General Studies Manual for UPSC and State Public Services Examinations 2014

Everyday Science and Technology
Module-1: Select Concepts & Applications in Physics

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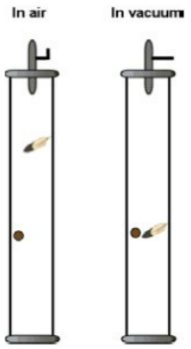
Chapter 1. Motion of freely falling bodies and projectile motion

Freely falling bodies

Vertical Free Fall of the Bodies and Air Resistance

Concept Notes 1.

- All objects in free fall experience same acceleration
- When there is no air, the acceleration of an object under free fall is **independent of its mass**
- When we let a coin and feather fall in an airless tube, **both reach the bottom at same time.**



In physics, acceleration is the rate at which the velocity of a body changes with time. *When an object falls towards the earth under gravity in the absence of air resistance, it is called a freely falling body*. All objects in free fall near the earth have the same acceleration called the acceleration due to gravity (g). The gravitational force acting on an object of mass (m) near the earth is its weight W = mg. The acceleration of an object in free fall is independent of its mass. As air resistance normally acts on a falling body and opposes its motion, the object falls at a slower rate than in free fall. When we drop a coin and a feather simultaneously in a tube fill with air and evacuated tube, we get the following observations.

- When the tube has air, coin which is heavier than the feather reaches the bottom of the tube more rapidly while the feather flutters down slowly.
- When there is no air in the tube, coin and the feather to fall together.

From this experiment we understand that air resistance affects the motion of a falling body. The air resistance on a falling body depends on its shape, size and speed.

Concept Notes 2.

- A skydiver with an unopened parachute falls quite rapidly and when the chute opens due to the shape and size of the body the air resistance increases and the descent is slowed.
- Automobiles are streamlined in shape to reduce air resistance and improve fuel consumption

Terminal Velocity

When a body falls, it accelerates due to gravity and the retarding force of air resistance increases with speed. This continues till the force of air resistance equals the weight of the object. Now the object no longer accelerates but falls with a constant speed called the terminal velocity. The terminal velocity is about 200 km/hr for a skydiver with an unopened parachute. While falling, the skydivers use a "spread-eagle" position to increase the air resistance and prolong the time of fall. When the parachute is opened, the fall is slowed by the additional resistive force.

Projectile motion

Any object which follows a path determined by the gravitational force and air resistance when an initial velocity is given, is called a projectile. A bullet shot from a rifle, a rocket after its fuel is exhausted, a javelin thrown by an athlete and a thrown cricket ball are examples of projectile. The path followed by a projectile is called its trajectory.

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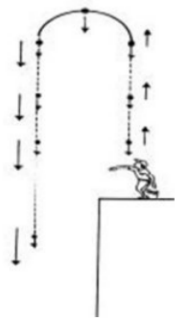
Vertical Projectile Motion

Concept Notes 3.

- When an object is thrown vertically upward, the maximum height attained by it is proportional to square of its initial velocity
- When an object is thrown vertically upward, time taken by it in reaching at the top point is equal to the time taken by it to reach back to ground
- Velocity of the body falling from a height h on reaching the ground is equal to the velocity with which it is projected vertically upwards to reach the same height h. Hence the upward velocity at any point in its flight is the same as its downward velocity at that point.

We often throw or toss things directly upward and this is an example of vertical projection. The initial velocity of the object is upward but the acceleration due to gravity is downward. Hence a vertically projected object at its maximum height stops instantaneously and changes its direction. Now it becomes a dropped object in free fall. If a body is projected vertically upwards its velocity gradually decreases and when the body reaches the maximum height its velocity becomes zero. The equations of motion for an object which is thrown upwards are as follows:



$$v = u - gt \quad \text{.....(1)}$$

$$s = ut - \frac{1}{2}gt^2 \quad \text{.....(2)}$$

$$v^2 = u^2 - 2gs \quad \text{.....(3)}$$

Where:
v= final velocity
u= initial velocity
g = gravitation acceleration

Maximum Height attained

Let a body be projected vertically upwards with an initial velocity u. As it moves upwards its acceleration is taken as –g. As the body goes up its velocity decreases and finally becomes zero (v = 0) when it reaches maximum height. Now the above equation (3) becomes:

$$-u^2 = -2gh$$

$$h = \frac{u^2}{2g} \quad \text{.....(4)}$$

This means that maximum height attained by a body is directly proportional to the square of its initial velocity u.

