(ii) The complementary colour of white light is green, red and blue

(iii) The complementary colour of yellow light is green and red.

Additive and Subtractive Mixing Of Colours

The primary colours (pigments) for mixing paints, inks and dyes are not the same for mixing lights, therefore *The primary colours for mixing in pigments used in colouring, photography and printing are **cyan**, **magenta** and **yellow**.*

Additive Mixing Of Colours

The more colours you add, the closer the result draws to white. Therefore, mixing of colored lights is called an additive color mixing system.

Points to note:

(i) Additive mixing of colour deals with primary colour of light colour not primary colour of pigments (paints and dyes)

(ii) Adding different colours of light together increases the number of wavelengths mainly present Movie film, Slide projector, Television and computer displays

Subtractive Mixing of Pigments

When a beam of light strikes the surface of a transparent medium such as glass, some of the light is reflected, some is absorbed and some is transmitted. Colour filters are chosen specifically for the colour of light they will that they will absorb and transmit. This process is called colour subtraction since many colours have been subtracted from white light.
The primary colours of pigments are the secondary colours of light (paints and that is magenta, cyan and yellow, absorb (subtract) light wavelengths and reflect back what defines the colour.

CHECK YOUR UNDERSTANDING

1. Why many clothing shops use daylight lamps made of blue glass?
   - *Because blue glass it act as colour filter, it absorbs the excess red and yellow light formed by the hot filament and the colours that pass through are in the same proportional as in day light.*

2. Why Red light is used for Danger Signs?
   - *Because red light is scattered the least by air molecules due to its highest wavelength so it is able to travel the longest distance through fog, smog and rain.*

3. A red bus with blue letter on it, stops in front of a yellow light at right. Describe the apperarance of the bus.
   - *In yellow light*
     - ✓ *The red bus will appear red because yellow is composed of green and red*
     - ✓ *The blue letters will appear black*

4. A plant with green leaves and red flowers is placed in
   (a) Green
   (b) Red
   (c) Blue light
   Solution
   (a) In Green light the leaves will appear Green, Red flowers will appear Black.
   (b) In Red light the leaves will appear Black, Red flowers will appear Red.
   (c) In green light the leaves will appear Black, Red flowers will appear Black.

5. A burglar is wearing a white shirt, yellow trouser and blue cap. He is observed by two witnesses. Anna is wearing red-tinted glasses, Brighton is wearing yellow-tinted glasses. How would each witness describe the burglar?
   Solution
   Anna:- Red shirt, Black trouser and Black cap
   - Red filter absorbs all colours except red. Yellow light reflected from the Bugler's (thief's) trouser and the blue light from the cap cannot pass through the red filter and so both trouser and cap appear black.

   Brighton:- Yellow shirt, Yellow trouser and Black cap
   - Yellow filter absorbs all colours except yellow. Yellow light reflected from the Bugler's trousers passes through the filter and so the trousers are seen as yellow and the blue light from the cap cannot pass through the red filter and so the cap appear black.

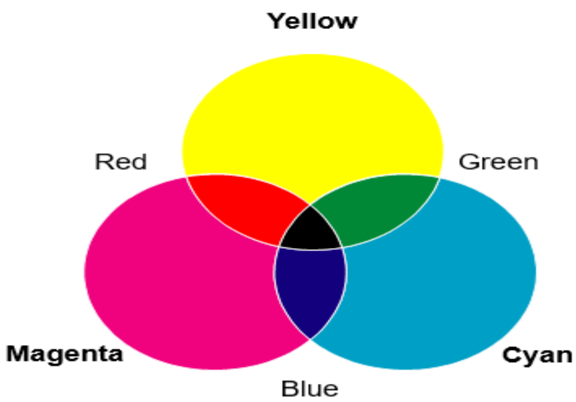
Attempt these Questions

1. Students are experimenting with the lighting for their school play. They want to produce some dramatic lighting effects. Determine the colour formed from a mixture of
   (a) Red and Blue light
   (b) Red, blue and Green light
   (c) Blue and Yellow light
   (d) Green and Magenta light
2. The current Australian flag has blue Red and white sections. Assuming each colour was produced by a single pigment, what colour would each section appear if illuminated by
   (a) Pure blue light
   (b) Pure Red light
   (c) Pure Yellow light
   (d) Yellow light which is made by combining red and green light

Points to note:

(i) Mixing two primary pigments produces a secondary pigment
(ii) The pigments act as filters that subtract one or more colours from the visible spectrum
(iii) Blue, red and green are, therefore, the secondary pigments.
(iv) Each primary pigment absorbs one primary colour:
   (a) Yellow absorbs blue and reflects red and green
   (b) Magenta absorbs green and reflects blue and red
   (c) Cyan absorbs red and reflects green and blue.
(v) Subtractive complementary colours combine

Diagram:



(vi) A secondary pigment absorbs two primary colours and reflects one:
   (a) Red absorbs green and blue and reflects red.
   (b) Green absorbs red and blue and reflects green.
   (c) Blue absorbs - red and green and reflects blue.
(vii) The primary pigments are the secondary colours of light and the secondary pigments are the primary colours of light.
(viii) If you mix a primary pigment with a secondary pigment you get total absorption (black).
(ix) Blue + yellow = black
(x) The primary pigments are the complements of the three primary colours of light Cyan complements red, magenta complements green and yellow complements blue. Applied in paintings and printing.

Why is the Sky Blue?

- It occurs when light moves through the atmosphere, most of the longer wavelengths pass straight through. Little of the red, orange and yellow light is affected by the air. This physical phenomenon is called Rayleigh scattering.
- This is because tiny particles bend high frequency light. (Oxygen, nitrogen) while Large particles bend low frequency light. (Methane, sulfur)
- Hence, much of the shorter wavelength light is absorbed by the gas molecules. The absorbed blue light is then radiated in different directions. It gets scattered all around the sky. Whichever direction you look, some of this scattered blue light reaches you. Since you see the blue light from everywhere overhead, the sky looks blue.
- When light passes through a clear fluid holding tiny particles in the air, the shorter blue wavelengths are shown more strongly than the red.

Violet is scattered most easily, so why isn't the sky violet?

- We have three types of color receptors in our retina. Our eyes are less sensitive to violet. Our eyes are more sensitive to light with blue frequencies.
- This scattering of the higher frequencies of light illuminates the skies with light on the BIV end of the visible spectrum.
- ROY have long wavelength with low frequency and least scattered while VIB are mostly readily scattered because they have short wavelength and high frequency.

R O Y G B I V

Why many clothing shops use daylight lamp made up of blue glass?

- Because blue glass acts as a colour filter, it absorbs the excess red and yellow light formed by the hot filament and the colours that pass through are in the same proportion as in daylight

Why is Red light used for Danger signals?

- Because red light is scattered the least by air molecules due to its highest wavelength so it is able to travel the longest distance through fog, rain and alike.

Sensitivity

- At sunset, the sun is low on the horizon, Sun can appear red because it travels through more atmosphere near sunset than at midday
- When looking at the sun it appears red because much of the blue light is scattered out leaving only the red. It's also basing on sensitivity of humans.α
- The sun at sunrise and sunset appears either yellow, orange, or red. The more particles in the atmosphere, the more scattering of sunlight, and the redder the sun appears.

Why are clouds white?

- Clouds appear white because they consist of water droplets that are many sizes and scatter all wavelengths equally. Larger particles scatter red as well as blue and hence look white. Dust or smoke, Milk and Colloidal suspension are other examples. Sunsets are red because all the other color frequencies are filtered out. Water looks greenish blue because water absorbs red light.
- The color of things depends on what colors are reflected or absorbed by molecules.

Points to note

- The colors of light that are reflected from a surface mix additively when the hit your retina.
- The subtractive part of the mixing is the light hitting the surface and part of it being absorbed or transmitted.
- A surface that reflects both red and green light will appear yellow by additive mixing of the red and green light that reaches your eyes
- We have so far been assuming that we are illuminating our colored filters and surfaces with uniform white light.
- But most light is not uniform white, or even white at all.
- How can we figure out what objects will look like in non-ideal or non-uniform light?

Check Your Understanding

1. The black line is the intensity distribution curve of a "daylight" CFL. The purple line is the reflectance curve of a magenta colored surface. What color does the surface appear to be when illuminated with this light?
   (a) Magenta
   (b) Red
   (c) **Blue**
   (d) Purple

2. A computer pixel is composed of red, green and blue lights. If the red and green ones are illuminated, what color does it appear from a distance?
   (a) Green
   (b) Red
   (c) **Yellow**
   (d) Blue
   (e) Magenta

05. REFRACTION OF LIGHT BY LENSES

A lens is a transparent or a translucent medium that alters the direction of light passing through it

Types of Lenses

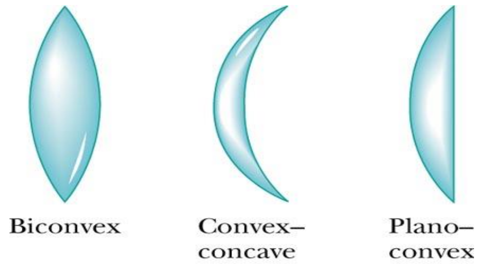
There are two main types of lenses based on their shape.

(i) Convex lenses
(ii) Concave lenses

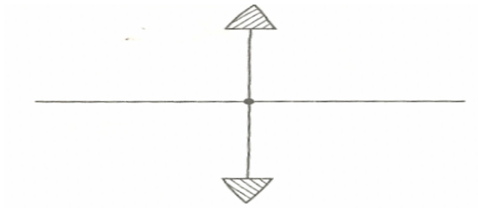
Convex/Converging Lenses

A convex lens is a transparent material which is thicker at its centre than at its edges. Convex lenses converge light. Convex lenses can be biconvex, piano-convex or converging meniscus as they are drawn down respectively.

Diagram:



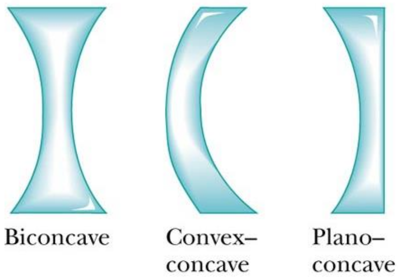
Symbol for convex lens



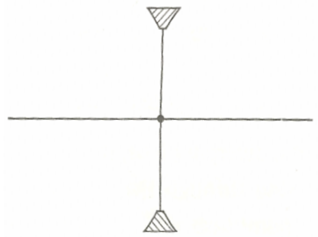
Concave/Diverging Lenses

A concave lens is a transparent material which is thicker at its edges than at its centre. Concave lenses diverge light. Concave lenses include biconcave, plan-concave and diverging meniscus lenses as they are here down respectively.

Diagram:



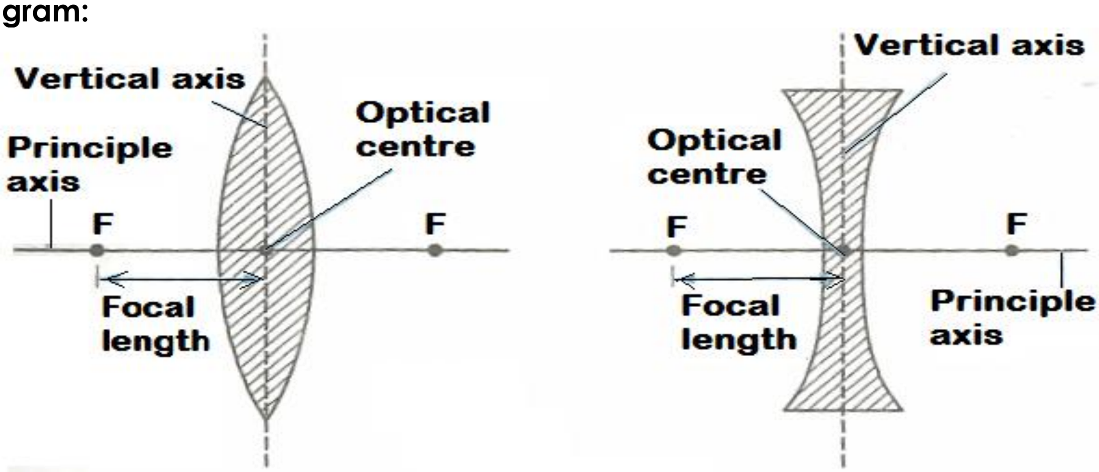
Symbol for concave lens



Terms Used On Thin Lenses

Consider the diagram below

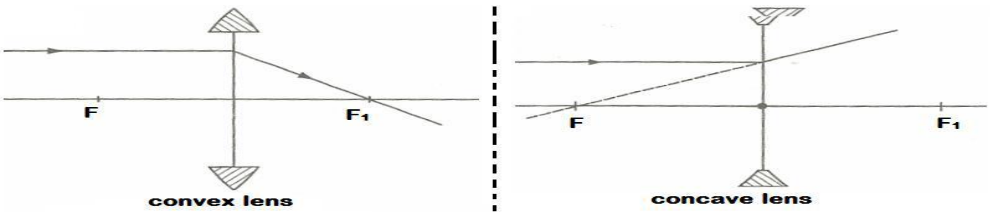
Diagram:



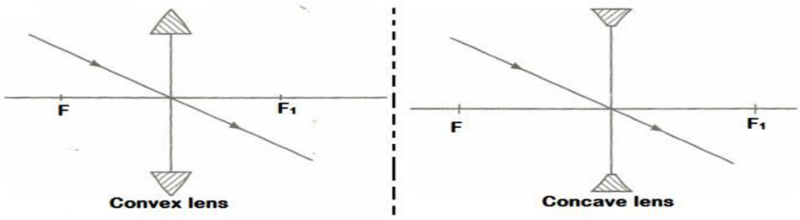
(i) **Optical centre**: This is the geometric centre of a lens.
(ii) **Centre of curvature, C**: This is the geometric centre of the sphere of which the lens surface is a part of.
(iii) **Principal axis:** This is an imaginary line which passes through the optical centre of the lens at a right angle to the lens.
(iv) **Radius of curvature, R**: is the distance between optical centre and the centre of curvature.
(v) **Principal focus/Focal point, F:** This is a point through which all rays travelling close and parallel to the principal axis pass through the lens.
(vi) **Aperture**: is the width of the lens, from one edge to another
(vii) **Focal length, f**: This is the distance between the optical centre and the principal focus

Construction of Ray Diagrams

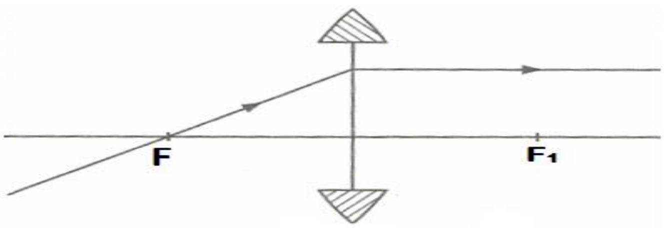
The following is the rules used to locate image in the lenses.
(i) Choose a suitable scale
(ii) Draw a principle axis and the lens
(iii) Draw object in the position
(iv) A ray of light travelling parallel to the principal axis passes through the principal focus
Diagram:



(v) A ray of light travelling through the optical centre goes undeviated (not refracted) along the same path.
Diagram:



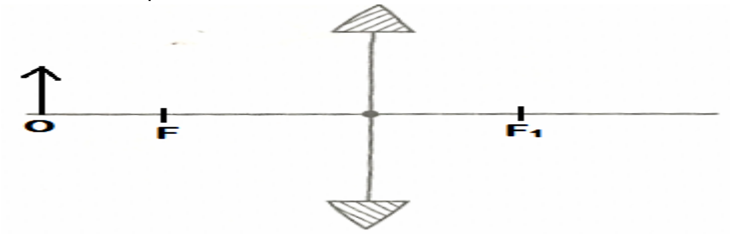
(vi) A ray of light travelling through the principal focus is refracted parallel to the principal axis
Diagram:



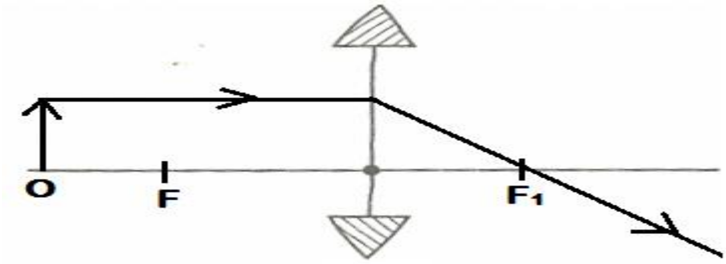
(vii) Measure the height and the distance of the image
(viii) Convert the measurements into actual units using the chosen scale

Example, 01
An object 0.05 m high is placed 0.15 m in front of a convex lens of focal length 0.1 m. Find, by construction, the nature, the position and the size of the image.
Solution:

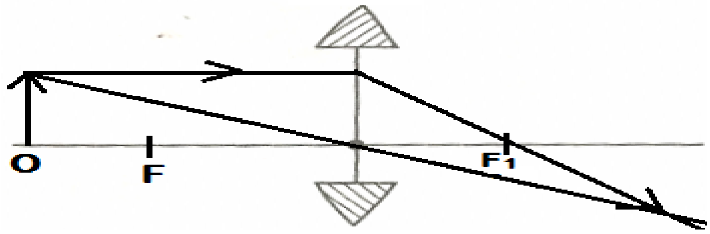
i. Choose a suitable scale e.g. choose 1cm ≡ 5cm
ii. Draw object in the position



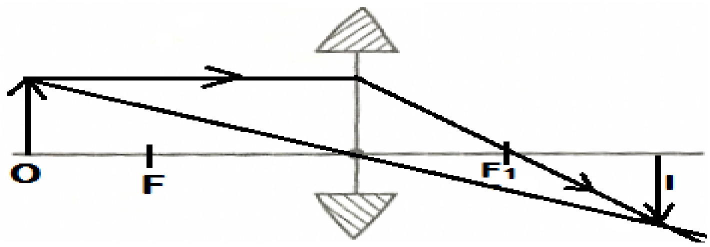
iii. A ray of light travelling parallel to the principal axis passes through the principal focus



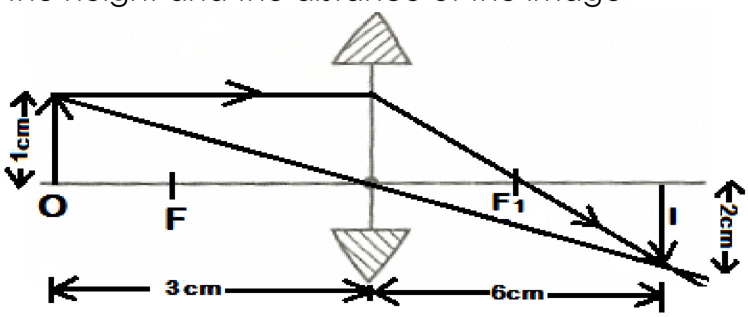
iv. A ray of light travelling through the optical centre goes unbent (not refracted) along the same path.



v. Draw the image of the object at the point of intersection of the refracted rays.



vi. Measure the height and the distance of the image



vii. Convert the measurements into actual units using the chosen scale

From the graph:

Image height, IH = 2cm x 5 = 10 cm = 0.1 m IH **from:** 1cm ≡ 5cm

2cm ≡ x?

X = 2cm x 5 = 10 cm = 0.1 m

Image distance, v = 6cm x 5 = 30 cm = 0.3 m

From: 1cm ≡ 5cm

6cm ≡ x?

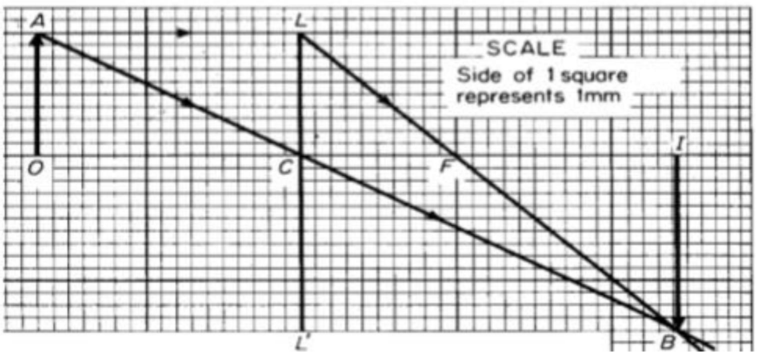
X = 6cm x 5 = 30 cm = 0.3 m

Therefore: The image is 0.1 m high and 0.3 m from the lens.

Check Your Understanding

1. An object 10 cm tall stands vertically on the principal axis of a convex lens of focal length 10 cm and at a distance of 17 cm from the lens. By means of accurate graphical construction find the position, size and nature of the image formed

   Answer



   (a) Position of the image = 24 x 1 = 24 cm from the lens
   (b) Size of the image = (14 x 1) = 14 cm tall
   (c) Nature of the image: The image is (i) Real and (ii) inverted
2. An object 10 cm tall stands vertically on the principal axis of a convex lens of focal length 10 cm and at a distance of 17 cm from the lens. By means of graphical construction find the position, size and nature of the image formed (Ans:- v = 24 cm, Image size = 14 cm, The image is Real and inverted)
3. An object 8 cm tall is placed 20 cm in front of a convex lens of focal length 16 cm. By means of accurate graphical construction, determine the position, size and nature of the image formed.
   (Ans: V = 60 cm, Size: = 24 cm, Nature: Real image)
4. An object 0.05 m high is placed 0.15 m in front of a convex lens of focal length 0.1 m. Find, by construction, the nature, the position and the size of the image. (Ans:- HO = 0.1, V = 0.3 m, Real)
5. An object is placed 12 cm from a convex lens of focal length 18 cm. using the ray diagram. Find the position of the image.(Ans:- v = -36 cm, same side)
6. An object is placed 10 cm from a concave lens of focal length 15 cm. using the lens formula, determine the nature and the position of the image. (ANS: Since, v = -6, The image is virtual and erect)
7. An object 2 cm high is placed 24 cm from a converging lens. An erect image which is 6 cm high is formed. Find focal length of the lens. (ANS: f = 36 cm)
8. The focal length of a converging lens is 10 cm. How far should the lens be placed from an illuminated object to obtain an image which is five times the size of the object on a screen? (ANS: u = 12 cm)

The Lens Formula

It given by formula;

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Linear Magnification

Magnification is a measure of the extent to which an optical system enlarges or reduces an image in relation to the object.

$$\boldsymbol{M = \frac{IH}{OH} or\ M = \frac{v}{u}}$$

Where:

IH = image height
OH = object height
v = distance of the image from the lens
u = distance of the object from the lens
M = magnification
Also multiplying v each term of the lens formula

$$\frac{v}{f} = \frac{v}{u} + \frac{v}{v}$$

Then

$$\boldsymbol{M = \frac{v}{f} - 1}$$

Multiplying u each term of the lens formula

$$\frac{u}{f} = \frac{u}{u} + \frac{u}{v}$$

Then

$$\boldsymbol{M = \frac{f}{u - f}}$$

Power of a Lens

This is defined as the reciprocal of a lens's focal length in meters. Opticians when asks for lenses, they ask it in terms of its power and not focal length.

$$\boldsymbol{Power = \frac{1}{Focal\ length\ in\ metres}\ (deopters)}$$

The shorter the focal length, the greater the power.

Real-Is-Positive Convention

To calculate the values of u and v a sign rule or convention is adopted. The rule is referred to as the **real-is-positive convention**.

Sign For real object and image	Sign For virtual object and image
u = + v = + f = +	u = + v = - f = -

Points to note:

i. Image distance is + for real and – for virtual
ii. Convex lenses have positive values of focal length, F = +
iii. Concave lenses have negative values of focal length, F = -
iv. For a concave lens, the image distance is always –

Example, 02
An object is placed 10 cm from a concave lens of focal length 15 cm. using the lens formula, determine the nature and the position of the image.
Data given:
Focal length, f =-15 cm
Distance of object, u = +10 cm
Distance of image, v = ?
Solution:-

From
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$
Making V the subject
$$V = \frac{uf}{u - f}$$
v = -150/25
v = -6
The image is virtual and erect

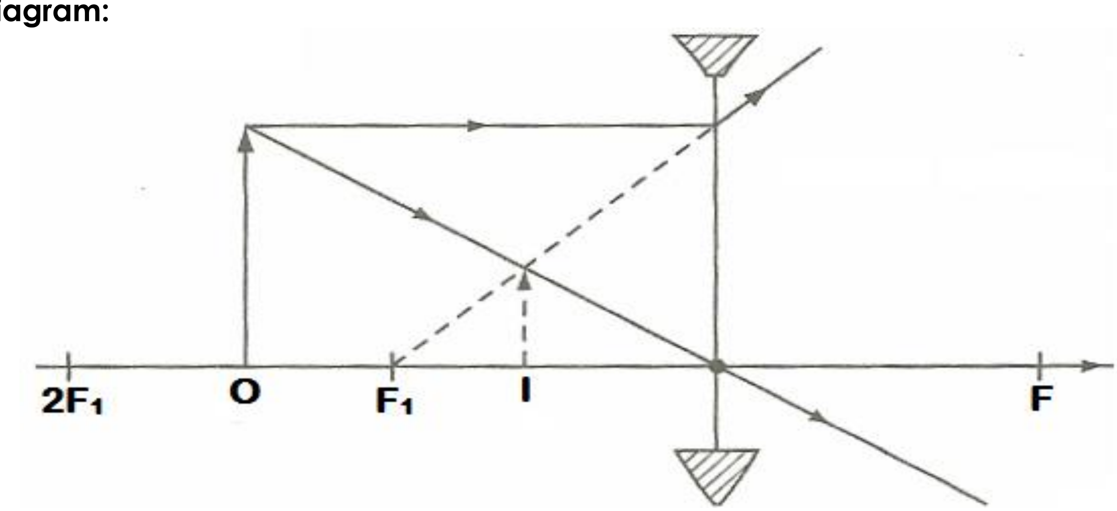
Example, 03
An object 2 cm high is placed 24 cm from a converging lens. An erect image which is 6 cm high is formed. Find focal length of the lens.
Data given:
Distance of object, u = +24 cm,
Distance of image, v = ?
Image height, IH = -6cm,
Object height, OH = 2cm
Focal length, f = ?
Solution:
From:
$$\boldsymbol{M = \frac{V}{u} = \frac{IH}{OH}}$$
$$\mathrm{V = \frac{u\,x\,IH}{OH}}$$
$$\mathrm{V = \frac{24\,x - 6}{2}}$$
The image distance, v = - 72 cm
Then: Make f the subject from
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$
$$\boldsymbol{f = \frac{uv}{u + v}}$$
$$\mathrm{f = \frac{-72\,x24}{24 - 72}}$$

The focal length, f = 36 cm

Example, 4
The focal length of a converging lens is 10 cm. How far should the lens be placed from an illuminated object to obtain an image which is five times the size of the object on a screen?
Data given:
Distance of object, u = ?
Distance of image, v = ?
Focal length, f = +10
Magnification, M = 5
Solution:
First: find v and u
From: M = $\frac{v}{u}$make v subject
v = M x u
v = 5u
$$From\ \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$
$$Then\ \frac{1}{f} = \frac{1}{u} + \frac{1}{5u}$$
Making u the subject makes
u = 6f/5
u = (6x10)/5
u = 12 cm
The lens should be at 12cm from the object

Image Formed by Concave Lens

Regardless the object position, a concave lens always forms a virtual, upright and diminished. The image is always on the same side of the lens as the object. When the object is brought closer to the lens the image becomes larger but it can never equal the size of the object.
Diagram:

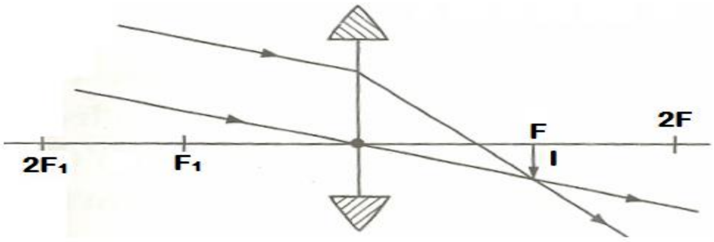


Properties of image formed
- Virtual
- Formed between the object and the lens
- Erect
- Diminished
- As U increase to infinity also V increase to F

Images Formed By convex Lenses

The characteristics of the image formed by convex lens will depend on the distance of the object from the lens

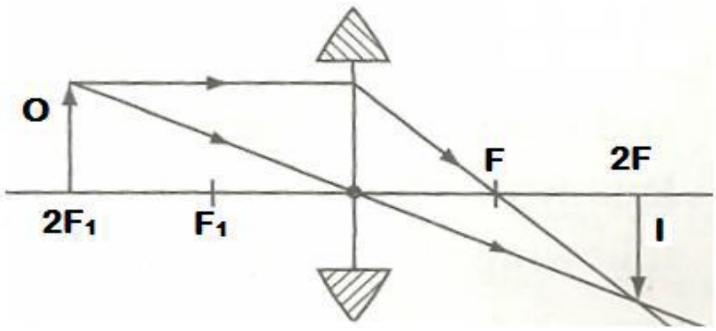
Object at Infinity (Very Far).
Diagram:



Properties of image formed

- It is real
- Formed at F
- Inverted (upside down)
- Diminished (smaller in size than the object)

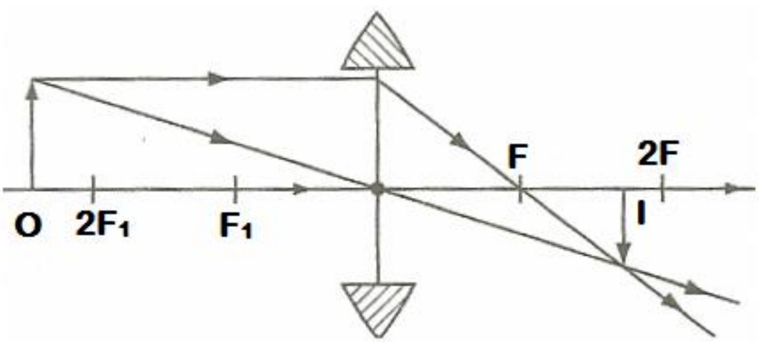
Object at $2F_1$
Diagram:



Properties of image formed

- It is real
- Formed at 2F
- Inverted (upside down)
- Same size as the object

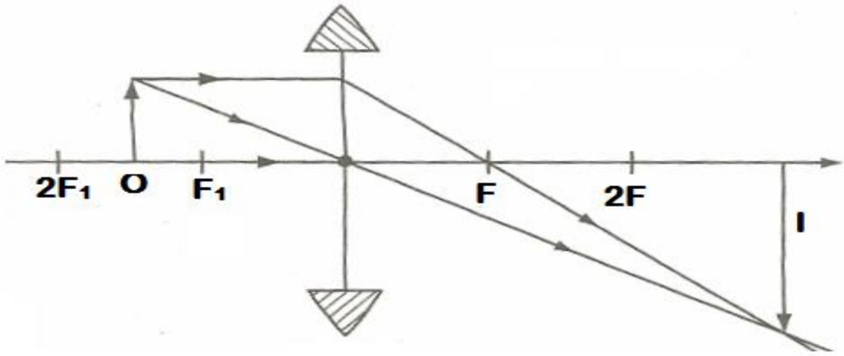
Object beyond $2F_1$
Diagram:



Properties of image formed

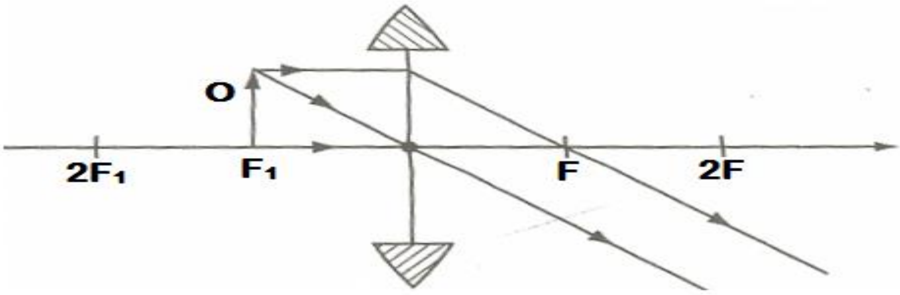
- It is real
- Formed between F and 2F
- Inverted (upside down)
- Diminished (smaller in size than the object)

Objects between F and 2F$_1$
Diagram:



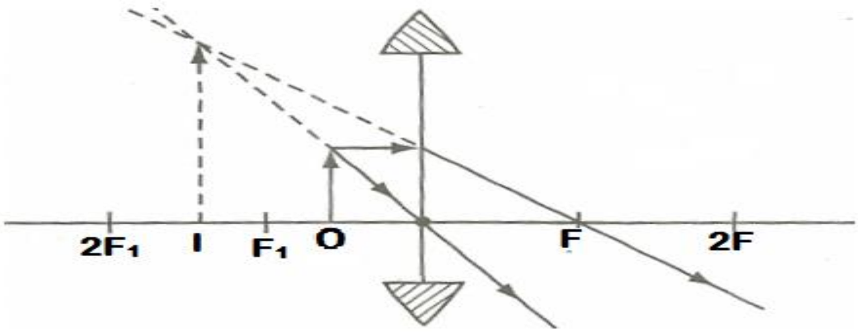
Properties of image formed
- It real
- Formed behind 2F
- Inverted (upside down)
- magnified (larger in size than object)

Object at F$_1$
Diagram:



Properties of image formed
- Real
- Formed at infinity
- Inverted (upside down)
- Magnified (larger in size than object)

Object between F$_1$ and Lens
Diagram:



Properties of image formed
- Virtual
- Image is behind the object
- The image is erect
- Magnified (larger in size than object)

Check Your Understanding

1. An object is at right angles to the principal axis of a convex lens. The object is 2mm high and is 12cm from the center of the lens which has a focal length of 8cm. Find the distance of the image from the center of the lens, and its height. Is it real or virtual? (Ans:- v=24cm, IH = 4mm and its real)
2. A convex lens is used to project an image of a light source onto a screen. The screen is 40cm from the light source and the image is thrice the size of the object. Calculate
   (a) The focal length of the lens used (Ans:- 7.5cm)
   (b) How far from the image must the lens be placed?(Ans:- v= 30cm)
3. A convex lens produces a virtual image which is four times larger than the object. The image is 15cm from the lens. What is the focal length of the lens? (Ans=12cm)
4. An object is 20cm from a convex lens. The real image formed is three times smaller than the object. Find the focal length of the lens. (Ans:- f = 5cm)
5. A convex lens of focal length 5cm produces an erect image which is five times the size of object. Find the distance of the object from the lens. (Ans:- u=6cm)
6. An object 37.5cm from a lens produces a real image 75cm from the lens. What type of the lens is it, and what is its focal length?(Ans:-convex, f = 25cm)
7. An object is 6cm from a lens, which produces a virtual image between the object and the lens. This is 2cm from the object. What type of the lens is it, and what is its focal length? (Ans:- concave, f = 3cm)
8. A convex lens produces an erect image which is twice the size of the objects. If the image is 8cm from the lens find the focal length of the lens. (Ans:- f = 2.67cm)
9. An object 4cm high is placed 20cm in front of a thin lens of focal length -5cm. calculate:-
   (a) The image distance (Ans:- v = 4cm)
   (b) The linear magnification (Ans:- M = 0.8)
   (c) The height of the image (Ans:- IH =3.2cm)
10. An object 2cm high is located 10cm in front of a thin lens of focal length 4cm. find:-
    (a) The image distance (Ans:- 6.67cm)
    (b) The magnification (Ans:- M= 0.67)
    (c) The height of the image formed. (Ans:- 1.33)
11. A screen is placed 80cm from an object. A lens is used to produce on the screen an image with a magnification 3.
    (a) Calculate the image distance (Ans:- u = 60cm)
    (b) Calculate the focal length of the lens. (Ans:- f = 12cm)
    (c) Is the lens converging or diverging? (Ans:- Converging)

06. OPTICAL INSTRUMENTS

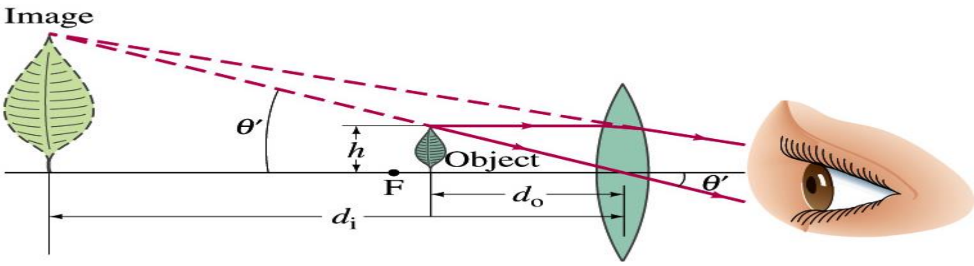
Optical instruments are devices which are used to help the human eye view small or distant objects more clearly. It uses a combination of lenses and/or mirrors to produce an improved image of an object.

i. Simple Microscope
ii. Compound Microscope
iii. Astronomical Telescopes
iv. Simple lens Camera
v. Projector lantern
vi. Human Eye

Simple Microscope

It consists of a biconvex lens which may be hand-held or placed in a simple frame. It is sometimes referred to as a **magnifying glass**. When an object is placed nearer such a lens than its principal focus, i.e., within its focal length, an image is produced that is erect and larger than the original object. The image is also virtual; i.e., it cannot be projected on a screen as can a real image.

Diagram:

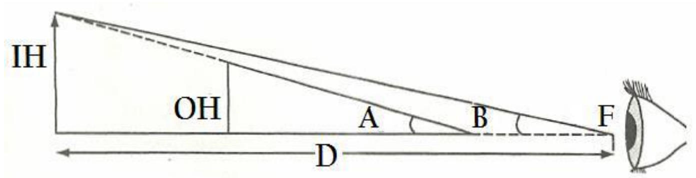


Mode of Action:

i. Object is placed at a distance shorter than the focal length of the lens, $d_o < f$ so object is between f and lens
ii. Virtual, upright and magnified image of the object is formed.
iii. The image appears clearest when it is about 25 cm from the eye, U = 25cm. This distance is called the **near point** (D).
iv. The nearer the object is to the lens, the further and larger the image formed.

Magnification

Consider the diagram below



Where:

A = angle subtended by the object
B = angle I subtended by the virtual image
D = distance between F and image

Lateral Magnification

The lateral magnification of a simple lens is the ratio of the image height (IH) to the object height (OH).

$$M = \frac{Hi}{Ho}$$

Linear Magnification

Linear magnification is also given by the ratio of the image distance v to the object distance u.

$$M = \frac{V}{u}$$

Angular Magnification

The angular magnification (M) of a simple microscope is the ratio of the angle subtended at the eye by the object when viewed through the magnifying glass (B) to the angle subtended at the eye by the object when viewed with naked eyes (A)

$$M = \frac{B}{A}$$

From the diagram above

$$Tan\ B = \frac{Hi}{D}$$

Since: angle B is small, it can be expressed as

$$B = \frac{Hi}{A} \ldots\ldots\ldots\ldots..1$$

If the angle B subtended by the virtual image. Ignoring the small distance between the eye and the magnifying lens

$$B = \frac{Hi}{V} = \frac{Ho}{V}$$

Then:

$$Tan\ A = \frac{Ho}{D}$$

Since: angle A is small, it can be expressed as.

$$A = \frac{Ho}{D} \ldots\ldots\ldots\ldots\ldots\ldots..2$$

Substitute eqn 1 and 2 in the formula M = B/A

$$M = \frac{OH}{u} \div \frac{OH}{v}$$

$$M = \frac{OH}{u}\ x \frac{v}{OH}$$

$$M = \frac{V}{u}$$

When the image is at the near point, v = -25 cm.

$$Take\ note\ that, m = \frac{v}{u}\ and\ v = -25$$

Therefore, using the lens formula,

$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}\ \ multiply\ V\ each\ term$

$It\ becomes\ \frac{v}{f} = \frac{v}{u} + \frac{v}{v}\ then, \frac{25}{f} = m - 1$

Therefore:

$$\boldsymbol{M = \frac{25}{f} + 1}$$

Point to note: - Angular magnification also is known as the **magnifying power**

Example 01,

A simple microscope with a focal length of 5 cm is used to read division of scale 1.5 mm in size. How large will the size of the divisions as seen through the simple microscope be?

Solution:

Focal length, f = 5cm, Object height, OH = 1.5mm and Image height, IH = ?

From:

$$M = \frac{25}{f} + 1$$

$$M = \frac{25}{5} + 1$$

M = 6

Then:

$$M = \frac{IH}{OH} \; make\ IH\ the\ subject$$

IH = OH x M

IH = 1.5 x 6

IH = 9mm

Therefore divisions will have a size of 9 mm when viewed through the simple microscope.

Uses

(i) It is used to view specimen in the laboratory

(ii) It is used to read small print

Check Your Understanding

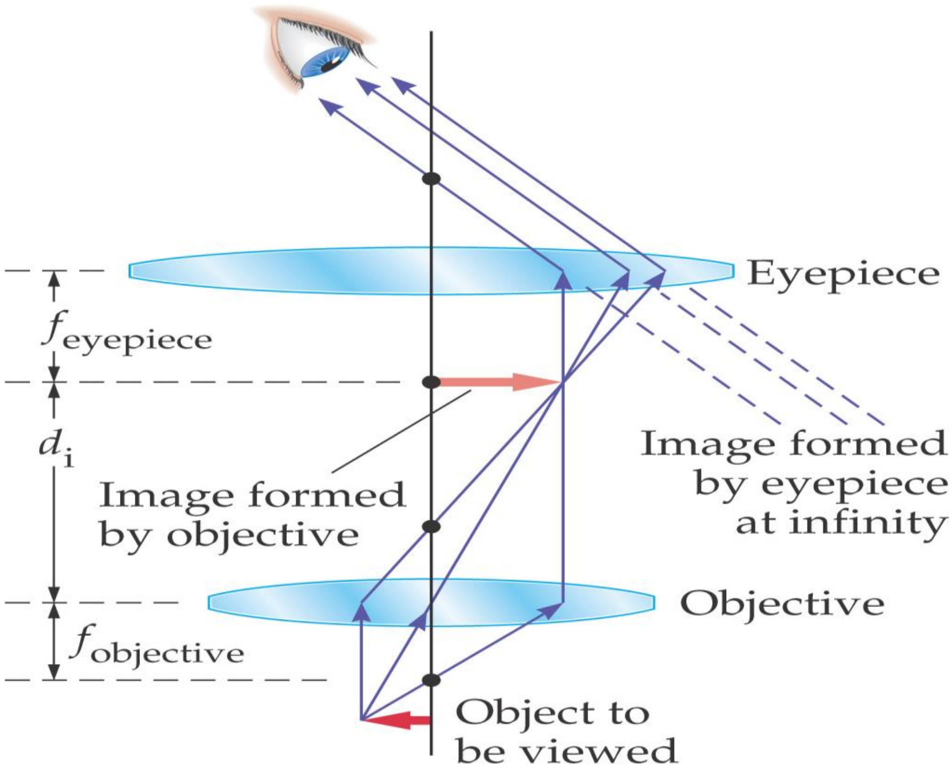
1. A small object is placed 3 cm from the lens of simple microscope. The focal length of the lens is 5 cm.
    (a) Find the linear magnification produced by the simple microscope
    (b) How far from the lens should you place the object in order to obtain maximum magnification of the image?
2. A magnifying glass of focal length 5 cm is used to magnify a small object held 4 cm from the optical centre of the lens. Determine the position and magnification of the image formed.
3. A simple microscope with a focal length of 5cm is used to read division of scale 1.5mm in size. How large will the size of the division as seen through the simple microscope be? (Ans:- 9mm)

Compound Microscope

A compound microscope is an optical instrument which is used to magnify very small objects like blood cells, bacteria which otherwise cannot be seen with the unaided eye Used to produce much greater magnification than that produced by simple microscope.

The essential parts of a compound microscope are **the two convex lenses of short focal length**. These lenses are

a) The objective lens
b) The eye piece



A compound microscope consists of the following parts:

i. *The objective lens:*
   - The objective lens of a compound microscope is a convex lens of very short focal length (F_0) i.e. F_0< 1cm
   - The object to be seen is kept very close to the objective lens

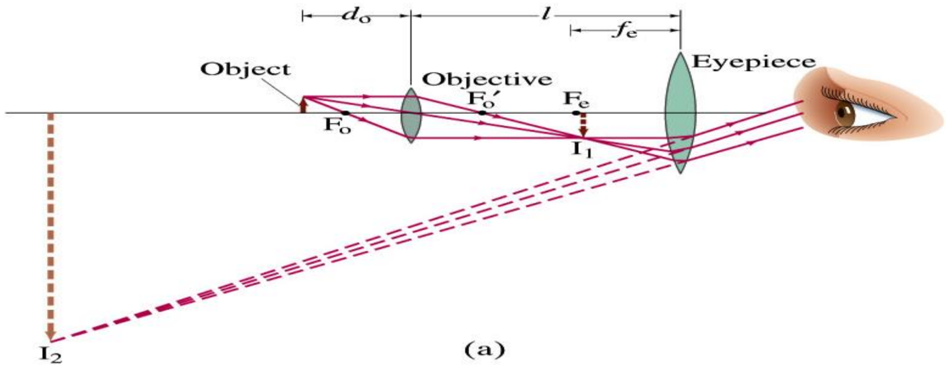
ii. *The eye piece:*
   - The eye piece of a compound microscope is also a convex lens of short focal length (F_e)
   - The focal length of the eye piece is greater than that of the objective lens $F_e > F_0$

iii. *Microscope tube:*
   - The objective lens and the eye piece are mounted coaxially (having a common axis) at the end of two brass tubes which can be made to slide into each other so that the distance between the two lenses can be adjusted.

The Mode of Action of a Compound Microscope

- The ray diagram below gives the principle of a compound microscope
- The object (O) is placed just outside the principal focus of the objective lens, f_o
- The objective lens forms a real, inverted and magnified image (I_1) of the object
- The image (I_1) acts as an object for the eye piece.
- The position of the eye piece is so adjusted that the image lies within the focal length of the eye piece *fe*

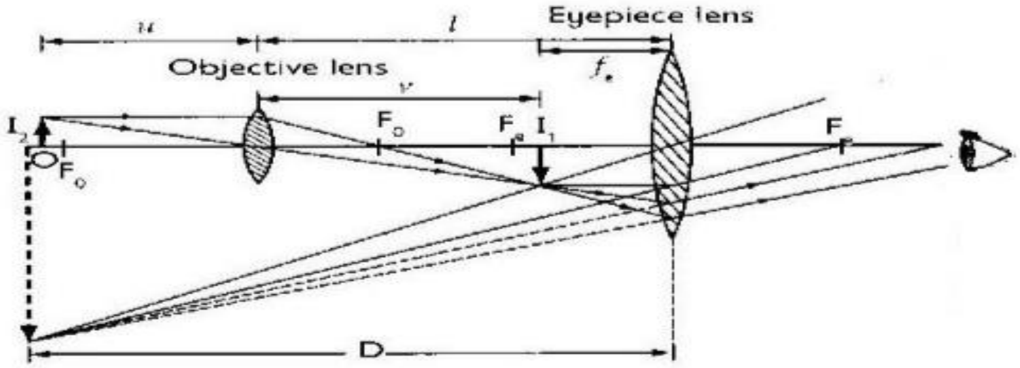
Demonstration



- To observe image clearly, the eyepiece lens is adjusted until the image is at the near point, D, from the eye.
- The final image I_2 is virtual and is magnified still further; it is inverted compared with the object. The final image I_2may appear 1000 times larger than the object

Magnifying Power of a Compound Microscope

The magnifying power of a compound microscope (m) is defined as the ratio of the size of the final image (I2) as seen through the microscope to the size of the object as seen with a naked eye.