Time of Ascent (t_1)

The time taken by a body thrown up to reach maximum height is called its time of ascent. Let t_1 be the time of ascent. At the maximum height its velocity v = 0. Equation (1) becomes

$$0 = u - gt_1$$

$$t_1 = \frac{u}{g}$$

Time of descent (t_2)

After reaching the maximum height, the body begins to travel downwards like a freely falling body. The time taken by a freely falling body to reach the ground is called the time of descent (t_2). In this case u = 0 and g is positive. Equation (2) becomes

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$$h = 0 + \frac{1}{2} g t_2^2$$

$$t_2^2 = \frac{2h}{g}$$

$$t_2 = \sqrt{\frac{2h}{g}}$$

By Equation (4)

$$h = \frac{u^2}{2g}$$

$$\therefore\ t_2 = \sqrt{\frac{2}{g} \times \frac{u^2}{2g}}$$

$$= \sqrt{\frac{u^2}{g^2}}$$

$$= \frac{u}{g}$$

The above discussion makes it clear that time of ascent is equal to the time of descent in the case of bodies moving under gravity.

Time of Flight

The time of flight is the time taken by a body to remain in air and is given by the sum of the time of ascent (t_1) and the time
of descent (t_2).

$$t_f = t_1 + t_2$$

$$= \frac{u}{g} + \frac{u}{g}$$

$$t_f = \frac{2u}{g}$$

Velocity of a body dropped from a hight

When a body is dropped from a height h its initial velocity u is zero. Let the final velocity on reaching the ground be v.

Equation (3) becomes

$v^2 = 2gh$

$v = \sqrt{2gh}$

At the same time, from Equation (4) we note that

$U = \sqrt{2gh}$

This means that:

Velocity of the body falling from a height h on reaching the ground is equal to the velocity with which it is projected vertically upwards to reach the same height h. Hence the upward velocity at any point in its flight is the same as its downward velocity at that point. The value of g at a place can be determined by noting the time taken (t) to cover a vertical height (h) in free fall

$$g = \frac{2h}{t^2}$$

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A coin was thrown vertically upwards and it rose to a length of 10 metre. The velocity with which the body was thrown upwards is ___:

A. 12 m/s
B. 14 m/s
C. 16 m/s
D. 18 m/s

Answer: [1]

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A coin was thrown vertically upwards and it rose to a length of 10 metre. The time taken by the body to reach the highest point is

A. 1.43 seconds
B. 1.96 seconds
C. 1.82 seconds
D. 2.35 second

Answer: [2]

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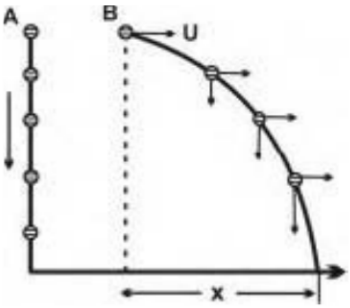
Horizontal Projectile Motion

A horizontally thrown ball and a bullet fired from a rifle held horizontally are the examples of projectiles in the horizontal direction.

Concept Notes 4.

- A body A which is freely falling and the body B projected horizontally from the same height at the same time will strike the ground simultaneously at different points. The two bodies will be at same vertical point at any point of time.

For this type of projection there is an initial velocity u only in the horizontal or x-direction. But there is no initial velocity in the vertical or y-direction.



However, there is acceleration in the downward direction due to gravity. Since there is no acceleration or force in the *x*-direction after it is projected, the projectile moves in this direction with a constant speed (*u*).

As the object moves horizontally, it also falls in the downward direction due to gravity. In the downward direction, the motion is the same as that of a dropped object.

Let us consider a body A which is allowed to fall freely and another body B projected horizontally with a velocity *u* from the same height and at the same time. The body B possesses simultaneously:

- Uniform horizontal velocity *u*
- A non-uniform vertical velocity *v*.

---

[1] Correct Answer is B. In this question
h = 10 m, v = 0, u = ?, g = -9.8 ms^{-2}
$v^2 - u^2 = 2gh$
$0 - u^2 = -2 \times 9.8 \times 10$
u2 = 196
u = 14 m/s

[2] 1.43 seconds.
v= u - gt
0 = 14 - 9.8 x t
t = 1.43 second

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As the body B travels down its vertical velocity (v) increases due to acceleration due to gravity. **But the horizontal velocity *u* remains constant.** Hence the body A which is freely falling and the body B projected horizontally from the same height at the same time will strike the ground simultaneously at different points. But the two bodies at any instant will be at the same vertical height above the ground. Thus the motion of a freely falling body is same as that of a horizontally thrown projectile. A stone released from a moving train behaves like the horizontal projectile B. As the path of B is a parabola, a stone released from a moving train also follows a parabolic path.

Oblique projection Motion

Consider a body which is projected at an angle with the horizontal. Let u be the initial velocity of the projectile and θ be the angle of projection. Initial velocity can be resolved into two components viz. (i) the horizontal component **u cos θ** and (ii) the vertical component **u sin θ**. The path of the projectile ACB is a parabola and CD (h) is the maximum height reached by it. The time (t) taken by the projectile to reach the maximum height is given by

$$t = \frac{u \sin \theta}{g} \qquad \ldots (1)$$

The maximum height reached is given by

$$h = \frac{u^2 \sin^2 \theta}{2g} \qquad \ldots (2)$$

The time of flight (t_f) of a projectile is defined as the time taken by it to reach the horizontal plane after its projection. It s given by

$$t_f = \frac{2u \sin \theta}{g} \qquad \ldots (3)$$

The distance between the point of projection A and the point B where the projectile strikes the horizontal plane again is called its range (R). It is given by

$$R = \frac{u^2 \sin 2\theta}{g} \qquad \ldots (4)$$

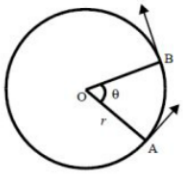
Equation (4) shows that the range is maximum when θ = 45° (because sin 90°= 1) . This is a consideration in several sports

Events such as shotput, javelin and golf where maximum ranges are desired. The player is expected to throw at an angle of 45° to achieve maximum range.

Chapter 2. Circular Motion

Uniform Circular Motion

When a particle moves in a circle with a constant speed then the motion is known as uniform circular motion.



We can consider an object moving in a circle with a uniform speed a round a fixed point O as centre. If the object moves from A to B so that the radius OA

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moves through an angle θ, its angular velocity (ω) about O is defined as the rate at which the radius vector sweeps. If t is the time taken by the object to move from A to B then,

$$\omega = \frac{\theta}{t} \qquad \ldots (1)$$

The unit of the angular velocity is rad s^{-1}. The time taken T by the object to describe the circle once is called the period of circular motion. It is given by:

$$T = \frac{2\pi}{\omega} \qquad \ldots (2)$$

If s is the length of the arc AB, then

$$s = r\theta$$

$$\frac{s}{t} = r\frac{\theta}{t} \qquad \ldots (3)$$

The linear velocity v of the rotating object is given by

$$v = \frac{s}{t} \qquad \ldots (4)$$

Substituting equation (1) and (4) in (3), we get:

$$v = r\omega \qquad \ldots (5)$$

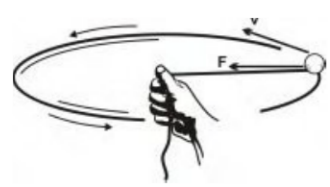
This is the relation connecting the linear velocity and the angular velocity of the object in circular motion.

Centripetal Force

Concept Notes 5.

- Centripetal force is the force that is directed toward the center of an orbital path/spinning object which keeps the revolving object in its orbit. This is in opposition to the "centrifugal force" - a kind of fictitious force that appears to try to pull the object away from the center of the orbit (due to inertia).
- The centripetal force causes acceleration towards the centre of the circle and this acceleration is called the centripetal acceleration.
- An artificial satellite orbiting around the earth does not fall down. This is so because the attraction of earth provides the necessary acceleration for its motion.
- Both Centripetal Force and Centrifugal Force play role in a Washing Machine
- Wheel of an automobile spins in mud because the centripetal force is not enough to hold the mud on tyre.