Magnification

The magnification produced by the objective lens Mo can be obtained using the relation

$$M_o = \frac{V}{u}$$

From the lens formula the magnification of the objective lens is obtained as

$$M_o = \frac{v}{f} - 1$$

But for the eyepiece magnification, it makes a virtual image, hence

$$M_e = \frac{v}{f} + 1$$

The total magnification (M) is given by the two lenses. That is,

$$M = M_o M_e$$

$$M = \left(\frac{v}{f} - 1\right)\left(\frac{v}{f} + 1\right)$$

Also, the distance, v, for the objective lens is approximately equal to l - f_e, where l is the distance between the two lenses.
Therefore,

$$M_o = \frac{l - f_e}{u}$$

The eyepiece lens acts as a simple magnifier. Assuming that the eye is relaxed, the angular magnification M_e is given by

$$M_e = \frac{D}{u} = \frac{D}{f_e}$$

The total magnification (M) is given by the linear magnification of the objective lens M_o multiplied by the angular magnification M_e of the eyepiece lens. That is

$$M = M_o M_e = \frac{l - f_e}{u}\ x\ \frac{D}{f_e}$$

But to produce large magnification, f_e and f_o must be very small compared to l, therefore,
$l - f_e = l$ also the object must be near f_o so that $u \approx fo$, thus

$$\boldsymbol{Total\ Magnification, M = \frac{Dl}{f_o f_e}}$$

Example 02,
A certain microscope consists of two converging lenses of focal length 10cm and 4cm for the objective and eyepiece, respectively. The two lenses are separated by a distance of 30cm. The instrument is focused so that the final image is at infinity. Calculate the position of the object and the magnification of the objective lens.
Solution:
For the objective lens

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f_o}$$

Where; F_o = 10cm
The objective lens forms a real image of the object at the principal focus of the eyepiece.
Thus; v = (30 – 4) = 26cm
Thus

$$\frac{1}{u} + \frac{1}{26} = \frac{1}{10}$$

The distance of object, u = 16.25cm

The magnification of the objective lens is given by:-

$$m_o = \frac{v}{u}$$

The magnificent given by objective lens, Mo = 1.6.

Check Your Understanding

1. A certain microscope consists of two converging lenses of focal length 10cm and 6cm for the objective and eyepiece, respectively. The two lenses are separated by a distance of 30cm. The instrument is focused so that the final image is at 30cm in front of the eyepiece. Calculate the position of the object and the magnification of the objective lens.

2. A compound microscope consists of an objective lens of focal length 8 cm and an eyepiece lens of focal length 4 cm. The two lenses are separated by a distance of 20 cm. When the microscope is focused, a virtual image is formed. Calculate the position of the object and the magnification of the first image.

3. In a compound microscope, the focal length of the objective lens is 4.0 cm and that of the eye piece is 3.3 cm and they are placed at a distance of 15.0 cm. A real object of size 2mm is placed 6 cm from the objective lens. By using the lens formula, calculate:
   (a) Position of the final image
   (b) The size of the final image viewed by the eye piece
   (c) Magnification produced by the arrangement of these lenses

4. A compound microscope consists of two lenses of focal length 12 cm and 6 cm for the objective lens and the eyepiece lens, respectively. The two lenses are separated by a distance of 30 cm. The microscope is focused so that the image is formed at infinity. Use graphical means to determine the position of the object. **(Ans:- u= 24cm)**

5. A parallel beam of light falls on a converging lens arranged so that the axis lies along the direction of the light which is brought to focus 25cm from the lens. The light then passes through a second converging lens of focal length 7.5cm placed at 30cm from the first lens. Calculate the position of the final image. **(Ans:- 15cm)**

6. An objective lens of a compound microscope forms an image of length 6 cm when an object is placed in front of it. The focal length of the objective lens and eyepiece lens are 10 cm and 4 cm respectively. If the distance separating the two lenses is 26 cm.
   (a) What is the size of the object?
   (b) At what distance from the eyepiece will a 6 cm image be formed?

Uses of a Compound Microscope

The uses of a compound microscope include the following:

(i) Magnifies microorganism such as bacteria which cannot be seen by naked eyes.
(ii) The compound microscope it is used to observe the Brownian motion in science
(iii) It is used to study the characteristics of the micro-organism and cells in biology
(iv) Used in hospitals widely to detect microorganisms in specimens provided by patients. A specimen is a small amount that is taken for testing like tissues or body fluids. Blood is an example of specimens. In hospitals microscopes can detect parasites such as plasmodium (a causative agent for malaria) in blood specimen.
(v) Check for infections caused by microorganisms.

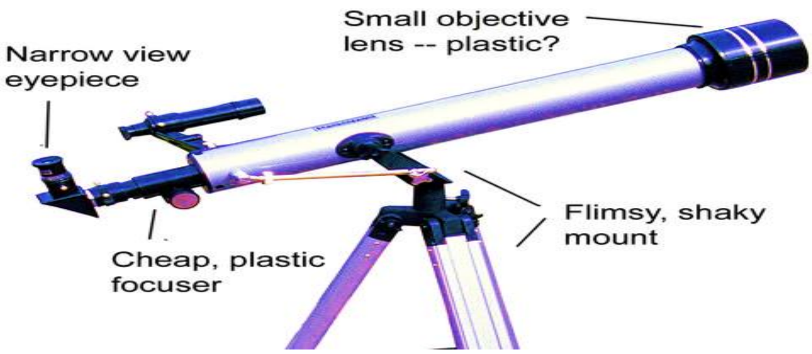
Some important terms used

• Emission	Letting light out
• Reflection	Sending back the sent waves
• Transmission	The ability to let radiation through
• Interference	Obstruction that prevents natural or desired outcome
• Dispersion	Splitting a white light into its components
• Scattering	Small amount of light being spread over a large area

Astronomical Telescope

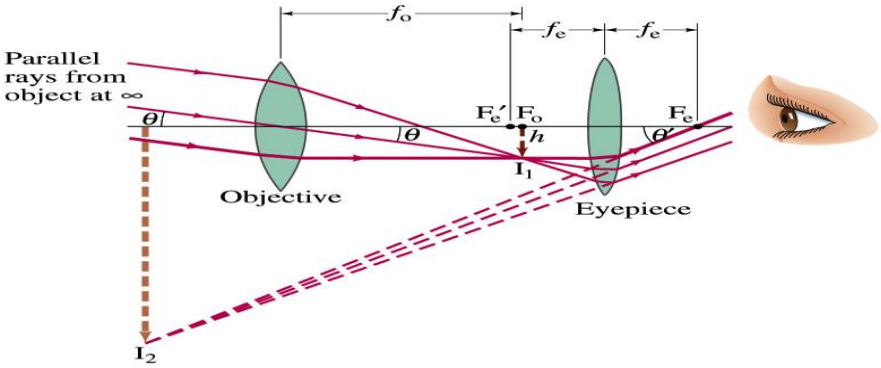
The Structure of an Astronomical Telescope

- An Astronomical Telescope is used to view heavenly bodies like stars, planets and satellites (generally bodies which are very far away from normal vision of human eyes



- Like compound microscope, it consists of two lenses, objective and the eyepiece.
  - The objective lens is of large focal length whereas the eye piece is of shorter one
  - The distance between the two lenses is adjusted by adjusting the tube length.

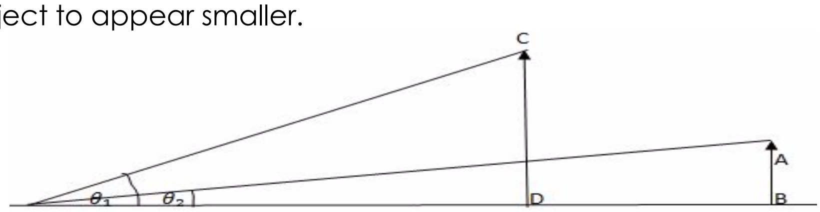
Consider the ray diagram for the working principle of the astronomical telescope below:



- The ray of light coming from a distant object from a parallel beam of light
- This parallel beam of light is focused by the objective lens in a plane passing through its focus and perpendicular to the axis and forms the image **I_1**
- The plane is known as the focal plane.
  - The objective lens forms a real image, inverted and diminished image of a distant object
- The eye piece is adjusted so that the image P^1Q^1 lies in its focal plane.
- The light beam, after striking the eye lens, emerges parallel and final magnified image **I_2** is formed at infinity
- When the telescope is adjusted in such a way that the final image is at infinity it is said to be in **normal adjustment.**
  - In this case the distance between objective lens and eyepiece is (f_o+f_e) this is the maximum separation between the objective lens and the eyepiece lens.

The Mode of Action of an Astronomical Telescope

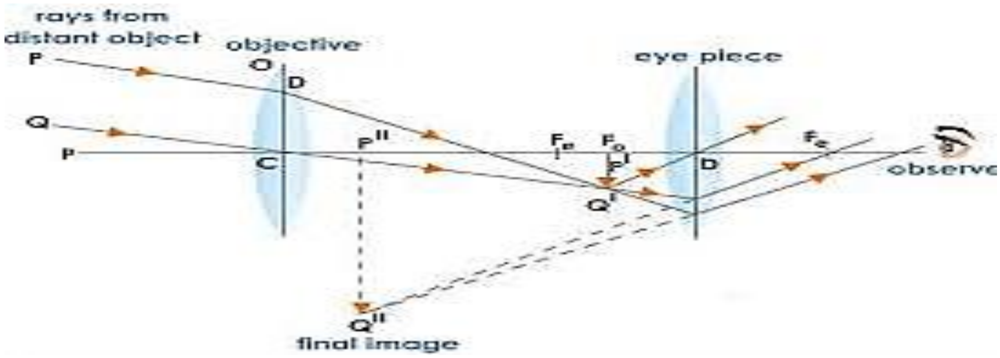
- The main reason for a distant object to be smaller is that the two objects subtend different angles at the eye.
- In other words, we can say that different angles subtended by the eye causes a distant object to appear smaller.



- The object AB and CD are of the same height.
  - The object CD is closer to the eye than AB.
  - The object CD appears to be taller than AB because angle θ_1 that CD subtends at the eye is greater than the angle θ_2 subtended by AB at the eye.
  - Images there can be made to appear large by bringing them closer to the eye.
- In a telescope the final image is magnified because it subtends a much greater angle at the eye than does a distant object observed without a telescope.

(i) The Magnification of an Astronomical Telescope

- The magnification of a telescope is defined as the ratio of the angel B (in radians) subtended by the final image at the eye to the angle X subtended by a distant object at the eye.
- Considering again this ray diagram for Astronomical Telescope:



- Let α be the angle subtended by the final image at the eye and θ is the angle subtended by a distant object.
- Thus, for telescope the magnification is given by:

$$M = \frac{\alpha}{\theta} \; angles\ in\ radians$$

$$M = \frac{P^1\hat{D}Q^1}{P^1\hat{C}Q^1}$$

$$M = \frac{\tan(P^1\hat{D}Q^1)}{\tan(P^1\hat{C}Q^1)}$$

- For small angle and in radians, $\theta = \tan\theta$

$$M = \frac{(P^1Q^1)}{(P^1D)} \div \frac{(P^1Q^1)}{(P^1C)}$$

$$M = \frac{(P^1Q^1)}{(P^1D)} \times \frac{(P^1C)}{(P^1Q^1)}$$

$M = \frac{P^1C}{P^1D}$ and then $M = \frac{P^1C}{P^1D} = \frac{f_o}{f_e}$

- From the ray diagram;
  P^1C = the focal length of the objective lens (f_o)
  P^1D = the focal length of the objective lens (f_e)
- Therefore the magnification for telescope is given by;

Point to note:

- If L is the distance of separation between the objective and eyepiece lens for normal adjustment is equal to $\mathbf{f_o + f_e}$

Differences between compound microscope and the astronomical telescope

Compound microscope	Astronomical telescope
Objective lens has a smaller focal length than the eye piece lens	Objective lens has a larger focal length than the eye piece lens
Distance between the objective lens and the eye piece is greater than $f_o + f_e$	Distance between the objective lens and the eye piece is equal to $f_o + f_e$
It is used to see very small objects	It is used to see distant astronomical objects

Example 03,
A refracting telescope has an objective lens with focal length of 5m and an eyepiece lens of focal length 0.02m. Calculate the magnifying power of such a telescope in its normal adjustment.
Solution
Given
Focal length of the objective lens, fo= 5cm,
Focal length of the eye piece lens, fe = 0.02m

$$M = \frac{f_o}{f_e}$$

$$M = \frac{5m}{0.02m}$$

Therefore the magnifying power is 250

Example 04,
A telescope is consisting of two lens of focal length 25cm and 4cm for objective lens and eyepiece lens respectively. The final image is found at distinct vision that is 25 cm in front of the eyepiece lens. Find the position of the first image from the eyepiece.
Solution

$$\frac{1}{f_e} = \frac{1}{u_e} + \frac{1}{v_e}$$

$$\frac{1}{4} = \frac{1}{u_e} + \frac{1}{25}$$

$$\frac{1}{4} - \frac{1}{25} = \frac{1}{u_e}$$

$$\frac{25-4}{100} = \frac{21}{100} = \frac{1}{u_e}$$

$$u_e = \frac{100}{21}$$

The position of the first image from the eyepiece is 4.76cm

Example 05,
An astronomer telescope has its 2 lens 78 cm apart. If the objective lens has a focal length of 75.5 cm. What is the magnification produced by the telescope under normal vision?
Solution

L= fo + fe
78 = 75.5 + fe
Fe = 2.5cm

$$M = \frac{f_o}{f_e}$$

$$M = \frac{75.5}{2.5} = 30.2$$

$$M = 30.2$$

:. The magnification is 30.2

Example 06,
The focal length of two thin converging lenses of focal lengths 25cm and 4cm respectively. It is focused on the moon which subtends an angle of 0.6° at the objective lens. The final image is formed at the observers least distance of distinct vision (25cm in front of the eyepiece). Find the diameter of this image.

- Where θ is the angle in radians subtended at the objective lens by the moon. From

$$\frac{2\pi r}{360^o} = \frac{l}{\theta^o}$$

Then

$$l = \frac{2\pi r\theta^o}{360^o}$$

Dividing by r both end

$$\frac{l}{r} = \frac{2\pi\theta^o}{360^o}\ and\ \frac{l}{r} = Radians$$

Since

$$Radians = \frac{\pi\theta^o}{180^o}$$

- In the previous figure:

$$\theta = \frac{h}{f_o}$$

Where fo is the focal length of the objective lens and θ is the angle in radians

$$\theta = \frac{h}{25}$$

H = 25 θ

$$H = 25\left(\frac{6}{10}x\frac{\pi}{180}\right)$$

$$H = 25\left(\frac{6}{10}x\ \frac{22}{7}x\frac{1}{180}\right)$$

The height of the image, h = 0.2619m

- The distance of this image from the eyepiece is obtained from the relation:

$$\frac{1}{f_e} = \frac{1}{u} + \frac{1}{v}$$

V= -25cm fe = 4cm

$$u = \frac{fv}{f+v} = \frac{4\ x\ 25}{4+25} = \frac{100}{29}$$

- The magnification, m of the lens:

$$M = \frac{v}{u}$$

$$M = 25 \div \frac{100}{29}$$

$$M = \frac{29}{4}$$

- Let the height of the final image of the moon be h:

$$M = \frac{H_i}{H_o}$$

$$Hi = MxH_o$$

$$Hi = \frac{29}{4}\ x\ 0.2619$$

Hi = 1.90cm

Hence the diameter of the final image of the moon will be 1.90cm

Notes:

- Observations of the universe today are best made from the Hubble Telescope.
- Outside the Earth's atmosphere, these telescopes suffer from less interference.

(ii) Uses of an Astronomical Telescope:

Astronomers use telescopes because they're much better than our eyes. Here are a few reasons:

1. Telescopes see lots of colours:-
   - ❖ Telescopes can collect light into a fine Colored object.
2. Telescopes collect lots of light
   - ❖ Our pupils we can only collect photons over a tiny area whereas telescopes can collect photons of huge areas
3. See fine details
   - ❖ Telescopes see fine details because of the wave nature of light and the nerves in our eyes; we can only see details about the same angular size as Jupiter's width. Telescopes can allow us to resolve fine details - like Jupiter's Great Red Spot.
4. Telescopes can record observations with cameras
   - ❖ You can see things with your eye and draw them, but telescopes can share observations with the world! This is especially important for convincing skeptics that what you saw was real!

Check Your Understanding

A telescope is made of two thin converging lenses of focal lengths 18cm and 6.25cm for objective and eyepiece respectively. It is focused on the moon, which subtends an angle 0.7° at the objective lens. If the final image is formed at the observers distinct vision (i.e. 25cm in front of the eyepiece), find the diameter of the image.

Projection Lantern

Projection lanterns are used to display a large image on a screen. One Example is the slide projector that is the optical inverse of a camera.

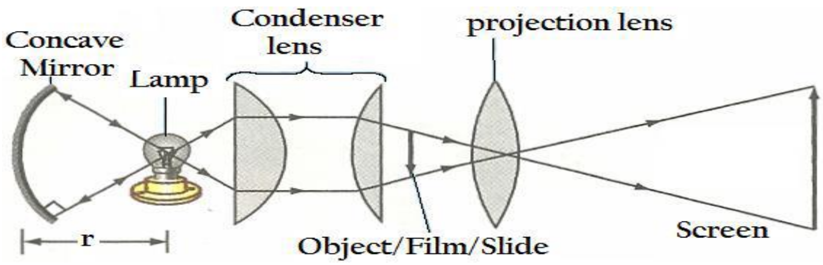
Mode of Action

An incandescent bulb positioned at the centre of curvature of a concave mirror. A concave mirror reflects light travelling away the condenser lens. In order to focus the light into a convergent beam

The beam falls on the slide or the photographic transparency (positioned between f and 2f) and proceeds through the image-forming projection lens.

The image formed on a distant screen. The image is focused on the screen by adjusting the projection lens in or out to changes the distance of the lens from the slide.

Diagram:



Magnification

$$\text{Given by:} - M = \frac{v}{u} = \frac{Hi}{Ho}$$

Uses of a projector

(i) Projection of films, slides and transparencies.
(ii) Projection of opaque objects, i.e. episcopic projection.
(iii) In searchlights and headlights.
(iv) In projection apparatus in industry for gauge and screw thread testing.
(v) In experiments such as projection of the spectrum, polarisation and interference.
(vi) Projection of minute objects, i.e. the projection microscope.

Example 06,

A projection lantern is used to project a slide measuring 3 cm x 3 cm onto a screen 12 m from the projection lens. If the size of the screen is 1.5 m x 1.5 m, how far from the lens must the slide be for the image to fill the entire screen?

Data given:

Image height, Hi = 1.5 m = 150 cm
Object height, Ho = 3 cm
Image distance, v = 12 m = 1200 cm
Object distance, u =?

Solution

$$M = \frac{v}{u} \text{ and also } M = \frac{H_i}{H_o}$$

$$\text{then,} \quad \frac{v}{u} = \frac{H_i}{H_o}$$

$$\text{Making } u \text{ the subject,} \quad u = v\, x \frac{H_o}{H_i}$$

$$u = 1200\, x \frac{3}{150} = 24cm$$

The slide must be at 24cm from the lens

Check Your Understanding

1. A lantern projector using a slide of 2cm x 2 cm projects a picture 1m x 1m onto a screen 12m from the projection lens.
   (a) How far from the lens must the slide be? (Ans:- u = 24cm)
   (b) Find the approximate focal length of the projection lens (Ans:- f = 23.5 cm)

The Lens Camera

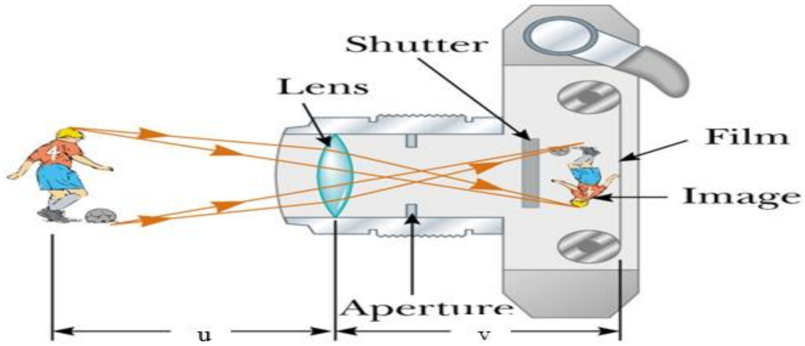
The Structure of the Lens Camera

Lens camera is an instrument which produces an image of object on the film using light. The basic physical principle of all cameras is the same in spite of the variation in the design of cameras.

The optical systems of the camera are very similar to that of the lantern projector but with the direction of light reversed.

- Lens camera consists of a
  (i) Light tight box
  (ii) A converging lens – that produces a real image at one end of the box
  (iii) A light sensitive film – where images is formed
  (iv) Focusing device - for adjusting the distance of the lens from the film
  (v) An exposure arrangement which provides the correct exposure
- The converging lens forms a real image of the object to be photographed.
  a) This image is diminished (smaller than the object and)
  b) This image is inverted
  c) This image is a real
  d) It is formed on the film
- The lens can be moved back and forward with the help of focusing any so that objects at different distances can be brought to the focus.
- An image is located on the film or plate when the shutter is open for a suitable amount of time as determined by the shutter speed.
- Light enters the camera Box and makes a picture of the object on the film "(The film is sensitive to light)

- The camera is equipped with a diaphragm or light entering the camera. It ensures that is incident centrally on the lens so that the distortion of the image formed is reduced



The Mode of Action of the Lens Camera

- The object is placed in such a way that a real inverted image of the object is formed on the film. The amount of light entering the film region can be adjusted by adjusting the aperture of the lens. The light tight box is painted black in the inside to avoid unnecessary reflection inside. A shutter is placed between the lens and the film. When a photograph is taken the shutter opens and closes quickly, thereby exposing the film to light for a short time to light entering the camera.
- The light sensitive photographic film is coated with a chemical emulsion of silver hydrogen compound which is very sensitive to light. A sharp image of the object is focused on the film by adjusting the distance of the lens from the film. There is a focusing ring which turns over a scale engraved on the lens. By means of this ring, the distance between the lens and the film can be adjusted by moving the lens forwards and backwards.
- Brightness of the image focused on the film depends on the focal length and the diameter of the lens. The amount of light that reaches the film increases as the size of the lens increases i.e. as the lens diameter increases, the brightness of the image formed on the film increases.

The Magnification of the Lens Camera

- Magnification of a lens camera is obtained as the ratio of the Image distance (v) and the object distance (u). Or
- Magnification of a lens camera is obtained as the ratio of the Image height and the object height

From the lens formula:

$$m = \frac{v}{u}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{u}{u} + \frac{u}{v} = \frac{u}{f} \; multiplying \; u \; each \; term$$

$$1 + m^{-1} = \frac{u}{f}$$

$$m^{-1} = \frac{u}{f} - 1$$

$$m^{-1} = \frac{u - f}{f}$$

$$\mathbf{m} = \frac{\mathbf{f}}{(\mathbf{u} - \mathbf{f})}$$

Example 07,

A lens camera is to be used to take a picture of a man 2m tall if the lens of the camera has a focal length of 10cm, calculate the minimum size of the film frame required, given that the man is 20.1m from the camera.

Solution:

- Magnification is given by:

$$m = \frac{f}{(u - f)}$$

Where;

F= 10cm, U = 20.1m = 2010cm

$$m = \frac{10}{(2010 - 10)} = \frac{1}{200}$$

- Let the size of the frame be h when the height of man is 2m.

$$\text{Then; } m = \frac{1}{200}$$

$$\text{But; } \frac{H_i}{H_o} = \frac{1}{200}$$

$$\text{Then; } H_i = \frac{1}{200} x\ 2 = \frac{1}{100} m$$

Hi = 0.01 m, 1cm or 10mm

- The film frame should be at least 10mm square.

Uses of Lens Camera

(i) The sine or video camera is used to take motion pictures.

(ii) High-speed cameras used to record movement of particles.

(iii) Closed-circuit television cameras used for surveillance in high-security

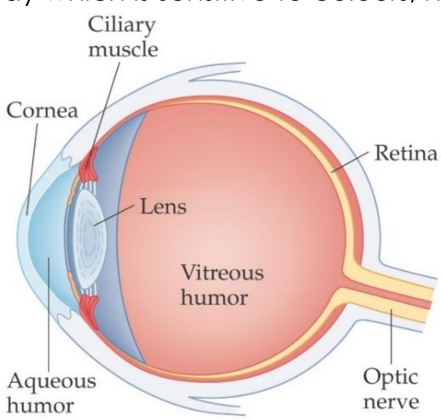
(iv) Digital cameras used to capture images

Class work,

1. A lens camera of focal length 10 cm is used to take the picture of a girl 1.5 m tall. Determine the magnification of the image if the girl is 10.1m from the camera.
2. A lens camera of focal length 15cm is used to take a picture of a man of height 1.7m. If the man is standing 8m ahead of the camera. Determine the:
   (a) Magnification of the image
   (b) Size of the image

Structure of the human eye

The eye is the organ of the body which is sensitive to colours, hence used in seeing.



(i) **Cornea**
The cornea is the transparent, outer part of the eye. It is the primary focusing tool of the eye. Function of cornea is to protect the eye

(ii) **Iris**
This is the part of the eye which is responsible for one's eye colour and regulates light. The Iris normally widens and squeezes the pupil to allow more/less light into the eye.

(iii) **Pupil**
The pupil is the dark opening in the centre of the coloured iris that controls the amount of light that enters the eye. The pupil functions in the same way as the aperture of a camera. The size of the pupil determines the amount of light entering the eye.

(iv) **Lens**
The lens is the part of the eye immediately behind the iris.
Function of lens is to focus light rays on the retina.

(v) **Retina**
The retina is the membrane lining the back of the eye that contains photoreceptor cells it reacts to the presence and intensity of light by sending an impulse to the brain via the optic nerve. The retina compares to the film in a lens camera.

(vi) **Optic nerve**
This is the, (million nerve fibres) structure which takes the information to the brain

(vii) **Sclera**
The sclera is the white, tough wall of the eye. This protects the eye.

(viii) **Vitreous humour**
The vitreous humour is a jelly-like substance that fills the body of the eye of refractive index 1.34. It is used to prevent the eye from collapsing due to change in atmospheric pressure.

(ix) **The aqueous humour**
The aqueous humour is the salt solution of refractive index n, 1.38. When we blink our eyes, a tiny drop washes the eye and keeps the cornea moist in order to avoid opaque

Working of the eye

- ❖ Light coming from an object enters the eye through the cornea and the pupil of the human eye and is focused by the lens on the retina. The eye lens converges these light rays to form a real, inverted and diminished image on the retina.
- ❖ The ciliary muscles change the shape of the lens, so it can focus at different distances. The vitreous and aqueous humors are transparent. Rods and cones on the retina convert the light into electrical impulses, which travel down the optic nerve to the brain and brain interprets the electrical signal in such a way that we see an image which is erect and of the same size as object.

Accommodation Power of the Human Eye

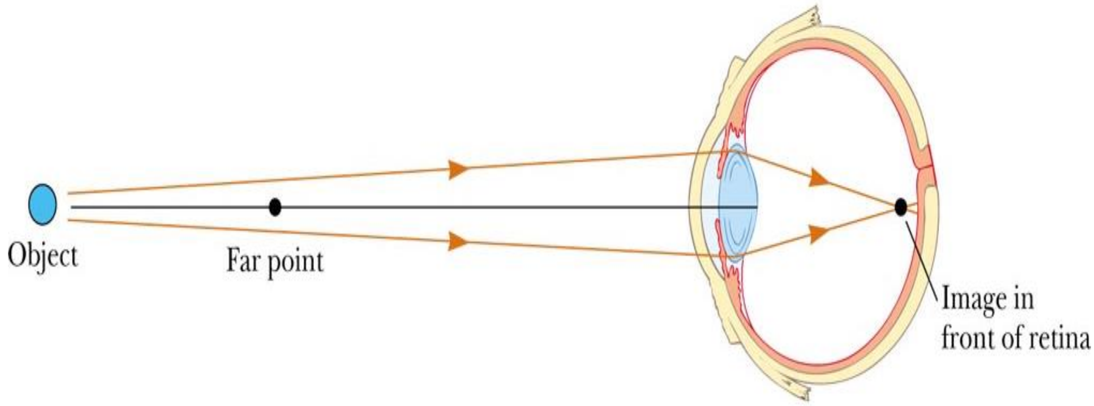
- Accommodation is the process whereby the eye alters its focal length of an eye lens by means of ciliary muscles in order to form images of objects at different distances.
  - ❖ Thickening or Thinning of the lens causes a change in its focal length.
  - ❖ To view near object, ciliary muscles contract, this makes the lens thicker.
  - ❖ In the relaxed state of ciliary muscles, the crystalline lens become thinner and enables the eye to see (view) distant objects.
  - ❖ The farthest point which can be seen clearly is called <u>the far point of the eye</u> and the nearest point is called <u>the near point of the eye</u>.
  - ❖ The corresponding distance from these points to the eye are referred to as the maximum and least distance of district vision respectively.
  - ❖ The distance between the near point and the far point is called range of vision
  - ❖ A normal eye (i.e. without defects of vision) has a far point at infinity and near point at a distance of 25cm from the eye.

The Defects of the Human Eye

- A normal eye can see all objects over a wide range of distances (25cm to infinity). Due to certain abnormalities, the eye is not able to see over such a wide range of distances. Such eye is said to be defective
- Such defective includes:
  a) Short-sightedness (myopia)
  b) Long-sightedness (hypermetropia)
  c) Astigmatism
  d) Presbyopia

(a) <u>Myopia or near-sightedness or Short-sightedness:</u>

- This defect causes person to see near object clearly while distant objects are not seen clearly. i.e. are seen as blurred images
  - Images of distant object are formed in front of the retina even when eye is totally relaxed. However, an object that is closer can be brought into focus



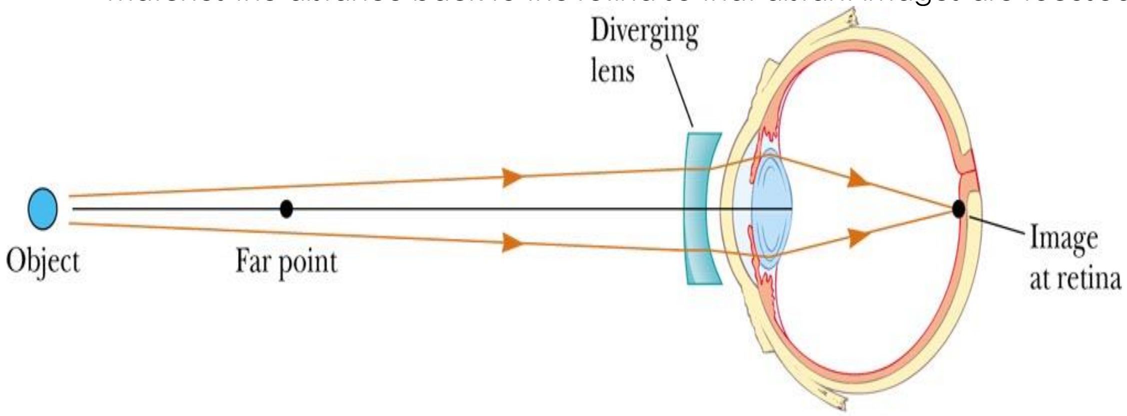
- In this situation the focal length of the cornea and the eye lens is so short that objects closer than the conventional (near point of 25cm) can be brought into focus. That's why this condition is called Short sightedness (near sightedness).

Causes of myopia:

- When the eye ball is too long
- When excessive curvature of the cornea, or
- When the refractive power of the lens is too strong

Correction of myopia:

- The solution is to provide eye glasses (or contract lenses) with negative lens or concave lens to help focus the image on the retina.
  - The negative lens weakens the strength of the cornea and eye – lens just enough so that the resulting focal length when the eye muscles are relaxed matches the distance back to the retina so that distant images are focused.



- The far point is the farthest distance for which the lens will produce a sharp image of a faraway object on the retina.
  - Objects located beyond the far point will be out of focus.

Example
The far point of a myopic person is 40 cm. What should be the power of the lens that he must use to see clearly?
Solution:-
Given: f = 40 cm = 0.4 m, Power =?

$$P = \frac{1}{focal\ length}$$

$$P = \frac{1}{0.4}$$

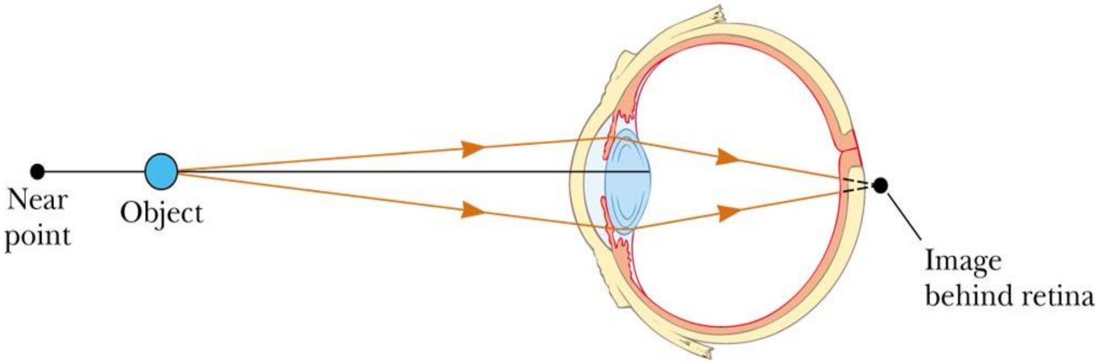
The power is 2.5

(b) **Hypermetropia or Hyperopia or far-sightedness**

- This defect causes a person to see distant objects only and short-distance objects are not seen clearly.
- The person with this condition, the strength of the cornea and the eye-lens combination is too weak when the eye muscles are totally relaxed. So the image of a distant object is formed behind the retina.

Causes of Hyperopia or far-sightedness:

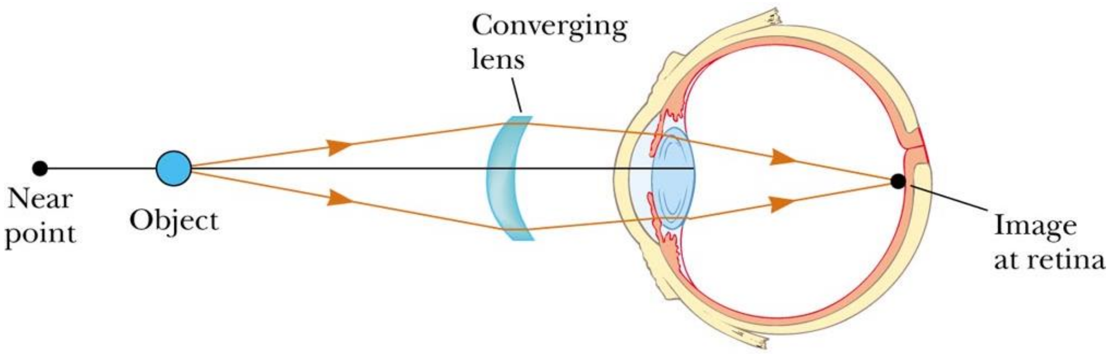
- When the eye ball is too short
- When the cilliary muscles are weak , thus are unable to change the shape of the eye lens appropriately to focus the image
- I.e. When the refractive power of the lens is too weak



- The near point is the closest distance for which the lens will produce a sharp image of a nearby object on the retina.
  - About 18 cm at age 10
  - About 25 cm at age 20
  - About 50 cm at age 40
  - 500 cm or greater at age 60

Correction of Hyperopia or far-sightedness:

- The solution is the opposite of myopia.
  - Victims should wear positive eye lenses which strengthen the cornea and the eye lens just enough so that the resulting focal length when the eye is relaxed matches the distance to the back of the retina.



(c) **Astigmatism**

- This occurs because of unequal curving of one or more of the refracting surfaces of the eye, usually the cornea. It prevents light rays lying in specific planes from coming to a focus on the retina, thus producing blurred vision.
- The eye cannot bring the vertical and horizontal lines in a '+' symbol in sharp focus at the same time.
- The problem is that the cornea of the eye lens is not symmetrical.

Causes of Astigmatism

- Normally the cornea is spherical in shape, but in Astigmatic eye the cornea is shaped more like an oblong rugby ball. The oblong shape causes light to focus on two points rather than just one point.

Correction of Astigmatism

- Astigmatism can be corrected by use of cylindrical lenses
- The solution is to use eye glasses whose lenses are not symmetrical in a complementary way.
- The cylindrical lens may be joint with additional positive or negative lenses.

(d) Cataracts:

- A cataract is a clouding of the lens, which prevents a clear, sharp image being produced
- A cataract forms because the lens is sealed in a capsule and as old cells die they get trapped in the capsule, with time this causes a clouding over of the lens making it partially or totally opaque. This clouding results in blurred images
- Cataracts usually progress slowly to cause vision loss and are potentially blinding if untreated

(e) Presbyopia

- This condition typically occurs in middle-aged people.
- The eye muscles gradually weaken with age, so that the range or accommodation is decreased.
- People with this condition cannot bring both near objects and far objects into focus due to age related causes of loss of elasticity of the lens.
- The weakening of the eye muscles often causes the focal length of the eye lens to increase as well so that many people of middle age tend to become far sighted.
- Since the problem is adequate accommodation, no single lens can correct it and people with this problem usual needs bifocals.
- Bifocals are glasses with two different lens strengths, one for near and one for distant objects.
- The usual arrangement is that the bottom half of the lens is the near strength and the top half is the far strength.

SIMILARITIES BETWEEN THE HUMAN EYE AND THE LENS-CAMERA

1. Both human eye and lens-camera have convex lenses which form diminished, real and inverted images
2. Both human eye and the lens-camera are blackened inside in order to prevent total internal reflection. Rays of light which are not received on the retina or camera film are absorbed by the choroid layer of the eye or the black surface inside the camera.
3. In the human eye the pupil controls the amount of light whole in lens camera a diaphragm controls the amount of light.
4. In the human eye the image is formed on the retina while in lens on the lens-camera the image is formed on the photographic film.
5. The human eye can adjust the focal length of its lens by contraction and relaxation of ciliary muscles in order to focus different objects at different distances, in lens-camera the objects can be focused by moving the lens forwards and backwards.

DIFFERENCES BETWEEN THE EYE AND LENS-CAMERA

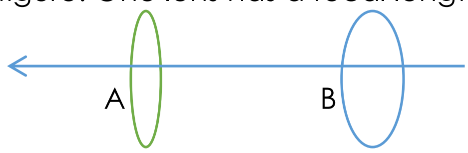
1. The human eye can alter its focal length by using ciliary muscles while the focal length of a lens-camera is fixed.
2. The eye has a fluid inside which assists for refraction while a camera has air inside
3. Light is refracted by the cornea, lens and fluid in the eye but it is refracted by the lens only in the lens-camera
4. The image formed on the film is processed chemically to produce the final image while the image in camera formed is converted to an electrical signal travels along the optic nerve
5. Eye remain open to constant changing pictures with continuous motion while shutter open to allow photo to be taken
6. When focusing, the lens in the human eye changes shape while in camera the lens moves forward and backwards with its shape being constant

Check Your Understanding

1. A convex lens of a focal length 5cm produces an erect image which is five times the size of the object. Find the distance of the object from the lens.
2. A camera with a lens of focal length 50mm is used to take a photograph of a man 1.7m tall. The man is 5.0m from the camera. What is the approximate height of the image on the film?
3. A close up of a document 15cm by 15cm is taken with a camera with a 40mm focal length lens. The document is 24cm from the lens. Find the distance of the film from the lens and the dimensions of the image.
4. An astronomical telescope used in in normal adjustment has an objective lens of focal length 60cm and an eye piece lens of focal length 5.0cm. what is the
   (i) Distance between the lenses
   (ii) The magnifying power.
5. A convex lens is used to project an image of light source on to a screen. The screen is 30cm from the light source, and the image formed is twice the size of the object.
   (i) What focal length lens is required?
   (ii) And how far from the source must it be placed?
6. The distance between the film and the lens camera is 6.25cm when it is focused on an object 1.5m from the lens. How far must the lens be moved, and in what direction in order to focus the camera on the distant object?
7. A telescope of 5m diameter reflector of focal length 18m is used to focus the image of the sun. using the distance of the sun from the Earth and diameter of the sun as 1.5×10^{11}m and 1.4×10^{9}m respectively, calculate the
   (i) Position of the image of the sun (Ans:- 18cm)
   (ii) Diameter of the image of the sun (Ans:- 16.8cm)
8. A projection lantern is used to give the image of a slide on a screen. If the image is 24m from the projecting lens, what is the position of the slide from the lens? (Ans:- The slide is 3m from the lens)
9. The near point of a longsighted patient is 90 cm.
   (a) Determine the focal length of a lens that can be used to enable the patient clearly see objects that are 25 cm from the eye
   (b) What is the power of the lens
   (c) What is the magnification of the lens?
10. A short sighted person is unable to clearly see objects that are beyond 150 cm from the eye. Determine
    (a) the focal length
    (b) power and
    (c) magnification of the lens that should be used to detect the eye defect

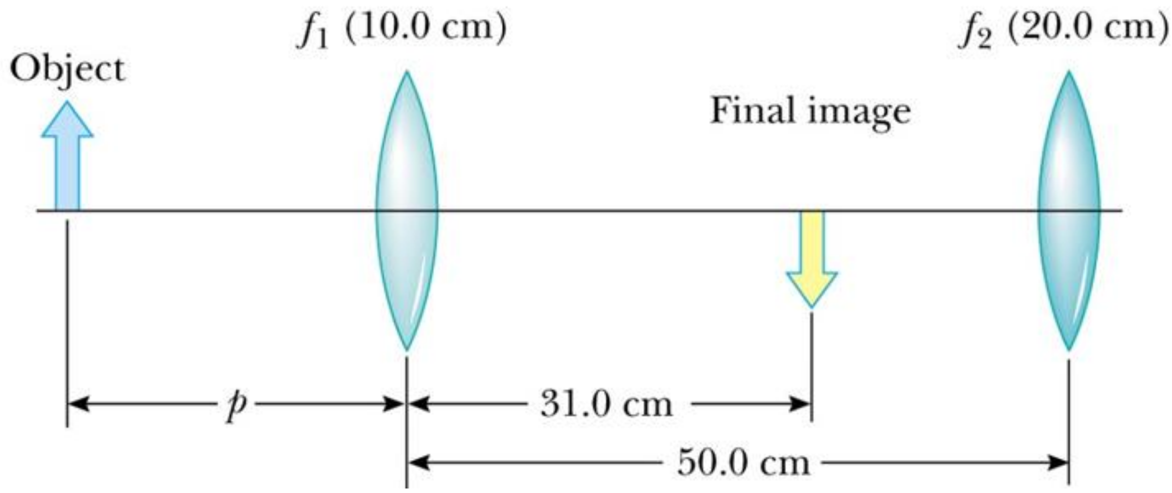
11. A patient requires a lens of -5 diopters in order to see far away objects clearly. Determine the
    (a) Focal length of the lens used
    (b) Far point of the patient 's eye
12. The near point of an eye is 50 cm
    (a) What focal length lens should be used so that the eye can clearly see an object 25 cm away? (ANS: f = 50 cm)
    (b) What is the power of this lens? (ANS: 2 diopters)
13. A farsighted man has a near point of 100 cm .Wearing his glasses; he can see objects that are 25 cm away .What is the focal length of the lens in his glasses?
14. A man whose least distance of distinct vision of 75 cm wants spectacles to allow him to read a book held at a distance of 25 cm from his eyes. Find the focal length of the lens he needs .Discuss briefly whether a short – sighted person can use a telescope without wearing any spectacles
15. Draw a clearly labeled diagram of a lens camera and explain briefly how the image of an object is focused on the film .A camera with a lens of focal length 15 cm is used to take a photograph of a man standing 4.5 m from the lens .Find the length of the image formed if the man is 1.75 m tall
16. In a compound microscope, the focal length of the objective lens is 4.0 cm and that of the eyepiece is 3.3 cm and they are placed at a distance of 15.0 cm. A real object of size 2 mm is placed 6 cm from the objective lens. By using the lens formula , Calculate
    (a) Position of the final image (Ans: 12 cm)
    (b) The size of the final image viewed by the eye (Ans:- = 33 cm)
    (c) Magnification produced by the arrangement of the lenses (Ans: 44 mm)
17. A compound microscope has an objective lens of focal length 2cm and eye piece of focal length 6cm. an object is placed 2.4cm from the objective lens. If the distance between the objective lens and the eyepiece lens is 17cm find:-
    (a) The distance of the final image from the eyepiece
    (b) The linear magnification
18. You are taking a picture of yourself with a camera that uses an ultrasonic range finder to measure the distance to the object. When you take a picture of yourself in a mirror with this camera, your image is out of focus. Why?
19. A and B below are two convex lenses correctly set up as a telescope to view a distant object as shown by the figure. One lens has a focal length of 5cm and the other of 100cm

    To distant object



    (i) What is A called and what is its focal length?
    (ii) How far from A is the first image of the distant object?
    (iii) What is the name of B?
    (iv) What acts as an object for B and how far B must be from it if someone looking through the telescope is to see the final image at the same distance as the distant object?
    (v) What is the distance between A and B with the telescope set up in [iv]?
20. Lenses used in sunglasses whether converging or diverging, are always designed such that the middle of the lens curves away from the eye. Why?
21. Why does a focal length of a mirror not depend on the mirror material when the focal length of a lens depends on the lens material?

22. Two converging lenses having focal lengths of 10.0 cm and 20.0 cm are placed 50.0 cm apart, as shown in Figure. The final image is to be located between the lenses, at the position indicated. (a) How far to the left of the first lens should the object be positioned? (b) What is the overall magnification? (c) Is the final image upright or inverted?



23. A plastic sandwich bag filled with water can act as a crude converging lens in air. If the bag is filled with air and placed under water, is the effective lens
    (a) Converging or
    (b) Diverging?

07. THERMAL EXPANSION OF SOLIDS

Definition:- *Thermal expansion is the tendency of matter to increase in dimensions due to rise in temperature*.

Why substances expand when heated?

- Substances expand when heated because its particles vibrate more rapidly. As a result, they collide and push each other further apart which is seen as an increase in dimension.