When we swing a stone tied to a string, we observe that the stone follows a circular path. But when we let the string slip through our fingers, we observe that the stone no longer follows a circular path but flies off in the direction of the instantaneous velocity. This direction is tangential to the circular path. We conclude that a force acting on the stone pulls it towards the centre of the circle. This force is called the centripetal force. Centripetal force is the force needed to make an object travel in the circular path. The centripetal force causes **acceleration towards the centre** of the circle and this acceleration is called the centripetal acceleration. The centripetal acceleration (a_c) of an object in uniform circular motion is given by



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$$a_c = \frac{v^2}{r} \qquad \ldots (6)$$

If m is the mass of the object then the centripetal force (F) is given by

$$F = \frac{mv^2}{r} \qquad \ldots (7)$$

In terms of angular velocity (w) of the object, equation (7) becomes

$$F = m\, r\, \omega^2 \qquad \ldots (8)$$

Example:

We suppose that we have a string which can be broken if we exert a force of 1500 Newton. If we attach an object with mass 8.3 kilogram at one of its end and whirl it horizontal direction in a circle of 80 cm, then what should be the maximum speed it can have, so that the string does not break.

The above equation will be arranged as follows:

$$F = m\omega^2 r \text{ or } \boldsymbol{m}\frac{v^2}{r}$$

$$1500 = 8.3 \text{ x } \frac{v^2}{0.8}$$

So

$$v2 = \frac{1500\ x\ 0.8}{8.3} \approx 144$$

v = 12 meter per second.

The above description was taught to us in our school days to explain why bucket carrying water is, when rotated in a vertical circle does not fall downward when the bucket is at highest point. This is because the necessary "centripetal" force is provided by the motion. When moon revolves around the earth, centripetal force is provided by gravitational force of Earth on moon. Similar is with artificial satellites, because as they move around the earth, the force of attraction of earth on the satellite provides necessary centripetal force.

Practical Applications of Centripetal Force

Artificial Satellites

An artificial satellite orbiting around the earth does not fall down. This is so because the attraction of earth ?

(a) Does not exist at such distance.
(b) Is neutralized by the attraction of the moon.
(c) Provides the necessary speed for its steady motion.
(d) Provides the necessary acceleration for its motion.

Answer: [3]

[3] D. The examiner wants you to decide between speed and acceleration. Please note that an artificial satellite moving round the Earth in a circular orbit possesses an acceleration which is "constant" in magnitude but "changing in direction". An artificial satellite revolves round the earth under centripetal acceleration. By the launch rocket, immediately before the satellite is established in the predetermined orbit, the speed given to it is 30, 000 km/hr. The speed must be great enough so gravity doesn't bring the satellite back to Earth, but not so great that

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Gravitational force between a satellite and the earth acts as a centripetal force, keeping the satellite in orbit

Washing Machines – Spin Dryer

The spin dryer of a washing machine removes excess water from the clothing by rotating at a high speed. The high speed of rotation creates a high *centrifugal force* for the water in the clothing which causes it to be pulled to the outside of the spinning portion of the washing machine and away from the clothes. However, it is the Centripetal force that keeps the clothes themselves away from the outer portion of the washing machine. This is provided by the walls of the rotating spin dryer. Since there is insufficient centripetal force affecting the water (only friction & surface tension holding it to the clothes), it flows to the outer walls and is separated from the clothes, which removes the excess water.

The less desirable case of lack of centripetal force is when the rear wheel of an automobile spins in mud. The adhesion of the mud to the wheel which is the centripetal force in this case is not enough to hold the mud on the tyre. So it comes off tangentially to the tyre's circular motion.

Centrifugal force

Concept Notes 6.

- Centrifugal force is in opposite direction to Centripetal force. On earth, it is minimum at poles and maximum at equator.
- In centrifuges, heavier particles move away from the centre while lighter particles remain near axis of rotation.
- When a sample of blood is centrifuged, the red blood cells accumulate at the bottom, because red blood cells are heavier than White Blood Cells.

We feel a force pushing us outward or away from the centre of curvature when we travel in a fast moving car rounding a sharp curve or in a rotating ride in an amusement park. This force is known as centrifugal force. It acts in the opposite direction to that of centripetal force. The centrifugal force is also given by

$$F = \frac{mv^2}{r}$$

When earth rotates about its own axis, the velocity of bodies near the equator is more than that at the poles. On earth the **centrifugal force is minimum at the poles and maximum at the equator**. This is the reason why the poles of the earth are found to be nearly flat and the diameters of earth along the equator and poles are different by 48 km. The centripetal force required for a car or a bicycle to go round a circular curve depends on its speed and the radius of curvature of the curve.