Expansion may cause the occurrence of the following observations:-

(a) The bridge or roof is fixed while the other side rests on rollers so that movements of the bridge or roof are allowed for during expansion and contraction
(b) Rail lines are laid in such a way that a gap is left at the junction of two rail bars
(c) Bottle containing cold liquid cracks if placed near a strong fire
(d) Thick walled glass tumblers break easily when hot liquids are poured into them

Terminologies

Thermal energy	This is the energy possessed by a body due to its temperature also called the heat content of the body. Increase in temperature also thermal energy increase
Heat	This is a form of energy transferred from one body to another due to difference in temperature. Transferred until reach thermal equilibrium.
Thermal equilibrium	This is the situation whereby the temperature of two or more body are equal
Temperature	This is the degree of coldness or hotness of a body.
Expansion	This is the process whereby object increase in its dimensions due to increase in temperature
Contraction	This is the process whereby object decrease in its dimensions due to increase in temperature

The differences between Heat and Temperature

	Heat	**Temperature**
Definition	Heat is energy that is transferred from one body to another as the result of a difference in temperature.	Temperature is a measure of hotness or coldness expressed in terms of any of several arbitrary scales like Celsius and Fahrenheit.
Symbol	Q	T
Unit	Joules	Kelvin, Celsius or Fahrenheit
SI unit	Joule	Kelvin
Particles	Heat is a measure of how many atoms there are in a substance multiplied by how much energy each atom possesses.	Temperature is related to how fast the atoms within a substance are moving. The 'temperature' of an object is like the water level – it determines the direction in which 'heat' will flow.
Ability to do work	Heat has the ability to do work.	Temperature can only be used to measure the degree of heat

Sources of Thermal Energy

The sources of thermal energy include;
(i) The sun
(ii) Combustion of fuels
(iii) Nuclear reactions and
(iv) Geothermal energy

DEMONSTRATION OF EXPANSION OF SOLIDS

In order to demonstrate the expansion of solid we can use following method

- The ball and Ring Experiment
- The Bar and Gap Experiment

(i) <u>The ball and Ring Experiment</u>

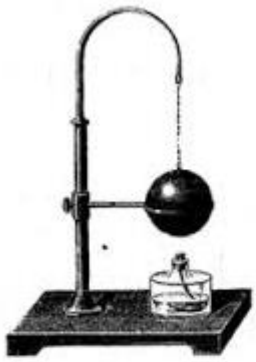
1st Case:

- When the ball is not heated then it will pass through the ring very easily because it has a small volume.

before heating

2nd Case:

- When the ball is heated, it will expand and increase in volume, so it will not pass through the ring.



heating

after heating

Expansion of Solids in terms of Kinetic Theory of Matter

- All matters are made of small particles that are in state of random motion.
- The relative increase in the size of solids when heated is therefore small.
- Hence when a solid metal is heated tends to expand due to that random motion of such particles.

Conclusion:

- A metal ball just slips through a metal ring before heating. This shows that diameter of the metal ball is slightly smaller than that of a metal ring.
- After heating the metal ball it does not slip through the metal ring. This shows that the diameter of the metal ball increases when heated.

Why Substance Expand?

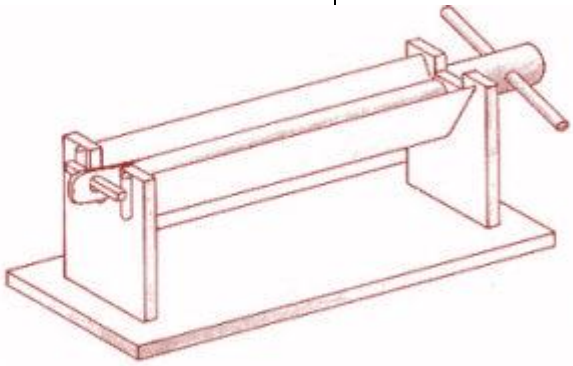
When a substance is heated the kinetic energy of the particles is increased , its particles move around more vigorously and tend to move away or separate farther from each other thus why the volume of substance increase and vice versa. All states of matter (solids, liquids and gases) expand when heated.

(ii) <u>The Bar and Gap experiment</u>

1stCase:
- When the Bar not heated (Not raised with temperature) then the dimension will remain constant.

2nd Case:
- When the Bar is heated (raised with temperature) then the dimension of the Bar will increase and eventually will not pass thought the Gap.

Forces due to expansion
- Normally Expansion and contraction is accompanied by tremendous forces.
- The presence of force indicates the expansion and contraction is Resisted.



Bar breaker
- Consists of a strong metal blocker with a pair of vertical jaws and a strong metal Bar.
- The metal bar has a wing nut at one end and an eye at the other end.
- The bar is placed between the two pair of Jaws
- A short cast iron is inserted in the eye of the bar.
- The bar is then heated it expands and the wing not screwed to tighten the bar against the jaws.
- The bar is then allowed to cool as it cools, it contracts the short cast Iron rod which presses against the jaws of the bar breaker, Resists the contraction of the Metal bar.
- The resistance to the contraction of the bar sets up very large forces which breaks the short cast Iron rod in the eye of metal bar, because the contracting bar is trying to pull itself through the small gap in the frame.

Thermal Expansion of Solids

The expansion of solid substance is so small that it is difficult to observe its changes

Linear Expansivity/Coefficient of Linear Expansion

Linear expansivity is the fractional increase in length per unit rise in temperature.
The SI unit for linear expansivity is K^{-1}
The magnitude of the thermal expansion of the solid depend on
(i) Length of the original sample
(ii) Rise in temperature and
(iii) The nature of the material heated

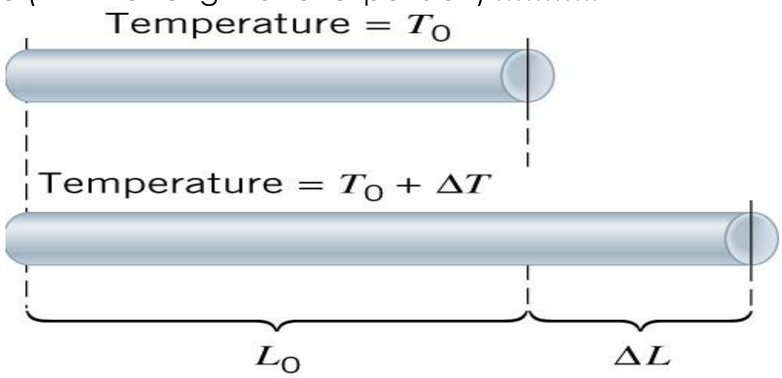
Mathematically:

$$\text{Linear expansivity } \alpha = \frac{Increase\ in\ length\ \Delta l}{Original\ length, Lo\ x\ Rise\ in\ temperature\ \theta}$$

$$\alpha = \frac{\Delta l}{Lo\ x\ \Delta\,\theta}$$

Making ΔL the subject, makes $\Delta L = \alpha Lo\Delta\,\theta$ …………………1

Since $\Delta L = L - Lo$ (L = Final length after expansion) ……….. 2



Then,

$L = Lo + \Delta L$ ………………………………………………………….. 3

$L = Lo + \alpha Lo \Delta\theta$

$L = Lo (1 + \Delta\theta)$

Where:

α = Linear expansivity

θ_1 = initial temperature, θ_2 = final temperature

$\Delta\theta = (\theta_2 - \theta_1)$ = rise in temperature,

$\Delta l = (L - Lo)$ = increase in length

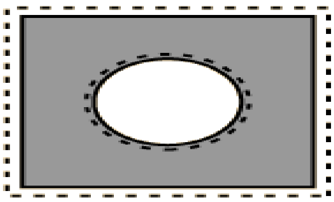
Lo = original length

L = new length after expansion

2. AREA EXPANSION

Over small temperature ranges, the thermal expansion is described by the coefficient of linear expansion. If the linear expansion is put in the form

$L = L_0[1 + \alpha\Delta T]$ then $A = L^2 = L_0^2[1 + 2\alpha\Delta T + \alpha^2\Delta T^2]$



In most cases the quadratic term above can be neglected since the typical expansion coefficient is on the order of parts per million per degree C, then $\alpha^2 \approx 0$. The expression finally becomes

$$A = A_0[1 + 2\alpha\Delta T]$$

This is equivalent to the expression at left.

3. VOLUME EXPANSION

Over small temperature ranges, the thermal expansion is described by the coefficient of linear expansion. If the linear expansion is put in the form

$$L = L_0[1 + \alpha\Delta T]$$

Then the expanded volume has the form

$$V = L_0^3(1 + 3\alpha\Delta T + 3\alpha^2\Delta T^2 + \alpha^3\Delta T^3)$$

In most cases the quadratic and cubic terms for linear expansion coefficients above can be neglected since the typical expansion coefficient is on the order of parts per million per degree C. then α^2 and $\alpha^3 \approx 0$. The expression then becomes:-

$$V = V_0(1 + 3\alpha\Delta T)$$

Also take note that, 3α is the value for volume expansivity γ ending into

$$\mathbf{V = Vo (1 + \gamma\Delta\emptyset)}$$

Linear Expansivity of different substances at a temperature between (0 – 100)°C

Substance	Linear expansivity (K^{-1}) x 10^{-4}
Aluminium	25.5
Brass	18.9
Copper	16.7
Iron	10.2
Steel	10.5
Glass	8.5
Pyrex glass	3.0
Invar	0.9

Worked Examples,

1. Copper rod has a length of 40cm on a day when the temperature of the room is 22.3^{0}C. What will its length become on a day when the temperature of the room is 30°C? Take the linear expansivity of copper 0.000017 $^0C^{-1}$

   Solution

   L_0 = 40cm
   θ_0 = 22.3°C
   θ_1 = 30°C
   L_1 =?

   $$\propto = \frac{L_1 - L_0}{L_0\ (\emptyset_1 - \emptyset_0}$$

   $$0.000017 = \frac{L_1 - 40}{40\ (30 - 22.3)}$$

   L_1 = 40.005236cm

2. A block of a certain metal 15.0 m long expands to 15.005 m when heated from 5°C to 85°C. Determine the linear expansivity of that metal.

   Data given

   Initial temperature, θ_1 = 5°C
   Final temperature, θ_2 = 85°C
   Temperature rise, $\Delta\theta$ = (85 – 5)°C = 80°C
   Original length, L_1 = 15.0 m
   New length, L_2 = 15.005 m
   Increase in length, (15.005 – 15.005) = 0.005 m
   Linear expansivity, a = ?

   Solution

   From:

   $$\alpha = \frac{\Delta l}{Lo\ x\ \Delta\theta}$$

   $$\alpha = \frac{0.005}{15.0\ x\ 80}$$

   α = **4.167 x 10^{-6} K^{-1}**

3. A part of a steel tape used by a surveyor is 9m at 25^{0}C. What is the overall length measured using this tape sixty seven times on a warm day corresponding to 38°C if the linear expansivity of steel is 1.1x10^{-5} per degree.

   Solution

   Given that,
   Original length, Lo = 9m
   Original temperature, Q_0 = 25°C
   Final length, L = ?

Final temperature, Q_1 = 38°C
Change in length $\Delta\theta = \emptyset_1 - \emptyset_0$

$$Linera\ Expansivity\ of\ steel, \propto = \frac{L - L_0}{L_0\ (\emptyset_1 - \emptyset_0)}$$

L = Lo (1 + $\alpha\Delta\theta$)
= 9 (1 + 1.1 x10^{-5} x 13)
= 9.001287
Overall length = 9.001287 x 67
The overall length = 603.086229m

4. A brick (30 cm x 18 cm x 10 cm) at 20°C, If the brick heated to a temperature of 150°C, what will be its new dimensions? (The coefficient of linear expansion of concrete is 1.2 x 10^{-5} K^{-1}
   Data given
   Initial temperature, θ_1 = 20°C and Final temperature, θ_2 = 150°C
   Rise in temperature, $\Delta\theta$ = ($\theta_2 - \theta_1$) = (150 – 20)°C = 130°C
   Linear expansivity, a = 1.2 x 10^{-5} K^{-1}
   Original length, L_l = 30 cm
   Original width, L_w = 18 cm
   Original height, L_h = 10 cm
   New length, L_{2l} = ?
   New width, L_{2w} = ?
   New height, L_{2h} = ?
   Solution
   From:-
   L = Lo (1 + $\alpha\Delta\theta$)
   1st solve for L_l when Lo= 30 cm
   L = ((30 x 130)1.2 x 10^{-5}) + 30
   L = (390 x 1.2 x 10^{-5}) + 30
   L = (390 x 1.2 x 10^{-5}) + 30 = 30.05 cm
   2nd solve for L when Lw = 18 cm
   L = ((18 x 130)1.2 x 10^{-5}) + 18
   L = 18.03 cm
   3rd solve for L when Lh = 10 cm
   L = ((10 x 130)1.2 x 10^{-5}) + 10 = 10.02 cm
   The new dimension is 30.05 cm x 18.03 cm x 10.02cm

5. A metal pipe which of 1M long at 40°C increases in length by 0.3% when carrying a stream at 100°C. Find the Coefficient of Linear Expansion
   Data given
   Initial temperature, θ_1 = 40°C
   Final temperature, θ_2 = 100°C
   Temperature rise, $\Delta\theta$ = (100 – 25)°C = 60°C
   Original length, Lo = 1 m
   New length, L = Lo + (Lox 0.03%) = 1 + 1x0.3 = 1.003 m
   Increase in length, (1.003 - 1) = 0.003 m
   Coefficient of Linear Expansion, α =?
   Solution

   $$\alpha = \frac{\Delta l}{Lo\ x\ \Delta\theta}$$

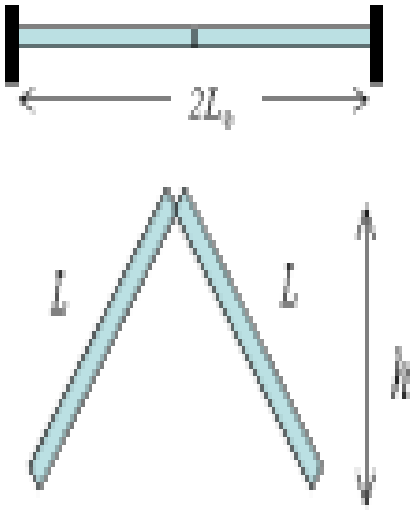
   $$\alpha = \frac{0.003}{1.0\ x\ 60}$$

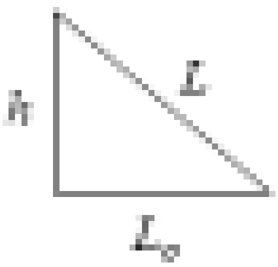
   α = **5.0 x 10^{-5} K^{-1}**

The Buckling of a Sidewalk

6. As a result of a temperature rise of 32 °C a bar with a crack at its centre buckles upward. If the fixed distance between the ends of the bar is 3.77 m and the coefficient of linear expansion of the bar is $2.5 \times 10^{-5}\ K^{-1}$, find the rise at the centre.

Solution





$\Delta\theta = 32^\circ C$

$\alpha = 2.5 \times 10^{-5}\ K^{-1}$

Lo = 3.77m/2 = 1.885m

H =?

L =?

Linear Expansivity

$L = \Delta L + Lo$

$L = Lo\ (1 + \alpha\theta)$

From Pythagoras' theorem

$L^2 = L_o^2 + h^2$

$h^2 = L^2 - L_o^2$

$= (L_o + \alpha\ L_o\ \Delta T)^2 - L_o^2$

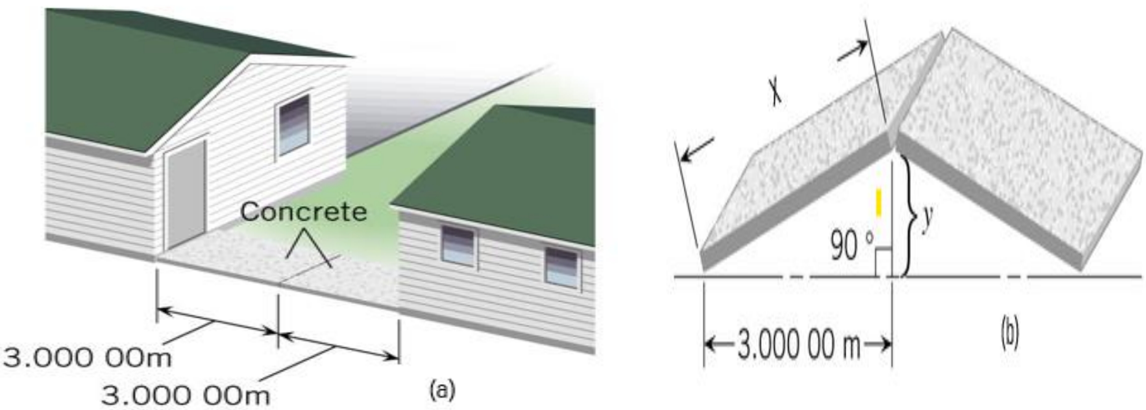
$= 2\ \alpha\ L_o^2 \Delta T + \alpha^2\ L_o^2\ \Delta T^2$

$h = (2\ \alpha\ \Delta T)^{½}\ L_o$ neglecting very small terms

$h = \{(2)(2.5 \times 10^{-5})(32)\}^{½}\ (1.885)$ m

***The rise at the centre is* 0.075 m**

7. A concrete sidewalk with a coefficient of linear expansivity of 12 x 10 ⁶ per °C is constructed between two buildings on a day when the temperature is 25°C. As the temperature rises to 38°C, the slabs expand, but no space is provided for thermal expansion so it appears as shown in part (b) of the drawing. Determine:-
   (i) The distance x and (Ans. 0,00047m)
   (ii) The rise *y* in part (b) of the sketch. (Ans:- 0.053m)



8. An iron plate at 20°C has a hole of radius of 8.92 mm in the centre, an iron rivet with radius of 8.95 mm at 20°C, inserted into the hole. To what temperature the plate must be heated for the rivet to fit into the hole. (Linear expansivity of iron is $1.24 \times 10^{-5} K^{-1}$).

Data given
Initial temperature, θ_1 = 20°C
Final temperature, θ_2 = ?
Original length, L_1 = 8.92 mm
New length, L_2 = 8.95 mm
Increase in length, $\Delta l = (L_2 - L_1)$ = (8.95 – 8.92) = 0.03 mm
Linear Expansivity, α =$1.24 \times 10^{-5} K^{-1}$ = $0.0000124 K^{-1}$

Solution

$$\alpha = \frac{\Delta l}{Lo \ x \ (\theta f - \theta i)}$$

Making θf the subject the equation becomes

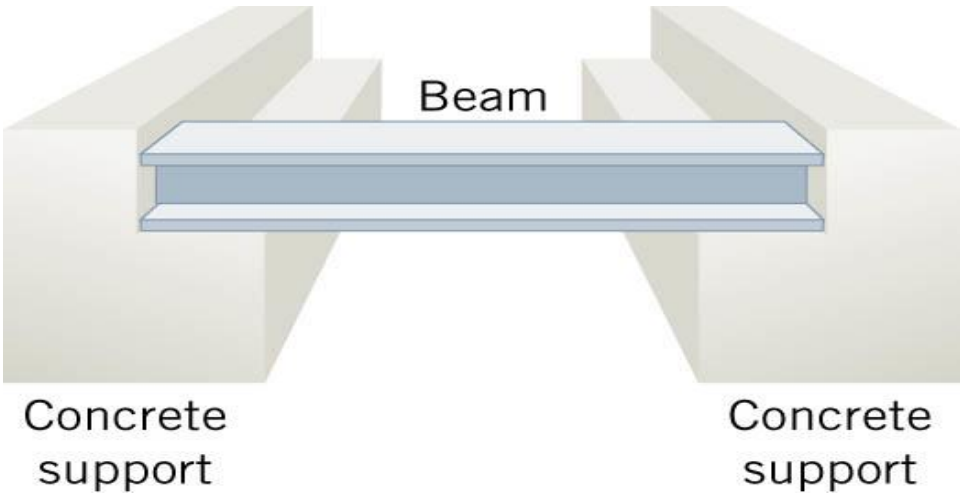
$$\theta f = \frac{\Delta l}{\alpha \text{ x } Lo} + \theta i$$

$$\Delta\theta = \frac{0.03}{0.0000124 \text{ x } 8.92} \quad 271.23$$

Since initial temperature is 20°C the plate must be heated to (20 + 271.23) °C = **291.23 °C** or slightly higher.

Stress on the beam

The beam is mounted between two concrete supports when the temperature is 23°C. What compressional stress must the concrete supports apply to each end of the beam, if they are to keep the beam from expanding when the temperature rises to 42°C?



Solution

Known that, $\Delta L = \alpha L_o \theta$, then:-

$$\text{Stress} = \frac{F}{A} = Y\frac{\Delta L}{L_o}$$

$$\text{Stress} = Y\alpha\,\Delta T$$

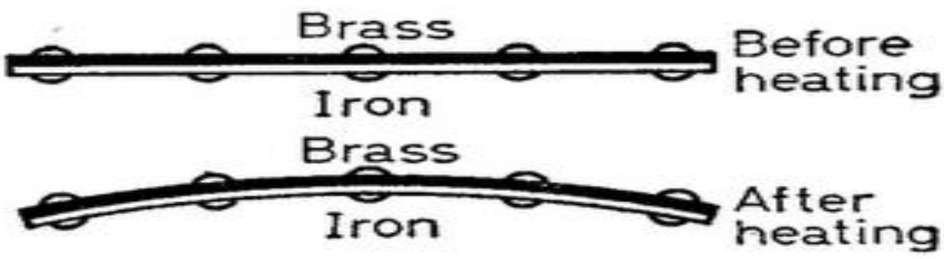
$$Stress = \left(2.0\times10^{11}\ \text{N/m}^2\right)\left[12\times10^{-6}\left(\text{C}^\circ\right)^{-1}\right]\left(19\,\text{C}^\circ\right)$$

$$Stress = 4.7\times10^{7}\ \text{N/m}^2$$

The Bimetallic Strip

The bimetallic strip consists of two different metals that expand at different rates when heated through the same temperature change.

Diagram:



Bimetallic strip

Points to note:-

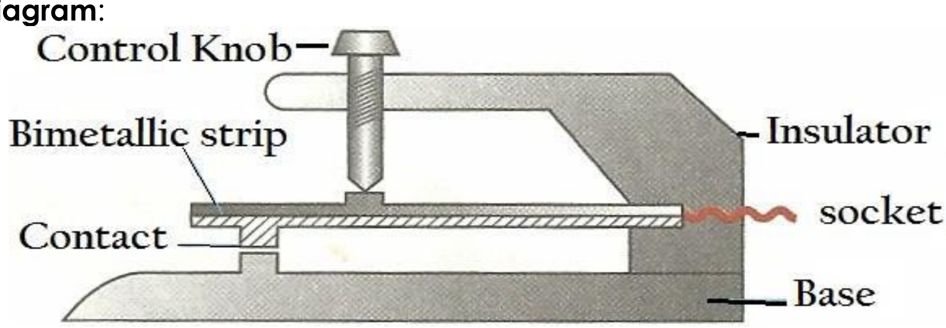
(i) The metal that expands faster forms the outside part of the curve while the one that expands more slowly is on the inside of the curve.
(ii) Brass expands and contracts twice as fast as steel.
(iii) temperature must be measured in Kelvin

Applications of the Expansion of Solids

The bimetallic strip used in thermostats, thermometers and valves. Thermostats are used in many appliances such as electric irons, heaters, refrigerators, air conditioners, fire alarms and Valves

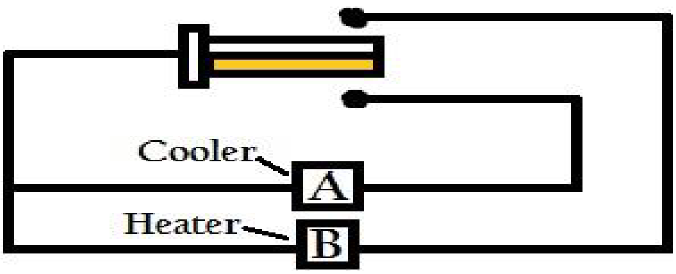
1. **Electric iron**
   - When metallic strip bend to break a circuit

   Diagram:



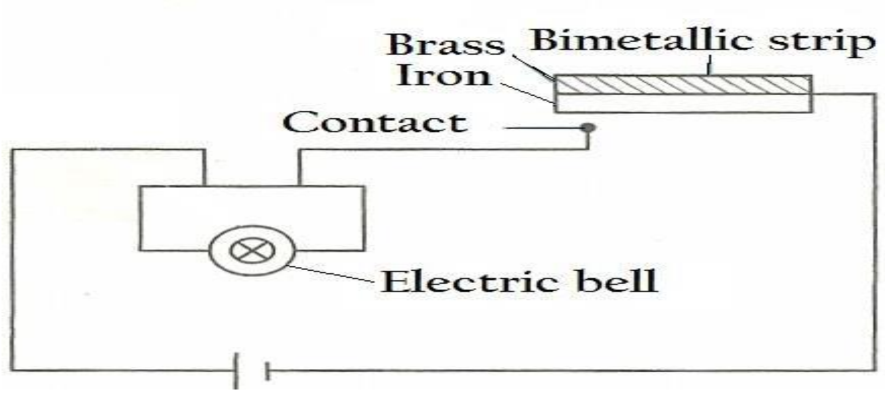
2. **Thermal condition of building**
   - When metallic strip bend to break/close a circuit to maintain temperature inside the building to a desired temperature.

   Diagram:

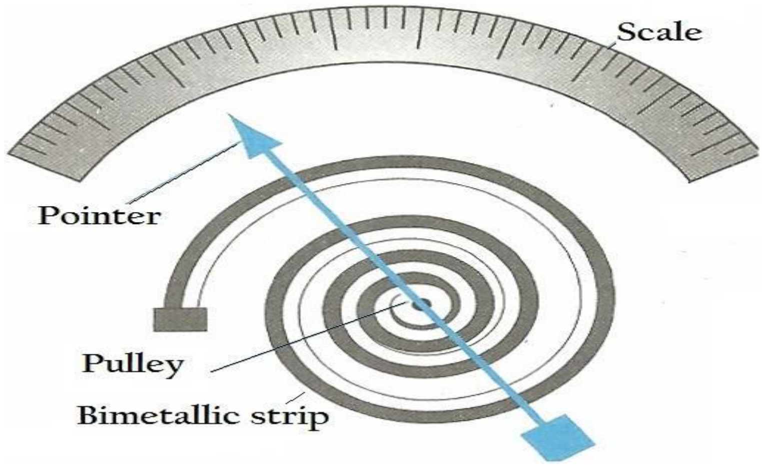


3. **Refrigerator**
   - When metallic strip bend to break/close a circuit to maintain temperature inside the refrigerator
4. **Air conditioner**
   - When metallic strip bend to break/close a circuit to maintain required temperature

5. **Fire alarms circuit**
   - When temperature rise metallic strip bend to close a circuit which complete the circuit and bell start to ring.
     Diagram:

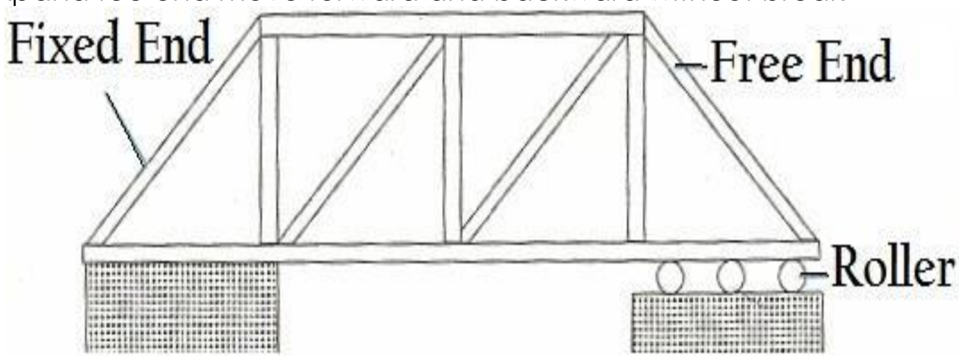


6. **Bimetallic thermometer**
   - When temperature rise metallic strip bend results the pointer to rotate across pulley. Used to measure temperature of inaccessible structures such as the engine of vehicles, marine ships and aeroplane.
     Diagram:



7. **Bimetallic Valve**
   - When metallic strip bend can close or open valve in some machines

8. **Applied in the design of bridges/house roofs etc.**
   - In order to prevent expansion one end left free with roller so when bridge expand fee end move forward and backward without break

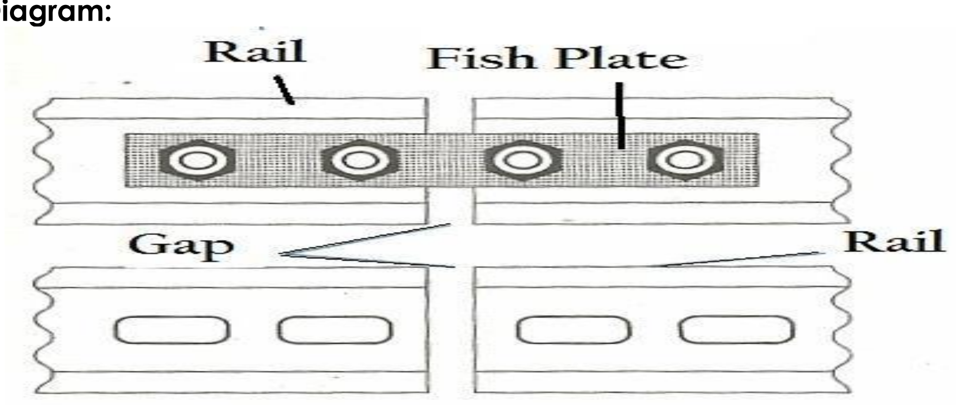


9. **Applied in the design of pendulum clocks**
   - Pendulums and balance wheels in clocks are compensated for expansion so that the clocks keep correct time even when temperatures change

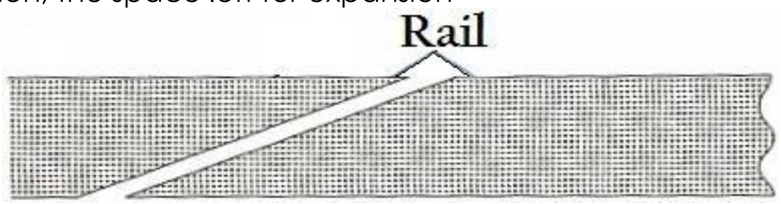
10. **Railway lines construction**

- In order to prevent expansion always gape left between two rails

  Diagram:



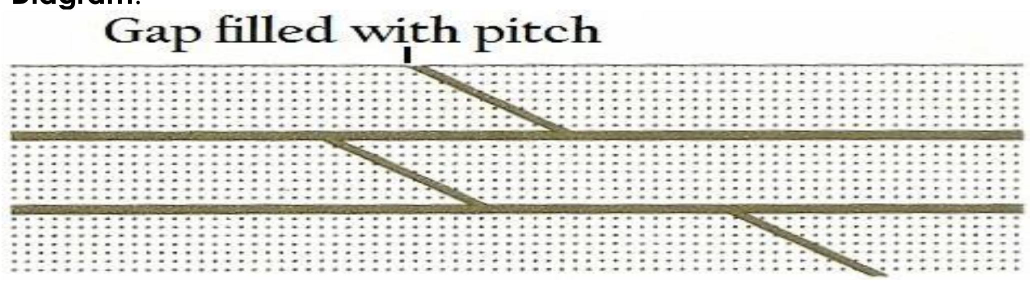
In addition, the space left for expansion



11. **Construction of road and pavement**

- In order to prevent expansion always gape left between the slabs. Gape filled with pitch

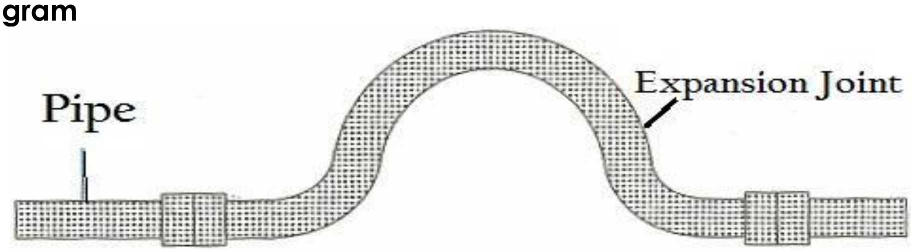
  Diagram:



12. **Applied in hot-water pipe**

- In order to prevent destruction which arise from expansion, pipe are fitted with expansion joint

  Diagram



13. The riveting of metals

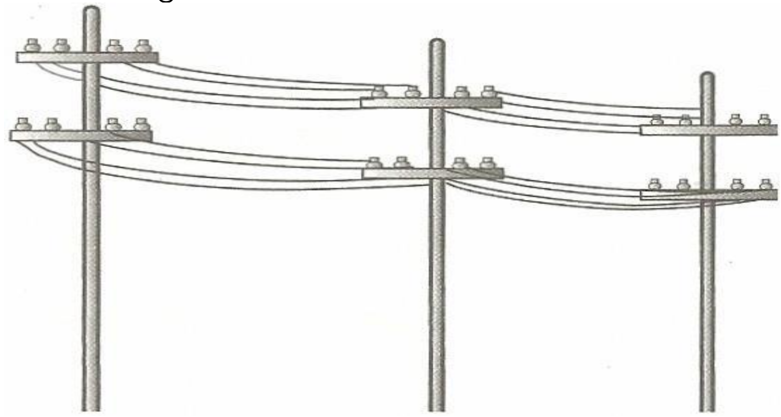
- A rivet is a small steel cylinder used for fastening two metal plates. Hot rivets are slipped through the holes and hammered while red hot. On cooling, they contract and pull the pieces of sheeting tightly together.

14. The rim and wheel

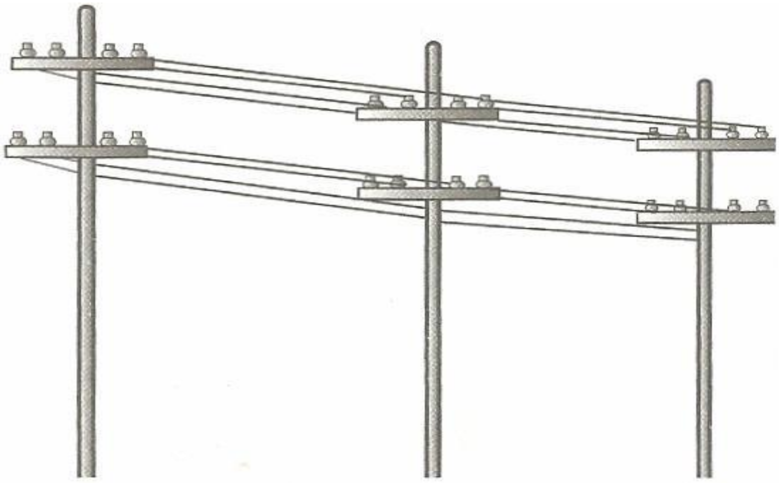
- Car wheels and train wheels fitted when red-hot. On cooling, they contract and fit very tightly and therefore do not require screws and nuts

15. Overhead telephone and electrical cables

- Overhead telephone and electrical cables left sagging during installation on a hot day to allow for contraction
  Diagram:
- During cold mornings



- During hot afternoons



Example 08,

A brass plate has a hole whose radius is too small for an iron rivet to fit into. Explain 2 different ways the rivet can be made to fit in the hole.

Answer

- By expanding the brass plate to a certain diameter that could make the iron rivet to fit into.
- By contracting the iron rivet to a certain diameter which could fit into the brass plate.

Modification

(i) The brass plate will be heated, the radius of the whole will increase and iron rivet can be fitted easily. When the brass plate cools the contraction of the whole will secure the rivet.

(ii) An iron rivet is kept at the cool place for it to contract (decrease in diameter) such that the diameter of the iron rivet is slightly smaller than the diameter of the hole.

Aluminium and ordinary glass jar fits so tightly so that it cannot be unscrewed should the jar and the lid be immersed in hot water or cold water? To loosen the lid?

Answer - Hot water

Explanation

- The aluminium expands more than the glass when heated though the same temperature change, so aluminium and glass expands by different amounts.

Some effects of expansion and contraction

1. Vessels made of thick or ordinary glass break easily if hot liquids are poured in them. (This is because the inside of the glass is heated and expands, while the outside remains cold and the same size. The force of expansion usually breaks the glass)
2. Riveting of two metal plates
   - Rivets are used in shipbuilding, boiler making, etc. to join metals sheets
   - Rivets are heated to red hot condition and are forced through holes in the two plates
   - The end of hot rivets contract and bring the plate tightly gripped to each other
3. Glass stoppers sometime stick in the necks of bottle.
   - By warming the neck of such a bottle gently, the stopper often comes out easily
4. Weathering of rocks
   - This is the action of sun, air and water on rocks, causing them to break
   - Hot sun shine makes the outside of a rock expand, and pieces break off due to the force of expansion
5. Steel tires or rims for wheels of railway engines are slightly too small when cold.
   - They are made red–hot and expand enough to fit the wheel. On cooling, the tires contract and fit tightly

Check Your Understanding

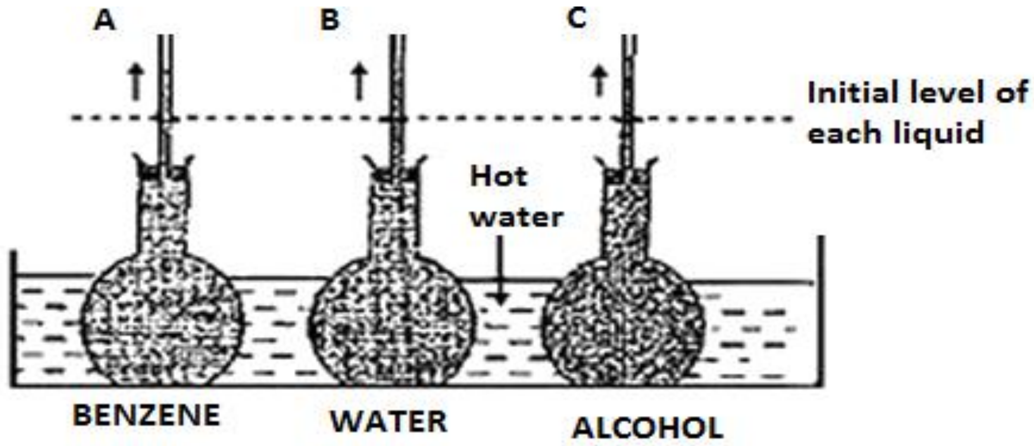
1. A block of concrete 5m long expands to 55.00412m when heated from 25°C to 100°C. Determine the linear expansivity of concrete (Ans:- $\alpha = 1.1x10^{-5}\ per\ C^{o}$)
2. An iron rod of linear expansion coefficient of 2.4 x 10^{-5} /°K and L_o is 60m, expands when heated through 100°C. Calculate the increase in length (Ans:- 0.144m)
3. If β is representing aerial expansivity and γ representing volume expansivity show that $\frac{\gamma}{\beta}$ = 1.5
4. The linear expansion coefficient of a certain metal is 2.8 x 10^{-5} /°C, the final length of a metal rod after being heated increased by 0.05%? Calculate the temperature reached in heating if the rod originally was at 20°C known that the original length of the rod is 20 m (Ans:- 37.86°C)
5. A copper wire which has an area of 25m^2 at 15°C. Find the increase in volume of the wire if its temperature is raised to 45°C. Linear expansivity of copper = 0.000017°C^{-1} (Ans:- 0.0255m^2)
6. Explain why a compound metal bar made up of two strips, one of iron and another of brass, bends when heated. Show how bimetallic strips may be used in making thermostat.
7. Explain how each of the following works:-
   (a) A bimetallic thermostat
   (b) A bimetallic thermometer
8. The difference in length between a brass and an iron rod is 14 cm at 10 °C. What must be the length of the iron for this difference to remain at 14 cm when both rods are heated to 100 °C? Given that the linear expansivity of brass = $19\ x\ 10^{-6}\ per\ K^{o}$) and iron = $12\ x\ 10^{-6}\ per\ K^{o}$) (Ans: L = 38 cm)
9. An aluminium plate has an area of 0.4m^2 when at a temperature of 30°C. The coefficient of linear expansivity of aluminum is 2.4 x 10^{-5} /°C
   (a) By how much should its temperature be raised so that its area may increase by 0.5%?
   (b) Briefly explain what is meant by areal expansivity.

08. THERMAL EXPANSION OF LIQUIDS

Liquids expand much more than solids for equal changes of temperature. That's why it is easier to observe expansion in liquids than in solids.

Demonstration

Consider the glass bulbs A, B and C filled to a short distance above the bulb with various liquids as shown below in order to make fair comparison.



The liquids in the stems will rise by different amounts when heated at the same environment.
Since the liquids have no shapes, they take the shapes of the vessels. Therefore they don't have linear and areal expansiveness. They have only volume expansiveness. When the liquids are heated, their volume does increase.

The level of the water will first drop due to increase in the volume of the container on heated. The increase in volume is due to the expansion of the container. The level of the water will then keep rising as the container due to the expansion of the water, its density decrease.

Apparent Volume Expansion of a Liquid

Apparent volume expansion of a liquid is equal to the actual expansion of the liquid less the increase in volume of the containing vessel up to the liquid level.

Volume Expansivity of a Liquid

This is the fractional increase in volume by which a liquid appears to expand per unit rise in temperature when heated in a vessel. Its unit is K^{-1} or $°C^{-1}$. It also called **coefficient of volume of expansion.**

$$Volume\ Exansivity, \gamma = \frac{Increase\ in\ volume\ of\ the\ liquid, \Delta V}{Original\ Volume\ of\ the\ liquid, Vo\ x\ Rise\ in\ temperature\ \Delta\theta}$$

$$\gamma = \frac{\Delta V}{Vo\ x\ \Delta\theta} = \frac{V - Vo}{Vo\ x\ (\theta f - \theta i)}$$

Where:
Original/initial volume of liquid = Vo
Final volume = V
Increase in volume of liquid = V – Vo
Initial temperature = θf
Final temperature = θi
Rise in temperature = Δθ = (θf – θi)
Volume expansivity = β

Volume Expansivity of some Liquids when heated Between (0 – 100)°C

Liquid	Volume Expansivity (K^{-1}) X 10^{-5}
Benzene	124
Gasoline	95
Glycerine	53
Kerosene	99
Mercury	18
Methanol	122
Water at 20°C	21
Water at 35°C	35
Water at 90°C	70

$$\gamma_{abs} = \gamma_{app} + \gamma_{vessel}$$

$$\gamma_{app} = \frac{V - Vo}{Vo \times (\theta f - \theta i)}$$

$$\gamma_{vessel} = \frac{V - Vo}{Vo \times (\theta f - \theta i)}$$

Example

A glass vessel marked 1000cm³ is completely filed with a liquid at a temperature of 10°C. If the vessel is heated to 90°C, find the volume of the liquid which will be expelled out of the vessel.

Given that:-

Given, V_0 = 1000cm³, $\phi_2 = 90°C\ and\ \phi_1 = 10°C$ and $\gamma_{glass} = 3\alpha$

Volume expansivity of the liquid γ_{Liquid} = 3.7 x 10^{-4} °C^{-1}

Linear expansivity of glass = 9 x 10^{-6} °C^{-1}

Solution

Increase in Volume of a liquid when heated to 90°C is $\gamma_{liquid}V_o(\phi_2 - \phi_1)$

Increase in Volume of the glass when heated to 90°C is $\gamma_{glass}V_o(\phi_2 - \phi_1)$

Volume of liquid expelled =$[\gamma_{liquid}V_o(\phi_2 - \phi_1)]$ - $[\gamma_{glass}V_o(\phi_2 - \phi_1)]$

Volume of liquid expelled = $V_o(\phi_2 - \phi_1)(\gamma_{liquid} - \gamma_{glass})$

$\gamma_{glass} = 3\ x\ 9\ x\ 10^{-6}°C^{-1} = 2.7\ x\ 10^{-5}°C^{-1}$

Volume of liquid expelled =$1000\ (90°C - 10°C)(37\ x10^{-5}°C^{-1} - 2.7\ x\ 10^{-5}°C^{-1})$

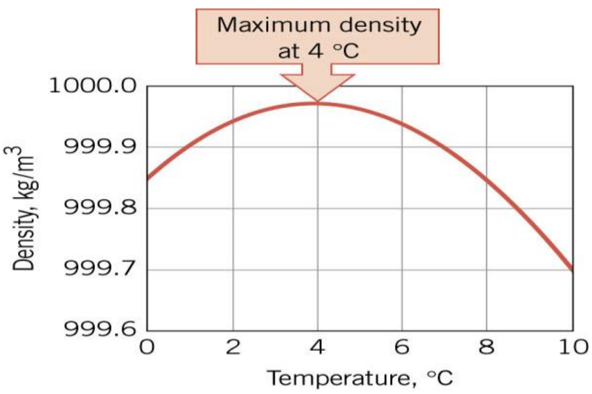
Volume of liquid expelled =$1000\ x\ 80\ \ x\ 3.43\ x\ 10^{-4}$

Volume of liquid expelled = 27.44cm³

Anomalous Expansion of Water

This is the decrease in the density of water when cooled from 4°C to 0°C.

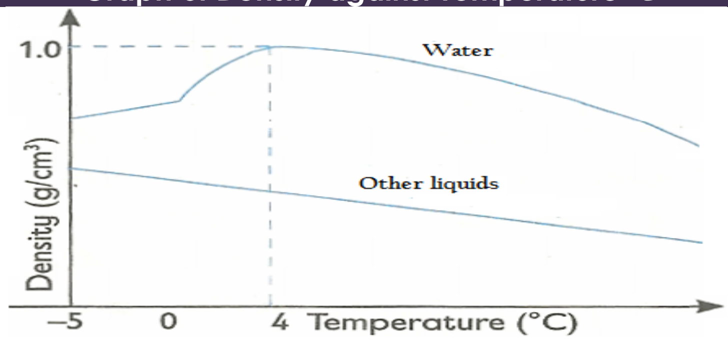
At 4°C, just above the freezing point, water reaches its maximum density. As the water cool further toward its freezing point, the liquid water expands to become less dense.



Effect of Water Anomalous Expansion

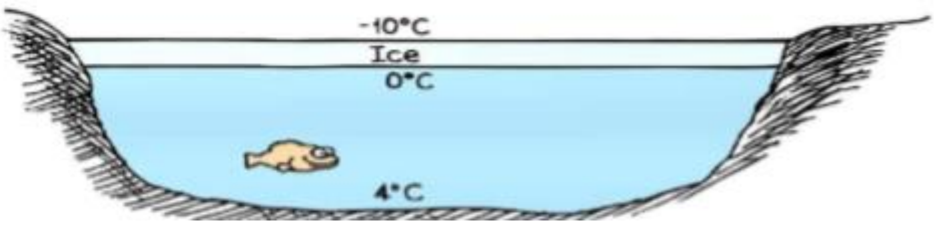
(i) A glass bottle filled with water and sealed cracks if cooled in a deep freezer
(ii) If water freezes in a pipe, it may cause the pipe to burst open due to expansion.
(iii) Icebergs, being less dense than water, float in oceans thus posing a danger to ships.

Graph of Density against Temperature ℃



The Application of Expansion of Liquids in Everyday Life

i. Due to small density from 4°C to 0°C ice float results fish and other aquatic life to survive in the water below the ice. This insulates the water below against heat loss to the cold air above. This allows aquatic life to survive in freezing environments. (see the figure below)



ii. The expansion of liquids used in liquid thermometers.
iii. Water in lakes and ponds usually freezes in winter.