Applications of Centrifugal Force

Centrifuges

The principle of centrifugal force is applied to the machines called centrifuges. They are used to separate materials of different weights or densities by spinning action. The liquid is rotated in a

the satellite escapes gravity out into space. This means that the speed, which is provided by the rocket is the source of the centrifugal force, and the attraction of the earth holds it from moving away from this centrifugal force. In this question Option D is correct answer.

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cylindrical vessel at a high speed with the help of an electric motor. The **heavier particles move away from the axis of rotation and lighter particles remain nearer to the axis of rotation**

Washing Machines

The spinning drum in a washing machine to separate water from clothes is a centrifuge

Other applications

- Centrifuges are used in separating blood cells from plasma. When blood samples are centrifuged, the heavier red cells reach the bottom and lighter white cells go to the top of the tube.
- **Cream from milk** is separated by centrifuges in dairy separators. Ultra centrifuges with speeds of the order of 5 x 10^5 rpm are used to **concentrate viruses in solution**. Centrifuges are used in **Uranium enrichment**. **Sugar crystals are separated from molasses** with the help of a centrifuge. **Honey is also separated from bees wax** with the help of a centrifuge.
- If a vehicle moves at very high speed over a curved path, the centrifugal force makes it topple. This is because the centrifugal force overcomes the frictional force between the road and the tyres of the vehicle. To prevent this, the curved tracks are always banked. It means that the outer edge of the road is slightly elevated at an angle Θ. This angle of elevation is given by

$$\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$$

Where g is acceleration due to gravity. Due to banking of curves the centrifugal force balances with frictional force and equilibrium is reached. Thus toppling of vehicles is prevented on curved roads. This is known as banking of tracks. The racing track is designed like a concave disc for the same reason.

In circus there during the cage of death event, a motor cyclist drives a motor cycle at a high speed on the inner walls of a spherical cage of iron. But he does not fall off the motor cycle even when he is upside down. The centrifugal force keeps the motor cyclist glued to his seat while driving his motor cycle inside the cage.

Chapter 3. Gravitation

Gravitation, or gravity, is the natural phenomenon by which physical bodies appear to attract each other with a force proportional to their masses. It is most commonly experienced as the agent that gives weight to objects with mass and causes them to fall to the ground when dropped. Kepler deduced three laws which accurately described the motions of planets about the sun. These laws formed the basis of the famous Newton's law of universal gravitation.

Kepler's Laws

Kepler's First law (Law of orbits)

Each planet moves around the sun in an elliptical orbit with the sun at one of its foci.

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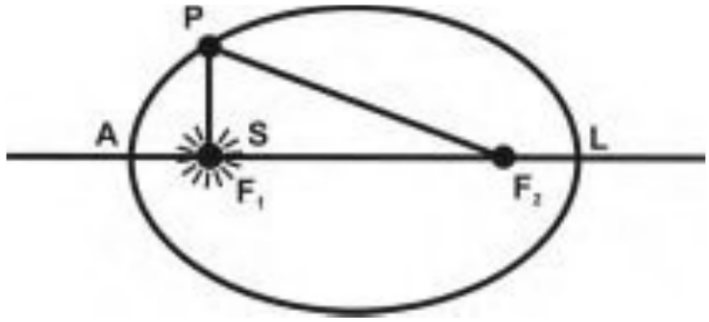
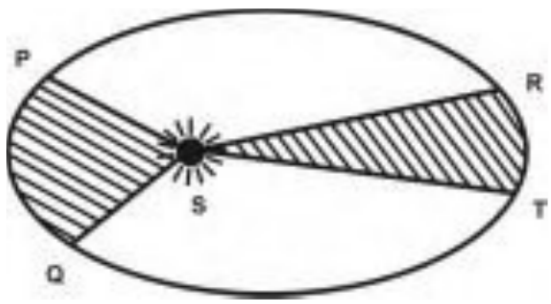
An ellipse is a closed curve such that the sum of the distances from any point P on the curve to two fixed points (F1 , F2) remains constant.



Second law (Law of areas)

As the planet moves in its orbit, a line drawn from the sun to the planet sweeps out equal areas in equal intervals of time.

Let PQS and RST be the areas swept by the line joining the planet and the sun in equal intervals of time. Kepler found that these areas are equal. Hence the speed of the planet around sun must be maximum at the perihelion position and minimum at the aphelion position.