Effects of Anomalous expansion of water

- A glass bottle filled with water and sealed cracks if cooled in a deep freezer
- A glass tumbler breaks when a hot liquid is poured in it because the inner wall expands quickly while due to poor conductivity of glass, the outer wall remains unexpanded
- If water freezes in a pipe, it may cause the pipe to burst open due to expansion.
- Icebergs being less dense than water, float in oceans thus posing a danger to ships.
- Weathering of rocks .This happen when water freezes in the cracks of a rock the volume of water increases .This causes the rock to break into small pieces

Check Your Understanding

1. Explain why when heating a liquid, its level initially decreases and then it Increases to become larger than the original level?
2. Mercury in a glass thermometer has a bulb of volume $0.4cm^3$ and a tube of cross sectional area of $20x10^{-5}cm^2$. Calculate
   (a) The apparent increase in volume of the mercury when the temperature rises from 0^oC to 100^oC
   (b) The distance between the fixed points

09. THERMAL EXPANSION IN GASES

Gases expand much more than solids and liquids when heated. This is because the particles in gases are not held closely together, as they are in solids and liquids, but are instead free to move in all directions. Three importance properties of expansion of gases includes pressure, volume and temperature.

Point to note:

The temperature must converted to Kelvin scale

Charles' Law

This law involves the relationship between the volume and the temperature of a fixed mass of a gas at constant pressure. The law state that

"***The volume of a given mass of a gas is directly proportional to the absolute (Kelvin) temperature provided that the pressure remains constant***"

Mathematically

$V \alpha T$

$V= K T$ – making K the subject

$K = \frac{V}{T}$

$$\boldsymbol{Therefore,} \quad \frac{V_o}{T_o} = \frac{V_1}{T_1}$$

Where:

V_o = initial volume

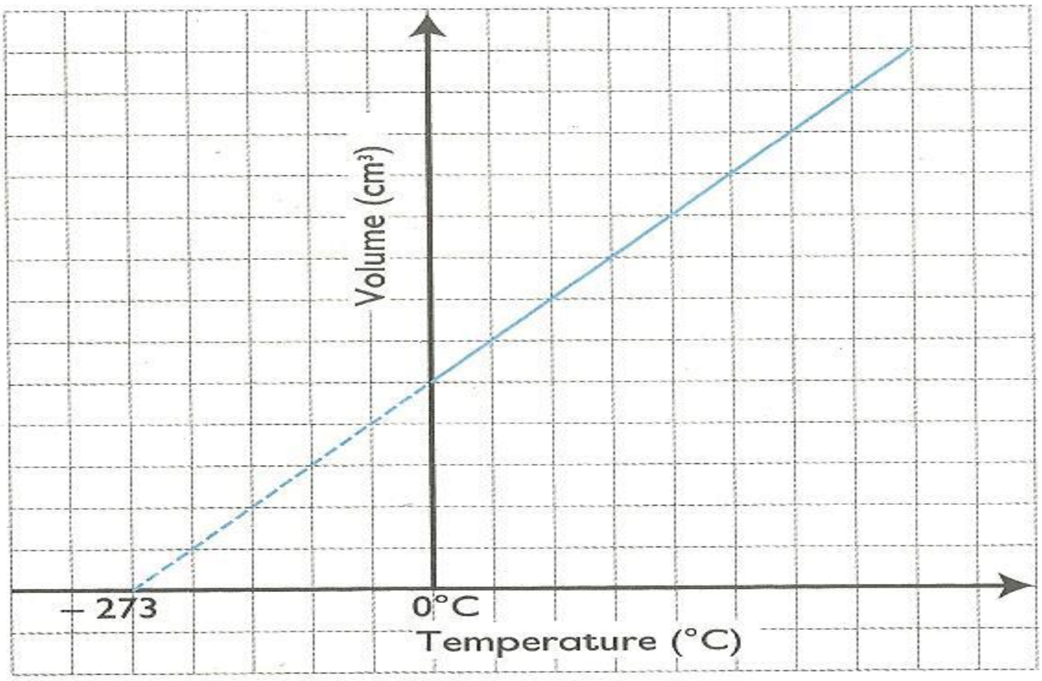
T_o = initial temperature

V_1 = final volume

T_1 = final temperature

Graphically:

Graph of Volume against temperature (K)



From the graph above it seems that as if temperature increased also volume increase and vice versa

Absolute Scale of Temperature

Absolute zero temperature is the lowest temperature that can be reached theoretically.

Conversion

T (K) = 273 +θ°C

θ°C = T(K) - 273

Example 01,
Change the following temperatures to Kelvin scale (a) 227°C (b) 83°C
Data given
(a) Temperature in Celsius, θ = 227°C
Temperature in Kelvin, K = ?
Solution
From: T (K) = 273 +θ°C
T (K) = 273 +227°C
T (K) = 500 K
(b) Temperature in Celsius, θ = 83°C
Temperature in Kelvin, K = ?
Solution
From: T (K) = 273 +θ°C
T (K) = 273 +83°C
T (K) = (273 +83) °K
T (K) = 356 K

Example 02
Change the following temperatures to Celsius scale 4K
Given Temperature in Kelvin, K = 4K
Temperature in Celsius, θ = ?
Solution
From: θ°C = T(K) – 273
θ°C = 4K - 273
θ°C = - 269°C

Example 03,
A gas occupies a volume of 20 cm^3 at 27°C and at normal atmospheric pressure. Calculate the new volume of the gas if it heated to 54°C at the same pressure. Given that the pressure is kept constant.
Data given
Initial volume, V_1 = 20 cm^3
Initial temperature, T_1 = 27°C
Final temperature, T_2 =54°
Final volume, V_2 = ?
Solution

$$From\ Charles'Law\ \frac{T_1}{V_1} = \frac{T_2}{V_2}$$

$$Can\ also\ be\ writen\ as\ \frac{T_1}{T_2} = \frac{V_1}{V_2}$$

$$Making\ V_2\ subject, = \frac{T_2\, xV_1}{T_1}$$

Also,
From: T_1(K) = 273 +θ°C
T_1(K) = 273 +27°C
T_1(K) = 300K
T_2 (K) = 273 +θ°C
T_2 (K) = 273 +54°C =327k
T_2 (K) = 327k

$$V_2 = \frac{327x20}{300}$$

The new Volume is 21.8cm3

Boyle's Law

This law involves the relationship between the volume and the pressure of a fixed mass of a gas at constant temperature. The law state that

"The volume of a given mass of a gas is inversely proportional to its pressure provided the temperature is kept constant"

Mathematically

$$V \, \alpha \frac{1}{P}$$

$$V = k\frac{1}{P}$$

Then

$$\boldsymbol{V_o P_o = V_1 P_1}$$

Where:

P_o = initial pressure

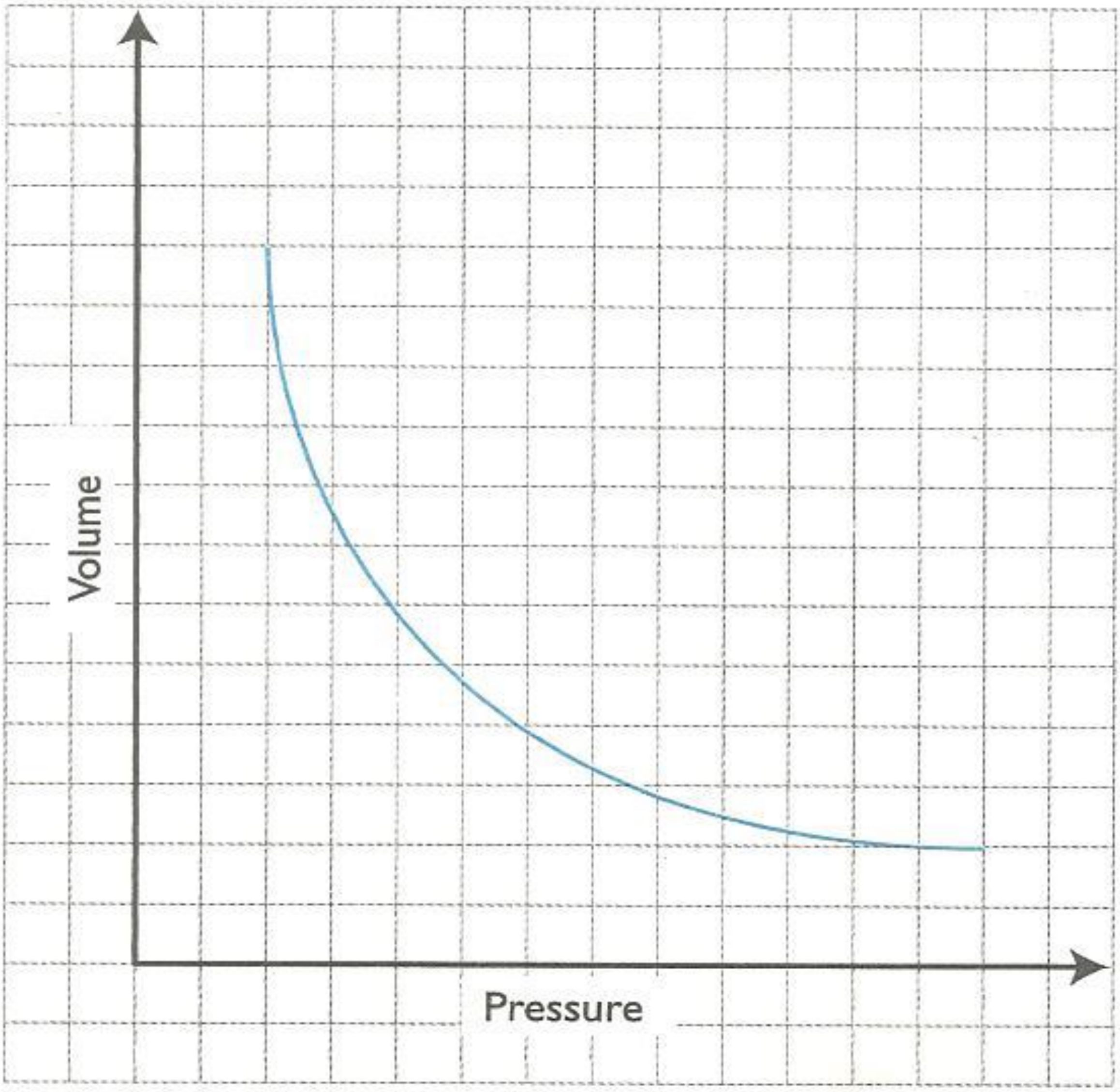
V_o = initial volume

P_1 = final pressure

V_1 = final volume

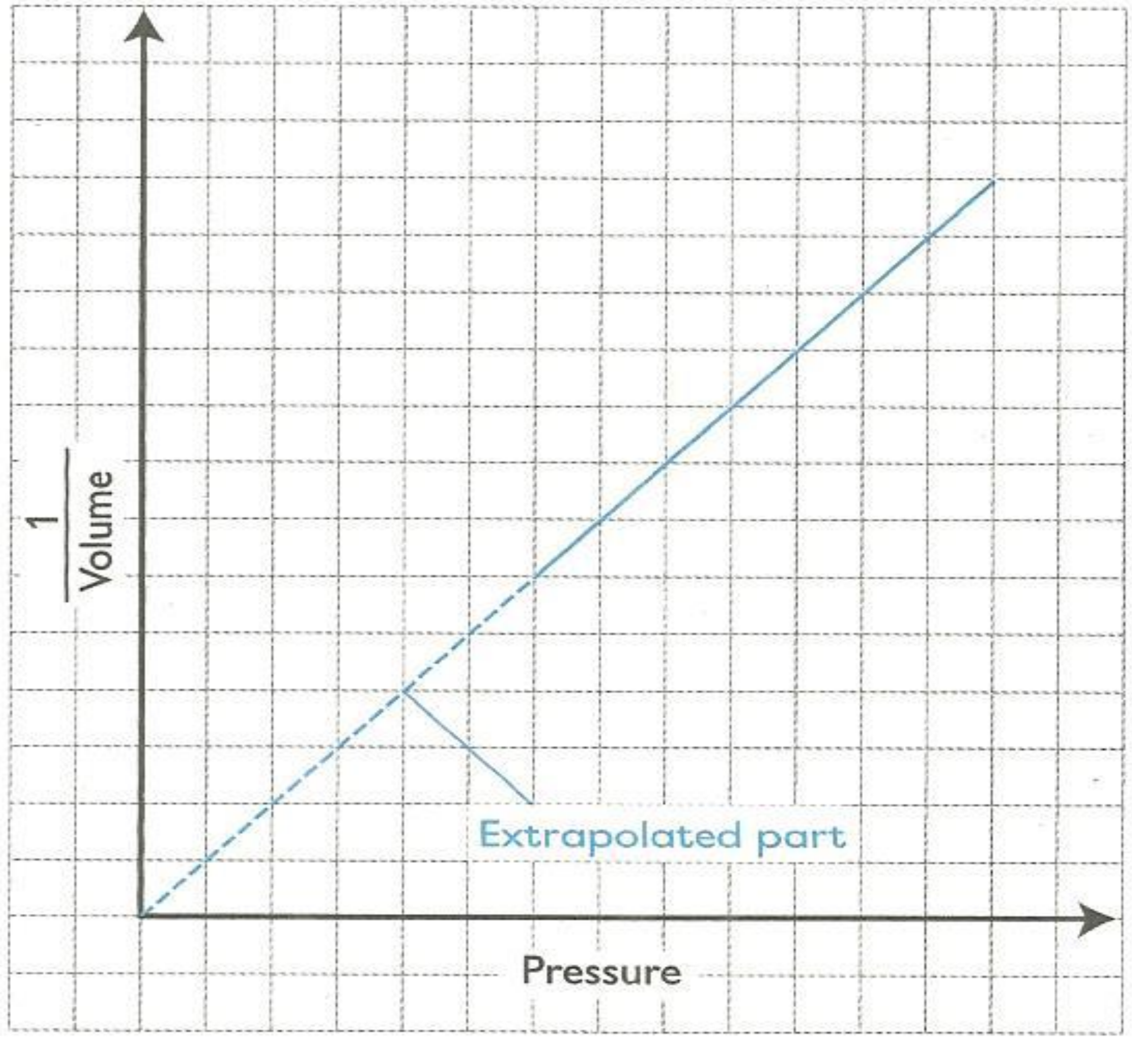
Graphically:

Graph of Volume against Pressure



- From the graph above it seems that as if pressure increased also volume decrease and vice versa

Graph of inverse of Volume against Pressure



- From the graph above it seems that as if pressure increased also inverse of volume increase and vice versa

Example 04,
A gas in a cylinder occupies a volume of 465 ml when the pressure on it is equivalent to 725 mm of mercury. What will be the volume of the gas when the pressure on it raise to 825 mm of mercury while the temperature is held constant?
Data given
Initial pressure, P_1 = 725 mmHg
Initial volume, V_1 = 465 ml +
Final pressure, P_2 = 825 mmHg
Final volume, V_2 = ?
Solution
From Boyle's law: $P_1V_1 = P_2V_2$ – make V_2 subject

$$Making\ V_2\ subject, = \frac{P_1V_1}{P_2}$$

$$V_2 \ = \frac{465\ x\ 725}{825} = 408.6$$

The volume of the gas will be 408.6ml

Pressure Law

This law involves the relationship between the temperature and the pressure of a fixed mass of a gas at constant volume. The law state that

"The pressure of a given mass of a gas is directly proportional to the absolute temperature provided the volume is kept constant"

Mathematically

$P \alpha T$

$$\frac{P_o}{T_o} = \frac{P_1}{T_1}$$

Where:

P_o = initial pressure

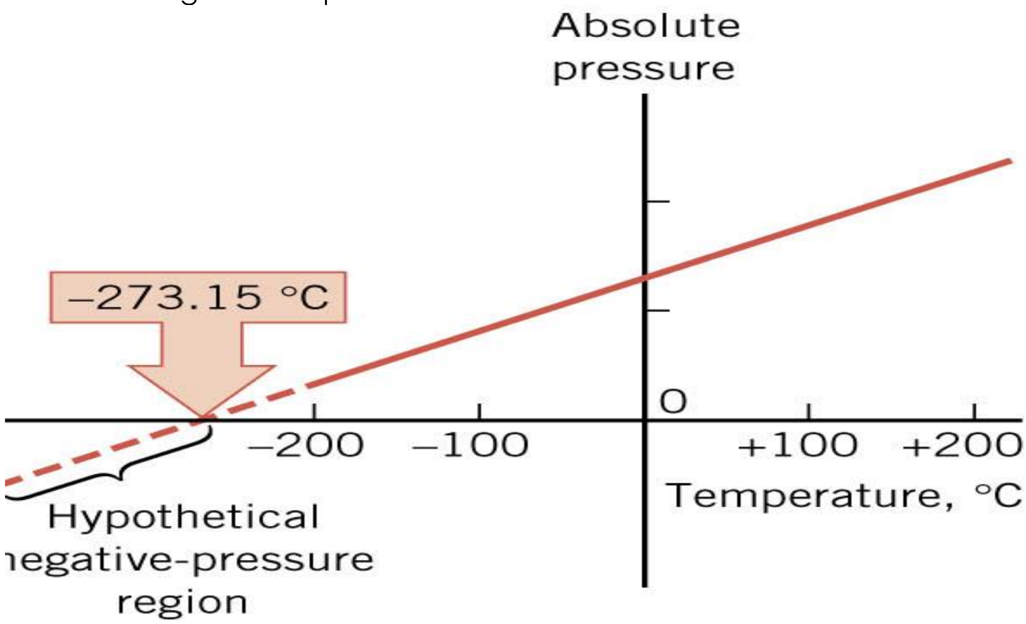
T_o = initial temperature

P_1 = final pressure

T_1 = final temperature

Graphically:

Graph of Pressure against temperature



From the graph above it seems that as if pressure increased also temperature increase and vice versa

Example 05,

A rigid metal container holds carbon dioxide gas at a pressure of 2 x 10^5 Pa and a temperature of 30°C. What temperature the gas be lowered for the pressure to reduce to half (1 x 10^5 Pa)?

Data given

Initial pressure, P_o = 2 x 10^5Pa

Initial temperature, T_o = 30°C = 303K

Final pressure, P_1 = 1 x 10^5 Pa

Final temperature, T_1 =?

Solution

From pressure law:

$\frac{P_o}{T_o} = \frac{P_1}{T_1}$ Make T_1 subject

$$T_1 = \frac{T_o P_1}{P_o}$$

$T_1 = \frac{303\text{K x } 1\text{x } 10^5\text{Pa}}{2\text{x } 10^5\text{Pa}}$

T_2 = 151.5K = -121.5°C

Example 06,
A gas in a fixed-volume container has a pressure of 1.6 x 10 Pa at a temperature of 27°C. What will be the pressure of the gas if the container heated to a temperature of 277°C?
Data given
Initial pressure, P_o = 1.6 x 10^5 Pa
Initial temperature, T_o = 27°C = 300K
Final temperature, T_1 =277°C = 550K
Final pressure, P_1 = ?
Solution
From pressure law:

$$\frac{P_o}{T_o} = \frac{P_1}{T_1} \; Make\ P_1\ subject$$

$$P_1 = \frac{P_oT_1}{T_o}$$

$$P_1 = \frac{1.6x\ 10^5 Pa\ x\ 550K}{300K}$$

P1 = 2.93 x10^5 Pa

General Gas Equation/General Gas Law

Combine all laws
V α T - Charles' law …………….. 1
V α $\frac{1}{P}$ - Boyle's law ………………. 2
P α T - pressure law ……………... 3
Combine equation 1, 2 and 3 we get
V α $\frac{T}{P}$, V = k$\frac{T}{P}$ - make k subject $K = \frac{PT}{V}$
Since K is constant

$$\boldsymbol{\frac{P_0V_0}{T_0} = \frac{P_1V_1}{T_1}}$$

Standard Temperature and Pressure (STP)

STP is a set of conditions for experimental measurements to enable comparisons between sets of data. The standard temperature is 0°C (273 K) while the standard pressure is 1 atmosphere (1.013 x 10^5 Pa or 760 mm of mercury).

Example 07,
A fixed mass of gas has a volume of 1.25 litres at a pressure of 76.0 cm of mercury and a temperature of 27.0°C. The gas expands to a volume of 1.55 litres raising the pressure to 80.0 cm of mercury. What is the final temperature of the gas in °C?
Data given
Initial pressure for mercury, P_1 = 76.0 cmHg
Final pressure mercury, P_2 = 80.0 cmHg
Initial volume mercury, V_1 = 1.25 dm^3
Final volume mercury, V_2 = 1.55 dm^3
Initial temperature mercury, T_1 = 27°C = 300K
Final temperature oxygen, T_2 = ?
Solution

$$From\ = \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$Making\ T_2\ the\ subject, it\ becomes = \frac{P_2V_2T_1}{P_1V_1}$$

$$T_2\ = \frac{80\ x\ 1.55\ x\ 300}{76\ x\ 1.25}$$

The final temperature of the gas is 391.58K = 118.58°

Example 08,
A sample of oxygen gas has a volume of 0.11 m^3 at a temperature of 12°C and a pressure of 8.1 x 10^4 Pa while a sample of nitrogen gas has a volume of 0.18 m^3 at a temperature of 22°C and a pressure of 1.013 x 10^5 Pa. Which gas will have the larger volume at STP?

Data given
Initial pressure for oxygen, Po_1 = 8.1 x 10^4 Pa
Initial temperature oxygen, To_1 = 12°C = 285K
Initial volume oxygen, Vo_1 = 0.11 m^3
Final temperature oxygen, To_2 =0°C = 273K
Final pressure oxygen, Po_2 = 1.013 x 10^5 Pa
Final volume oxygen, Vo_2 = ?
Initial pressure for nitrogen, Pn_1 = 1.03 x 10^5 Pa
Initial temperature nitrogen, Tn_1 = 22°C = 295K
Initial volume nitrogen, Vn_1 = 0.18 m^3
Final temperature nitrogen, Tn_2 =0°C = 273K
Final pressure nitrogen, Pn_2 = 1.013 x 10^5 Pa
Final volume nitrogen, Vn_2 = ?

Solution

$$\boldsymbol{For\ Oxygen\ gas} = \frac{Po_1Vo_1}{To_1} = \frac{Po_2Vo_2}{To_2}$$

$$Volume\ Vo_2\ of\ Oxygen = \frac{Po_1Vo_1To_2}{To_1Po_2}$$

$$Volume\ Vo_2\ of\ Oxygen = \frac{8.1x\ 10^4\ x\ 0.11\ x\ 273}{285\ x\ 1.013\ x\ 10^5}$$

$$Volume\ Vo_2\ of\ Oxygen = 0.084m^3$$

$$\boldsymbol{For\ Nitrogen\ gas} = \frac{Pn_1Vn_1}{Tn_1} = \frac{Pn_2Vn_2}{Tn_2}$$

$$Volume\ Vn_2\ of\ Nitrogen = \frac{Pn_1Vn_1Tn_2}{Tn_1Pn_2}$$

$$Volume\ Vn_2\ of\ Nitrogen = \frac{1.013\ x\ 10^5\ x\ 0.18\ x\ 273}{295\ x\ 1.013\ x\ 10^5}$$

$$Volume\ Vn_2\ of\ Nitrogen = 0.17m^3$$

At STP, nitrogen gas would have a volume twice that of the volume of oxygen gas.

Example 09,
A fixed mass of gas occupies a volume of 0.001 m^3 at a pressure of 76 cmHg. What volume does the gas occupy at 17.0°C if its pressure is 72 cmHg?

Data given
Initial pressure for mercury, P_1 = 76.0 cmHg
Final pressure mercury, P_2 = 72.0 cmHg
Initial volume mercury, V_1 = 0.001 m^3
Initial temperature mercury, T_1 = 0°C = 273K
Final temperature oxygen, T_2 = 17°C = 290K
Final volume mercury, V_2 = ?

Solution:

$$From = \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$V_2 = \frac{P_1V_1T_2}{T_1P_2} = \frac{76\ x\ 0.001\ x\ 290}{273\ x\ 72}$$

The volume of the gas is 1.12 x 10^{-3} m^3

Example 10,
100 cm^3 of gas A was collected at 10°C and 78.0 cmHg pressure, while 120 cm^3 of gas B was collected at 50°C and 70.0 cmHg pressure. Which of the two gases is denser at STP?
Data given
Initial pressure for A, PA_1 = 78.0 cmHg
Initial temperature for A, TA_1 = 10°C = 283K
Initial volume for A, VA_1 = 100 cm^3
Final temperature for A, TA_2 =0°C = 273K
Final pressure for A, PA_2 = 76.0 cmHg
Final volume for A, VA_2 = ?
Initial pressure for B, PB_1 = 70.0 cmHg
Initial temperature for B, TB_1 = 50°C = 323K
Initial volume for B, VB_1 = 120 cm^3
Final temperature for B, TB_2 =0°C = 273K
Final pressure for B, PB_2 = 76.0 cmHg
Final volume for B, VB_2 = ?
Solution

$$\boldsymbol{For\ Gas\ A}\ = \frac{P_{A1}V_{A1}}{T_{A1}} = \frac{P_{A2}V_{A2}}{T_{A2}}$$

$$Volume\ V_{A2}\ = \frac{P_{A1}V_{A1}T_{A2}}{T_{A1}P_{A2}}$$

$$Volume\ V_{A2}\ = \frac{78\ x\ 100\ x\ 273}{283x\ 76}$$

$$Volume\ of\ gas\ A\ = 99cm^3$$

$$\boldsymbol{For\ Gas\ B}\ = \frac{P_{B1}V_{B1}}{T_{B1}} = \frac{P_{B2}V_{B2}}{T_{B2}}$$

$$Volume\ V_{B2}\ = \frac{P_{B1}V_{B1}T_{B2}}{T_{B1}P_{B2}}$$

$$Volume\ V_{B2}\ = \frac{70\ x\ 120\ x\ 273}{323x\ 76}$$

$$Volume\ of\ gas\ B\ = 93.42\ cm^3$$

At STP, gas B has large volume than gas A so gas A is denser than gas B

Example 11,
250 cm^3 of a gas are collected at 25°C and 750 mm of mercury. Calculate the volume of the gas at STP
Data given
Initial pressure for mercury, P_1 = 750 mmHg
Final pressure mercury, P_2 = 760 mmHg
Initial volume mercury, V_1 = 250 cm^3
Initial temperature mercury, T_1 = 25°C = 298K
Final temperature oxygen, T_2 = 0°C = 273K
Final volume mercury, V_2 = ?
Solution:

$$\boldsymbol{From\ General\ Gas\ Equation}\ = \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

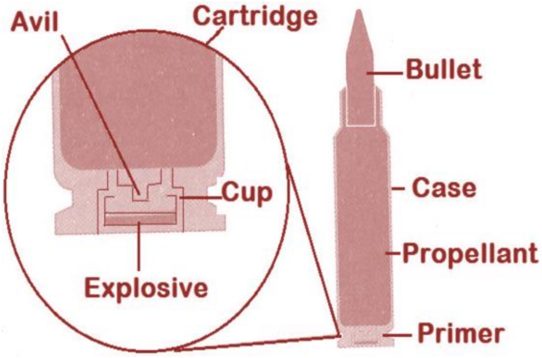
$$Volume\ V_2\ = \frac{P_1V_1T_2}{T_1P_2}$$

$$Volume\ V_2\ = \frac{750\ x\ 250\ x\ 273}{298x\ 760}$$

$$\boldsymbol{Volume\ of\ a\ Gas\ = 226.01\ cm^3}$$

Applications of the Expansion of Gases

1. **Firing bullets from guns**
   - **Diagram:**

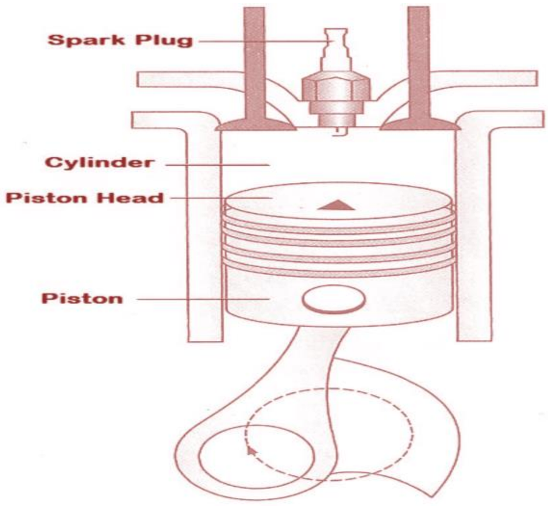


When the trigger pulled, the firing pin hits the primer resulting in a minor explosion. The flame from this explosion ignites the powder (contain nitrocellulose), which it burns very rapidly releasing a lot of heat, resulting in increased pressure within the casing

i. Nitrocellulose is a highly flammable material made by treating cellulose with concentrated nitric acid, used to make explosives and celluloid
ii. The expansion takes place in the cartridge or round of ammunition

2. **Land and sea breezes**
   - Land and sea breezes are a result of expansion of air caused by unequal heating and cooling of adjacent land and sea surfaces.

3. **The piston engine**
   - The internal combustion engines used in vehicles have four basic parts
   Diagram:



Carburettor
- In this part fuel mixed with air or is sprayed through the fuel injector. This part also called **fuel injector**

Cylinders
- The mixture goes into a cylinder, which is a long air pocket like steel can with one end open

Spark plugs
- In this part, the mixture is ignited and releasing heat. This heat increases the pressure inside the cylinder result push the piston head down the cylinder

Pistons
- The downward movement of the piston pushes a rod that turns a crankshaft. The turning crankshaft provides the motion to turn the wheels. As the piston pushed down in the cylinder, other engine parts keep it from blowing out of the cylinder. The piston then pushed back up into the cylinder.

Check Your Understanding

1. State:- Charles' Boyle's and Gay Lussac's laws
2. Explain the following observations as to why:-
   (a) Deep sea animals cannot survive at regions with shallow waters
   (b) A deflated balloon bursts when in the open on a hot day.
   (c) Water bubbles seem to increase in size as they rise from the bottom of a tank.
   (d) Electric wires are seen to sag when it's hot but looks very straight when cold.
   (e) Fish living in polar regions such as in Antarctica do not die even when temperature falls below 0^oC
3. The volume of a liquid at 20^0C and 90^0C are $5.5x10^{-4}m^3$ and $5.6x10^{-4}m^3$ respectively. Calculate the apparent volume expansivity of the liquid. (Ans:- 2.6×10^{-4} $^oC^{-1}$)
4. A round bottomed flask is filled with water colored red. The flask is then closed with a rubber stopper fitted with a capillary tube. State and explain what happens to the level of the colored water in the tube if the flask is heated over a Bunsen burner.
5. The apparent volume expansivity of alcohol in glass is $1.55x10^{-4}$ $^0C^{-1}$. The linear expansivity of glass is $9x10^{-6}$ $^0C^{-1}$ Calculate the absolute volume expansivity of alcohol in glass. (Ans:- $1.82x10^{-4}$ $^0C^{-1}$)
6. A glass vessel marked $1000cm^3$ is completely filled with a liquid at a temperature of 15^0C. If the vessel is heated to 90^0C, find the volume of the liquid which will be expelled out of the vessel. (Ans:- $37.275cm^3$)
   [volume expansivity of the liquid = $4.7x10^{-4}$ $^0C^{-1}$, linear expansivity of glass = $9x10^{-6}$ $^0C^{-1}$]
7. A glass bottle of volume $20cm^3$ contains $19.9cm^3$ of mercury at 0^0C. At what temperature should mercury fill the bottle of the same volume? (Ans:- 27.917^oC)
   [Absolute volume expansivity of mercury = 0.00018 per ^0C and volume expansivity of glass = 0.000004 per ^0C]
8. In an experiment to determine the apparent volume expansivity of a liquid, a glass flask closed by a stopper fitted with a glass tube of internal diameter 0.4cm was used. The flask was filled with the liquid until the liquid level, in the glass tube rises just above the stopper. The flask and its contents were then heated from 20^0C to 50^0C. The liquid level in the glass tube was observed to raise through 27cm. find the apparent volume expansivity of the liquid given that the volume of the liquid was $120cm^3$ at 20^0C.
9. A fixed mass of gas has a volume of 12 litres at a pressure of 76.0 cm of mercury and a temperature of 27.0°C. The gas lowers its volume by 1.5 litres raising the pressure to 80.0 cm of mercury. What is the final temperature of the gas in °C? (Ans:- -233.53^oC)
10. A fixed mass of gas occupies a volume of 0.001 m^3 at a pressure of 76 cmHg. What volume does the gas occupy at 17.0°C if its pressure is 72 cmHg? (Ans:- 9.47×10^{-4} m^3)
11. 500 cm^3 of a gas are collected at 20°C and 450 mm of mercury. Calculate the volume of the gas at STP (Ans:- $293cm^3$)
12. The volume of a gas collected at a temperature of 36^0C and at a pressure of 78cmHg is $130cm^3$.
    a) Find its volume at S.T.P (Ans:- 133.42 cm^3)
    b) When is a given mass of a gas said to be at S.T.P? (Ans:- when the temperature falls to 0^oC and a pressure becomes 760mmHg)
13. A grandfather's clock is controlled by a swinging brass pendulum of length 1.3m at a temperature of 20^oC. ($\alpha = 19x10^{-6}$ $^oC^{-1}$) (Ans:- (a) 1.005m, (b) slower)
    a) What is the length of the pendulum rod when the temperature drops to zero?
    b) If the period of a pendulum is given by $T = 2\pi\sqrt{\frac{l}{g}}$ where l is its length, does the change in the length of the brass rod cause the clock to run fast or slowly?
14. The volume of a bubble at the base of a container of water is $3cm^3$ the depth of water is 30cm. the bubble rises up the column until the surface. Explain what happens to the bubble as it rises up the water column and determine the volume of the bubble at a point 12cm below the water surface. (Ans:- $3.05cm^3$)

10. HEAT CONTENT

Heat content is the Energy possessed by a body which causes vibration of its atoms, ions or molecules. In addition, it called **internal thermal energy**

Points to note:

(i) Heat content is due to random motion of the particles that make up the object
(ii) Different materials have different heat content
(iii) Measurement of thermal energy involves indirect measurement
(iv) The heat content of a substance determined by its heat capacity

Factors That Determine the Heat Content

The heat content of a substance is determined by its

(i) Mass of that substance
(ii) Temperature change of that substance
(iii) Specific heat capacity

Heat Capacity of a Substance

Heat capacity of a substance is the amount of heat required to raise the temperature of a given mass of a substance by 1K. It denoted by letter C, SI unit of heat capacity is J/K

Mathematically:

$$\boldsymbol{Heat\ Capacity, H.C = \frac{Quantity\ of\ Heat\ absorbed,\ H}{Rise\ in\ Temperature, \Delta\emptyset}}$$

Specific Heat Capacity

Specific heat capacity of a substance is the heat required to produce a 1K or 1°C in 1kg. It denoted by letter c, SI unit of specific heat capacity is J/kg K

Mathematically:

$$\text{Specific Heat Capacity, S. H. C} = \frac{\text{Quantity of Heat absorbed,}\ \text{H}}{\text{mass x Rise in Temperature,}\Delta\emptyset}$$

Then, Quantity of Heat = MCΔθ

Specific Heat Capacities of Some Materials

Materials	S.H.C (J/kg°C)	Materials	S.H.C (J/kg°C)
Water	4200	Aluminium	900
Sea water	3900	Glass	700
Methylated spirit	2500	Steel	500
Paraffin	2200	Iron	480
Ice	2100	Copper	390
Steam	2010	Brass	320
Mercury	1395	Lead	130

Example 01,

In an experiment to determine the heat capacity of steel, 100KJ of heat energy was supplied to a block of steel initially at 22°C. If the final temperature of the block was 219°C, determine the heat capacity of steel.

Data given

Initial temperature, θ_1 = 22°C, Final temperature, θ_2 = 219°C

Heat supplied, H = 100KJ = 100000J

Heat capacity, C = ?

Solution

From:

$$\text{Heat Capacity, H. C} = \frac{\text{Quantity of Heat absorbed,}\ \text{H}}{\text{Rise in Temperature,}\Delta\emptyset}$$

Then: H.C = $\frac{H}{\Delta\emptyset} = \frac{100000J}{197K}$ = 507.60J/K

C = 507.60J/K

Example 02,
The temperature of a 6kg block of copper rises from 15°C to 30°C on being heated. Determine the amount of heat energy supplied to the block. (Specific heat capacity of block is 390Jkg°C)

Data given
Mass of copper, m = 6kg
Initial temperature of copper, θ_1 = 15°C
Final temperature of copper, θ_2 = 30°C
Temperature change, $\Delta\theta$ = (30-15)°C =15°C
Specific heat capacity of copper, C = 390Jkg°C
Heat supplied, H = ?

Solution
From: H = $mc\Delta\theta$
H = 6 x 390 x 15
H = 35 100J

How Specific Heat Capacity Determined
If a liquid of known mass and temperature putted in the inner container and a solid/liquid of known mass and temperature is added to the liquid the specific heat capacity of any substance can be calculated/determined of one of substance specific heat capacity are known.

Determination of Specific Heat Capacity
If the heat loss controlled when mixing the water, the heat energy gained by the cold water is equal to the heat energy lost by hot water due to the principle of conservation of energy.

Assume a Hot Iron is added to the Calorimeter Containing Cold Water
Mass of water = m_1
Mass of copper and stirrer = m_2
Mass of hot iron = m_3
Initial temperature of water and calorimeter = θ_1
Initial temperature of hot iron = θ_2
Final temperature (iron + water + calorimeter) = θ_3
Specific capacity of water = C_1
Specific capacity of calorimeter = C_2
Specific capacity of iron = C_3

But:
If the hot iron added to the cold water, the hot iron loss heat energy and cold water gain heat energy

From:
Principle conversion of energy, **Heat gain = heat loss**
Therefore: Heat gain by water + Heat gain by calorimeter = heat loss by hot iron

But:
Heat gain by water = $m_1C_1(\theta_3 - \theta_1)$
Heat gain by calorimeter = $m_2C_2(\theta_3 - \theta_1)$
Heat lost by iron = $m_3C_3(\theta_2 - \theta_3)$

Then:
Heat gain by water + Heat gain by calorimeter = Heat loss by hot iron
$m_1C_1(\theta_3 - \theta_1) + m_2C_2(\theta_3 - \theta_1) = m_3C_3(\theta_2 - \theta_3)$
$((m_1C_1 + m_2C_2)(\theta_3 - \theta_1) = m_3C_3(\theta_2 - \theta_3)$ make C_3 subject

$$C_3 = \frac{(m_1C_1 + m_2C_2)\,(\emptyset_3 - \emptyset_1)}{m_3\,(\emptyset_2 - \emptyset_3)}$$

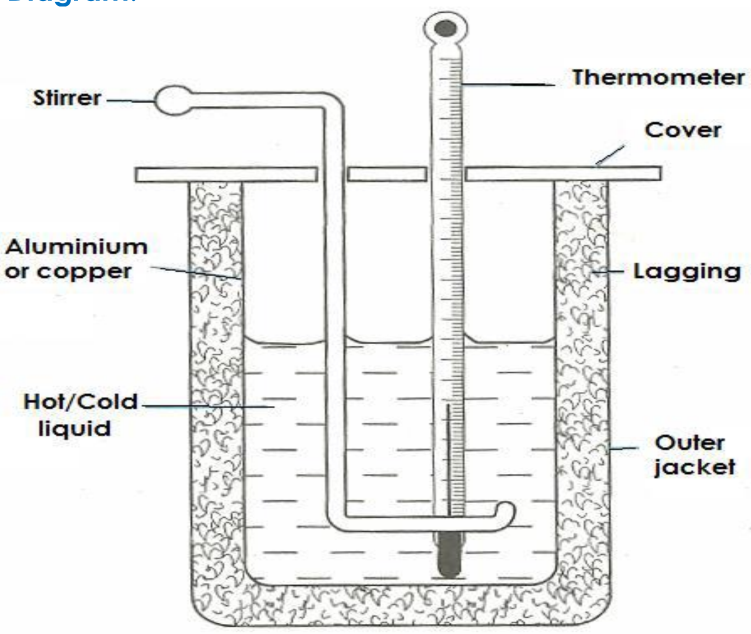
Calorimeter

Calorimeter used to control the loss of heat energy when determining specific heat capacities

(i) Inner container and stirring rod are made of the same material always aluminium or copper

(ii) The heat loss is reduced by the lagging materials (bad conductor) and the cover

The calorimeter Diagram:



Example 03,

A piece of copper of mass 40g at 200°C is immersed into a copper calorimeter of mass 60g containing 50g of water 25°C. Neglecting heat losses, what will the final temperature of the mixture be?

Data given

Mass of water, m_w = 50g = 0.05kg

Mass of calorimeter, m_c = 60g = 0.06kg

Mass of copper, m_{hc} = 40g = 0.04kg

Initial temperature of water +calorimeter, θ_i = 25°C

Initial temperature of copper, θ_f = 200°C

Specific capacity of water, C_w = 4200 J/kgK

Specific capacity of copper, C_c = 390 J/kgK

Final temperature (water + copper + calorimeter), θ_e = ?

Solution:

From:

The Principle of conversion of energy, **Heat gain = Heat loss**

Therefore:

Heat loss by hot Copper = Heat gain by water + Heat gain by copper calorimeter

$M_{hc}C_c(\theta_f - \theta_e) = M_wC_w(\theta_e - \theta_i) + M_cC_c(\theta_e - \theta_i)$

$3120 - 15.6\,\theta_e = 210\,\theta_e - 5250 + 23.4\,\theta_e - 585$

Putting like terms together

$-15.6\,\theta_e - 210\,\theta_e - 23.4\,\theta_e = -3120 - 5250 - 585$

$-249\,\theta_e = -8955$

$$\theta e = \frac{8955}{249}$$

The final temperature of the mixture, θ_e = 35.96°C

Example 04,
A brass of cylinder of mass x was heated to 100°C and then transferred into thin aluminium can of negligible heat capacity containing 150g of paraffin at 11°C. If the final steady temperature of the paraffin attained was 20°C determine the value of x

Data given
Mass of brass, m_1 = x
Mass of paraffin, m_2 = 150g = 0.15kg
Initial temperature of paraffin, θ_3 = 100°C
Initial temperature of brass, θ_1 = 11°C
Final temperature (paraffin + brass), θ_2 = 20°C
Specific capacity of paraffin, C_2 = 2200 J/kgK
Specific capacity of brass, C_1 = 320 J/kgK

Solution:
From:
Principle conversion of energy, Heat gain = Heat loss
Therefore:
Heat gain by Parafin = heat loss by a brass metal block
Then:
$m_1C_1(\theta_3 - \theta_1) = m_2C_2(\theta_2 - \theta_3)$ - make m_1 subject
$m_1 = (m_2C_2(\theta_2 - \theta_3)\ C_1(\theta_3 - \theta_1)$
$m_1 = (m_2C_2(\theta_2 - \theta_1))/(C_1(\theta_3 - \theta_2)$
$m_1 = (0.15 \times 2200(20 - 11))/(320(100 - 20)$
$m_1 = (330 \times 9)/(320 \times 80)$
$m_1 = 2970/25600$
$m_1 = 0.116$ kg
A brass of cylinder of mass x is 0.116 kg = 116g

Example 05,
A block of metal of mass 0.20kg at a temperature of 100°C is placed in 0.40kg of water at 20°C.if the final steady temperature of the water is 24°C, determine the specific heat capacity of the metal. (Neglect heat absorber by the container)

Data given
Mass of water, m_1 = 0.4kg
Mass of metal block, m_2 = 0.2kg
Initial temperature of water, θ_1 = 20°C
Initial temperature of metal block, θ_2 = 100°C
Final temperature (water + metal block), θ_3 = 24°C
Specific capacity of water, C_1 = 4200 J/kgK
Specific capacity of metal block, C_2 = ?

Solution:
From:
Principle conversion of energy, Heat gain = heat loss
Therefore:
Heat gain by water = heat loss by metal block
Then:
$m_1C_1(\theta_3 - \theta_1) = m_2C_2(\theta_2 - \theta_3)$ - make C_2 subject

$$C_2 = \frac{m_1 C_1(\emptyset_3 - \emptyset_1)}{m_2\,(\emptyset_2 - \emptyset_3)}$$

$$C_2 = \frac{0.4\ x\ 4200\ (24 - 20)}{0.2\ (100 - 24)}$$

C_2 = 442.1 J/kgK

Example 06,
A block of aluminum of mass 0.5kg at a temperature of 100°C is dipped in 1.0kg of water at 20°C. Assuming that no thermal energy is lost to the environment, what will the final temperature of the water to at its thermal equilibrium?

Data given
Mass of water, m_1 = 1.0kg
Mass of aluminum, m_2 = 0.5kg
Initial temperature of water, θ_1 = 20°C
Initial temperature of aluminum, θ_2 = 100°C
Final temperature (water + aluminum), θ_3 = ?
Specific capacity of water, C_1 = 4200 J/kgK
Specific capacity of metal block, C_2 = 900 J/kgK

Solution:
From:
Principle conversion of energy
Heat gain = Heat loss
Therefore:
Heat gain by water = heat loss by metal block
Then:
$m_1C_1(\theta_3 - \theta_1) = m_2C_2(\theta_2 – \theta_3)$ - make θ_3 subject
$(m_1C_1 + m_2C_2)\ \theta_3 = m_2C_2\theta_2 + m_1C_1\theta_1$

$$\emptyset_3 = \frac{m_2C_2\emptyset_2 + m_1C_1\emptyset_1}{m_1\ C_1 + m_2\ C_2)}$$

$$\emptyset_3 = \frac{0.5\ x\ 900\ x\ 100 +\ 1\ x\ 4200\ x\ 20}{1\ x4200 + 0.5\ x\ 900)}$$

$$\emptyset_3 = \frac{45000 +\ 84000}{4200 + 450)}$$

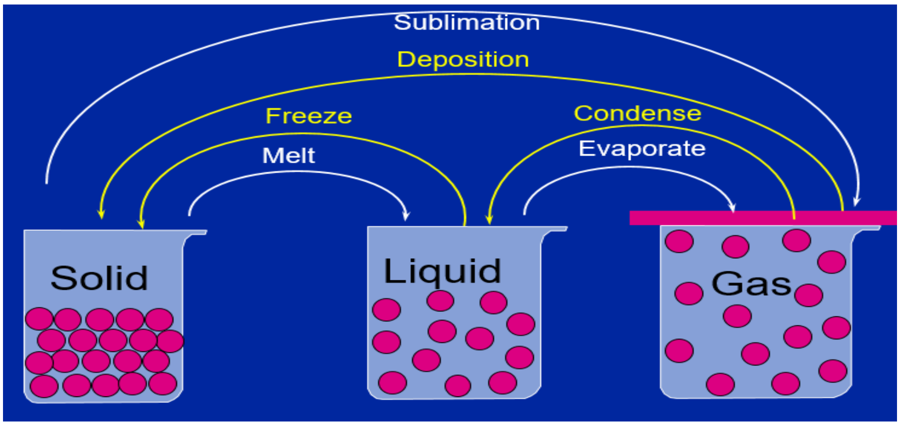
The temperature of water at its thermal equilibrium is 27.74°C

Check Your Understanding

1. A waterfall is 100m high and the difference in temperature between the water at the top and that at the bottom is 0.24. calculate the specific heat capacity of water in 1 decimal place (Ans:- 4201.7J/kg°C)
2. An insulated vessel holds 0.1kg of water at 85°C. How much water at 25°C must be poured into the water to cool it to 60°C? (Ans:-0.07kg)
3. The specific heat capacity of acetic acid is approximately one-half times that of water. Equal masses of water and acetic acid at 20°C and 80°C respectively are mixed together in an insulated cup. What will the temperature of the mixture be at thermal equilibrium? (Ans:- 40°C)
4. A block of metal of mass 0.5kg at a temperature of 100°C is placed into 2.4kg of water at 18°C. If the final temperature of the metal and water is 29°C, what is the specific heat capacity of the metal? (Ans:- 3123.3J/Kg°C)
5. A heating element rated 2kW is used to raise the temperature of 5kg of water through 60°C. Calculate the time required. SHC of water = 4200J/kg°C (630s)
6. A heater rated 120W is placed in a liquid of mass 8.5kg. When the heater is switched on for one hour, the temperature of the liquid rises from 20°C to 270°C. Determine the specific heat capacity of the liquid. (Ans: 203.29J/kg°C)
7. The temperature of 100 g of water was raised from 20 °C to 40 °C in 10 minutes by a heating coil of resistance 5.0 ohms and carrying a current of 2A. Calculate the percentage of energy lost to the surroundings. (Ans:- 70%)

As we studied in form one, matter can undergo three state changes. The states being solid, liquid and gas. Consider the diagram below.