Third law (Law of periods)

The squares of the periods of revolution of the planets are proportional to the cubes of their mean distances from the sun.

If R is the mean distance of the planet from the sun and T is the period of its revolution the third law states that

$$T^2 \propto R^3$$

$$\frac{T^2}{R^3} = \text{a constant}$$

As per this law, the planets with the mean distances from the sun, their orbital periods and velocities are listed in the table.

Planet	Time Period (Earth Years	Mean Distance from Earth ($x10^9$ m)	Mean Velocity ($x\ 10^3$ m/s)	T2 / R3 ($x10^{-25}$) years2 /km3
Mercury	0.241	57.91	47.875	2.991
Venus	0.615	108.21	35.056	2.985
Earth	1	149.6	29.806	2.987
Mars	1.881	227.94	24.144	2.988

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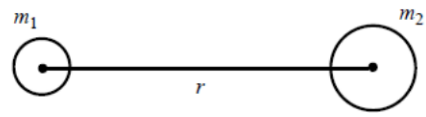
Jupiter	11.862	778.3	13.072	2.985
Saturn	29.458	1427	9.651	2.986
Uranus	84.015	2869	6.804	2.99
Neptune	164.788	4498	5.438	2.984
Pluto	248.4	5900	4.732	3.004

A century later, Newton demonstrated that Kepler's laws were the consequence of a simple force that exists between any two masses. Newton's law of gravitation and laws of motion, provide the basis for the motion of planets and satellites

Newton's universal law of gravitation



Everybody in the universe attracts every other body with a force which is directly proportional to the product of the masses of the two bodies and inversely proportional to the square of the distance between them. If m_1 and m^2 are the masses of two bodies separated by a distance r, the force of attraction F between them is given by:

$$F = \frac{G m_1 m_2}{r^2}$$

..where G is the universal constant of gravitation. The value of G = 6.67 x10^{-11} N m^2 $Kg^{-2.}$

The force of gravitation is directed along the line joining the two bodies. If m1 = m2 = 1 kg and r = 1 m then F = G

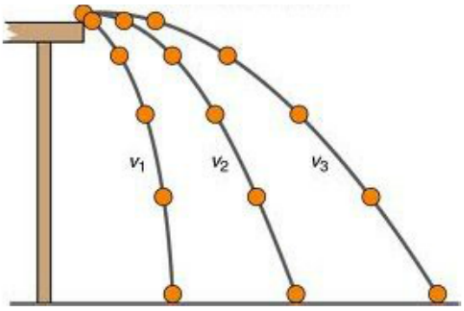
Thus the gravitational constant is equal to the force of attraction between two bodies each of mass 1 kg separated by a distance of 1 metre.

Artificial Satellites

Concept Notes 7.

- Selection of tangential speed is very much important in case of launch artificial satellite launches. They are projected with such a speed that the "radius" of their curved path is "greater" than the radius of earth. However, not such a high speed that the satellite leaves the orbit and gets lost in space.
- The speed of an artificial satellite does NOT depend upon its mass. This implies that at a particular distance from earth, all objects would move at same speed of revolution.
- Higher the orbit is, lower is its speed, so when a satellite moved from higher orbit to lower orbit, its speed increases.
- If we throw the satellite of a speed lesser than 7900 meters per second or 28500 kilometers per hour, it will simply fall on earth. The speed higher than this will **produce an elliptical orbit**. However if this speed is more than 11.2 kilometers per second, it will escape the earth's gravitation field and will never come back.
- Equator or the places near to equator are found suitable for launching the satellites as it will save efforts.
- Satellites are launched in Eastward direction, it also saves efforts.

When we throw a stone with some speed in the horizontal direction, it will follow a curved path and fall on the ground. When we throw the stone with a greater speed, it will follow a curved path that is even bigger than the previous one. Thus, greater is the speed, greater is the radius of the curved path as shown in the adjacent graphics:



Now, if we have such a powerful device to throw this stone with such a tremendous speed that radius of the curved path it follows becomes little bigger than the radius of earth, we cannot expect it to return to earth. Rather, it will keep on revolving around the earth. This

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is how the artificial satellites work. **They are projected with such a speed that the "radius" of their curved path is "greater" than the radius of earth.**

Gravitational pull of earth would provide the necessary centripetal force that is needed to keep it in its particular orbit. Here, we should note that **speed of the satellite is carefully chosen** so that it provides necessary force to keep it revolving. This implies that:

F (Gravitational) = **F** (centripetal)

So $m\frac{v^2}{r}$ = mg

∴

v^2 = rg

V= $\sqrt{rg}$

From the above formula, we first note that there is no place for **m ,** which means that the **speed of an artificial satellite does NOT depend upon its mass.** This implies that at a particular distance from earth, all objects would move at same speed of revolution.