Diagram:



Melting Point

Melting is the change of state from solid to liquid and **Melting point** is the definite temperature of a pure substance to melt. At melting point the substance absorbs heat but the temperature does not change until the substance has completely melted.

Freezing Point

Freezing is the change of state from liquid to solid and **freezing point** is the Temperature at which a liquid changes into a solid without a change in temperature. During solidification a substance loses heat to its surround but its temperature does not fall

The freezing point of a pure substance is the same as its melting point. Example, water freeze and melt at 0°C

Factors Affecting Freezing Point

- The freezing point is affected by the presence of:

(i) Impurities

- The disrupt the freezing point by impurities is called **freezing point depression**
- When an impurity is added its freezing point is lowered i.e. its freezing point decreases.
    - The depression in freezing point increases with the increase in concentration of the solute because on adding the solute the vapour pressure of solution becomes lower than that of pure solvent. Since freezing point is the temperature at which vapour pressure of liquid and solid phase are equal, therefore, for the solution, this will occur at a lower-temperature.
    - For example the freezing point of water is O °C under normal atmospheric pressure. If we add sugar or salt to this water its vapour pressure lowers and freezing point decreases.
- Generally, when 1 mole of any non-electrolyte is dissolved in 1 litre of water the depression in freezing point of water is 1.86°C.

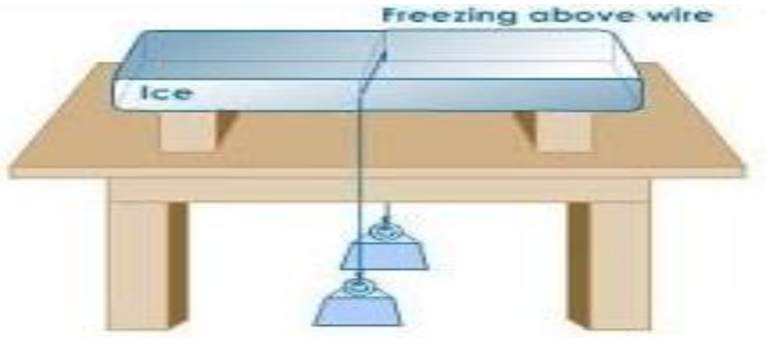
(ii) Pressure change

- **Regelation is** the phenomenon of melting under pressure and re-freezing when the pressure is reduced.
- The disrupt the freezing point by impurities is called **freezing point**
- The melting point of ice falls by 0.0072°C for every additional 100000 Pa (1×10^5 Pa) of pressure.

  For Example, a pressure of 1.27×10^7 Pa is needed for ice to melt

The Phenomenon of Regelation

- Regelation is the Refreezing process which takes place when the wire is observed to Cuts right through the ice block and falls on the floor.



Boiling Point

Boiling point is the temperature at which all liquid change into gas

Mechanism of Boiling

The molecules at the surface of the liquid gain more kinetic energy move faster and are able to overcome intermolecular forces holding them together and hence escape.

Points to note:

(i) At the boiling point the vapour pressure of the liquid becomes equal to atmospheric pressure
(ii) Each pure substance has an exact boiling point.
(iii) At the boiling point the heat energy supplied is used to change the water from the liquid to vapour state
(iv) At the boiling point does not raise the temperature.

Boiling Point of Some Pure Substance

Substance	Boiling point (°C)	Substance	Boiling point (°C)
Hydrogen	-253	Mercury	357
Oxygen	-183	Aluminium	2 467
Ethyl alcohol	78.4	Copper	2 567
Water	100	Iron	2 750

Factors Affecting Boiling Point

– The boiling point is affected by the presence of:

(i) Impurities:

– impurities raise the boiling point of a liquid (its boiling point is elevated)
  - The elevation in boiling point increases with increase in concentration of the solute because when adding the solute vapour pressure of the solution becomes lower than pure solvent. Thus the solution has to be heated more to make the vapour pressure equal to atmospheric pressure. Thus the boiling point gets elevated (increased).
  - For example boiling point of water is 100°C under normal atmospheric pressure. If we add sugar or salt to this water its vapour pressure becomes lower and boiling point increases.

– Generally, when 1 mole of any non-electrolyte is dissolved in 1 liter of water the elevation of boiling point is 0.53 °C

(ii) Pressure change
  - pressure raise the boiling point of a liquid
  - the boiling point of water is 100°C at pressure of 1 x 10^5 Pa and 101°C at pressure of 1.05 x 10^5 Pa of pressure
  - Also as altitude increase pressure decreases, hence boiling point lowers

Conclusion

(a) The impurities present in a liquid pull its two fixed points away from each other i.e. the freezing point is lowered while the boiling point is raised.
(b) The depression in freezing point and the elevation in boiling point increases with increase in the concentration of the solute or impurity i.e. these are the colligative properties that depends only on the no. of moles of the solute. They are independent of the nature of the solute.
(c) If a substance expands on solidifying, e.g., water, then the application of pressure lowers its melting point. If a substance contracts on freezing, the pressure raises its melting point, e.g., paraffin wax.
(d) The freezing point of water is lowered by 0 .007 °C per atmosphere increase in pressure, whereas that of paraffin wax increases by 0.04 °C per atmosphere increase in pressure.
(e) When a liquid is heated, its temperature rises and eventually remains constant.
(f) Boiling is the process of forming bubbles of vapour inside the body of a liquid rising to the surface of a liquid. The process usually depends on external pressure above the liquid.

Boiling Point Of Water at Different Altitudes

Altitude(m)	Pressure (mmHg)	Boiling point (°C)
300	732	99.0
600	706	98.0
900	681	97.0

Evaporation is the change of state from liquid to gas (vapour)
Points to note:

Evaporation is more rapidly when there is **windy**, **sunny** and **less humidity**

Different Between Boiling and Evaporation

Boiling	Evaporation
Occurs at a definite temperature which is boiling point	Occurs at any temperature
Occurs within a liquid with formation of bubbles	Occurs at the surface of the liquid
Has no cooling effect	Has cooling effect
Takes place rapidly	Takes place slowly

Latent Heat

Latent heat is the heat absorbed/gives out when matter changes its state without change in temperature.

Latent Heat of Fusion

Latent heat of fusion is the heat absorbed when matter changes from solid to liquid at a constant temperature.
Points to note:

(i) if matter melt it means latent heat of fusion increase
(ii) if the liquid change to solid means the latent heat of fusion gives up or decreased

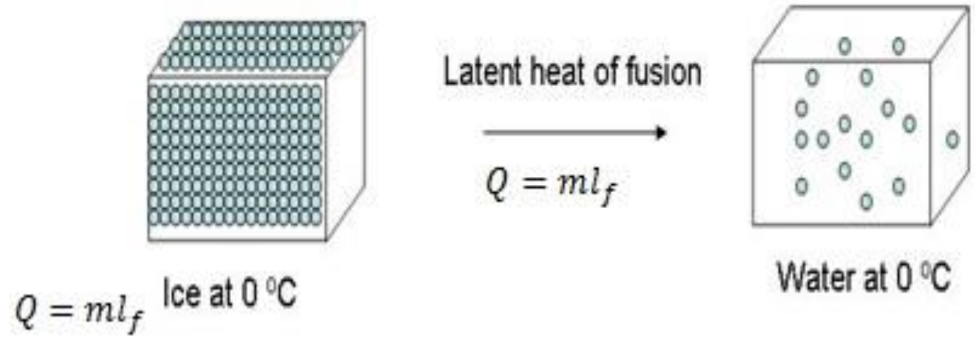
Specific Latent Heat of Fusion

Specific latent heat of fusion of a substance is the quantity of heat energy required to change completely a unit mass (1kg) of the solid to liquid at its melting point.
Its SI Unit is **J/kg**
Mathematically:

$$Lf = \frac{H}{m}$$

Melting/Freezing Point Of Substance at STP

Substance	Melting/freezing point (°C)	Latent heat of fusion (J/kg)
Aluminium	659	396000
Copper	1086	134000
Iron	1535	293000
Water	0	335000
Mercury	-39	11000
Ethyl alcohol	-117	105000



Latent Heat of Vaporisation

Latent heat of vaporisation is the heat absorbed when matter changes from liquid to gas (vapour) at normal boiling point.

Points to note:

(i) if matter form vapour means latent heat of vaporisation increase
(ii) if the vapour change to liquid means the latent heat of vaporisation gives up or decreased

Specific Latent Heat of Vaporisation

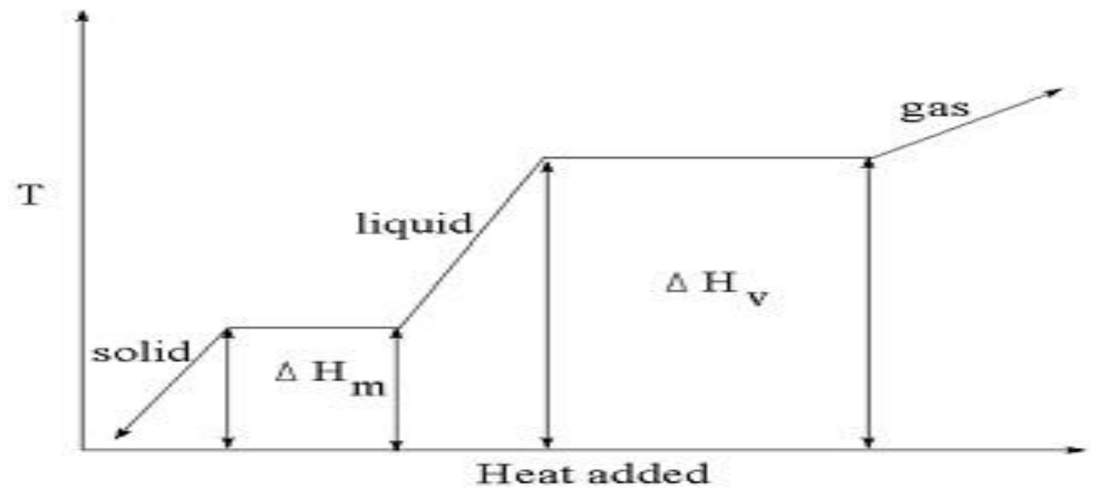
Specific latent heat of vaporisation of a substance is the quantity of heat energy required to change completely a unit mass (1kg) of the liquid to gas at its boiling point. Its SI Unit is **J/kg**

Mathematically:

$$Lv = \frac{H}{m}$$

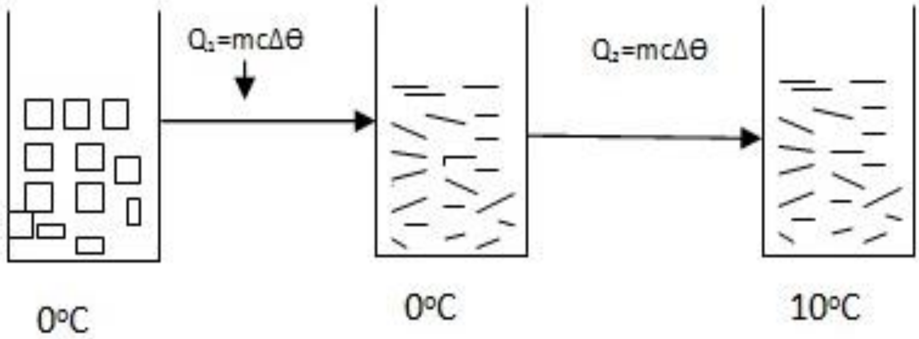
H = m x Lv

GRAPHICAL REPRESENTATION OF CHANGE OF STATE



Example 01

8g of ice at 0°Cis heated so that it forms water at 10°C. Calculate the total quantity of heat required to do so given that the Specific Heat Capacity of water 4200 J/KgK. The specific latent heat of fusion of ice is 334000J/KgK.



QT = $Q_1 + Q_2$

QT = $Mlf + MC\Delta\theta$

QT = 0.08 x 334000 + 0.008 x 4200 x 10

QT = 3008

The energy required is 3008 Joules

Example 02

0.6 kg of ice at - 10°C is dropped into 2kg of Water 49°C contained in a Copper calorimeter of mass 0. 15kg. If the final temperature of the Mixture is 20°C fin d the specific latent Heat of fusion of ice.

Where: Specific Heat capacity of ice = 2.1 x 10^3 J/ Kg°C

Specific Heat capacity of copper = 420 J/ Kg °C

Specific Heat Capacity of Water = 4200 J/ Kg ° C

Solution

Heat gained by ice from - 10 °C to 0°C = (0.6 x2100 x10) = 12600J

Heat gained when ice at 0°C to water at 0°C = 0.6L;

Where L is the latent heat of fusion of ice

Heat gained by cold Water in warming up from 0°C to 20°C = (0.6x4200 x 20)

= 50400 J

Heat lost by Copper + Water from 49°C to 20°C = 0.15x420x29 + 2x4200x29

But

Total Heat gained = Total Heat lost

12600 + 0.6 L + 50400 = 243600 + 1827

L = (245427 – 63000) ÷ O.6

L = 304,045 J/ Kg

Example 03

The Specific Latent Heat of vaporization of liquid is 2260000J/kg, Specific Latent Heat of fusion of ice is 334000J/kg, the Specific Heat Capacity of ice is 2100J/kgK, Specific Heat Capacity of water 4200J/kgK, calculate the heat required to convert 2kg if ice at -12°C to steam at 100°C.

Solution

$Q_T = Q_1 + Q_2 + Q_3 + Q_4$

$Q_T = MC\theta + ML_f + MC\theta + ML_v$

$Q_T = (2\times2100 \times 12) + (2\times334000) + (2\times4200\times100) + (2\times2260000)$

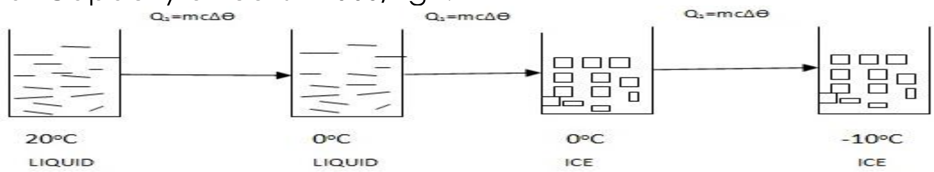
$Q_T = 50400 + 668000 + 840000 + 4520000$

$Q_T = 6078400J$

Therefore; the heat required to convert 2kg of ice to steam is 6,078,400J

Example 04

A refrigerator can convert 400g of water at 20^0C to ice at -10^0C in 3hrs. Find the average rate of heat extraction from water in J/sec given that the Specific Heat Capacity is 4200J/kgK. The Specific Heat Capacity of fusion of ice is 336000J/kg. The Specific Heat Capacity of ice is 2100J/kgK.



Qt = Q1 + Q2 + Q3

Qt =$MwCw\Delta\theta$ + MLf + $MiCi\Delta\theta$

= 0.4 x 4200 x 20 + 0.4 x 336000 + 0.4 x 2100 x 10

= 176400J

$$Power = \frac{Energy}{Time}$$

$$Power = \frac{176400}{10800}$$

∴ **The average rate of heat extraction is 16.3 J/s.**

Example 05,

How much heat would be required to change 1.5kg of ice at -10°C to stream at 120°C.? The specific heat capacities of ice, water and stream are 2144J/kg°C, 4186 J/kg°C and 2010 J/kg°C respectively

Data given

Mass of ice/water/stream, m = 1.5kg

Ice Temperature change, $\Delta\theta i$ = (0 - -10)°C = 10°C

Water Temperature change, $\Delta\theta w$ = (0-100)°C = 100°C

Stream Temperature change, $\Delta\theta s$ = (120-100)°C = 20°C

Specific capacity of ice, C_i = 2144 J/kg°C

Specific capacity of water, C_w = 4186 J/kg°C

Specific capacity of stream, C_s = 2010 J/kg°C

Specific Latent heat of fusion, L_f = 335000 J/kg

Specific Latent heat of vaporisation, L_v = 2270000J/kg

Heat require to raise the ice temperature, H_i = ?

Heat require to melt ice, Hm = ?

Heat require to raise the water temperature, Hw = ?

Heat require to convert water to stream, He = ?

Heat require to raise the stream temperature, Hs = ?

Heat required to change ice to stream, Ht = ?

Solution:

But: Ht = Hi + Hm + Hw + He + Hs

Then:

$H_i = mc_i\Delta\theta_i$ = 1.5 x 2144 x 10 = 3216J

Hm = m x Lf= 1.5 x 335000 = 502500J

$H_w = m_w c_w \Delta\theta_w$ = 1.5 x 4186 x 100 = 627900J

He = m x Lv = 1.5 x 2270000 = 3,405,000J

$Hs = m_s c_s \Delta\theta_s$ = 1.5 x 2010 x 20 = 60300J

From: Ht = Hi + Hm + Hw + He + Hs

Ht = 3,2160J + 502, 500J + 627, 900J + 3,405,000J + 60,300J

Ht = 4, 627, 860J

Point to note: - Stream has much more thermal energy than liquid thus why steam is used in engines to convert thermal energy to mechanical energy

Latent Heat of Vaporization basing on time intervals

Experiment on Specific latent heat of vaporization, SLHV of water

1. Weigh a dry clean beaker
2. Pour some water at 0°C
3. Gently heat the water and stir
4. Record the time after which the water in the beaker starts boiling
5. Continue heating and stirring the water until all the water in the beaker has boiled away.
6. Record the time taken by the water to vaporise

Method of calculation

- Mass of beaker = m_1 kg
- Mass of beaker + water = m_2 kg
- Time taken to boil = t_1 minutes
- Time taken to boil away = t_2 minutes
- Specific heat capacity of water = C_w
- Specific latent heat of vaporization of water = L J/kg
- Heat gained by water = $(m_2 – m_1)C_w$ x 100
- Heat gained by steam = $(m_2 – m_1)L$

$$\frac{Heat\ gained\ by\ steam}{Heat\ gained\ by\ water\ up\ to\ B.P} = \frac{Time\ taken\ to\ evaporate\ (boil\ away)}{Time\ taken\ to\ boil}$$

$$\frac{(m_2 - m_1)L}{(m_2 - m_1)C_w\,x100} = \frac{t_2}{t_1}$$

$$\mathbf{L = \frac{100C_wt_2}{t_1}}$$

Example 06

In an experiment to determine the specific latent heat of vaporization of water, a certain amount of water was heated in a beaker. The water boiled in 15 minutes and vaporized completely in 80.7 minutes. If the specific heat capacity of water is known to be 4.2 x 10^3 J/kg°C, calculate the specific latent heat of vaporization of water.

Solution

Specific heat capacity of water, C_w = 4.2 x 10^3 J/kg°C
Time taken to boil the water, t_1 = 15 minutes
Time taken to vaporise all the water, t_2 = 80.7 minutes
If the boiling of water is 100°C, then

$$\mathrm{L} = \frac{100C_wt_2}{t_1}$$

$$\mathrm{L} = \frac{100 \text{ x } 4.2 \text{ x } 10^3 x\ 80.7}{15}$$

$$\mathrm{L} = 2259.6 \text{ x } 10^3 J/kg$$

The specific latent heat of vaporization is 2259.6 kJ/kg

Practical applications of latent heat and its effects in our day to day lives

When liquid evaporate latent heat of is absorbed from the liquids if no heat is supplied from outside this result cooling.

(i) Cooling drinks

- An ice-cube is more effective in cooling a drink on a summer's day than would be an equal mass of cold water. One could say that a little ice cools a lot of water.

(ii) Heating with steam

Heating with steam
A scald (burn) from steam is always more painful than that from boiling water. This is because steam condenses on the skin, and in so doing releases the latent heat of vaporisation. This heat energy causes vibrations which traumatise the skin tissue, creating the sensation of pain. (It is always advisable to cool the area with cold running water.)

(iii) Aftershave or skin tonic

- When applied to the face makes the wearer feel fresher. Because these preparations contain alcohol, which is a volatile liquid, evaporation takes place quickly, so the skin feels cooler and fresher.

(iv) Wrapping a damp cloth around bottles

- Campers often realise that it is more effective to wrap a damp cloth around bottles or cartons of milk to keep them cool, rather than placing them in a jar of water. The water evaporating from the cloth around the milk takes heat energy from the milk, thereby cooling it.

(v) Anaesthetized skin before injection

- Very often a nurse or doctor, before giving a patient an injection, will rub the area first with a volatile liquid. This acts as an antiseptic but also, as the liquid evaporates quickly, the skin is left cooler and slightly anaesthetized (deadened)

(vi) Sponging the forehead

- To help a person with a very high temperature, which is more effective: to sponge the forehead with cold water or with tepid water? The warm (tepid) water is better. Because of its higher temperature, the tepid water will evaporate at a faster rate. It is then the latent heat absorbed from the body which cools the patient down.

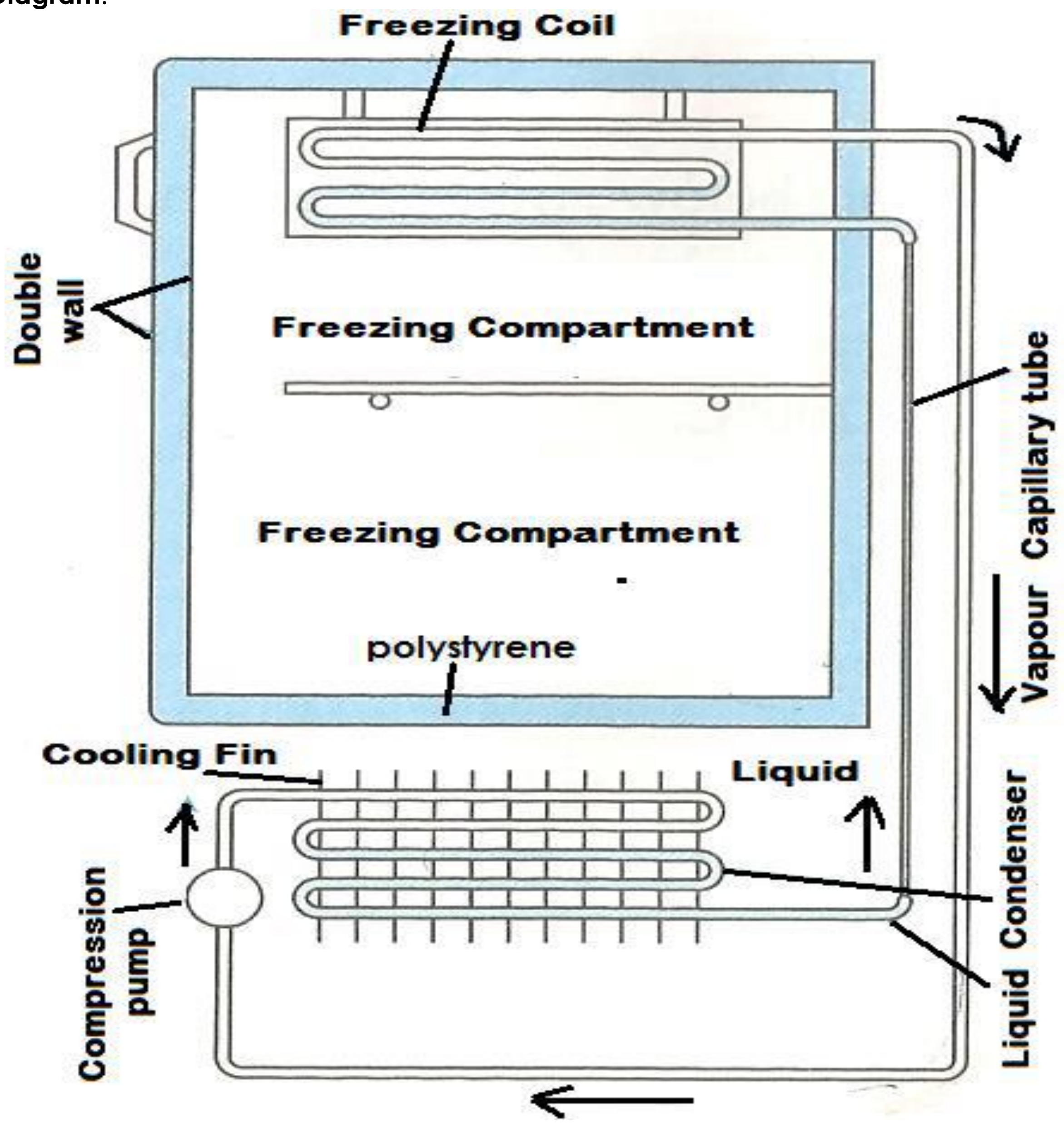
(vii) Cooling Of Human Body

- When it is too hot, sweat glands release water which then evaporates from the skin taking away latent heat of vaporisation. This cause body to cool

(viii) The Refrigerator

- Cooling of refrigerator is due to evaporation of Freon (chlorofluorocarbons (CFCs) which contribute to global warming) inside a copper coil surrounding the freezing unit. It uses polystyrene as thermal insulator.
- It uses the evaporation of a liquid to absorb heat. You probably know that when you put water on your skin it feels cool. As the water evaporates it absorbs heat and creates the cool feeling. Rubbing alcohol feels cooler THAN water because it evaporates at a lower temperature and quicker than water.
- The liquid, or refrigerant, used in a refrigerator evaporates at an extremely low temperature so it can create freezing temperatures inside the refrigerator. If you were to place your refrigerator's refrigerant on your skin it would freeze your skin as it evaporates.

Diagram:



Mechanism of Refrigerator

(a) The refrigerator works by using latent heat. A special liquid with a high S.L.H. and low boiling point like Freon is pumped through a system of closed pipes through a valve.

(b) A compressor maintains a higher pressure on one side of the expansion valve than on the other.

(c) Because the pressure of the liquid is reduced when it passes through the valve, it expands and vaporises, absorbing the necessary latent heat from inside the fridge (the cold body).

(d) On the high pressure side of the valve the vapour is compressed and liquefies once again, releasing its latent heat of vaporisation to the surroundings (the warm body) through the cooling fins which makes the compartment to cool.

(e) We may notice that pipes at the back of a refrigerator are warm, and it is important to allow sufficient space for the circulation of air.

(f) This process repeater and cause the temperature in the refrigerator become quite low.

Check Your Understanding

1. Steam is bubbled into a vessel containing a quantity of water and 20g of ice at 0^oC. The mass of the vessel and its contents is then found to increase by 2g. Calculate the percentage of ice melted. Given that S.H.C of water = 4200J/kg^{o}C, S.L.H of vaporization of water = 2.268×10^6J/kg and S.L.H of fusion of ice = 3.36×10^5J/kg. (Ans:- 90%)
2. A metal cylinder of mass 0.10kg and S.H.C 360J/kg^{o}C was heated to 110^{o}C and transferred to a vessel of negligible heat capacity containing 0.15kg of a liquid at 12^{o}C, if the final steady temperature was 20^{o}C; calculate the specific heat capacity of the liquid. (Ans:- 3300J/kg^{o}C)
3. A 20kW immersion water heater is used to heat 5.0×10^{-3} kg of water from 23^{o}C to 100^{o}C. Given that 30% of the heat is lost to the surroundings, determine the time used in heating the water [The S.H.C of water = 4200J/kg^{o}C; density of water = 1000kg/m^3] (Ans:- 8.66 sec)
4. A piece of metal with a mass of 200g at a temperature of 100^{o}C is quickly transferred into 50g of water at 20^{o}C. Find the final temperature of the system. [specific heat capacity of water = 4200J/kg^{o}C, specific heat capacity of a metal is 400J/kg^{o}C](Ans:- 42.07 ^{o}C)
5. The temperature of 0.20kg of water is raised from 10^{o}C to the boiling point in 5 minutes by a steady supply of heat. Calculate
   (i) The rate of heat supply (Ans:- 252W)
   (ii) The time taken after boiling starts to boil away all the water (Ans:- 30min)
   (S.H.C of water = 4200J/kg^{o}C, S.L.H of vaporization of water = 2.268×10^6J/kg)
6. Steam at 100^{o}C was passed into 500g of cold water at 8^{o}C until its temperature rose to 100^{o}C. Calculate the mass of steam that condensed to warm the water, if no heat was lost during the operation. (S.L.H of vaporization of water = 2.3×10^6J/kg, S.H.C of water = 4200J/kg^{o}C). (Ans:- 0.084kg)
7. A beaker containing water is heated from a temperature of 20^{0}C to 100^{0}C. State and explain what happens to the mass, volume and density of the water.
8. A copper block of mass 0.67kg is suspended in a freezing mixture at -50^{o}C for some time and then transferred to a large volume of water at 0^{o}C. A layer of ice is formed. (S.L.H of water = 2.3×10^6J/kg, and and S.H.C of copper 400J/kg^{o}C).
   (i) explain why ice is formed
   (ii) What will be the temperature of the copper block after this change is complete? And Calculate the mass of ice formed. (Ans:- 0.04kg)
9. An ice 600g at -20^{0}C is dropped into 2000g of water at 49^{0}C contained in a copper calorimeter of mass 0.15kg. If the final temperature is 20^{0}C, find the specific latent heat of fusion of ice.
   Specific heat capacity of ice = 2.1×10^3 J/kg^{0}C,
   Specific heat capacity of copper = 420 J/kg^{0}C
   Specific heat capacity of water = 4.2×10^3 J/kg^{0}C
10. An iron bar of mass 80g is heated from a temperature of 15^{0}C to a temperature of 65^{0}C. How much heat is absorbed by the bar, given that iron has a specific heat capacity of 460J/kg^{0}C?
11. In an experiment to determine the specific latent heat of vaporization of water, a certain amount of water was heated in a beaker. The water boiled in 20.2 minutes and vaporized in 80.8minutes. If the Specific heat capacity of water = 4.2×10^3 J/kg^{0}C, calculate the Specific latent heat of vaporization of water.
12. A refrigerator can convert 0.4kg of water at 20^{0}C to ice at -20^{0}C in 3hours. Find the average rate of heat extraction from the water in joules per second.

13. A piece of metal of specific heat capacity 840J/kg^{0}C and mass 30g is heated to a temperature of 99^{0}C and then dropped into a cavity in a block of ice at 0^{0}C. Find the amount of ice that will melt.
14. An immersion heater rated 120W is placed in a liquid of mass 5kg. When the heater is switched on for 20 minutes, the temperature of the liquid rises from 25^{o}C to 135^{o}C.determine the specific heat capacity of the liquid.
15. Explain briefly with the aid of diagram why the freezing cabinet of a domestic refrigerator is fixed in the upper part and not in the lower part of it.
16. In an experiment to determine the specific heat capacity of water using a thick walled copper calorimeter, the following observations were made;
    Mass of calorimeter = 900g,   Initial (room) temperature of calorimeter = 24.0^{0}C
    Specific heat capacity of copper = 400J/kg^{0}C,
    Temperature of the boiling water = 100.0^{0}C
    Final temperature of the calorimeter = 86.0^{0}C,
    Mass of calorimeter + water = 1280.0g
    What value for the specific heat capacity of water do these figures give?
17. In an experiment to determine the specific heat capacity of a piece of metal, the following results were obtained:-
    Mass of piece of metal = 200g, Initial temperature = 25^{0}C
    Final temperature = 80^{0}C, Heat absorbed by the piece of metal = 1430J
    Calculate the specific heat capacity of the piece of metal
18. A steam of mass12g at 100^{o}C is bubbled into water of mass 700g at 0^{o}C. The final temperature of the mixture is Q. if the heat absorbed by the container is negligible, determine Q given that specific latent heat of vaporization of steam is 2260kJ/kg, specific heat capacity of water = 4200J/kg^{o}C
19. A lump of metal of mass 2.5kg at 200^{o}C is immersed into a lagged calorimeter of negligible heat capacity containing 1.2kg of water at 20^{o}C. The temperature of the mixture after thoroughly stirring attained an equilibrium temperature of is 36^{o}C. Given that, the specific heat capacity of water is 4200J/kg^{o}C) determine the specific heat capacity of the metal.
20. A water boiler containing 150kg of water at a temperature of 20^{0}C is connected to the 240V power supply. Given that the resistance of the heating coil in the boiler is 25Ω, how many kilowatt-hours of electricity will be consumed if the water in the boiler is heated for 1.52 hours to a temperature of 40^{0}C?(Ans:- 3.5KwH)
21. Explain the following observations
    (a) When one wipes spirits on the skin he feels cold.
    (b) Water being heated while covered boils faster than uncovered water.
    (c) When snow is pressed by the hands, it melts to water. The water then freezes immediately after the hand is removed.
    (d) The boiling point of water in Dar is higher than at the top of Mt. Meru.
22. When a falling hailstone is at a height of 2.00 km its mass is 2.50 g. What is its potential energy? Assuming that all of this potential energy is converted to latent heat during the fall, calculate the mass of the hailstone on reaching the ground. Take the specific latent heat of fusion of ice to be 3.36×10^5 J kg^{-1} and the acceleration due to gravity to be 9.81 m s^{-2} (Ans:- , P.E = 49g, m_i=2.354 g)

11. INTRODUCTION OF HEAT TRANSFER

Heat as an energy, can transferred from one place to another in three ways:-

(i) conduction of heat
(ii) convection of heat
(iii) radiation of heat

Conduction of Heat

Conduction is the transfer of heat though matter from a region of high temperature to region of low temperature without actual movement of the medium

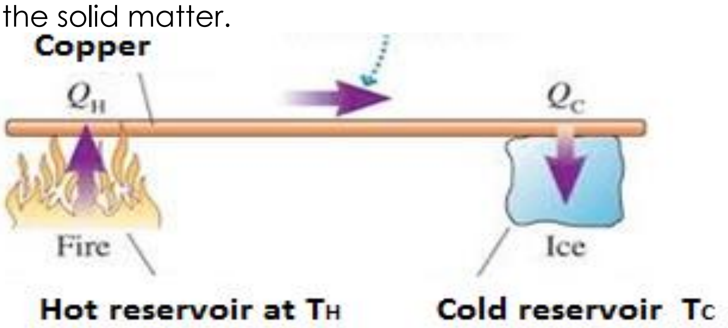
The Concept of Conduction of Heat

- Heat is a form of energy which flows as a result of temperature difference.
- Consider objects A and B.

- Let θ_1 to be the temperature of object A and
  θ_2 to be the temperature of object B , Such that θ_1 is greater than θ_2
- Then the heat energy therefore flows from object A toward object B.

Conduction:

- Conduction is the transfer of heat through matter (solids) from a region of high temperature to the region of low temperature.
- The movement of energy from one atom to another without the movement of the matter itself.
- The atom is bonded to neighbouring atoms, when heat is supplied to a part of solid matter, the atom is vibrating, and the vibration is passed on to the neighbouring atom through the bonds. This process spreads the heat throughout the solid matter.



How Transferred?

When heat is supplied to one part of a solid, the atoms vibrate faster. This vibration is passed on to neighboring atoms through the bonds. This spreads the heat throughout the object.

- Conduction is the transfer of heat energy through solids, for example, metals.
- Generally solid substances contain particles which are close together. Each particle vibrates at one position but cannot move to another position.
  - Solid materials differ greatly in their ability to conduct heat.

Good and Bad Conductors of Heat

- Solid materials differ greatly in their ability to conduct HEAT.

Good conductors

- These are the substances which allows the passage of heat energy easily example all metals
- But the rate of conduction differ from one another
- Metals contain tiny particles called electrons (particles that carry electricity through metals) which are free to move inside the metal and carry energy from hotter places to colder places.
- When the metal is heated the electrons which move around the lattice structure carry thermal energy from a region of high temperature to region of low temperature.

Good conductor	Bad conductor
copper	Air
Silver	Glass
Aluminum	Wood
Brass	Asbestos
Iron	Water
Steel	

Bad conductors

These are materials which do not allow the passage of heat and electricity e.g Non – metals, woods. Sometimes are called thermal Insulator e.g. glass, plastic, clothes, rubber and wood

The factor affecting the rate of conduction of heat

(i) The rate of conduction of heat is inversely proportional to the length of material. The longer is the material the more the time it takes to conduct heat and vice versa.

(ii) The rate of conduction of heat is inversely proportional to the cross sectional area of the material perpendicular to the heat flow. The larger is the cross section area the faster is the rate of conduction of heat.

(iii) The rate of conduction is directly proportional to the difference in temperature between the two ends of the material. The higher the temperature difference the higher the rate of conduction of heat and vice versa

(iv) The rate of conduction depends on the thermal conducting of the material (nature). The thermal conductivity is the measure of the rate at which a material conducts heat the higher the thermal conducting of the material, the higher is the rate of conduction of heat vice versa.

How Can We Minimize Conduction?

It can be minimized by **thermal insulator**. Thus why in boiler, hot-water pipes and in the textile industry thermal insulator are used

Also can be prevented by keep the place vacuum or filling with fluid, Example, double-glazed windows used in our house in cold region.

Not only that in our houses we use carpets curtains and drought excluders

Application of Conduction

(i) Cooking vessels are made of metal, which are good conduct.

(ii) Aluminium is used in making motor engines, piston and cylinders due to its low density and high thermal conductivity

(iii) Our closes is thermal insulator in order to prevent heat loss from our body

(iv) The bottoms of cooking pots need periodic cleaning to remove layers of soot, which impede the flow of heat
(v) Fiberglass is used under roofs of buildings to prevent heat loss in cold areas
(vi) Sawdust is used for lagging hot-water pipes

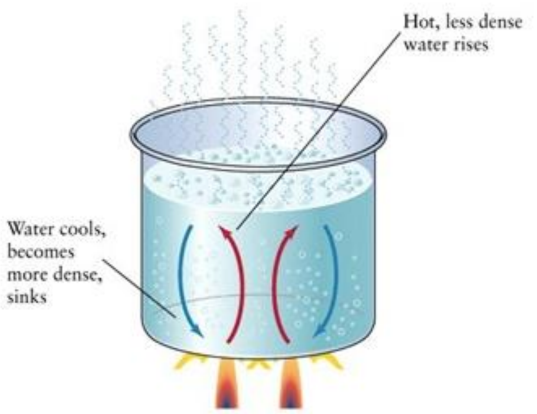
Conduction of Heat Energy through fluids

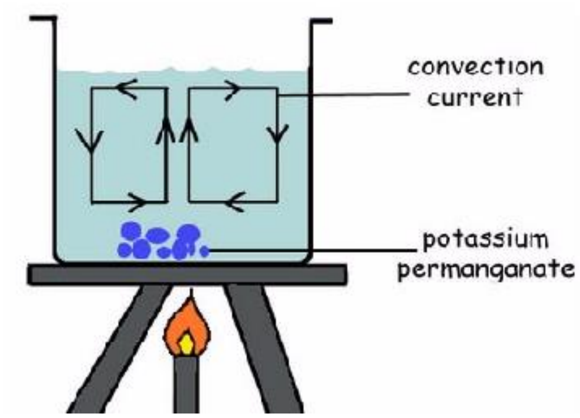
- All liquids expect mercury are poor conductors of heat.
- Gases are far worse conductors of heat than liquids.
- Fluids are bad conductors of heat. They transfer heat by means of convection

Convection of Heat

Convection is the transfer of heat in fluid (liquids and gases) which involves actual movement of the medium. If temperature of fluid increases it tend to cause convection current which circulate heat continuously throughout the fluid.

Diagram:



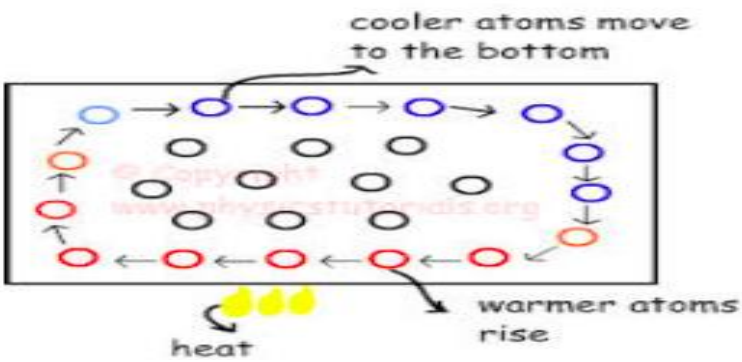


Convection in Fluids in Terms of Kinetic Theory of Matter

- Convection currents are the currents of a liquid that move from the bottom to the top of the liquid container when the liquid is heated.
- The heated liquid expands and becomes less dense and so can float upwards and replaced by colder denser liquids that sinks.

Convection in gases

- Convection air current occurs due to the unequal Heating of the Earth's atmosphere by the sum. (Thus current called strong convection current).



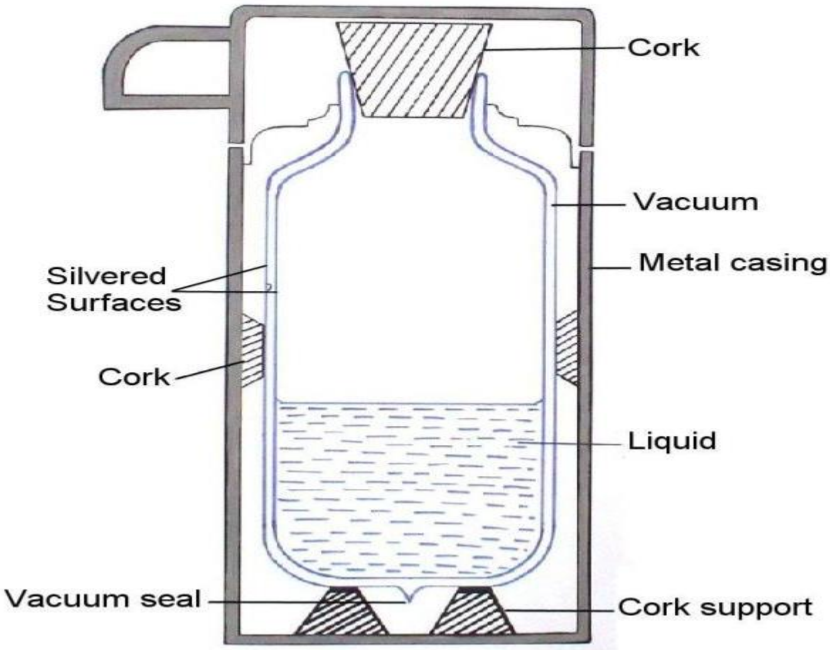
How Can We Minimize Convection?

It can prevented by keep the place vacuum, Example, vacuum flask prevent heat loss by vacuum.

Thermos Flask

Thermos flask is a device used to hold hot or cold liquid for long period. It consists of a double-walled glass (polished by coated with a thin layer of aluminium) container with vacuum between the walls. It has a stopper made of insulating materials

Diagram:



How Thermos Flask Prevents Heat Lost?

It holds by guarantying that heat loss by conduction, convection and radiation is highly minimized or completely prevented.

How vacuum flask prevent heat losses.

The vacuum prevents the loss of heat through all three ways as follows;

(i) Conduction	The container made by glass prevents heat loss by conduction since glass is poor conductor. Also by closing the vacuum using the stopper made of rubber or wood.
(ii) Convection.	Convection is prevented by the space between the walls of the vacuum.
(iii) Radiation.	Radiation is prevented by the use of silvered surfaces which reflects any radiant energy coming from inside or outside the flask.

Application of Convection

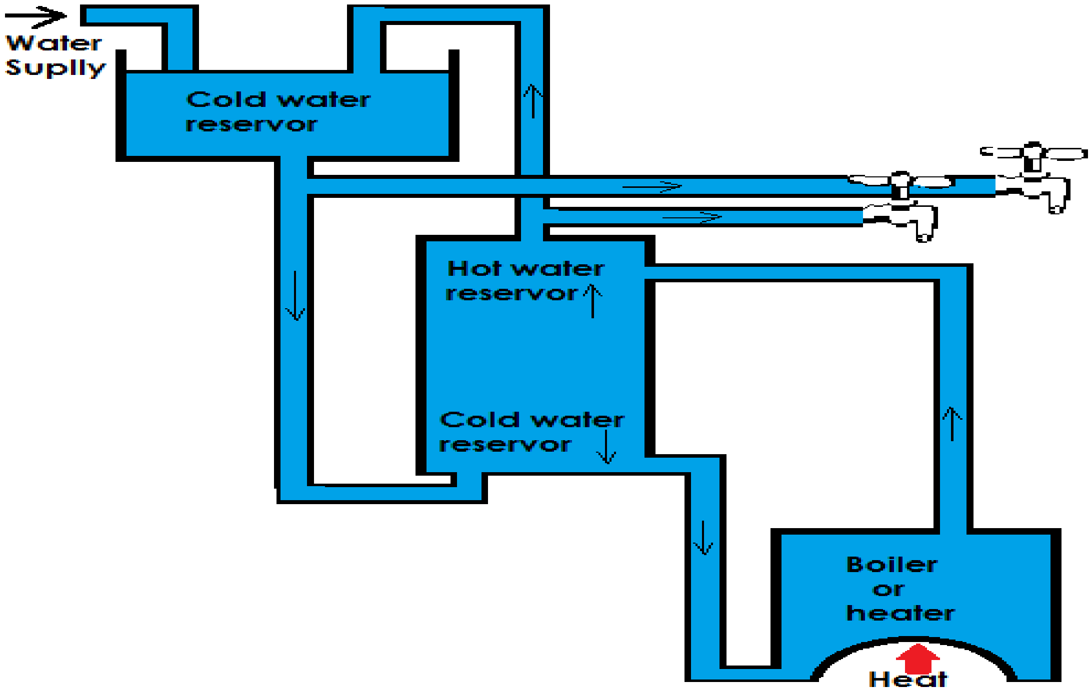
(i) Domestic hot water supply system

This system uses convection current to move warm water from the boilers to where it is needed.

- Hot water moves from the boiler to where it is used under convection current.
  - Convection currents are used to circulate hot water from a boiler in a domestic hot water system.
  - The system consists of a boiler/heater, a hot water storage tank and cold water supply tank (system) all connected by pipes.
  - When water is heated (electrically or by fire) at the button of the boiler, it expands and become less dense, and so rises to the top.
  - The hot water in the boiler passes through the outlets at the top of the boiler into the upper part of the hot water storage tank.

- The lower portion of the storage tank is filled with cold water from the cistern, which is high enough to drive the hot water out when the hot water tap T is open.
- The cistern is fitted with a ball-cock which maintains the level of water in the cistern by allowing water in when the level falls.

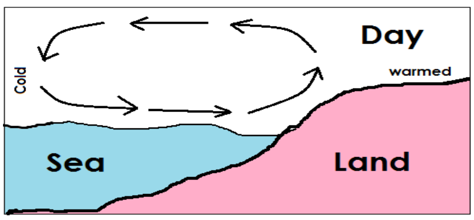
Diagram:



(ii) Land and sea breezes

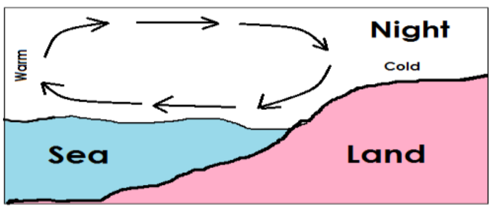
During the day the heat from the sun warm the land with its air than the sea surface with its air. The warmed air in the land increases kinetic energy and tends to decrease its density which cause the air to rise, the cold air from the sea surface comes to replace the warmed air, which result wind from the sea to the land. This called **sea breeze**

Diagram:



During the night the land lose heat and become cold than sea surface which result to air at sea surface to increases kinetic energy and tends to decrease its density and rise, the cold air from the land surface comes to replace the warmed air which results to wind from the land to the sea called **land breeze.**

Diagram:



(iii) Air conditioning systems

This system relied on convectional currently to heat of cool a room.

- When it is hot, cool air is blown into the room from the air conditioner.
- This sinks to the bottom of the room taking place of the less dense warmer air (warmer air rises and is lead out to be cooled the recirculates).
- When it is cold, the heated is turned on heating the surrounding air. The heated air rises up and cold air moves down to take the place of the rising warm air.

This forms convectional current which continue to circulate until the air in the room is at the desired temperature.

Radiation of Heat

Radiation is the heat transfer between two or more bodies by means of electromagnetic waves that do not need material medium.

Points to note:-

(i) It takes place in a vacuum
(ii) All bodies at temperature above absolute zero emit some radiant energy
(iii) Between the sun and the earth's atmosphere is a vacuum
(iv) Radiant travels with the speed of light
(v) Radiant can be reflected
(vi) Radiant can be absorbed
(vii) Radiant can be transmitted

Radiant Detector

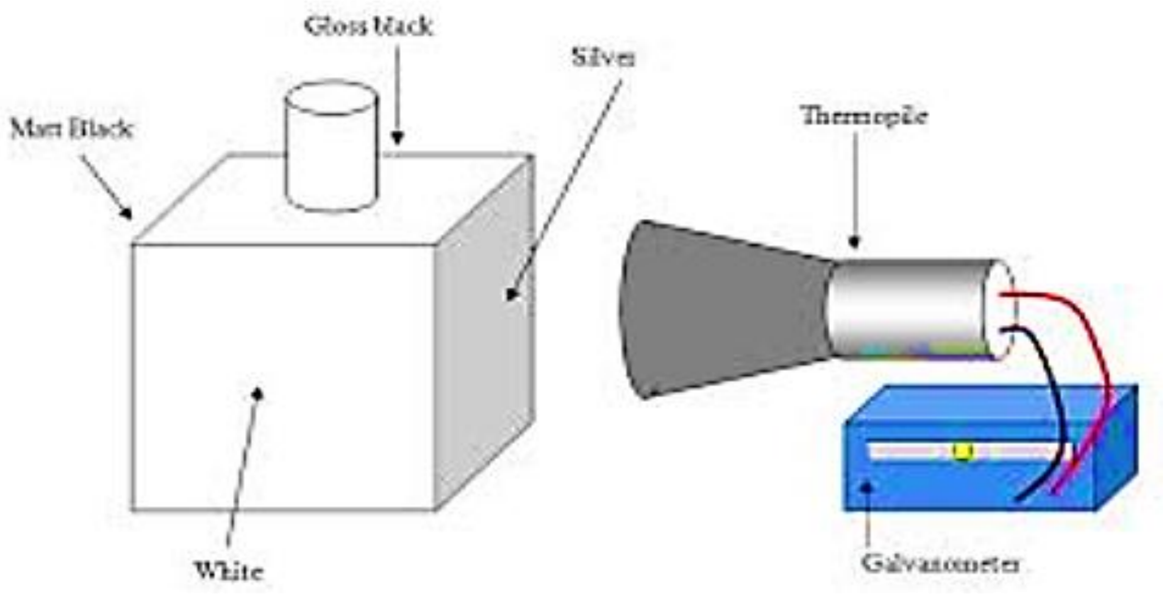
There are two instrument which can be detect radiation, include

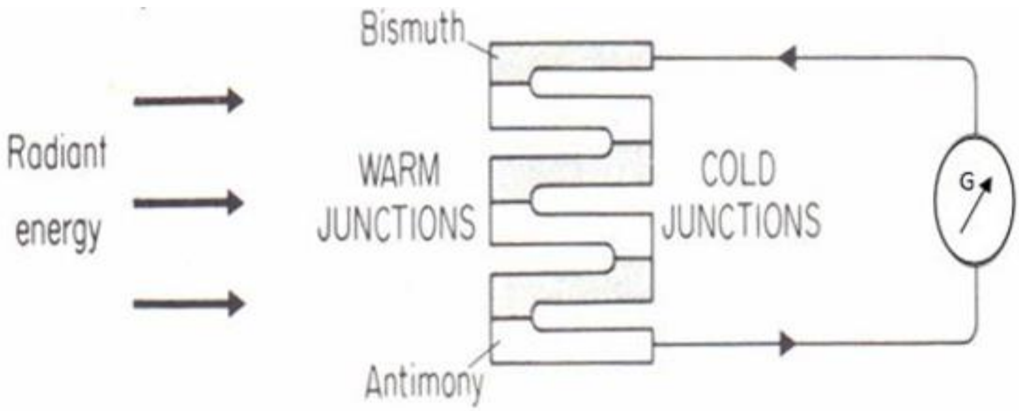
i. Thermopile
ii. Liquid in thermometer

Thermopile

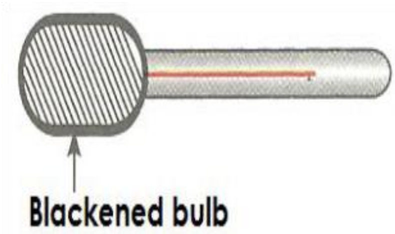
When radiation falls on the hot junction, the thermal energy is converted/transformed into electrical energy which cause the galvanometer to deflect

Diagram:





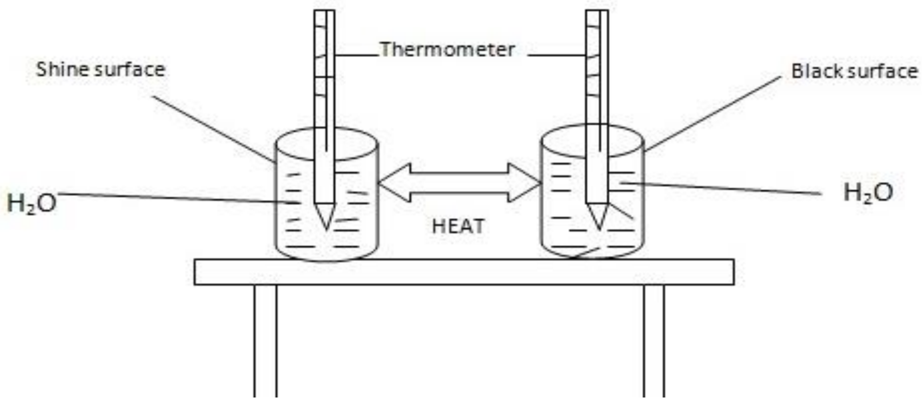
Liquid in Thermometer
The bulb should blackened
Diagram:



Experiment to investigate the absorption and emission of radiant heat

Apparatus:
- Two container (shinny and black) surfaces.
- Two thermometers A and B
- Water Heat source

Procedure:
- Fill the containers with water to about 2/3 full.
- Place the containers close to the heat source
- Insert thermometers A and B into water contained in the shiny and black surface respectively.



Observations:
- Thermometers B records high temperature than thermometer A because the black surface absorbs heat faster than the shine surface.
- When the heat source is removed, thermometer B record lower temperature than thermometer A because a good absorber of heat is a good emitter of heat.
- This means that black surfaces absorbs radiant heat energy better than shinny surfaces

Absorbers, Emitters and Reflectors

Absorber
Absorber is the material/surface that delivers/gain all radiant energy. A surface that absorbs all radiant is called **black body.** Example, black cooking vessel, black clothes dry faster than others coloured clothes etc.

Emitter
Emitter is the material/surface that lost/delivers out all radiant energy. A surface that emitters all radiant is called **black body**

Reflector
Reflector is the material/surface that bounces back all radiant energy. Example, solar cookers etc.

Generally

(i) Good radiator is a good absorber and poor reflector
(ii) Poor radiator is poor absorber and good reflector

Uses of good and bad radiator of thermal energy

(i) In hot countries houses are white painted so that little absorption of heat occur during the day and keep the house cool.
(ii) Water tanks and clothes in tropics are preferably white in order to reflect radiant energy.
(iii) Refrigerators are painted white to minimize absorption of heat.
(iv) Petrol tanks are painted a bright silver to reflect as much heat as possible to prevent petrol boil in the tanks.

12. Evaporation of Liquids

Evaporation is gradual change of state from liquid to gas that occurs at the surface of a liquid.

Points to note:

i. Liquid evaporate when molecules at water surface absorb greater thermal energy than molecules forces at water surface
ii. For liquid with strong intermolecular force (bonds) takes long time to evaporate
iii. Since evaporation cause cooling effect the left liquid is evaporated so the kinetic energy decreases by evaporated one.
iv. Liquid evaporate quickly is called volatile liquid Example, spirit

Factors Affecting Evaporation of a Liquid

There are several factors which affect evaporation of liquids when heated. These factors include the following:

(i) Nature of the liquid:

- Normally liquids evaporation differs depending on the nature of liquid.
- Volatile liquids evaporate faster than non-volatile liquids, which evaporate slowly.
- Alcohol evaporates faster than other liquids like water.
- The boiling point of alcohol is 78^0C while that of water is 100^oC.

(ii) Pressure above the liquid (atmospheric pressure):

- When the atmospheric pressure is high, the rate of evaporation may be reduced.

(iii) Surface energy of the liquid:

- This forms a boundary or skin between the liquid and the atmosphere.
- The surface energy prevents molecules with lower kinetic energy from escaping into the atmosphere.
- Some liquids such as alcohol have low surface energy, hence they evaporate rapidly.

(iv) Temperature

- An increase in temperature increases the rate of evaporation.
- At high temperature the molecule are able to break out of the surface of the liquid and evaporate because they possess high kinetic energy (K.E).
- E.g. wet clothes hung on a line dry quickly on warm day

(v) Surface area

- We said that evaporation occur on a surface of a liquid.
- So when a surface area of a liquid is large also the rate of evaporation will be high because more molecule are escaping the surface of the liquid

(vi) Concentration

- The concentration of the evaporating liquid in the surrounding air will determine the rate of its evaporation.
- When the concentration of the evaporating of liquid in air is high, the evaporation will be low and vice versa.

(vii) Rate of flow of air

- Rate of flow of air determine the evaporation of liquid.
- In a wind environment the molecule will be carried away when arriving soon on the surface of liquid hence there is high rate of evaporation.

Check Your Understanding:

1. Why molecules do escapes when the liquid is heated?
    - When the liquid is heated, the molecules tend to gain (absorb) kinetic energy hence the random speed of the molecules increases.
    - The process of evaporation of liquid can be explained using Kinetic Theory.
    - When a liquid is left to evaporate in a closed container, the pressure of the vapour in the container gradually increases.

Vapours

- The molecules in a liquid are in a state of continuous motion and some of those at the liquid surface will gain sufficient energy to escape from the surface hence called vapour. This phenomenon is known as evaporation.
- Most liquids evaporates at any temperature, however liquids may vary in the rate at which they evaporate at ordinary temperature.
- Alcohol and ether evaporate rapidly but lubricating oil and mercury hardly evaporate.
- The number of molecules leaving the surface, will increase with temperature as the liquid contains more energy at a higher temperature.
- The rate of evaporation may be increased by:
    (a) Warming the flask gently.
    (b) Increasing the area of the liquid surface.
    (c) Blowing a stream of air across the surface.
    (d) Reducing the pressure above the liquid surface.

Saturated vapour

- When a liquid is in a closed container the space above the liquid is full of vapour, and the vapour is then described as a saturated vapour - this means that the density of the liquid molecules in the air is a maximum.
- This is due to molecules continually escaping and reentering the liquid.
- At any moment the number of molecules leaving the surface will be equal to the number returning to it and so a dynamic equilibrium is set up.

Vapour pressure is the pressure created by the vapour of a substance that forms above of a liquid of the same substance.

The properties of saturated vapour

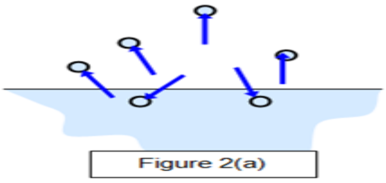
- This vapour will exert a pressure and if there is sufficient liquid the air above the liquid surface will be saturated with vapour; the pressure that this saturated vapour exerts is known as the saturated vapour pressure (s.v.p.) of the liquid at that temperature.
- Notice that since the velocity of the molecules increases with temperature the saturated vapour pressure also increases with temperature, and therefore the temperature of the vapour must be specified when quoting its saturated vapour pressure (s.v.p.)

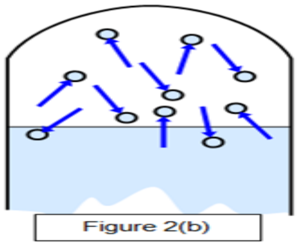
<u>The Effect of Temperature on Saturated Vapour Pressure (S.V.P) of a Liquid</u>

Saturated vapour pressure (S.V.P):

- Is the pressure exerted by vapour when a liquid is heated and reaches a state of Equilibrium where eventually the rate at which the molecules leave the liquid is equal to the rate at which others return to it.
- The Height, of mercury represents the saturated vapour pressure of the liquid in the flask.
- Saturated vapour pressure increases with the increase in Temperature

Which shows the saturated state among the two figures?





Boiling point (B.P):

- Is the temperature reached where the saturated vapour pressure (S.V.P) is equal to external atmospheric pressure
- The Boiling point of alcohol is 78^oC water is 100^oC and pressure of the atmosphere as 76cm of mercury.
- The intersection of the normal atmosphere pressure line with the liquids S.V.P curve.

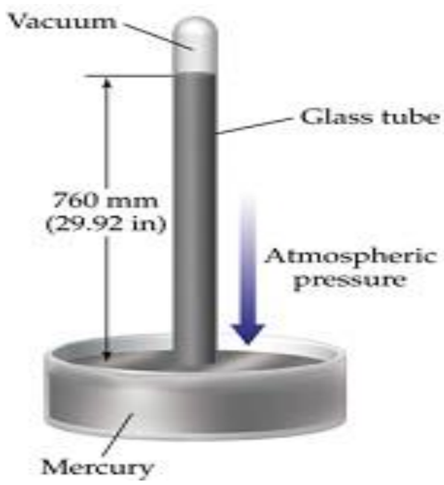
Ambient pressure

- Other gases that may be present beside the evaporating liquid also introduce pressure these are called ambient pressure e.g. atmospheric pressure.

Measuring saturated vapour pressure

- Saturated vapour pressure is measured when vapour pressure is equal to atmospheric air by using **Mercury Barometer**.

- A standard mercury barometer has tube with height about 76 cm closed at one and with an open mercury filled receiver at the base.



- The mercury in the tube adjusts until the weight of mercury column balance at atmospheric pressure (A.P) exerted on reservoirs.
- High A.P exerts more force on the reservoir forcing the mercury in higher column. Lower pressures allow the mercury to drop to lower level in the column by lowering the reservoir.
- At a pressure of 1atm = 760mm height of mercury.
- When you squirt a few drop of a liquid into mercury will form layers. Some of these liquid will evaporate at some time will condense and form saturated vapor pressure which force the mercury level down.
- This gives S.V.P the level of mercury has been forced down.

Vapour Pressure (VP)
Vapour pressure is the pressure Created by the vapour of a substance.
Points to note
i. Dynamic equilibrium is the point in which molecules leaves and re-enter liquid in equal rate called dynamic equilibrium.
ii. During dynamic equilibrium the vapour is said to be saturated.

Types of Vapour Pressure (VP)
It into three categories include
i. Saturated vapour pressure
ii. Unsaturated vapour pressure
iii. Ambient pressure

Saturated Vapour Pressure (SVP)
Saturated vapour pressure is the pressure created by the vapour of the same a substance when dynamic reached substance
Unsaturated Vapour Pressure (USVP)
Unsaturated vapour pressure is the pressure created by the vapour of the same substance when dynamic not reached
Ambient Pressure (AP)
Ambient pressure is the pressure created by the vapour of a substance and other gas pressure
Points to note:
i. A substance of high vapour at room temperature is called **volatile**
ii. At SVP the rate of evaporation and condensation is equal
iii. Each liquid has its SVP
iv. Liquid boil when SVP and AP are equal
v. Increase in Temperature the rate evaporation increases

Measurement of SVP
Since saturated vapour pressure is pressure it measured by mercury barometer. It given by SVP = (760 - x) mmHg
Where:
SVP = saturated vapour pressure
760 mmHg = atmospheric pressure (atm)
X mmHg = vapour pressure

The Concept of Humidity

- **Humidity** is the measure of the extent to which the atmosphere contains water vapour (moisture).
- This is the water vapor in the atmosphere.
- Water vapor enters in the atmosphere by evaporation from different source of water like river, ocean etc.
- Also transpiration form humidity.
- The amounts of water vapor depend on the temperature of place so cause the water vapor varies from location and location.
- Also the level of saturation depends on temperature and availability of water.

Sources of Humidity
i. Evaporation from rivers, lakes and oceans
ii. Transpiration (evaporation of plant leaves)

The Formation of Dew
- Water vapor condenses to form dew, frost and clouds.
- **Dew**: These are deposits formed when the temperature fall slowly in the drops of water vapour.

Dew point (D.P):

- This is the temperature to which air must be cooled to become saturated.
- For example in an air container, if water vapour at pressure of 8mm of mercury were to be cooled, dew would form at 7.9^{0}C.
- So **dew point** is the temperature at which vapor would become saturated.

Measurement of Relative Humidity

Absolute humidity:

- is the mass of water vapour present in a unit volume of it
- Usually expressed in grams per cubic metre (g/m^3).
- Also **Absolute humidity (AH)** is called the density of water vapor in saturated air
- The absolute humidity is not very frequently used since in practice we're more often concerned with the degree of wetness of the air.

Relative Humidity (R.H):

- Is the ratio of the mass of water vapour actually in a unit volume of air to that is required to saturate it at the same temperature.
- **Relative humidity** is the measure of water vapor in a mass of air compared to the amount of water vapor that would be in air if was saturated.

$$\boldsymbol{RH} = \frac{\textbf{Mass of water vapour}}{\textbf{Volume of air required to saturate the air at the same temperature}}$$

- It is common practice to quote relative Humidity as a fraction or a percentage.

Thus;

Mathematically:

$$RH = \frac{M_1}{M_2}\ x\ 100\,\%$$

Where; M_1 = mass of water vapour actually present in a unit of given volume of air.
M_2= mass of water vapour required to saturate the air at the same temperature.

- **Relative Humidity** is also defined as the saturation vapour pressure of water at the dew point divided by the saturation vapour pressure of water at the original air temperature.

$$RH = \frac{SVP\ at\ dew\ point}{SVP\ at\ air\ temperature}$$

Note:

- The low value of relative humidity of air means that evaporation takes place readily from the surface of water.
- The high value of relative Humidity then evaporation does not take place readily from the surface of water.
- Cotton manufacturing industries are constructed on sites where the relative Humidity (R.H) Is High. Cotton fibers must not become too dry, otherwise they become Brittle and hence cause difficulties in spinning. In contrast, a dry atmosphere is required by ware House for the storage of food, Tobacco and assembling of certain electrical components.
- Air – conditioning plants are installed in ships and buildings for the purpose of moderating Humidity.

Example 01,
The relative density of a place was measured at 25⁰C and found to be 54.0%. if the absolute humidity is 24.5 g/m³, determine the actual water vapour density at this experiment

Data given:
Current temperature, = 25⁰C
Absolute humidity, AH = 24.5 g/m³
Relative humidity, RH = 54.0 %
Actual vapour pressure, AP =?

Solution

From:

$$RH = \frac{Actual\ vapour\ density}{Saturated\ Vapour\ density}\ x100\,\%$$

$RH = \frac{AP}{AH}\ x100\,\%$ make AP the subject

AP = (RH x AH)/100
AP = (54.0 x 24.5)/100
AP = 1323/100
AP = 13.23 g/m³

Measurement of Relative Humidity

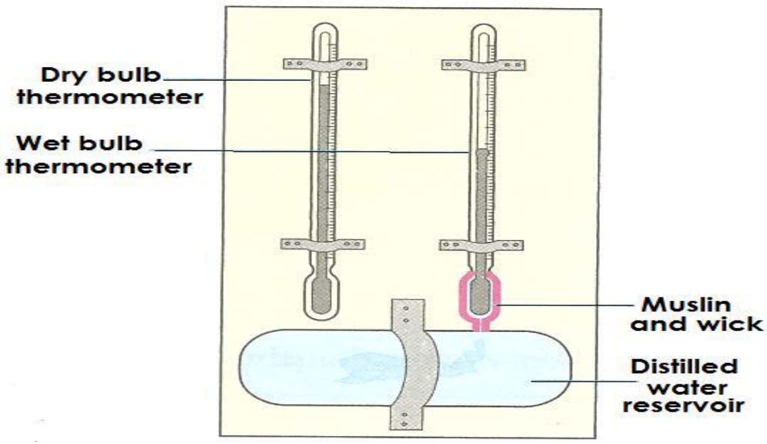
It measured by **dry and wet bulb hygrometer** and **Renault hygrometer**

Dry and Wet Bulb Hygrometer

It consist dry bulb thermometer which used to measure the temperature of the surrounding air while wet bulb which is wrapped with piece of cloth around the bulb which immersed in a reservoir of water which cool the wet thermometer

(a) Wet and dry bulb hygrometer are the most simple and common way of measuring humidity.
(b) This type of hygrometer uses two basic mercury thermometers, one with a wet bulb and one with a dry bulb.
(c) Evaporation from the water on the wet bulb causes its temperature reading to drop, causing it to show a lower temperature than the dry bulb.
(d) The reading of the wet bulb thermometer is normally found to be several degrees below that of the dry bulb
(e) Relative humidity is calculated by comparing the readings using a **calculation table** that compares the ambient temperature (the temperature given by the dry bulb) to the difference in temperatures between the two thermometers.

Diagram:



Take an example

- If the dry the temperature is 30^{0}C when the wet bulb temperature is 20^{o}C then the wet bulb depression is 10^{o}C the rate Evaporation depends on the amount of water Vapour present in the air.
- The less moisture the air has the greater the difference between the two thermometers reading. The difference is therefore greatest for dry air and zero for saturated air.

The wet bulb thermometer reads a lower temperature than the dry bulb thermometer. After that the different between two thermometer is help us to got exactly relative humidity by using **psychometric table**

Points to note:

i. If RH 100% means no evaporation or condensation
ii. If RH 100% means wet and dry thermometer read the same temperature
iii. If RH 0% means evaporation rate is high than condensation rate
iv. A small different indicate a high RH and vice versa
v. If RH (0-10)% means the clouds is clear
vi. If RH (10-50)% means the clouds is partial clouds
vii. If RH (50-90)% means the clouds is partial sunny
viii. If RH (90-100)% means the clouds is overcast

Example 02,

The relative humidity of a place was measured at 25^{0}C and found to be 54%. If the absolute humidity is 25g/m^3, determine the actual water vapour density at this temperature.

Solution

Actual vapour density = RH x AH

Actual vapour density = 54% x 25g/m^3

Actual vapour density = 13.5g/m^3

Example 03,

The dew point in a room at a temperature of 15^{0}C is 10^{0}C. If the saturated vapour pressure at these two temperatures is 30 mmHg and 15mmHg respectively, calculate the relative humidity.

Solution

$$RH = \frac{\text{Saturated vapour pressure at dew point}}{\text{Saturated vapour pressure at air temperature}}\ x\ 100\%$$

$$RH = \frac{15\text{mmHg}}{30\text{mmHg}}\ x\ 100\%$$

Relative Humidity, RH = 50%

Example 04,

The dew point in a room at a temperature of 12^{0}c is 10^{o}C if saturated vapor pressures at these two temperatures are 15.6mm and 10.9mm of mercury respectively calculate the Relative Humidity.

Solution

Required: To find relative humidity, RH.

$$RH = \frac{\text{Saturated vapour pressure at dew point}}{\text{Saturated vapour pressure at air temperature}}\ x\ 100\%$$

$$RH = \frac{10.9}{15.6}\ x\ 100\%$$

Relative Humidity, RH = 70%

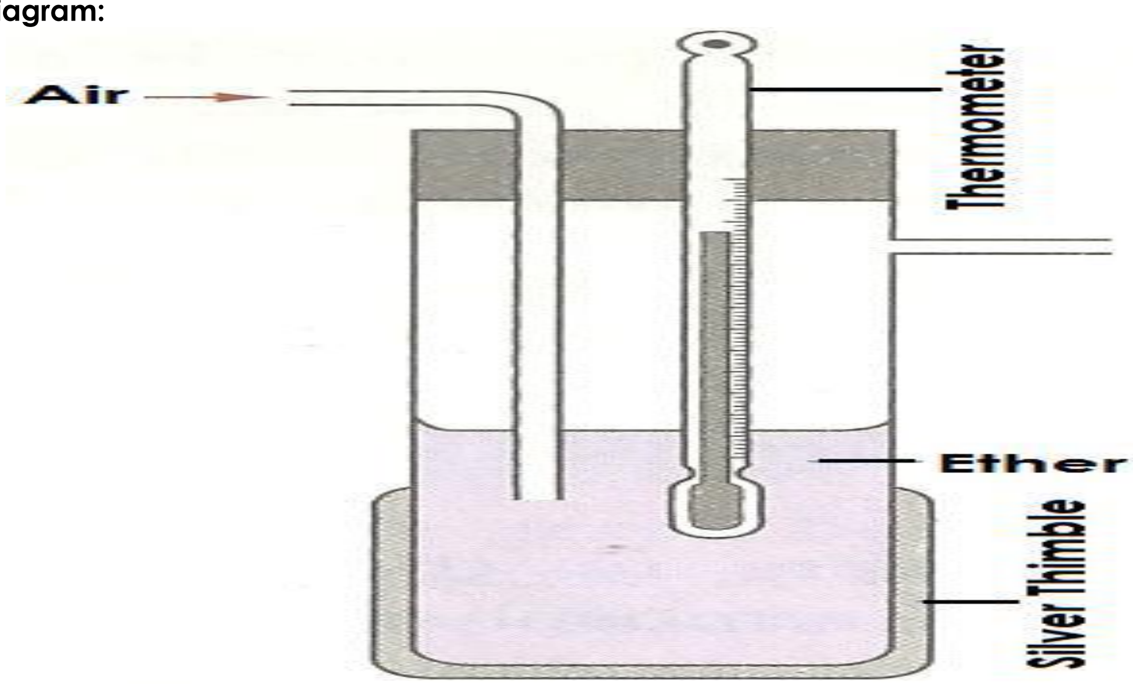
Check Your Understanding

1. Why do people prefer white shawl to wrap around a baby to keep the baby warm? Choose the best alternative.
    A. White shawl is a poor conductor
    B. White shawl indicates cleanliness
    C. White shawl is the poor radiator
    D. White shawl has pockets of cold air which is trapped in it
    E. White shawl is a good reflector of heat √
2. The dry bulb temperature reading of a hygrometer is 22^0C and the wet bulb temperature reading is 15^0C. What is the RH? **(ANS: 68.2%)**
3. The dry bulb temperature reading of a hygrometer is 40^0 C and the wet bulb temperature reading is 30^0 C. What is the RH? **(ANS: 25%)**
4. The relative density of a place was measured at 25^0 C and found to be 71.7%. if the absolute humidity is 25.80 g/m^3, determine the actual water vapour density at this experiment **(ANS: AVD = 18.5 g/m^3)**

Renault Hygrometer

It consists of an enclosed thin silver tube containing ether and a thermometer. There is also a tube through which air can be pumped into the ether.

Diagram:



Mechanism of Renault Hygrometer

The heat transfer from atmosphere to ether by convection in a tube, Ether evaporates result cooling of the silver tube surface. Cooling continues until air adjacent to the outside surface of the tube becomes saturated with water vapour. Some water vapour condense outside the tube to form **dew**

Applications of Humidity

(i) It used by meteorological departments to forecast the weather
(ii) It used to determine the appropriate site to locate cotton
(iii) Electrical and electronic components are usually transported and stored in a dry air
(iv) RH at operation room in hospital is 50%
(v) It used in storage and transport of food items

The terms related to humidity in daily life

- Water in the atmosphere exists in different forms example: Clouds, Rain, Snow, Hail stones, Mist, Fog and Smog.

- **Cloud**
  This is a visible mass of water or ice particles in the atmosphere from which rain and other forms of precipitation fall.
- **Rain**
  This is the water condensed from vapour in the atmosphere and falling in drops.
- **Snow**
  This is the water vapour in the atmosphere that has frozen into ice crystals and falls to the ground in the form of flakes.
- **Hailstone**
  These are pellets of ice and hardened snow that falls like rain
- **Mist**
  This is a thin fog, a thin grey cloud droplets that condenses in the atmosphere just above the ground.
- **Fog**
  A thick mist, condensed water vapour in the air at or near ground level.
- **Smog**
  This is a mixture of fog and smoke or other airborne pollutants such as exhaust fumes.
- **Dew**
  This is condensed water formed on solid surface.
- **Dew point**
  A temperature at which the air cannot hold all the moisture in it and dew begins to form. Also it can be taken as the temperature below which the water vapour in a volume of humid air at a given constant barometric pressure will condense into liquid at the same rate at which it evaporates.

Application of evaporation

1. Evaporation of perspiration cools our bodies.
2. Evaporation of water from the earth keeps the air moist and provides the moisture for clouds. Thus evaporation has an important influence on weather and climate.
3. It is important also in air conditioning, refrigeration, and distilling. Substances are evaporated in a partial vacuum to speed evaporation or to prevent deterioration by heat. Instant coffee and frozen orange juice is evaporated in this way, and so are blood plasma, vaccines, and antibiotics such as penicillin. Camphor is purified by sublimation.
4. In industry, the principles of evaporation and refrigeration are used to great extent in the treatment, separation, handling and storage of materials in any of the three states of matter - Solid, Liquid or Gas. Distillation concerns the separation of liquid mixtures by evaporation processes.
5. Evaporation of sea water to produce salt
6. Evaporation ponds are used to prevent pesticides, fertilizers and salts from agricultural waste water from contaminating the water bodies they would flow into.

13. CURRENT ELECTRICITY

Electric current is the rate at which electric charge passes through the conductor. The charged particle can be negative or positive. The push called Voltage is used to cause the charge flow.It Measured by **Ammeter**

Mathematically:

$$I = \frac{Q}{t}$$

Where:

I = electric current

Q = quantity of charge

t = time taken by charge to rotate circuit

Make subject Q

Q = It

$$I = \frac{Coulombs}{seconds} = ampere = A$$

The common SI unit of I is ***ampere (A)***

Electric Potential Different (P.d)

Electric potential different is the work done per unit charge in moving electric charge from one point to another point

Mathematically:

P.d = work done/charge moved

$$V = \frac{w}{Q}$$

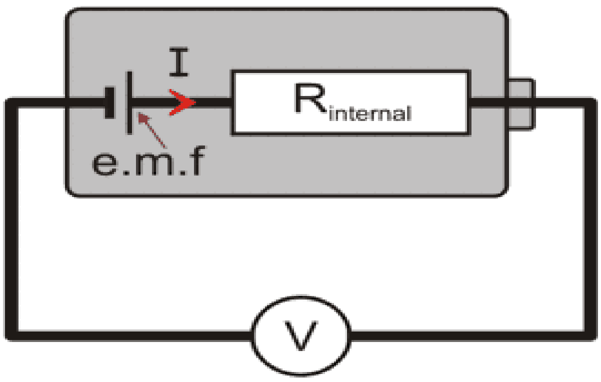
From: V =w/Q

I = Joules/ Coulombs = J/C = Volt = 1

The common SI unit of P.d is ***Volt (v)***

Electromotive Force (e.m.f)

Electromotive force of a cell is a potential different across the cell terminals when there is no current flowing through it. It also called **voltage**. It is measured by a **voltmeter**

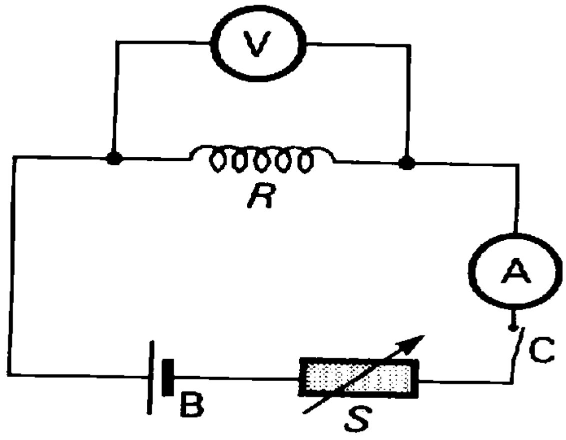


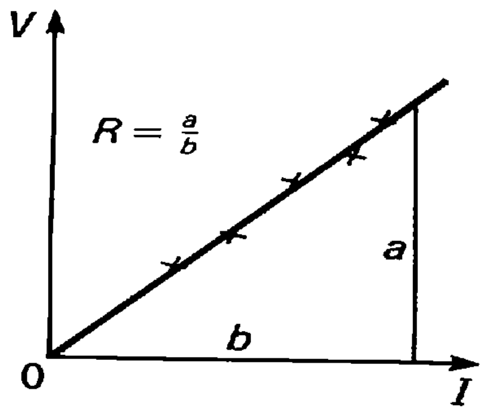
Points to note:

a) e.m.f is not a force
b) e.m.f is a process of convert mechanical energy to electrical energy
c) cell provide e.m.f which set up potential different
d) e.m.f driving electric current in a circuit
e) e.m.f of simple cell is 1.0V and e.m.f of dry cell is 1.5V
f) terminal voltage is the voltage across the cell when electric current drawn
g) Resistance across a cell is called internal resistance. Dry cell has an internal resistance of about 0.5 Ω up to 1.0 Ω

Potential difference (pd)

This is the volt across the resistor in a circuit. The SI-unit of the potential difference is Volts (V)





RESISTANCE (R

This is the opposition to the flow of the electric current. Sometimes it is defined as the ratio of the Voltage and current across the terminal of the conductor.

The SI-unit of the resistance is Ohms (Ω).
A resistor is every component which uses electricity, because everything that allows current to pass through it has some degree of opposing its passage.

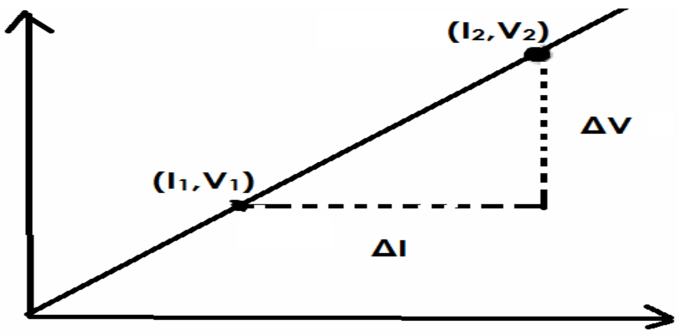
TYPES OF THE RESISTOR

We can group resistor into;

(i) Fixed resistor. The resistor whose resistance is constant. E.g. 4Ω resistor etc
(ii) Variable resistor. The resistors whose resistance is not constant. E.g. Variable resistor/ Rheostat.

Ohm's Law

It's States that;
"***The potential difference across a solid conductor is directly proportional to the current passing through it, provided that temperature and other physical factors are kept constant***"
Mathematically:
V a I
V=KI
Where:
K= constant = R = resistance
Graphically:-



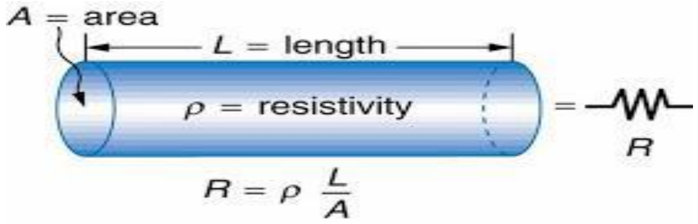
From the graph on the left

$$Slope = \frac{\Delta V}{\Delta I}$$

Slope = Resistance

Factor Affecting Resistance

Consider the diagram:-



1. **Length of the conductor**
   The longer the wire the higher the resistance and vice versa
   $$R \alpha l$$
2. **Temperature**
   The higher the temperature, the higher the resistance and vice versa
   a) Constant wire. (Copper alloy), Changes to a very small extended thus why used in a standard resistance.
   b) Connecting wire used in a circuit has a very low resistance to prevent energy wasted in form of heat to maximum.
3. **Types of material**
   Nichrome wire has more resistance than a copper wire of a same dimension.
   (i) Nichrome wire is used in heating element of electric fires
   (ii) Copper wire is mostly used for connecting wires
4. **Cross-section area**
   A thin wire has more resistance than a thick conductor.
   $$R \alpha \frac{1}{A}$$
   Combining the relation $R \alpha \frac{1}{A}$ and $R \alpha l$
   Then:
   $$R \alpha \frac{l}{A}$$
   Remove proportionality constant
   $$R = k\frac{l}{A}$$
   Where:-
   k = resistivity which denoted by letter ρ
   $$\rho = \frac{RA}{l}$$
   Resistivity is the ability of a material to oppose the flow of an electric current. It SI unity is Ohm metre (Ωm).

Resistivity of Material at 20⁰C

Material	S.W.G	Diameters	Resistance/m	Resistivity (ΩM)
Aluminium				27×10^{-8}
Chromium				1.3×10^{-7}
Copper				1.68×10^{-8}
Iron				9.71×10^{-8}
Lead				2.1×10^{-7}
Silver				1.6×10^{-8}
Constantan	32,30,28,26	0.28,0.31,0.37,0.45	7.9,6.3,4.4,3.1	4.9×10^{-7}
Nichrome				1.0×10^{-6}
Glass				$1 \times 10^{9} - 1 \times 10^{13}$
Quartz				7.5×10^{17}

Example 01,

What is resistance of a copper wire of length 20m and diameter of 0.080 cm?

Data given:

Length, l = 20m

Diameter, d = 0.080m = 0.0008m, Radius, r = 0.0004m

Area, A = πr^2

Resistivity, ρ = 1.68 x 10^{-8}ΩM

Resistance, R = ?

Solution

From:

$$Resistance, R = \frac{\rho l}{A}$$

$$Resistance, R = \frac{1.68\ x\ 10^{-8} x\ 20}{3.14\ x\ 0.0004\ x\ 0.0004}$$

$$Resistance, R = 0.67\Omega$$

Example 02,

A steel bar has a length of 2.3m and diameter of 2 x 10^{-5}m. What is resistance? (Resistivity, ρ is 10.5 x 10^{-8}ΩM)

Data given:

Length, l = 2.3m

Diameter, d = 2 x 10^{-5} m, Radius, r = 1 x 10^{-5}m

Area, A = πr^2

Resistivity, ρ = 10.5 x 10^{-8} ΩM

Resistance, R = ?

Solution

From

$$Resistance, R = \frac{\rho l}{A}$$

$$Resistance, R = \frac{10.5\ x\ 10^{-8} x\ 2.3}{3.14\ x 1.0\ x\ 10^{-5}\ x\ 1.0\ x\ 10^{-5}}$$

$$Resistance, R = 769.10\Omega$$

Check Your Understanding

1. A wire of length 40 m and cross – sectional area 0.8 mm^2 has a resistance of 10Ω. What is the resistivity of the material of the wire? (ANS: ρ = 2x10^{-7} Ωm)
2. What length of a wire of cross –sectional area 0.2mm^2 and resistivity 0.072 μΩm is needed to wind a coil of resistance 9 Ω. (Ans:- L = 25m)
3. The resistance of a certain wire is 12 Ω. What are the resistance of another wire of the same material but with half the length and half the radius of the first wire? (Ans:- R = 24 Ω)
4. The resistance of a wire is 10Ω. Calculate the resistance of a same wire of the same length but whose diameter is twice that of the first wire. (Ans:- 2.5 Ω)
5. Find the resistance of a wire of 1100 cm long , 0.2 mm diameter and of resistivity 1.57 x 10^{-6} Ω m (Ans:- R = 546.7 Ω)
6. Electron in hydrogen atom revolves around the nucleus with frequency 6.0 x 10^{-4} per second .Calculate the current in the orbit .Given that charge on an electron = 1.6 x 10^{-19} coulomb. (Ans:- I = 9.6 x 10^{-5} A)
7. Find the length of constantan wire of diameter 0.1cm needed to make a resistance of 3Ω. Take the resistivity ρ of a wire to be 4.9 x 10^{-7}Ωm (Ans:-4.8m)

RESISTOR

Resistor is a device which offers restrictions to the flow of an electric current. It used to control the magnitude of current and voltage according to ohms law

Types of Resistor

It divided according to the material used to made it and the value of resistance offered

Types of Resistor Due To Material Used

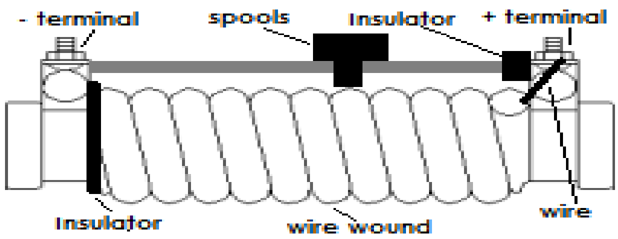
There different resistor which made from different material, include the following

(i) Wire wound resistor
(ii) Carbon resistor
(iii) Metal film resistor
(iv) Metal oxide film resistor

Wire Wound Resistor

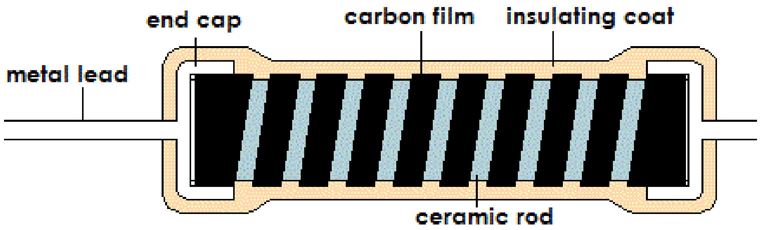
It made up winding wires made of certain metallic alloys into spools (used to control amount of resistance)

Diagram:



Carbon Resistor

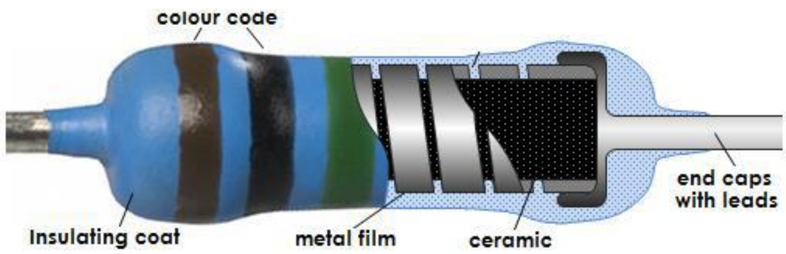
It made by mixing carbon granules with varying amount of clay and moulding them into cylinders



Metal Film Resistor

It made up of a stable ceramic core coated with metal oxide such as nickel chromium. It more accuracy and more expensive than carbon resistor

Diagram:



Metal Oxide Film Resistor

It made up of a stable ceramic core coated with metal alloys such as tin oxide

Types of Resistor Due To Value Offered

Resistor created from different value may be fixed or variable resistance value

(i) Fixed resistor
(ii) Variable resistor

Fixed Resistor

- It has a resistor value which cannot change. For Example, 2Ω, 3Ω, 4Ω etc. Example, most carbon resistor are fixed resistor

Variable Resistor

- It has a resistor value which can change. Example, potentiometers, thermistors and photo resistors and rheostat

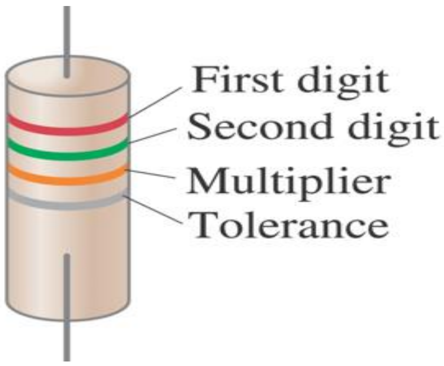
Resistor Colour Codes

- Resistor which used electronic device always painted different colour texture called **band**. The band represent the exactly value of resistance. It contain fourth band with different meaning.