But the above formula says that v is dependent upon r. The above formula now we derive again as follows:

F (Gravitational) = **F** (centripetal)

$$\frac{GMm}{r^2} = m\frac{v^2}{r}$$

In the above formula, G is the universal gravitational constant and M is the mass of earth. We arrive at v as follows:

$$m\frac{v^2}{r} = \frac{GMm}{r^2}$$

$$v = \sqrt{\frac{GM}{r}}$$

Here we come to two conclusions:

- v is dependent upon r because **V=** $\sqrt{rg}$
- **v is inversely proportional to r because** $v = \sqrt{GM/r}$

Here we conclude that higher the orbit is, lower is its speed. When we whirl a small string with an small object tied at one of its and also allow to get it rolled around our finger, we find that the smaller the radius of the circle is, higher is its speed.

- So, when a satellite moved from higher orbit to lower orbit, its speed increases.

Since, g= 9.8 square meters per second and radius of earth is 6.4 x 10^6 meters, we conclude that

V = $\sqrt{rg}$ =$\sqrt{6.4\ x\ 10^6\ x9.8}$ = 7.9 x 10^3 meters per second = 7.9 kilometers per second

Thus, if we throw the satellite of a speed lesser than 7900 meters per second or 28500 kilometers per hour, it will simply fall on earth. But the speed higher than this will produce an elliptical orbit.

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However if this speed is more than 11.2 kilometers per second , it will escape the earth's gravitation field and will never come back.

This value of 11.2 kilometers per second is known as escape velocity and it explains why we have the gaseous atmosphere which does not go away from earth. On moon the escape velocity is 1.9 kilometers per second and molecules of any gas formed on moon would have velocity more than this value and that is why moon has not gaseous atmosphere.

Launching a satellite needs tremendous forces, because providing it an speed of 28500 kilometers per second is not an easy task.

Launching a satellite on Equator versus Poles

Earth is not round and we all know that its radius on poles is smaller than its radius on equators. The away we move from centre of earth, lower is the gravitational force and this is the reason that the gravitational pull is minimum at Equator. So, **Equator or the places near to equator are found suitable for launching the satellites** as it will save efforts.

Launching a satellite in eastward versus westward direction

We know that Earth rotes from west to east, the satellites are launched in Eastward direction so that the speed of earth's rotation which comes nearly 462 meters per second will provide it additional push. (40000 x 1000 ÷24÷60÷60=462 (though exact speed is 465.1 meters per second))

Chapter 4. Types of Orbits

Concept Notes 8.

- An artificial satellite is always falling towards earth, but it has enough tangential velocity to continue fall indefinitely.
- Centripetal force on the satellite balances the gravitational attractive force of the earth. This balance does not depend upon the mass and size of the satellite.

The core principle of an orbit is that as a satellite or object moved tangentially, it falls toward the earth / other body, but it moved so quickly that earth / body will curve away beneath it. Thus we can understand that gravity pulls this object into a curved path as it attempts to fly off in a straight line. A satellite has enough tangential velocity to miss the orbited object, and will continue falling indefinitely.

In other words, when the satellite is moving in the orbits, it stays in position because the centripetal force on the satellite balances the gravitational attractive force of the earth. This balance depends on the following:

- Distance from the earth
- Tangential speed of the satellite
- Earth's radius
- Gravitational force of the earth.