Table of Colour Codes

Colour number	Colour	tolerance
0	Black	
1	Brown	±1%
2	Red	±2%
3	Orange	
4	Yellow	
5	Green	
6	Blue	
7	Purple	
8	Grey	
9	White	
	Gold	±5%
	Silver	±10%
	No colour	±20%

Diagram:



(i) First band – first digit
(ii) Second band – second digit
(iii) Third band (**multiplier**) – number of zero
(iv) Fourth band (**tolerance**) – percentage accuracy

The value is given by

R = 4th band of 1st digit 2nd digit multiplier

Example 03,

From a the diagram of resistor above find the exactly resistance

(i) First band (Red) – 2
(ii) Second band (Green) – 5
(iii) Multiplier (Orange) – 3 = 000 number of zero
(iv) Tolerance (gold) – ±5%

Therefore: R = ±5% of 25000Ω

The actual value resistance is ±5% of 25000Ω

COMBINATION OF RESISTORS

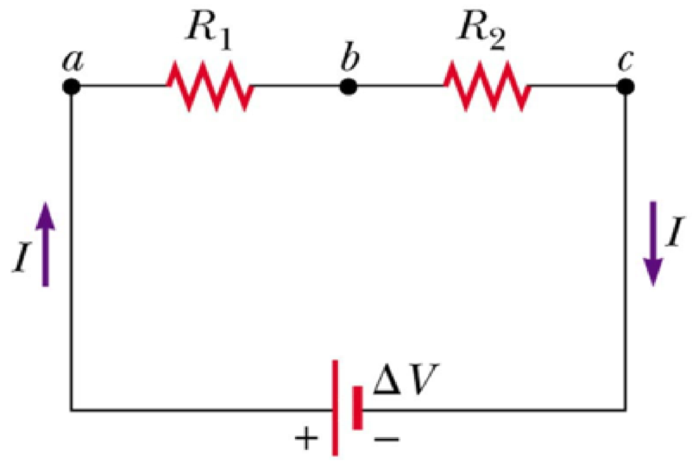
There are two main methods of connecting circuits component include:

i. Series connection
ii. Parallel connection

In series the total resistance is higher than individual resistors
In parallel the total resistance is lower than individual resistors
Parallel arrangement result low resistance
Parallel arrangement is used in house wiring

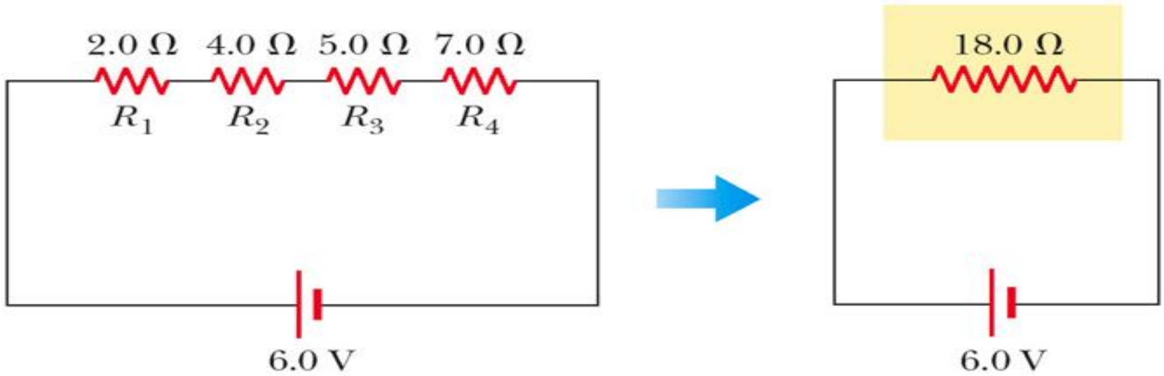
SERIES CONNECTION

In this series arrangement the resistors are connected end to end.



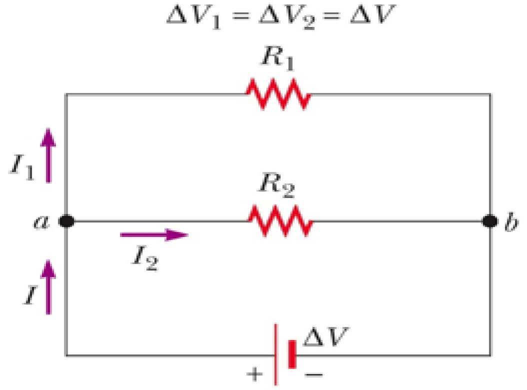
From:
P.d across the battery = Sum of P.d around a conducting path
Therefore: $V = V_1 + V_2$ --------- (1)
But: I = same at all points round circuit
From: V = IR
Now: $V = IRt$ --------- (2)
$V_1 = IR_1$ --------- (3)
$V_2 = IR_2$ --------- (4)
Substitute: equation (2),(3) and (4) into (1)
Then: $Rt = R_1 + R_2$
Therefore:
Total resistance (Rt) for resistor in series is equal to the sum of individual resistance.
$\mathbf{R_t = R_1 + R_2 + \ldots\ldots + R_n}$
Where: Rn = the last resistor

- The equivalent resistance of a series combination of resistors is the algebraic sum of the individual resistances and is always greater than any of the individual resistors



PARALLEL CONNECTION

Resistors are connected across two common points in a parallel arrangement.



Therefore: $I = I_1 + I_2$ --------- (1)
But: V = same at all points round circuit
From: I = V/R
Now: $I = V/R_t$--------- (2)
$I_1 = V/R_1$ --------- (3)
$I_2 = V/R_2$ --------- (4)
Substitute: equation (2), (3) and (4) into (1)

$$Then\ \frac{V}{R_t} = \frac{V}{R_1} + \frac{V}{R_2}$$

Therefore:
"In parallel, the reciprocal of the equivalent resistance is the sum of the reciprocal of each individual resistor"

$$\mathbf{\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_n}}$$

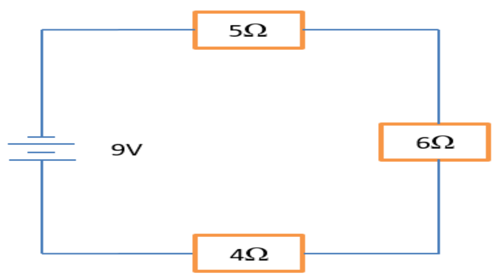
Where: Rn is the last resistor
SPECIAL CASE:
Consider only two resistors in parallel R_1 and R_2

$$From\ \frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_t} = \frac{R_2 + R_1}{R_1 R_2}$$

$$\boldsymbol{Then\ R_t = \frac{R_1 x R_2}{R_1 + R_2} = \frac{Product}{Sum}}$$

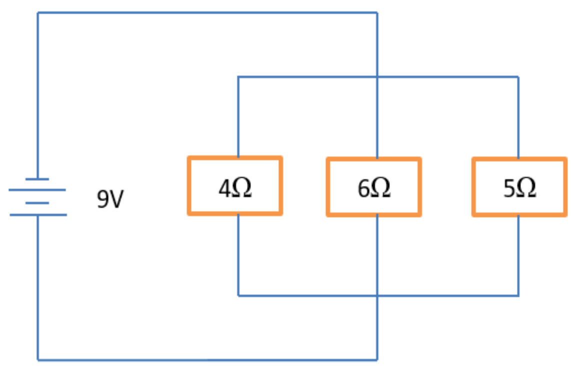
Example 04,
Consider the diagram below



(a) What is the total resistance of the circuit?
(b) What current flows in the circuit?
(c) What is the potential drop across each resistor?

Data given
Electromotive force, E = 9V
First resistor, R_1 =4 Ω
Second resistor, R_2 =6 Ω
Third resistor, R_3 =5 Ω
Total resistance, Rt= ?
Electric current, I = ?
Solution:
(a) Total resistance, R_t = ?
Since arrangement is series
$R_t = R_1 + R_2 + R_3$
$R_t = 4 + 6 + 5$
$\mathbf{R_t = 15\ \Omega}$
(b) Electric current, I = ?
From: I = E/Rt
I = 9/15
I = 0.6A
(c) Potential drop across R_1, V_1 = ?
From: $V_1 = IR_1$
$V_1 = 0.6 \times 4$
$\mathbf{V_1 = 2.\ 4V}$
Potential drop across R_2, V_2 = ?
From: $V_2 = IR_2$
$V_2 = 0.6 \times 6$
$\mathbf{V_2 = 3.\ 6V}$
Potential drop across R_3, V_3 = ?
From: $V_3 = IR_3$
$V_3 = 0.6 \times 5$
$\mathbf{V_3 = 3.0V}$

Example 05,
Consider the diagram below



(a) What is the total resistance of the circuit?
(b) What total current flows in the circuit?
(c) What is current across each resistor?
(d) What is total current through the circuit?

Data given
Electromotive force, E = 9V
First resistor, R_1 =4 Ω
Second resistor, R_2 =6 Ω
Third resistor, R_3 =5 Ω

Solution:

(a) Total resistance, R_t = ?

Since arrangement is series

$$Then\ \frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_t} = \frac{1}{4} + \frac{1}{6} + \frac{1}{5}$$

$$\frac{1}{R_t} = \frac{37}{60}$$

R_t = 1.62 Ω

(b) Total Electric current, I_t = ?

From: It = E/R_t

I_t = 9/1.61

I_t = 5.55 A

(c) Electric current across R1, I1 = ?

From: I_1 =V/R_1

I_1 = 9/4

I_1 = 2. 25V

Electric current across R_2, I_2 = ?

From: I_2 = V/R_2

I_2 = 9/6

I_2 = 1. 5V

Electric current across R_3, I_3 = ?

From: I_3 = V/R_3

I_3 = 9/5

I_3 = 1.8V

(d) Total Electric current, It = ?

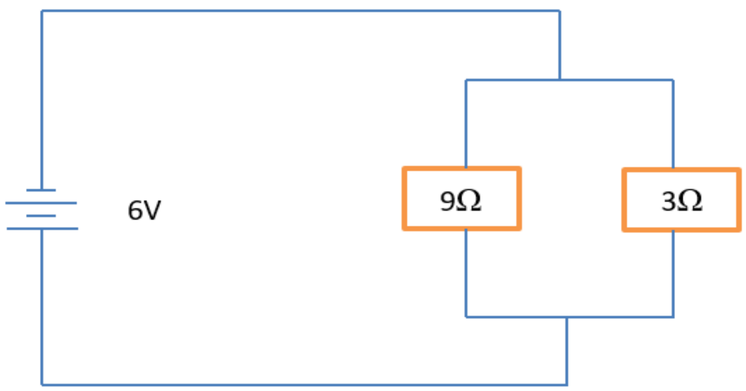
$I_t = I_1 + I_1 + I_3$

I_t = 2.25 + 1.5 + 1.8

I_t = 5.55 A

Example 06,

Two resistors 3Ω and 9Ω are in parallel are connected in the circuit with the p.d of 6V as shown in the diagram below



Calculate

(i) Equivalent resistance
(ii) Current in the circuit
(iii) Current in each resistor
(iv) P.d in each resistor

Solution

(i) The equivalent resistance

$$R_t = \frac{R_1 x R_2}{R_1 + R_2}$$

$$R_t = \frac{3\ x\ 9}{3+9} = \frac{27}{12}$$

Then the equivalent resistance is 2.25Ω

(ii) Current in the circuit

$$I = \frac{V}{R_r}$$

$$I = \frac{6}{2.25}$$

The current in the circuit is 2.67A

(iii) Since the resistors are in parallel, the p.d in each resistor is equal i.e. 6V
Therefore,
Voltage in 3Ω resistor is 6V and from

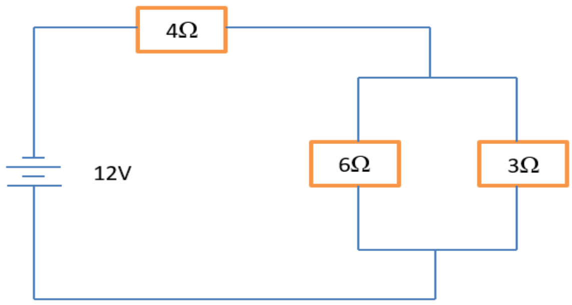
$$I = \frac{V}{R}$$

$$I_3 = \frac{6}{3} and\ I_9 = \frac{6}{9}$$

Then, the current in 3Ω resistor is 2A while that in 9Ω is 0.667A

(iv) The p.d in each resistor is **6V**

Example 07,
Calculate the current and potential difference in 3Ω resistor from the figure below



Solution
Find total resistance,

$$R_t = \frac{R_1 x R_2}{R_1 + R_2} + R_3$$

$$R_t = \frac{6\ x\ 3}{6+3} + 4 = \frac{18}{9} + 4 = 6\Omega$$

$$The\ current\ in\ the\ circuit = \frac{V}{R} = \frac{12}{6} = 2A$$

The current passing through the 4Ω resistor is 2A, hence the voltage in 4Ω resistor is
IR = 2×4 = 8V
The total voltage = Voltage in 4Ω resistor + Voltage in parallel
12 = 8 + Voltage in parallel
Hence,
Voltage in parallel = 12 – 8 = 4V

But voltage in parallel is same, ie Voltage in 6Ω resistor = Voltage in 3Ω resistor = 4V

$$From\ Ohm's\ law\ I = \frac{V}{R}$$

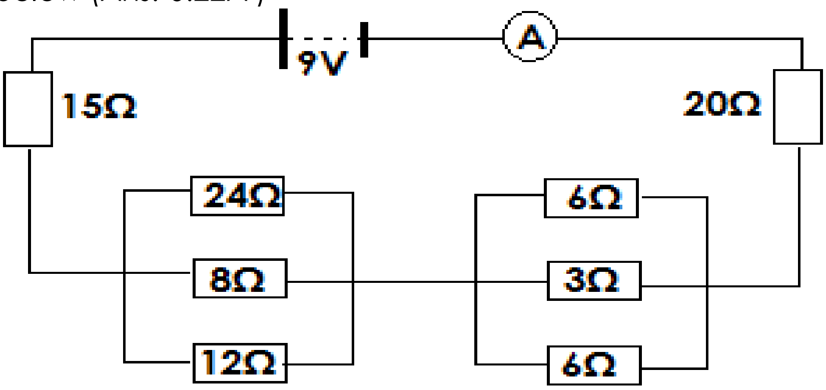
$$From\ Ohm's\ law\ I = \frac{4}{3}$$

Current in 3Ω resistor is 1.33A and the voltage is 4V

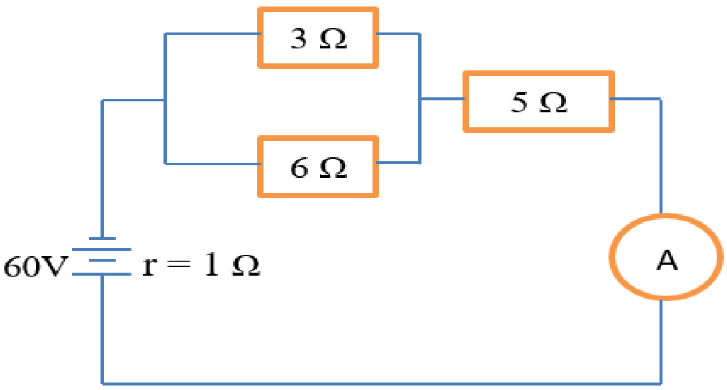
Check Your Understanding

1. If the resistance is doubled and the potential difference across it is reduced to one third, what is the ratio of old current to new current (Ans:- 6:1)
2. A parallel arrangement of 3 Ω and 6 Ω resistors is placed in series with an 8 Ω resistor. If a p.d. of 30V is connected across the whole circuit. Calculate:-
   (i) The quivalent resistance (Ans:- 10Ω)
   (ii) The current in the circuit (Ans:-3A)
   (iii) The current in each resistor (Ans:- R_8 =3A, R_6 =1A, R_3 =2A)
   (iv) The voltage in each resistor. (Ans:- V_8 =24V, V_6 and V_3 =6V)

3. Determine the current reading on the ammeter in the circuit shown in the diagram below (Ans:-0.22A)



4. (a) (i) State Ohm's law.
   (ii) List the laboratory apparatus required to verify the Ohm's law.
   (b) From the figure below, find
   (i) the current in the 5Ω resistor, (Ans:-7.5A)
   (ii) the currents through the 3Ω and 6Ω resistors (Ans:- I_3 =5A, I_6 =2.5A)



5. A circuit has 1Ω resistor which is in series with a parallel arrangement of 6Ω and 3Ω, and a p.d of 12V is connected across the whole circuit. Calculate the current in each of the resistor connected in parallel. (Ans:- I_6 =1.3A, I_3 =2.67A)

CELL ARRANGEMENT OF CELLS

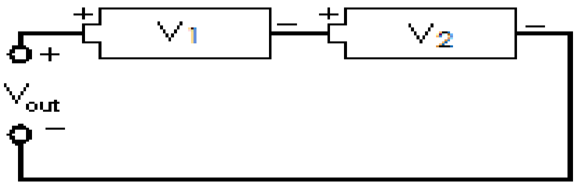
(i) Series arrangement
(ii) Parallel arrangement

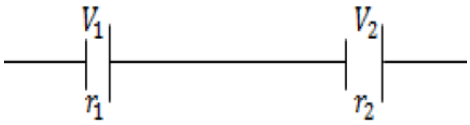
Series Arrangement of Cells

In this series arrangement the positive terminal of one cell connected negative terminal of another cell

Diagram:

When two cells with voltage $V_1$and V_2 internal resistance r_1 and r_2 respectively are in series as shown below;





When batteries are wired in series, the equivalent voltage is additive;- $V_t = V_1 + V_2$
And the equivalent internal resistance will be $r_t = r_1 + r_2$

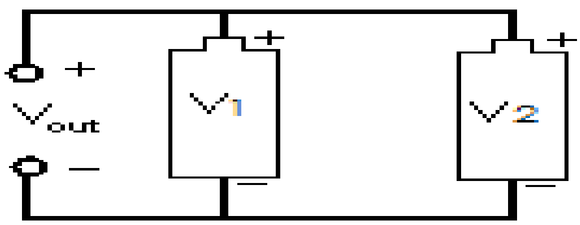
(i) Electric current same at each cell
(ii) Total voltage across cells is equal to the sum voltage of the individual cells, thus why torch light uses this arrangement

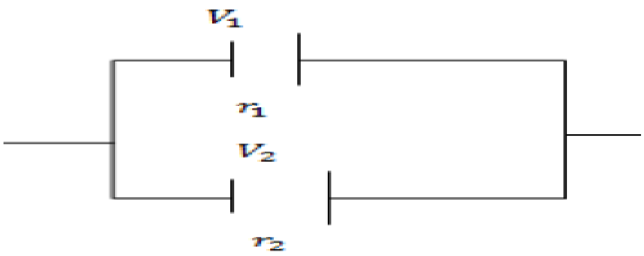
Parallel Arrangement of Cells

In this parallel arrangement, all positive terminals of cells connected together and negative terminal of cells connected together

Diagram:

When two cells with voltage V_1 and V_2 and internal resistance r_1 and r_2 respectively are in parallel as shown below;





The equivalent voltage will be $V_t = V_1 = V_2 = V$
And internal resistance will be considered as two resistors in parallel

$$r_t = \frac{r_1 x r_2}{r_1 + r_2}$$

Points to note:

(i) voltage same at each cell
(ii) Total Electric current across cells is equal to the sum Electric current of the individual cells, thus **why lead acid accumulator uses this arrangement**

Example 08,

Two cells of E.m.f 6V each and internal resistance of 6Ω and 5Ω respectively are connected across a 10Ω resistor. Find the current in the circuit if the cells are

(i) In series
(ii) In parallel

Solution

(i) In series

$V_t = V_1 + V_2$

$V_t = 6V + 6V$

$V_t = 12V$

$Rt = 6 + 5 + 10 = 21\Omega$

$$Current, I = \frac{V_t}{R_t}$$

$$Current, I = \frac{12}{21}$$

The current in the circuit is 0.57A

(ii) In parallel

$V_t = V_1 = V_2$

$V_t = 6V$

$$R_t = \frac{r_{1\,x}r_2}{r_1 + r_2} + 10$$

$$R_t = \frac{5\ x\ 6}{5 + 6} + 10$$

$r_t = 12.73\Omega$

$$Current, I = \frac{V_t}{R_t}$$

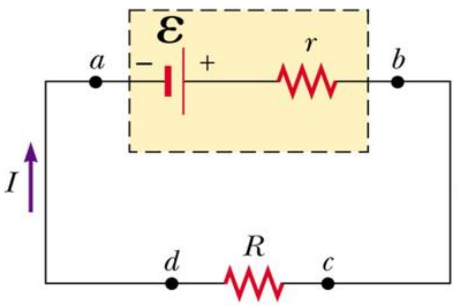
$$Current, I = \frac{6}{12.73}$$

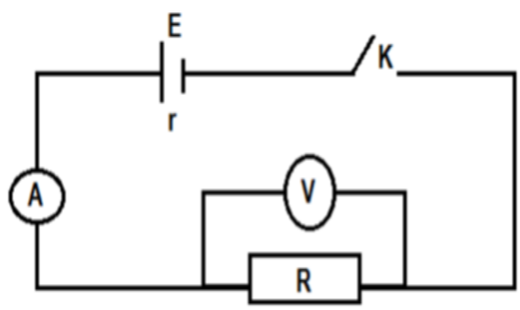
The current in the circuit is 0.47A

Internal Resistance of a Cell

Cell has internal resistance that opposes flow of electric current which results into a potential drop across the circuit. ε is equal to the terminal voltage when the current is zero

Diagram:





V = IR

But: R and r are in series, the effective resistance is R + r

Then: E = I(R+r)

E = IR+Ir

$V_t = V + V_1$

Where:

$Ir = V_1$= voltage drop of the cell

IR = V = voltage across resistor

Graphical Method:-

Assume E is constant, therefore r will be constant and R is variable.

From: E = I(R+r) – make I^{-1} subject

$$\frac{1}{I} = \frac{R}{E} + \frac{r}{E}$$

$$\frac{1}{I} = \frac{1}{E} \cdot R + \frac{r}{E}$$

Y = m x + C

Voltage drop is the reduction in voltage in an electrical circuit between the battery (source) and load. The amount of the drop is given by Ohms Law.

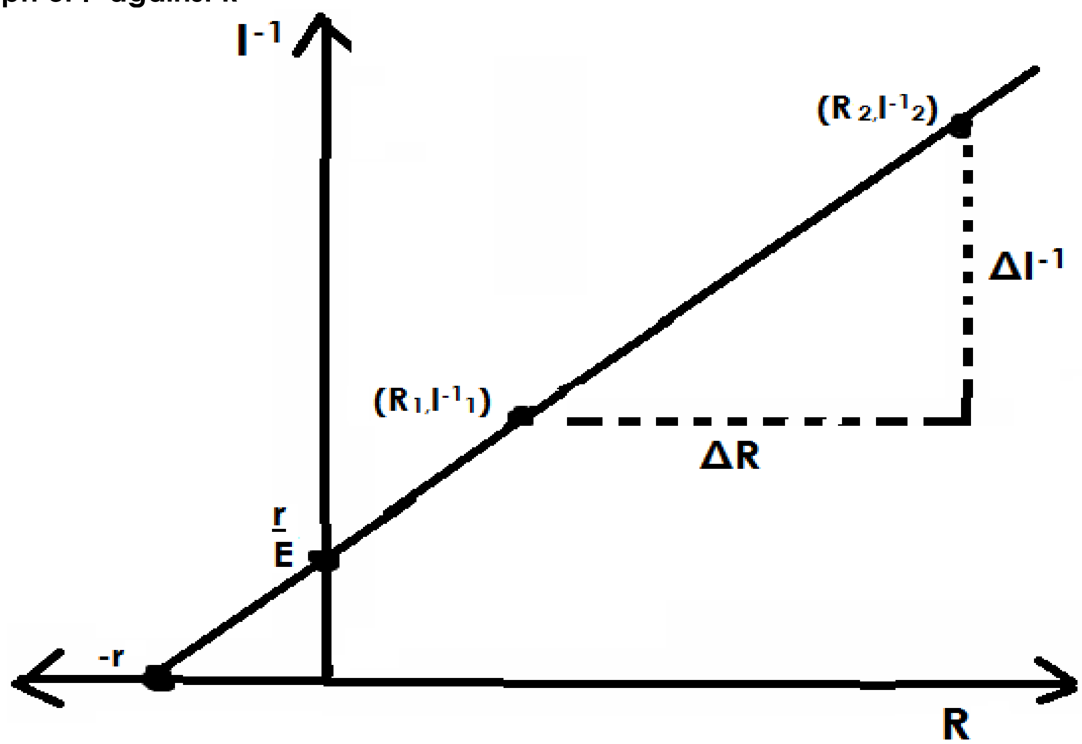
So the voltage drop *across a circuit* measures how much energy would be dispersed by a unit charge going through that circuit. The voltage drop across the circuit is equal to *the voltage of the battery.*

Similarly, a voltage drop across a resistor in a circuit is the energy dispersed by a unit charge going through a single resistor in the circuit.

Terminal voltage (V) is the voltage drop across the terminals of the cell or battery when charge is flowing out of it and it is due to external resistance

Electromotive force (E) of the cell refers to the potential difference across its terminals when no charge is flowing out of it i.e. when the circuit is open

Graph of I^{-1} against R



Where:

$$Slope = \frac{\Delta I^{-1}}{\Delta R}$$

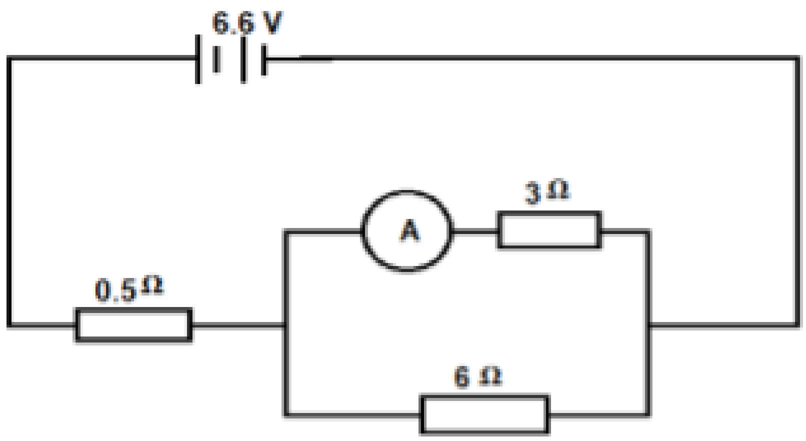
Slope = The reciprocal of electromotive force (e.m.f)

I-1 (when, R/E = 0) intercept = r/E

R (when, I^{-1}= 0) intercept = -r

Check Your Understanding

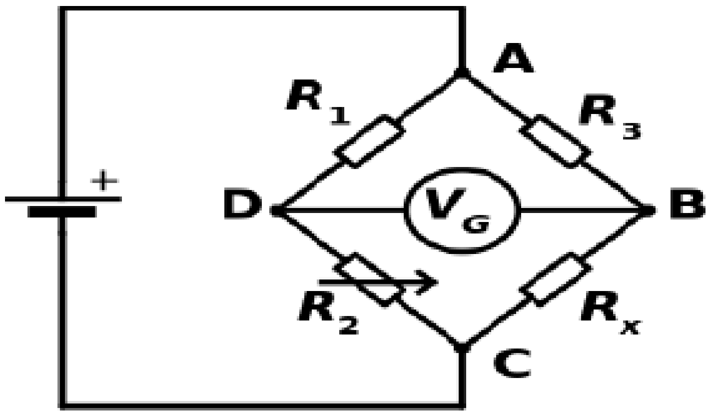
1. A string of 20 Christmas light are connected in series with a 3.0 V battery. Each light has a resistance of 10Ω. The terminal voltage is measured as 2.0 V. What is the internal resistance of the battery? (Ans:- 100Ω)
2. A battery has an internal resistance of 0.02 Ω and an e.m.f of 1.5 V. If the battery is connected with 5 - 15 Ω light bulbs connected in parallel, what is the terminal voltage of the battery? (Ans:- 1.49V)
3. Suppose we have a car battery with an e.m.f = 13.8 V, under a resistive load of 20 W, the voltage sags to 11.8 V.
   (a) What is the battery's resistance? (Ans:- 1.18Ω)
   (b) What is the rate at which energy is dissipated in the battery? (2.36w)
4. What is the internal resistance of cell when there is current of 0.4A, when a battery of 6 V is connected to a resistor of 13.5Ω? (Ans:- r = 1.5 Ω)
5. What is the maximum current of a battery of e.m.f 3.0 V and internal resistance of 1.0Ω (Ans:- I = 3 A)
6. An old cell with an e.m.f of 1.7 V has an internal resistance of 0.8 Ω. How much current will initially flow it its terminals are short – circuited?
   (Ans:- I = 2.125A)
7. A dc source with an internal resistance of 0.11 Ω is connected across a length of nichrome wire having a resistance of 20 Ω .If a voltmeter across the nichrome indicates a drop of 5 V, what is the e.m.f of the source? (Ans:- emf = 5.0275 V)
8. A cell with an e.m.f of 1.4 V and internal resistance of 0.05 Ω is placed in a circuit with several resistors. The cell provides 0.52 A to the circuit. What is the terminal voltage of the cell? (Ans:- V = 1.374 V)
9. The potential difference across the cell when no current flow through the circuit is 3 V. When the current I = 0.4A is flowing, the terminal potential difference falls to 2.8 V. Determine the internal resistance (r) of the cell.
   (ANS: r = 0.5 Ω)
10. A cell supplies a current of 0.6A through a 2 Ω resistor and a current of 0.2A through a 7 Ω resistor. Calculate the e.m.f of the cell and the internal resistance (Answer: E.m.f = 1.5 V, r = 0.5Ω)
11. A complete circuit consists of a 18 V, battery and a resistor R. The terminal voltage of the circuit is 15.8V and the current is 4A. What is:
    (a) The internal resistance, r of the battery. (ANS: r = 0.55 Ω)
    (b) The resistance R of the circuit resistor. (ANS: R = 3.95 Ω)
12. In the circuit shown below, the battery has an e.m.f of 6.6 V and internal resistance of 0.3 ohms. Determine the reading of the ammeter. (ANS:- 1.571A)



Wheatstone bridge

Wheatstone bridge is an electric bridge circuit used to measure the unknown resistance of a conduct.

Diagram:



Procedures

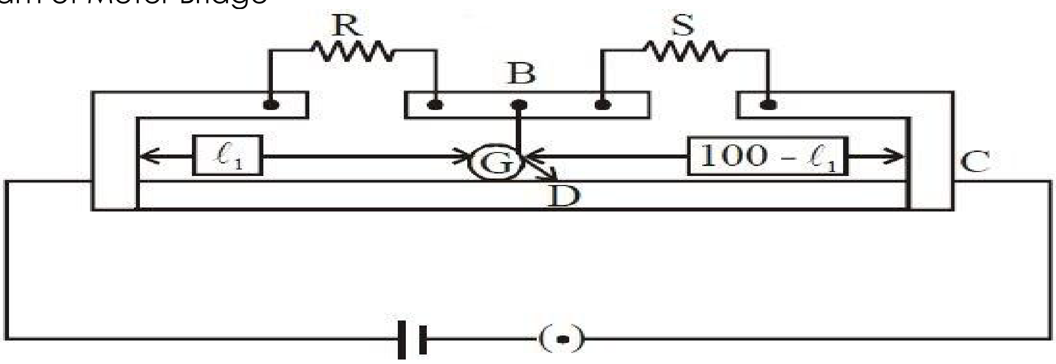
Consider the Wheatstone bridge above in which three resistors are known. When the galvanometer read zero then the ratio of the resistance on each side is equal.
From that ratio we can find the Unknown resistor as

$$\frac{R_3}{R_1} = \frac{R_x}{R_2}$$

And the value of **Rx** can be found by making it the subject.

$$R_x = \frac{R_2 R_3}{R_1}$$

Sometime the unknown resistance can be found using Meter bridge.
Diagram of Meter Bridge



At balance point D, the galvanometer point at zero and the equation of Meter bridge is

$$\frac{R}{L_1} = \frac{S}{100 - L_1}$$

The unknown resistance **R** can be found by making it the subject

$$R = \frac{S}{100 - L_1} \, x \, L_1$$

Where:
The thick-edged areas are busbars of almost zero resistance

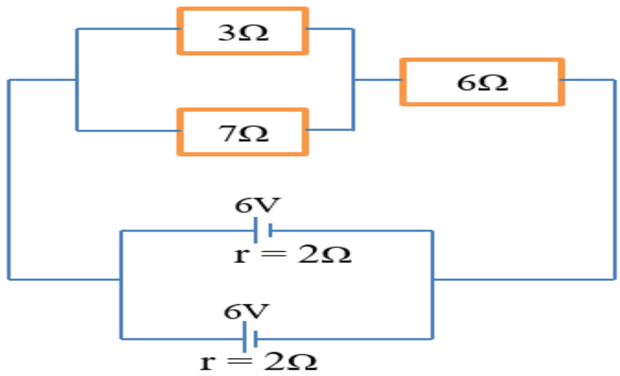
How to Use Meter Bridge

(i) Connect known resistor S and unknown resistor R.
(ii) Move voltage (p.d) gauge until no deflection (no p.d across xy)
(iii) Measure the length L_1 and L_2 $(100 - L_1)$
(iv) If no p.d across xy means
The expression can be used to determine the value of unknown resistor.

CLASS WORK

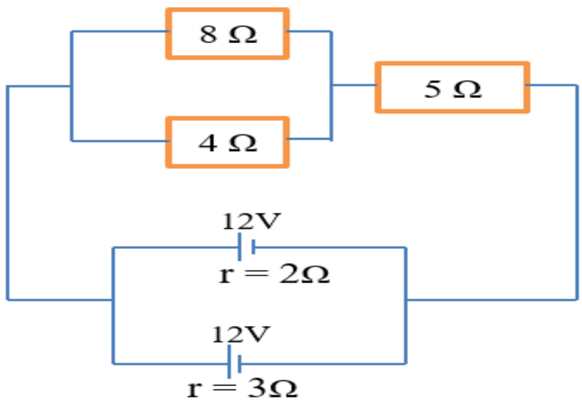
1. Two resistors of resistances 3Ω and 5Ω are connected in the gaps of the metre bridge. At what point on the wire of the bridge will a centre – zero galvanometer show no deflection?

2. Find the current and potential difference in resistors of 6Ω, 3Ω and 7Ω



3. A supply of e.m.f 4V and internal resistance of 1Ω is connected to two resistors of 12Ω and 4Ω in parallel. Calculate,
   (i) Resistance of the parallel combination
   (ii) Current taken from the supply
   (iii) Terminal p.d of the supply
   (iv) Current through each parallel current

4. Use the figure below to answer the questions that follow



   Find
   (i) Current in the circuit
   (ii) Current in 8Ω resistor
   (iii) Voltage across 5Ω resistor
   (iv) Voltage across 4Ω resistor
   (v) Equivalent resistance
   (vi) Voltage lost

5. A cell of emf 1.5V and internal resistance of 0.5Ω is connected across 4Ω resistor. Calculate the current, the voltage in the resistor and the voltage lost

6. Three cells each of e.m.f 1.5V and internal resistance 0.6Ω are in parallel. The group of cells is connected across a conductor of 1Ω resistance. Calculate the current in the circuit.

HEAT EFFECT OF AN ELECTRIC CURRENT

I hope you've come across relation between temperature and resistance. Then, you must also know that resistance results into heat energy.

Factors Affect Heat Quantity

It depends on the following factors

(i) Resistance of conductor
(ii) Magnitude of electric current
(iii) Time taken the current pass

Resistance of Conductor (HαR)

The higher the heat, the higher the resistance and vice versa

Magnitude of Electric Current (HαI^2)

The higher the heat, the higher the electric current and vice versa

Time Taken the Current Pass (Hαt)

The time taken the heat, the higher the temperature and vice versa

Joule's Law

It tells us the relation between resistance, current and heat generated. State that **"When an electric current passed through a conductor the heat evolved in a given time is direct proportional to the resistance of the conductor in Ohm's multiplied by the square of the current in ampere".**

Joule is a work-done when a current of 1 Ampere flow in a conductor with a p.d of 1Volt in 1 second.

Mathematically:

$$\frac{H}{t} \alpha R I^2$$

H $\propto$ tRI^2 - remove proportionality constant

H =ktRI^2 - constant, K = 1

H =I^2Rt

But: R and I can be made subject into

$$R = \frac{V}{I} \text{ and } I = \frac{V}{R}$$

Substituting R and I in the formula **H =I^2Rt**, results into two more formulas

$$\text{Therefore Heat}, H = I^2Rt = ItV = \frac{V^2}{R}t$$

Classwork

An electric kettle with a coil of resistance of 12Ω is used to heat 1kg of water from room temperature of 300K up to its boiling point. If the kettle operate from main supply of how long will it take for water to boil?

ELECTRICAL POWER

Electrical power is the rate of potential different or electrical power is the rate at which electrical energy is dissipated.

P = p.d/time = w/t

P = QV/t = ItV/t = IV

P = IV

$$\text{Therefore Power}, P = I^2R = IV = \frac{V^2}{R}$$

Example 09,
An electric kettle with a coil of resistance of 12Ω is used to heat 1kg of water from room temperature of 303K up to its boiling point. If the kettle operate from main supply of how long will it take for water to boil?
Solution

$$\text{Heat gained by water (MwCwQ)} = \text{Heat lost by electric kettle,} \frac{V^2}{R}t$$

$$1 \text{ x } 4200 \text{ x } 70 = \frac{240^2}{12}\ t$$

$$\frac{12}{240^2}\text{x } 1 \text{ x } 4200 \text{ x } 70 = \ t$$

The time expected for water to boil is 61.25 sec

Example 10,
An electric kettle draws a current of 10A when connected to the 220V mains supply. If all the energy produced in 5 minutes is used to heat 2kg of water. Calculate

(i) the power of the kettle and the rise in temperature
(ii) the energy produced in 5 minutes
(iii) the rise in temperature
(Specific heat capacity of water = 4200 $Jkg^{-1}K^{-1}$)

Data given:
Electric current, I = 10A, Electromotive force, V = 220V
Mass of water, m = 2kg, Tame taken foe current, t = 5min = 300sec
Specific heat capacity of water, c = 4200 Jkg-1K-1
Solution

(i) Power of the kettle, p ?

$$Power\ P = \frac{Energy}{Time}$$

$$Power\ P = \frac{ItV}{t} = IV$$

P = IV= 10 x 220 = 2200W = 2.2 kW
P = 2.2 kW

ii. Energy produced, H = ?
H = Power, P x time, t = pt = 2200 x 300 J
H = 660 kJ

iii. Rise in temperature, Δθ= ?
Heat = energy gained by water
H = mcΔθ – make Δθ subject

$$\Delta\theta = \frac{H}{MC}$$

$$\Delta\theta = \frac{660000}{2x4200}$$

Δθ = 78.57K

Electrical Appliance

Electrical appliance is the device uses heating element to produce heat energy. Nichrome wire is among of heating elements due to its high melting point. The common Electrical appliance include

- Heaters, Electric iron, Bulbs, kettles, Cookers
- fridges and air condition
- Televisions and computers

Rating Of the Electrical Appliance

Rating of the appliance is the rate at which the appliances dissipate energy. Each electrical appliance has rating which enables us to know energy dissipated
For Example, an appliance marked 3000W, 240V dissipates energy at the rate of 3000Joules per second when connected to 240V

Examples of power Ratings of Electrical Appliance

Electrical appliance	***Power ratings at 240V***
Electric iron	1000W (1KW)
Hair dryer	400W
Colour TV	300W
Refrigerator	120W
Light bulb	5W - 50W

(i) When voltage lowed results decrease in rating. For Example, when mains supply fall to 230V instead of 204V the rating will decrease to 1836.8W instead of 2000W.
(ii) If voltage increased result increase in rating which damage the appliance due to over heating

Measurement of Electrical Power

Power companies like TANESCO usually measure the electrical energy units in **kilowatt hours (KWh)** (simply called unit)
A kilowatt-hour is the energy supplied in one hour by an electric appliance at the rate of 1000Watts.
1KWh = (1KW x 1hour)J = (1000W x 60 x 60)J
1KWh = 3600000J = 3600KJ
Conversion: Power can be expressed into Horse-power (hp).
1hp = 746watts. We can find the cost that we can pay per unit.

Example 11,

A television set rated 200W is switched on for 5Hours every day. How much energy does it consumer in 30 days
Data given
Power released, P = 200W
Time taken, t = 5Hrs = 3600x5x30 = 540000 s
Energy released, E = ?
Solution
From: P = E/t – make E subject
E = Pt
E = 540000 x 200
E = 108000000J = 1.08×10^{8}J= 1.08×10^{5}kJ

Example 12

What is the cost of using an electric Iron rated 240V, 2000W for 2 Hours if the Electrical energy costs Tshs 100 per Unit (1 Unit = 1 Kwh).
Solution
Total energy used for 2hrs = (2000W X 2hr).
= 4000Wh=4Kwh
The cost of using the appliance
1Kwh = 100Tsh
4 Kwh = X
x = (4Kwh x 100Tsh)/IKwh
x = 400 Tsh
The cost of using appliance = 400Tsh

Example 13

A projector bulb is stamped 1Kw, 240V. Find the power it consume when connected to the 220V supply.

Solution

We know the resistance of the conductor is constant i.e. doesn't change even if current or voltage change

Given P = 1Kw = 1000W and V = 240V

From

$$Power = IV = \frac{V^2}{R}$$

Then find the resistance of the bulb

$$R = \frac{V^2}{P} = \frac{240^2}{1000} = 57.6\Omega$$

Now, if this bulb is connected to 220V supply. The power will be

$$P = \frac{V^2}{R} = \frac{220^2}{57.6} = 840.277W$$

The power it consume is 840Watt

Example 13

An electric bulb is rated 60 W, 240 V. Determine:

(a) The resistance of the filament

(b) The current flowing through the bulb when it is connected to the mains supply

Solution

(a) Given: P = 60W, V = 240 V

From

$$Power = IV = \frac{V^2}{R}$$

Then find the resistance of the bulb

$$R = \frac{V^2}{P} = \frac{240^2}{60} = 960\Omega$$

(b) Now, the current, I will be

$$I = \frac{P}{V} = \frac{60}{240} = 0.25A$$

Check Your Understanding

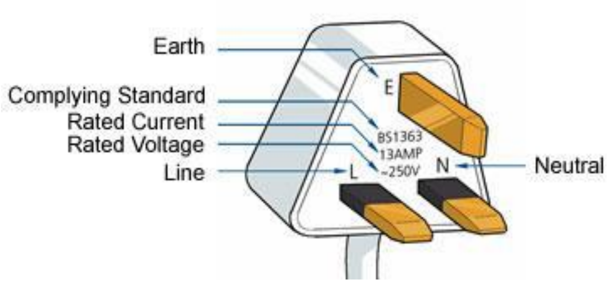
1. An electric cooker has a coil of resistance 5000□. If is operated on a 250 V mains supply for 1 hour, how much heat energy does it produce? (ANS:E = 45kJ)
2. A television set rated 200W is switched on for 5Hours every day. How much energy does it consume in 30 days ANS: E = 1.08 x 10^5kJ
3. A house has five rooms, each with a 60W, 240V bulb. If the bulbs are switched on 7:00p.m to 10:300p.m Determine the power consumed by bulbs per day. ANS: P = 1.05kWh
4. A bulb rated 120 V, 75 W burns continuously for two days. Given that the cost of one unit (1kW) is 320 Tsh .Determine the:
   (a) Total electrical energy consumed ANS: 3.6 kWh
   (b) Total power bill Answe1152 Tsh

ELECTRICAL INSTALLATION OF A HOUSE

Domestic electricity is supplied by two cables, live (L), Neutral (N), the third cable is Earth to provide extra safety

Three Pin Plug

It consist of all three cables include Live cable, Neutral cable and Earth cable with a fuse connected to live cable, sometimes fuse can connected to neutral cable which is not safe



(i) Live cable (L)
(ii) Neutral cable (N)
(iii) Earth cable (E)

Live Cable (L)

The live cable is 240V relative to the neutral. The current in the live cable alternates 60 times a second (60 Hz). It represent by **brown colour** or **red colour**

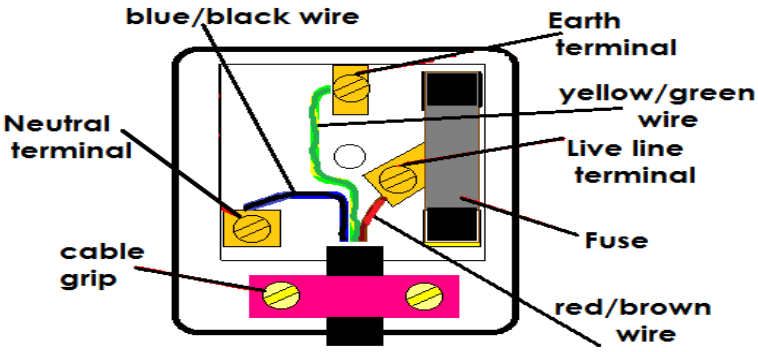
Neutral Cable (N)

The Neutral cable is earthed at the power station. This to ensure current at neutral cable remains **zero potential** so it cannot give an electric shock on touching. It represent by **blue colour** or **black colour**

Earth Cable (E)

The earth cable introduces to provide extra safety especially in electrical appliances. It represent by **yellow colour** or **green colour**

Diagram:



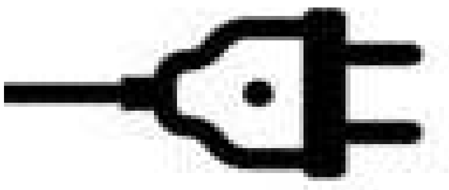
Points to note:

(i) The earth pin usually longer than the other two which used to open socket
(ii) Switch must be off when you push the plug into the socket

Two Pin Plug

It consist only two cables include live cable and Neutral cable an appliance use two pin plug its body not connected to earth.

Diagram:



Points to note:

i. All connection should be tight, with no loose strands of wire
ii. Cable should firmly clamped without damage insulation

Fuses

Fuse is a safety device used to protect an electric circuit against excess of current. It may be piece of copper or tin lead wire (inside casing) which melts when current through it exceeds a specific predetermined value

The two main uses of a fuse are:-

(i) Is used to prevent large current from entering the circuit
(ii) Prevent electric appliance from damage due to large electric current

Types of Fuse

There are several types of fuses in use, includes

i. Cartridge fuses
ii. Rewireable fuse

Cartridge Fuses

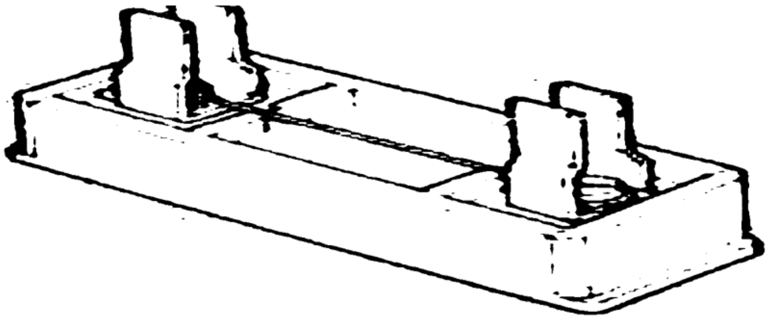
It consists of a porcelain tube with metal end caps to which the fuse element is attached

Diagram:

Rewireable Fuse

This kind of fuse, fuse element is carried in a removal fuse link made of porcelain or other insulating material

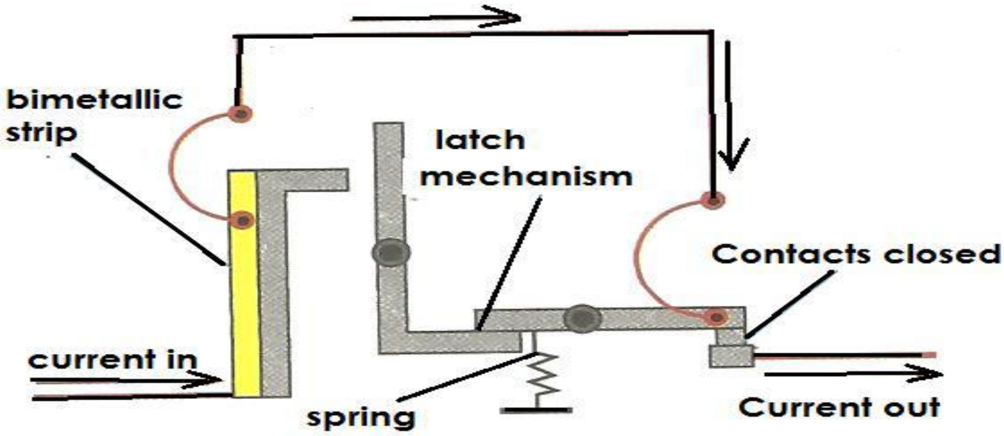
Diagram:



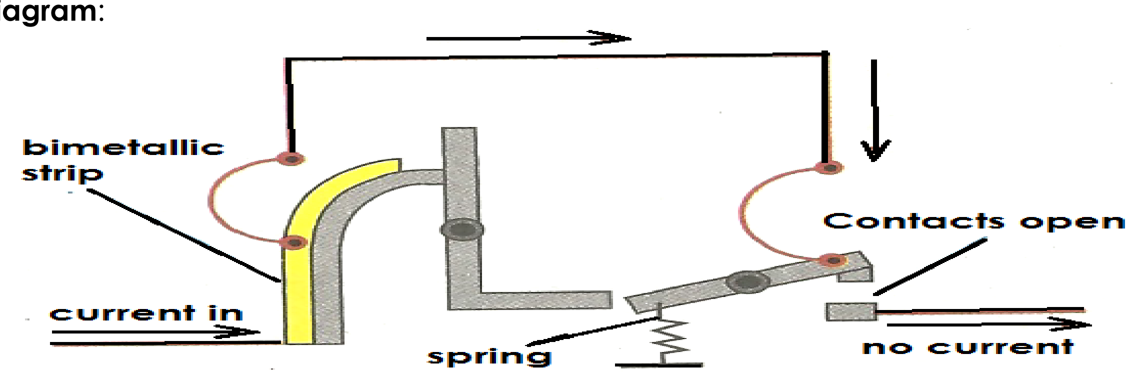
Circuit Breakers

Circuit breaker is a type of switch that cuts off the flow of electric current when the current exceeds a specific value.

Diagram:



Mechanism of Circuit Breakers
When current exceed tend to increase the temperature and bimetallic strip bend to push latch mechanism, enable the spring to cut off current
Diagram:



Example
You have a choice of fuses 1A, 3A, 5A, 9A, 13A, 15A and 30A. Find the best fuse for
(i) 240V, 7.2Kw refrigerator
(ii) 240V, 2Kw electric iron
(iii) 220V, 900w TV screen
(iv) 240V, 3000w stabilizer

Solution
(i) Refrigerator
V = 240V, P = 7.2Kw
From P = IV
$$Then, Current\ I = \frac{P}{V}$$
$$Current\ I = \frac{7200}{240} = 30A$$
Best fuse for refrigerator is 30A

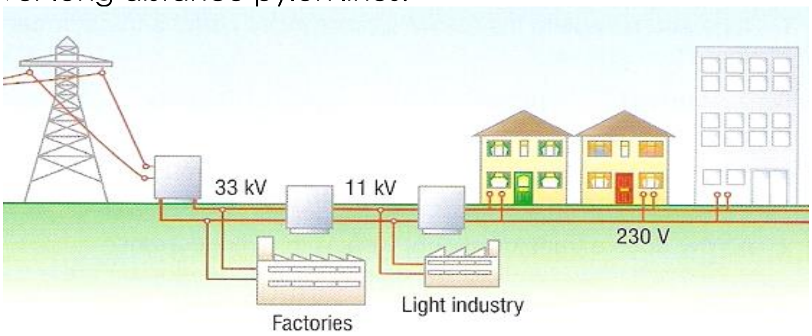
(ii) Electric iron
V = 240V, P = 2Kw
From P = IV
$$Then, Current\ I = \frac{P}{V}$$
$$Current\ I = \frac{2000}{240} = 8.33A$$
Best fuse for an electric iron is 9A

(iii) Screen
V = 220V, P = 900w
From P = IV
$$Then, Current\ I = \frac{P}{V}$$
$$Current\ I = \frac{900}{220} = 4.09A$$
Best fuse for the screen is 5A

(iv) Stabilizer
V = 240V, P = 3000w
From P = IV
$$Then, Current\ I = \frac{P}{V}$$
$$Current\ I = \frac{3000}{240} = 12.5A$$
Best fuse for that stabilizer is 13A

The National Grid

The National Grid is the system of cables used to deliver electrical power from power stations to consumers. The higher the voltage used, the greater is the efficiency of energy transmission. Lower voltages result in higher electric currents and greater energy loss to heat due to the resistance of the cables.
At power stations the output voltage of the generators is stepped up by transformers from 25kV to 132kV. The voltage may be further increased to up to 400 kV for transmission over long distance pylon lines.



The voltage is reduced in stages by step-down transformers to different levels for different types of consumer. The lowest level is 230V for domestic use. The final step-down transformer will be at sub-station within a few hundred metres of each group of houses.

DOMESTIC WIRING CIRCUIT

The current from power plant connected to consumer unit where house wiring starts. Consumer unit is the single box/unit where main switch, main fuse and distribution board

Types of Domestic Wiring Circuit

There two types include

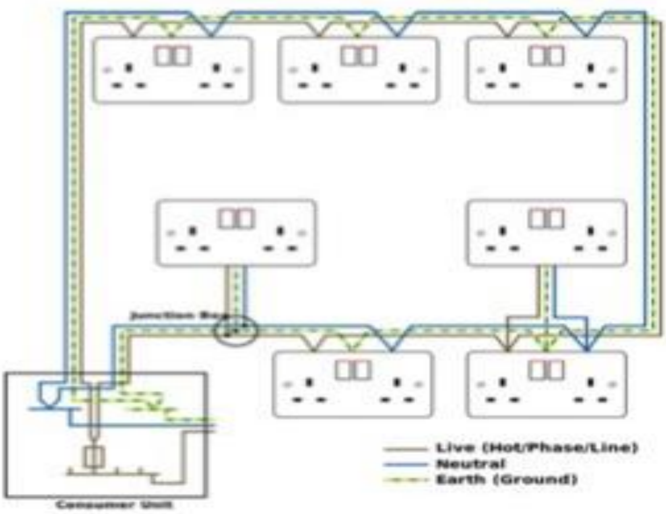
i. Ring main circuit
ii. Lighting (Tree system) circuit

Ring Main Circuit

This is a cable which begins and ends at the consumer unit. It compose 30A fuse.
The ring system consists of the three wires L, N and E, forming three separate rings round the house. This method of wiring is universally used in wiring. Lamps and other appliances are connected in parallel so that each of the appliances can be controlled individually.
When a connection is required at a light or switch, the feed conductor is looped in by bringing it directly to the terminal and then carrying it forward again to the next point to be fed.
The switch and light feeds are carried round the circuit in a series of loops from one point to another until the last on the circuit is reached.

Advantages of ring system

(i) It is less expensive. This system involves les wiring and is cheaper to set up.
(ii) All appliances can be joined in series
(iii) Less power is consumed
(iv) It can work even at low voltage supply
(v) Moreover each appliance is operated by a separate fuse.
(vi) If the fuse blows off, only that appliance is to be checked.

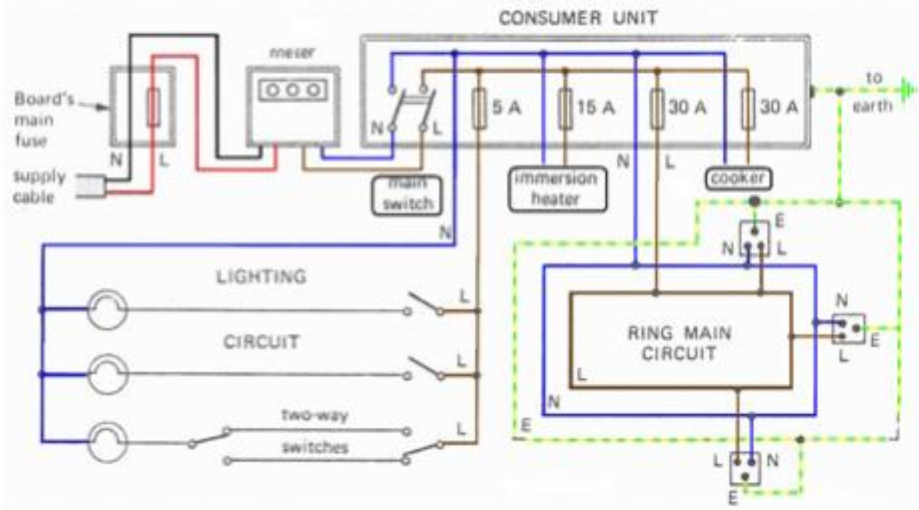


Disadvantages of ring method of Wiring

(i) Length of wire/cables required is more and voltage drop and copper losses are therefore more
(ii) Looping – in switches and lamp holders is usually difficult.

Tree (lighting) Circuit

In the tree system, the L and N wires from the cable are connected to two bus bars in the distribution box.
As branches to different sections of the house from the distribution box, the method is referred to as the tree system.
A fuse is used for domestic lighting. The bulbs and the plug point for the fan or table lamp are connected in this circuit, each in parallel across L and N, and operated by a separate switch on the livewire side.



The fuse is connected to two or more three-pin power plug points which can be used for irons, toaster, hot plates, etc. The third wire is the earth wire connected to the metal body of the appliance which is earthed.

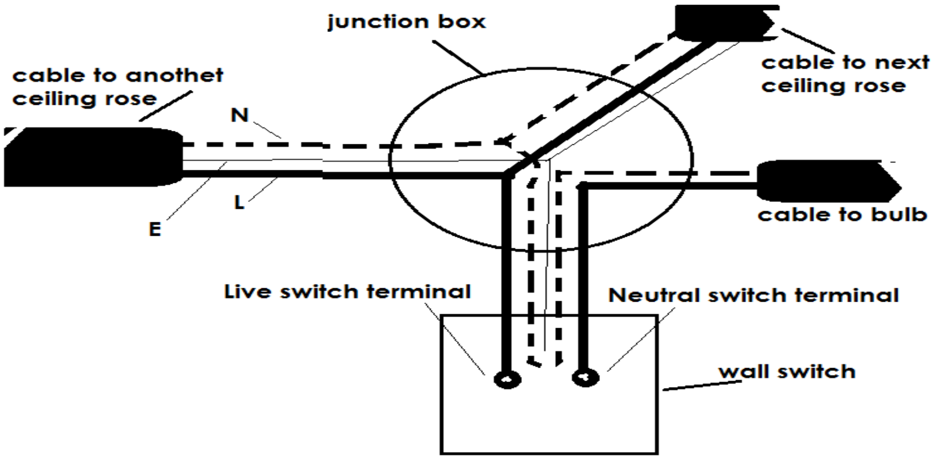
Disadvantages of tree system of wiring

(i) If a fuse blows off, two or more appliances have to be checked.
(ii) Too many wires of different ratings crowd into the distribution box from different sections of the house.
(iii) If extra points are required at a later stage there may not be place in the distribution box for extra wires.

Types of Lighting Circuit

There are two types
(i) Loop in lighting circuit
(ii) Junction box lighting circuit

Loop In Lighting Circuit
All three cables from consumer unit run to each ceiling roses, one after the other. From Each rose another set of cables runs to the switch which operates the light
Diagram:



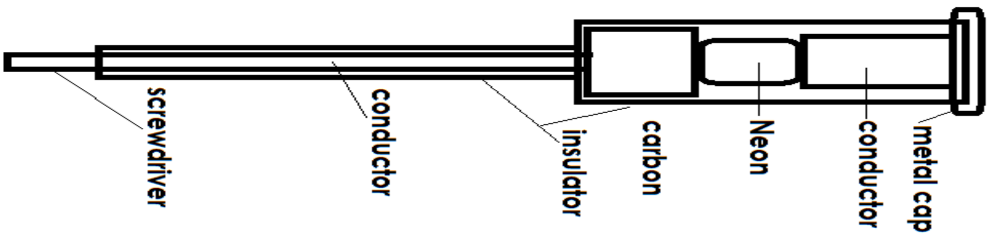
Junction Box Lighting Circuit
All three cables from consumer unit run to one junction box to another, where one cable runs to the light and another run to the switch for that light.

Checking and rectifying electric faults.
In order to check and rectify the electrical faults, one should have the necessary equipment and materials
(i) A tester for testing flow of electric current
(ii) A multimeter for testing any fault, e.g. caused by two conductors being in contact when they should not be. Also it will test where there is an open circuit due to a broken resistor or conductor or blown fuse.
(iii) Appropriate connecting wires and fuses to replace faulty ones.

Repairing Electrical Appliances Faults

Live mains lead indicators and Multimeter are device important when checking electrical appliances faults. Also test where there is an open circuit due to a broken resistor or conductor or blown fuse.

Live Mains Lead Indicator
It made up of for, of a screwdriver with a hollow insulting handle containing a tiny neon discharge tube. One electrode connected to metal probe of the screwdriver and another electrode connected to metal cap of the handle through a high carbon resistor
Diagram:



When metal probe inserted into live socket and touch the metal cap with finger, the current leaks to the earth through the body and the neon tube glows.

Multimeter
Multimeter is the single meter for measure current (both a.c and d.c) voltage and resistance. It has a range switch precise readings can be taken. It divided into **moving coil Multimeter** and **digital Multimeter**
Diagram:

Repair Faults Procedure

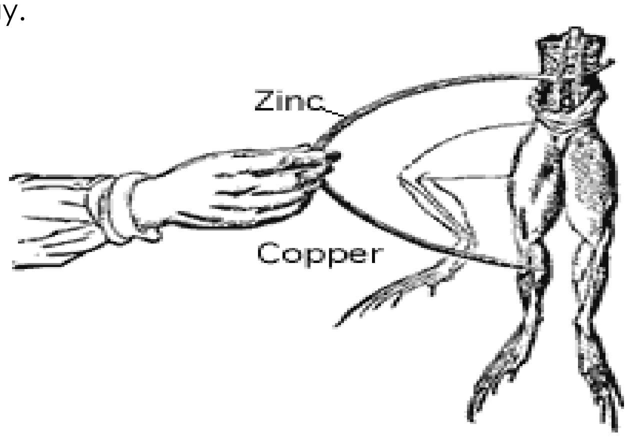
If electrical appliance fails to work the following procedure should be done
i. Check by using live mains lead indicator if there is power or not
ii. Check the cable from the socket to the appliance
iii. If no fault open the plug and check the fuse, if no is detected
iv. Check each cable for continuity by using a Multimeter
v. If cable are working good, check the fault is in the element by using a Multimeter
vi. If element is in fault, replace element as repair may not be possible
vii. If element has no fault , look for loose connection, these should be made firm and/or cleaned of rust and other dirt

Source of Faults
Faults in domestic system can arise due to
i. When fuse blows or melt
ii. Wire cutting
iii. Wire joining
iv. Socket getting dirty
v. Switches breaking

CELLS

History
In 1791, Galvani noticed that a circuit created with two different metals, when touched on the ends of the leg of a dead frog, would cause it twitch. The two metals were creating an electric current within the frog's leg, causing the muscles to contract.

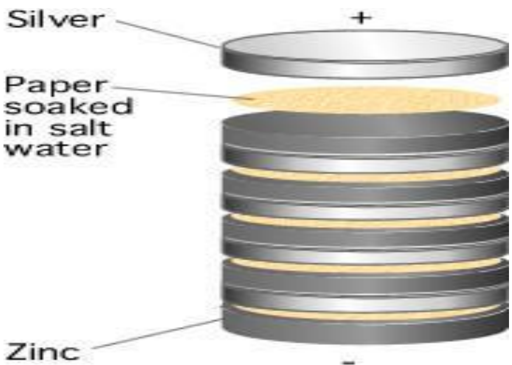
Early batteries were an improvement of this method transferring chemical energy into electrical energy.



In order to provide a potential difference or electro-motive force (e.m.f) a store of energy is required. One such method is a battery or cell. The common usages of the term battery are any device that converts chemical energy into electrical energy. However, strictly speaking, the term battery is used when several electrical cells are connected together to provide a source of a potential difference in a circuit. If it is just a single chemical source then it is called a cell.

Galvani's Frog's Leg Experiment
The first battery was invented in 1793 by Alessandro Volta. Just as the two different metals touching the wet skin of a frog's leg, caused an electrical current to flow, early batteries increased the voltage that could be produced by stacking a pile of discs made from silver and zinc sandwiched between paper soaked in a salt water solution as shown in Figure below of Volta, we use the Volt as the unit of potential difference an emf.

Volta's battery of cells



Hence, a cell is a set up used to cause a flow of electric current in a conductor. Cells store chemical energy so current caused by reaction to release and accept electrons. Also is called **electrochemical cell**

TYPES OF ELECTROCHEMICAL CELL

i. Primary cell
ii. Secondary cell

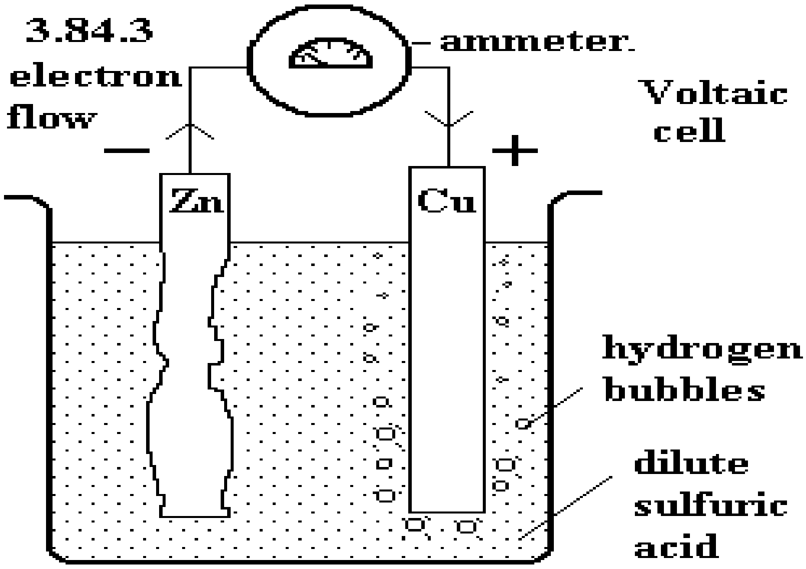
PRIMARY CELL

Primary cell is the kind of cell in which current generated through electrolysis. Electrolytes replaced after some time. It called voltaic cell. Example, of primary cell

i. A Simple cell
ii. Leclanché cell
iii. Dry cell

SIMPLE CELL

A simple cell can be made by putting a small amount of dil. sulphuric acid in a glass vessel in which copper and zinc plates are immersed. A galvanometer/Ammeter connected in series to measure the current delivered by the cell.



Dissociation:

H_2SO_4 (aq) $yields \rightarrow$ 2 H^+ (aq) + SO_4^{2-} (aq)

H_2O(l) $yields \rightarrow$ H^+ (aq) + OH- (aq)

Cation present: Only H^+

Anion present: OH^- (aq) and SO_4^{2-} (aq)

At anode:

Zinc metal dissolved into solution to form zinc Cation which reacts with sulphate anion to form zinc sulphate until sulphate anion fished from electrolyte

$Zn^+ + SO_4^{2-} \rightarrow ZnSO4$

At cathode:

Hydrogen cation discharge to liberate hydrogen gas (bubbles)

$2 H^+ + 2e \rightarrow H_2$

Action of simple cell

The action of a simple cell can be explained as follow

The Zinc plate dissolves in the sulphuric acid solution and liberates electrons into the external circuit

$$Zn - 2e^- \rightarrow Zn^{2+}$$

The Zn^{2+} ions enters the solution

The acid has hydrogen ions which are attracted towards the negative charged copper plate and they receive electrons to form hydrogen bubbles around the plate and some escape into air

$$2H^+ + 2e^- \rightarrow H_2$$

Zinc is a cathode and Copper is Anode. The chemical reaction in cell creates p.d between the plates causing electrons to flow when the plates are joined with a wire. The electrons flow is maintained by the chemical changes that occur when zinc dissolves in the acid. The potential difference is maintained as long as Zinc is not completely dissolved in the dil.sulphuric acid to form zinc sulphate. The e.m.f of a simple cell is approximately 1.0V

Defects of a Simple Cell

Current drop is the main reason why simple cell is no longer used as a source of electric current due to the following reason

i. Local action
ii. Polarization

Local Action

It is a process whereby a cell is used up when there is no external current flowing. This is due to the impurities in the commercial zinc. Impurities include Iron, Lead and carbon. When commercial zinc is used in a simple cell, bubbles of hydrogen are seen escaping from the zinc plate. These impurities act as the second plate and make the zinc to dissolve in the acid even when the cell is not in use.

How to Minimize Local Action

The problem can be minimized by amalgamating the zinc with mercury. When zinc is coated with mercury only the pure zinc is exposed to the acid. The zinc then will dissolve in the solution only when cell supply current to the external circuit.

Polarization

It is caused by the formation of hydrogen bubbles around the copper plate. The bubbles insulate the plate and prevent other positive hydrogen from receiving electrons to become neutral. Also hydrogen ions accumulating at the copper plate repels other Hydrogen ions (This defect is called back e.m.f and opposes or weakens the main e.m.f of the cell). This increases the resistance of the cell.

How to Minimize Polarization

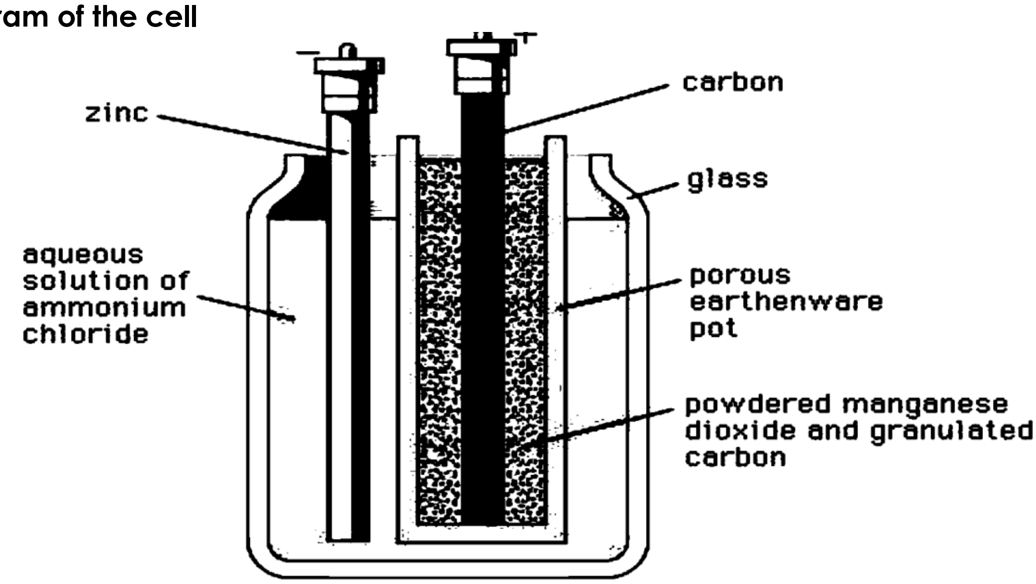
It can be minimized by using suitable oxidizing agents called Depolarizer. Example of depolarizer is Potassium dichromate. It oxidizes hydrogen and form water.

LECLANCHÉ CELL

The cell uses an aqueous solution of ammonium chloride (Sal ammoniac) as the electrolyte. The cathode is amalgamated zinc rod. The anode is a carbon rod fixed in a porous pot, containing a powdered mixture of carbon and manganese (IV) oxide (manganese dioxide) acts as a depolarizer as it is seen in the diagram below.

(i) Polarization is reduced by manganese dioxide (slow depolarizer) but when large current is drawn Polarization takes place
(ii) Leclanché cell exist today as dry cell

Diagram of the cell



Action of the Leclanche cell

The electrolyte Ammonium chloride dissociate into the ions

$NH_4Cl \rightarrow NH_4^+ + Cl^-$

At the cathode, the zinc plate dissolves in solution to form zinc ions. Electrons are released to the anode via the external circuit.

$Zn - 2e^- \rightarrow Zn^{2+}$

The electrons arriving at the anode from the cathode neutralize the ammonium ions to form ammonia and Hydrogen gases.

$2NH_4^+ + 2e^- \rightarrow 2NH_3 + H_2$

The ammonia gas dissolves in the solution while the hydrogen gas react with the manganese dioxide (Depolarizer) to form water and manganese oxide.

$MnO_2 + H_2 \rightarrow H_2O + MnO$

Disadvantage of Leclanché cell

- The depolarizing action is slow that it cannot be used to provide a continuous current.

Advantage of Leclanché cell

- It can be used in electric circuit where intermittent currents are required.
- The Leclanché cell has an e.m.f of up to 1.5V.

THE DRY CELL

It is a modified Leclanché cell in which the main electrolyte is a paste of Starch and ammonium chloride. The action of the dry is similar to that of the Leclanché cell described above.

The paste is prevented from drying by sealing the top of the cell with some insulating materials.

Advantage of dry cell

- It give large current and has shorter recovery (depolarizing) time than the wet type cells hence useful for a great variety of applications

Disadvantages of dry cell

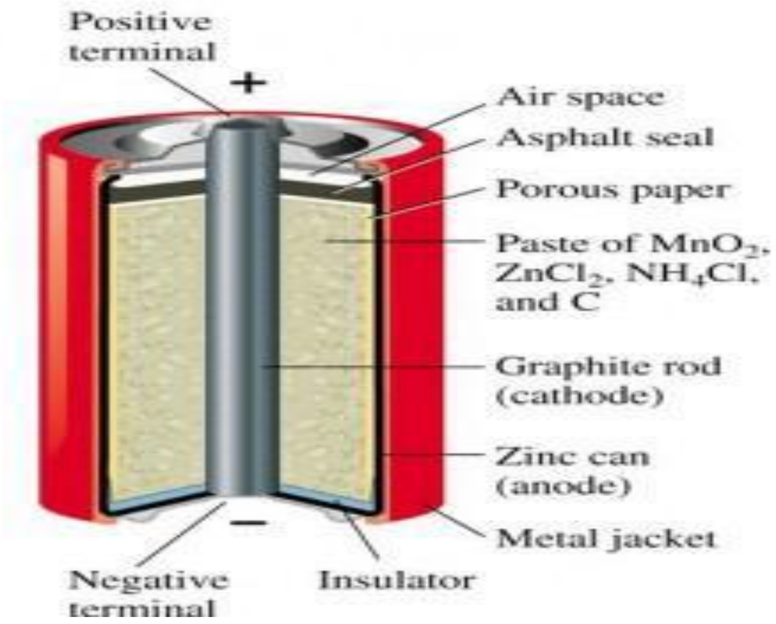
- Local action is not eliminated in these cells; hence they have a storage life ranging from a few months up to several years if stored in a cool place.

NB:

(i) Ammonium chloride (NH_4Cl) and zinc chloride act as electrolyte

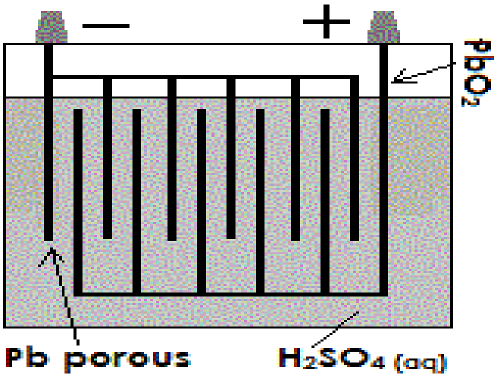
(ii) manganese dioxide depolarizer mixed with zinc anode

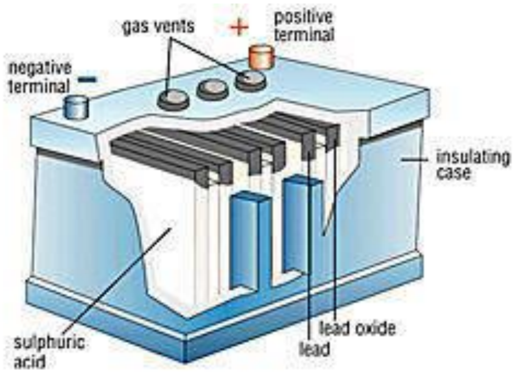
Diagram:



Uses of Dry Cell
It used to operating radios, electronic calculators and other small electrical device
The accumulator (Secondary Cell)
Accumulator is sometimes called secondary cell. They can be recharged after they have run down. This is done by passing a d.c. current from a dynamo or similar device through the cell in the opposite direction to that in which the cell usually supplies current in an external circuit.
This type of the cell is also called a storage cell or accumulator. Some common accumulators are Lead-acid, nickel-calcium, alkaline and chloride accumulators.
Advantages of accumulators
- They have very low internal resistance and can give large current with little drop in the terminal potential difference.

Lead Acid Battery
It consists of two plates of lead immersed in sulphuric acid. The acid is in plastic container. Two or more such cells may be connected to form a single battery. The positive terminal is Lead (IV) oxide and the negative terminal is Lead.
It consist more than one lead ferrous cell, made up of **lead peroxide** as anode, **porous lead metal** as cathode and **sulphuric acid** as electrolytes. An electrode is separated by insulator called **separator**. Cathode joining together to form negative terminal while anode joining together to form positive terminal
Diagram:





Charging Of Lead Acid Battery
The aim of charging is to drive all the acid out of the plate and return it to the electrolyte. Before the accumulator is used it must be charged. A current of 2A may be allowed to flow across the terminal of the cell. The positive terminals of the cell and the source of current e.g. dynamo must be connected together. Similarly, the negative terminals must be connected together.
If the cell is fully charged its e.m.f is 2V, and the cell is ready for use. It can light, say, 2V electric lamp connected across its terminals.
Points to note:
(i) The current will flow in the reverse direction to the charging current.
(ii) During discharging, the terminals are coated with Lead sulphate and during recharging; the plates are restored to Lead (IV) oxide and lead.
(iii) The accumulator must not be allowed to discharge below the stated values of p.d or else it will not be possible to recover it on recharging.
(iv) When battery full charged battery are said to be **sulphated**
(v) Main advantage of lad acid cell is its ability to recharge
(vi) Its major disadvantage are its size and weight
(vii) Never allow lead acid cell fully discharged

Discharge of Lead Acid Battery

Discharge is the process of cells to provide electrical energy. Energy is produced by reaction between electrolyte and active material of the electrode. This low concentration of the electrolyte (sulphuric acid), during discharge lead peroxide become lead sulphate and porous lead become lead sulphate

Taking Care of Accumulators

The following are some care tips on how to care for lead acid batteries

(i) Cell should be charged regularly and should never left discharges
(ii) The acid level is should be retained by adding distilled water when necessary
(iii) Terminal should be clean and greased
(iv) Rough handling should be avoided
(v) The cells should be not be short circuited, e.g. connect two terminal
(vi) The rate specified by manufacture should not exceeded during charging

Uses of Accumulators

(i) Electric cells are very useful when no mains supply of electricity is available or when connecting to a main supply of electricity would be inconvenient.
(ii) Used to power domestic appliances such as portable radios, torches, calculators and watches are example of devices that use primary cells.
(iii) It is possible to buy rechargeable batteries for these devices. These are secondary cells to start the engine and to run all the electrical circuits.
(iv) This cell is recharged by the alternator when the car is in use.

Example:

An accumulator rated 90Ah and operating in a circuit for 9hours. What current can it deriver.

Then, Capacity = 90Ah
Time = 9hours
90Ah = Current x time
90 = C x 9
C = 10A
The current that can be delivered is 10A

Example:

A 12V car battery of 0.040Ω is recharged by passing the current through it in reverse direction using a charger battery of 14V and 0.50Ω. Calculate the charging current. (Answer Current, I = 3.7A)

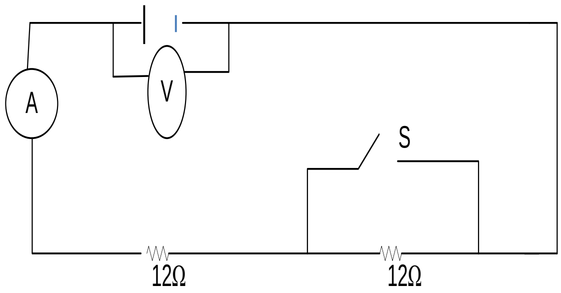
The Lead-acid accumulator has 2V per cell and low internal resistance. For any loss due to evaporation must be replenished with distilled water only. No acid should be added unless there has been some spilled from the cell.
Accumulator must be charged regularly using the charging current recommended by the manufacturers. When they are not in use for long time the accumulator must be charged at least once in every month.

Uses of electric cells

(i) They are useful when no mains supply of electricity of current is available.
(ii) They are used in portable radio, torches, calculator and watches
(iii) A car has a powerful secondary cell to start the engine and run all the electrical circuits. This is recharged by the alternator when the car is in use.

CLASS WORK

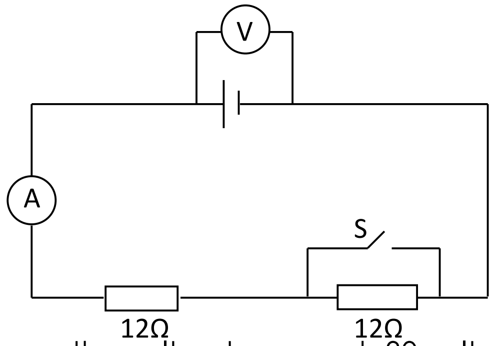
1. Give the factors which determine the resistance of a wire
2. State Ohm's law and Joule's law of heating.
3. Derive an expression for an equivalent resistors R_t for R_1 and R_2 connected
    i. In series
    ii. Parallel
4. The resistance of a copper wire is found to be 10Ω. Calculate the resistance of a copper wire of the same length but whose radius is twice that of the first wire.
5. A wire of length 8m and diameter 0.1cm has a resistance of 5Ω. Calculate the resistivity of the wire.
6. A fine wire has a resistance of 4Ω for every 100cm. When a coil made from this wire is connected to a 50V supply a current of 25 mA flows
    (i) What is the length of the wire making this coil?
    (ii) Determine the resistivity of this wire if its diameter is 0.35 mm
7. A wire of length 2m and a cross-sectional area of $0.5mm^2$ has a resistance of 2.2Ω. Calculate the resistivity of the material making up the wire.
8. A 2m long resistance wire of cross section 0.5 mm^2 has a resistance of 1.0Ω. Find
    (i) The resistivity of the material
    (ii) The length of the wire that would give a total resistance of 0.50Ω when placed in parallel.
9. The following observation was made in connection with the circuit diagram illustrated below:



    When switch **S** is open the voltmeter (v) records 1.0V but when switch **S** is closed, the voltmeter records 1.6V. Calculate:-
    (i) The e.m.f of the cell.
    (ii) The internal resistance of the cell.
10. A wire of length 1.2m and diameter of 0.64mm has a resistance of 2.4Ω. Calculate the resistance of a wire of length 0.80m and diameter 0.32mm of the same material. (Ans:- 6.4Ω)
11. Two resistors of resistances 3Ω and 5Ω respectively are to be connected in the gaps of a meter-bridge. At what point on the wire of the bridge will a centre-zero galvanometer show no deflection?(Ans:- L = 37.5cm from the end of 3Ω)
12. A battery of e.m.f 12V and internal resistance 1.5Ω is connected to a 4Ω resistor. Calculate:-
    (a) The total resistance of the circuit (Ans:- 5.5Ω)
    (b) The current through the battery (Ans:- 1.091A)
    (c) The p.d across the cell terminals as the current flows (Ans:- 1.64V)
13. (a) Differentiate between primary cells and secondary cells.
    (b) Name two advantages of lead-acid accumulator has over a dry cell.
14. A coil of resistance wire is immersed in liquid in a calorimeter of a total heat capacity 950 J/K. If the temperature rises from 9^0C to 29^0C in 5 min. When a steady current of 4A is passed, find:
    (a) the resistance of the wire
    (b) the p.d. across it

15. The p.d across the terminals of a cell is 1.1V when a current of 0.2A is being drawn from the cell. If the p.d across the cell is 1.3V when a current of 0.1A is being drawn, determine:-
    (a) The cell's e.m.f
    (b) The internal resistance of the cell
16. A battery of unknown e.m.f, E, and an internal resistance, r, is connected in series with an ammeter and a variable resistor, R. The current in the circuit was found to be 2.0A when the value of R was 4.0Ω and 1.5A when the value of R was 6.0Ω. Determine the values of E and r (Ans:- E = 12V, r = 2Ω)
17. A 6V cell of negligible internal resistance is connected to a resistor and drives a current of 3A through it. Another cell of 1.5V and internal resistance r is connected in series with the first, the current remains 3A. What is the value of r?
18. A potential difference of 6V is maintained between the plates of a copper voltammeter and 0.66g of copper is deposited. Calculate the electrical energy consumed by the voltammeter.
19. How long will it take an immersion heater of power 500w to boil away a mixture of 0.05kg of water and 0.02kg of ice initially at 0^oC?
    SLF of ice = $3.36x10^5$ J/kg
    SLV of water = $2.25x\ 10^6$ J/kg
    SHC of water = $4200J/kg^oC$
20. Solve the following problems
    i. A current of 2A is observed to flow through a conductor when a potential difference of 50V is applied between its ends. Calculate the resistance of the conductor.
    ii. Find the length of the constantan wire of diameter 1cm needed to make a resistor of 3Ω . Take the resistivity of a wire as $4.9 \times 10^{-7}\Omega m$.
21. Solve the following problems
    i. A current of 2A is passed through a conductor of resistance 10Ω for 5 minutes. Calculate the quantity of heat dissipated in the conductor.
    ii. The current in an electrical appliance operating from a 240V supply in 5A. How much energy is used up in operating it for 20 minutes?
    iii. The resistance of a heating coil of an electrical hot water system is 100 Ohms. If the coil operates from a 240V supply calculate the rate at which the coil consumes electrical energy.
22. A cell can supply a current of 1.2A through two 2Ω resistors connected in parallel. When they are connected in series, the value of the current is 0.4A. Calculate the e.m.f and internal resistance of the cell. (Ans:- E= 1.8V, r = 0.5Ω)
23. If the electrical energy is charged at the rate of Tsh. 150/- per kilowatt hour, calculate the total cost of using the following for the whole month of August;
    - ✓ a 100w light bulb for 8hours daily
    - ✓ a 1.5Kw electric iron for 1 hour and 30 minutes once a week
    - ✓ a 6000w electric cooker for 2hours daily
    - ✓ a 1000w music system for 30min daily
    - ✓ a 1kw electric kettle for 10 minutes daily
24. Explain the terms Polarization and local action. Explain how these effects can be reduced.
25. (a) What is meant by electromotive force of a cell?
    (b) A battery consist of three accumulators in series each having an emf of 2V. A secondary battery consists of four dry cells also in series, each having an emf of 1.5V. What is the emf of each battery?
    (c) Why could we get bigger current from the battery of accumulators?

26. A cell has emf of 1.5V and internal resistance of 1Ω, and connected to two resistances of 2Ω and 3Ω in series. Find the current flowing and the p.d. across each resistance.
27. The following observation was made in connection with the circuit diagram illustrated below.



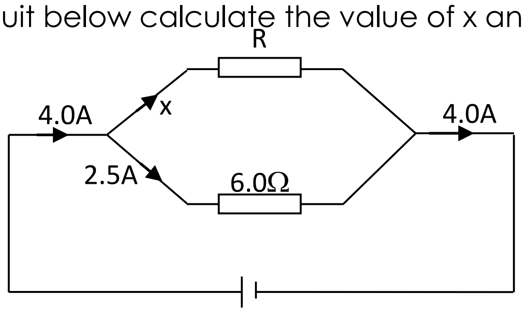
When switch S is open, the voltmeter records 30 volts but when switch S is closed, the voltmeter records 18 volts. Calculate

(a) the e.m.f. of the cell

(b) the internal resistance of the cell

28. (a) State Ohm's law.

(b) In the circuit below calculate the value of x and R.



(c) Resistances of 2Ω and 3Ω are connected in series with a cell. A high resistance voltmeter connected across the 3Ω resistor reads 1.0V, but this increases to 1.2V when an extra 2Ω resistor is connected in parallel with the first 2Ω resistor. Calculate the e.m.f. and the internal resistance of the cell.

29. Values of the current I, passing through a coil for corresponding values V of the potential difference across the coil as measured on a voltmeter are shown in table 2 below. The voltmeter has a zero error which has not been allowed for in the reading given:

I (amperes)	0.05	0.20	0.35	0.50	0.65
V (volts)	0.85	2.80	4.74	6.70	8.65

(a) Plot a graph to show the relation between V as ordinate (y-axis) and I

(b) Use the graph to determine the resistance of the coil

30. An electric kettle is rated 2kW, 240V and then filled with cold water. It takes 5 minutes to boil it. Calculate:

(a) The resistance of the element in the kettle.

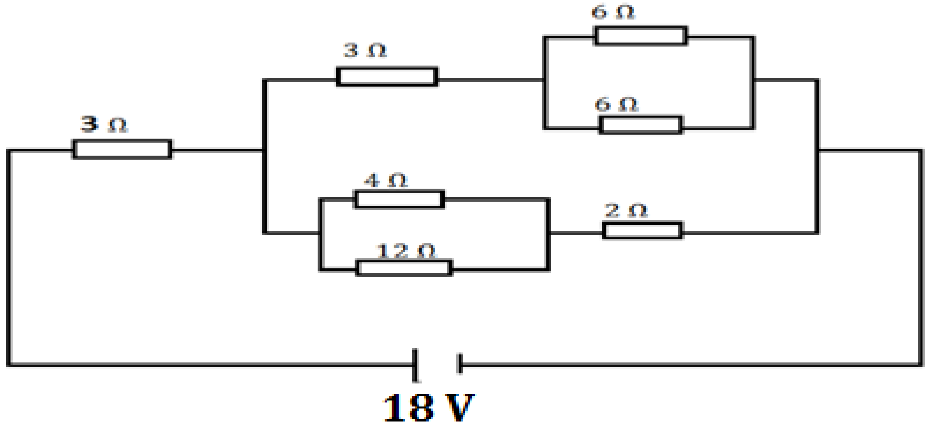
(b) Average weekly cost of using the kettle, that is filled six times each day with cold water which is then boiled (1 kWh costs Tsh 200/=)

31. When a particular cell is on an open circuit, the p.d. between its terminals is 1.5V.When a 10Ω resistance is connected between its terminals the p.d. falls to 1.0V and when 10Ω resistances is replaced by a resistance R the p.d. becomes 0.5V. What is:

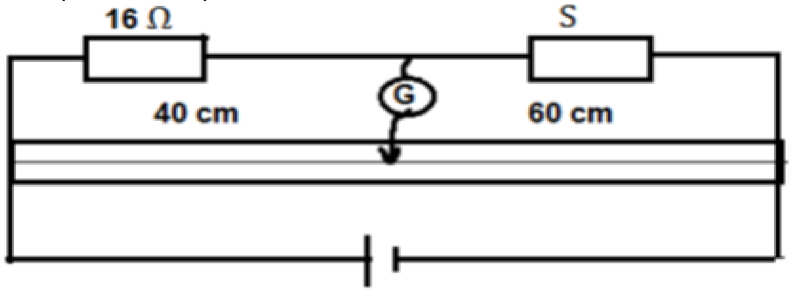
(i) internal resistance of the cell

(ii) the value of R

32. Find the current in the 12 Ω resistor **(ANS: I = 0.429 A)**

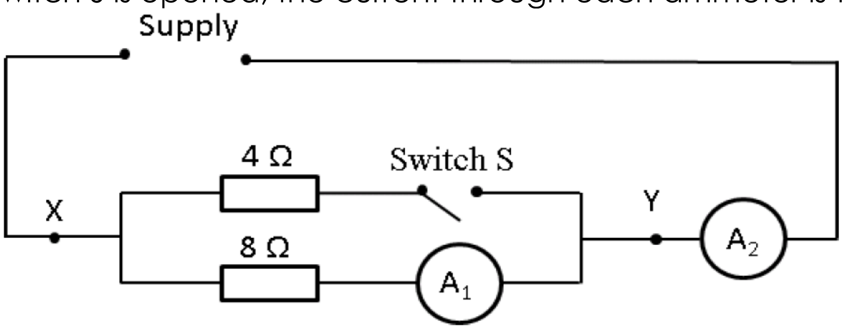


33. Find the value of the unknown resistor S in the balanced meter bridge circuit in the figure below (Ans:- 24Ω)



34. (a) Mention where and how Ohm's law cannot be applied.
    (b) The figure below shows two resistors, whose resistances are 0.4Ω and 0.6Ω, connected in parallel. They are part of a circuit, which carries a current **I**, and the current in the 0.4Ω resistor is 1.5A. Calculate
    (i) the p.d between the points marked A and B in the diagram (Ans:- 0.6v)
    (ii) the current i in the 0.6Ω resistor (Ans:- 1A)
    (iii) the current I in the circuit (Ans:- 2.5A)

35. Can you explain why the headlights of a car dim when the starter motor is in operation? (Ans:- The heavy current cause a p.d within the battery)
36. If the resistances of the ammeters in Figure below are ignored, explain each of the following observations:
    (i) When switch S is closed, the current through A_1 is less than that through A_2.
    (ii) When switch S is opened, the current through A_2 falls.
    (iii) When switch S is opened, the current through each ammeter is the same.



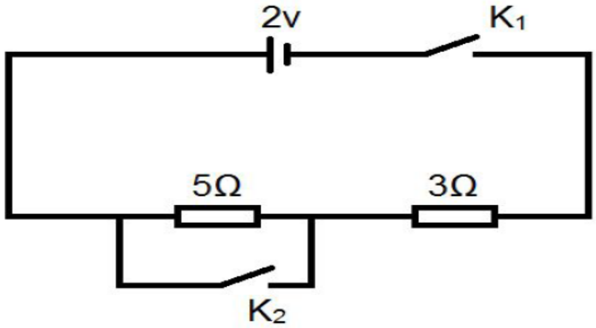
37. In an experiment to determine an e.m.f (E) and internal resistance (r) of a cell. The following tools were provided:- a battery, a switch (K), a voltmeter (V) an ammeter (A) and a rheostat (Rh).
(a) The switch, rheostat, ammeter and 2 dry cells were connected in series then connect a voltmeter parallel to the 2 dry cells
(b) The rheostat was adjusted until the value of the resistance was maximum
(c) The switch was turned on and the ammeter reading I (Amps) and voltmeter reading V (Volts) were recorded
(d) The procedure in (b) was repeated by adjusting the rheostat from maximum to minimum and (c) to get five sets of readings
(e) The observations were recorded in a tabular form as follows

Ammeter reading (A)	Voltmeter reading (V)
0.9	2.7
0.8	2.4
0.7	2.1
0.6	1.8
0.5	1.5

(f) i) Plot a graph of V against I
ii) Obtain the slope S and V intercept

iii) What is the significant of the slope S and V intercepts obtained in (ii) above?

38. Use the diagram below to calculate the current when
(a) Switch K_1 is closed while K_2 is open.
(b) Both switches K_1 and K_2 are closed.
(c) Switch K_1 is open while K_2 is closed.



THE END

By Benezeth Omulangira Mutalemwa
0713 – 575 – 000
0752 – 575 – 000
0736 – 575 – 000
benmutalemwa@gmail.com