But it does not depend upon:

- ✖ Mass of the satellite
- ✖ Size of the Satellite

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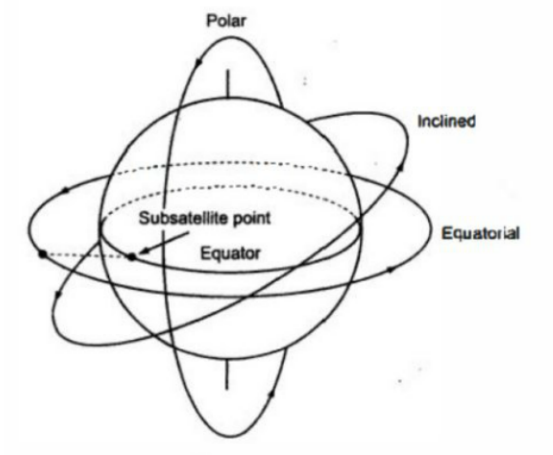
There are three major types of orbits viz. **Polar, Inclined and Equatorial**. The Polar Orbits cover the poles, Equatorial are above the equator and inclined orbits are inclined from the equatorial orbit. They are shown as below:



Geostationary Orbit (GEO)

If we need a satellite for the purpose which needs this satellites to remain at a particular distance from earth at all the time, then we need **circular orbits so all the points on circular orbit are at equal distance from earth's surface**. The **circular equatorial orbit** is exactly in the plane of equator on the earth. If the satellite is moving in the circular-equatorial orbit and its angular velocity is equal to earth's angular velocity, the satellite is said to be moving along with the earth. This satellite would appear stationary from the earth and this orbit would be called **Geostationary Orbit**. Thus the features of geostationary satellite are given in the following concept notes:

Concept Notes 9. Features of Geostationary Orbits

- **The** orbit is circular
- **The orbit is** in equatorial plane **i.e. directly above the equator and thus inclination is zero.**
- **The** angular velocity of the satellite is equal to angular velocity of earth
- Period of revolution is equal to period of rotation of earth.
- **Finish one revolution around the earth in exactly one day i.e. 23 hours, 56 Minutes and 4.1 seconds**
- **There is** ONLY one geostationary orbit.

Geosynchronous Orbit

There is a difference between the geostationary and geosynchronous orbits. We should note that while other orbits may be many, there is ONLY ONE Equatorial orbit, i.e. the orbit which is directly above the earth's equator. Sometimes we send a satellite in the space which though has a period of revolution is equal to period of rotation of earth, but its orbit is **neither equatorial nor Circular**. So, this satellite will finish one revolution around the earth in exactly one day i.e. 23 hours, 56 Minutes and 4.1 seconds, yet it does NOT appear stationary from the earth. **It looks oscillating** but NOT stationary and that is why it is called **Geosynchronous**.

So, the main features of a geosynchronous satellite are as follows:

Concept Notes 10. Features of Geosynchronous Orbits

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- **The orbit is** NOT circular
- **The orbit is** NOT in equatorial plane **i.e. directly above the equator, it's** in inclined orbit
- **The** angular velocity of the satellite is equal to angular velocity **of earth**
- Period of revolution is equal to period of rotation of earth.
- **Finish one revolution around the earth in exactly one day i.e. 23 hours, 56 Minutes and 4.1 seconds**
- **There are** many geosynchronous orbits**.**

Please note that it is practically NOT possible to achieve an absolute geostationary orbit. So, the terms geostationary and geosynchronous are used alternatively.

Advantages of GEO satellites

- Most communications satellites in use today for commercial purposes are placed in the geostationary orbit, because one satellite can cover almost 1/3 of Earth's surface, offering a reach far more extensive than what any terrestrial network can achieve.
- The geosynchronous satellites remain stationary over the same orbital location, users can point their satellite dishes in the right direction, without costly tracking activities, making communications reliable and secure
- GEO satellites are proven, reliable and secure - with a lifespan of 10-15 years.
- GEO systems have significantly greater available bandwidth than the Low Earth Orbit -LEO and Medium Earth Orbit -MEO systems. This permits them to provide two-way data, voice and broadband services that may be unpractical for other types of systems.
- Because of their capacity and configuration, GEOs are often more cost-effective for carrying high-volume traffic, especially over long-term contract arrangements. For example, excess capacity on GEO systems often is reserved in the form of leased circuits for use as a backup to other communications methods.

Disadvantages of GEO Satellites

- ✓ GEO systems, like all other satellite systems, *require line-of-sight communication paths between terrestrial antennae and the satellites*. But, because GEO systems have fewer satellites and these are in a fixed location over the Earth, the opportunities for line of sight communication are fewer than for systems in which the satellites "travel" across the sky. This is a significant disadvantage of GEO systems as compared to LEO and MEO systems, especially for mobile applications and in urban areas where tall buildings and other structures may block line-of-sight communication for hand-held mobile terminals.
- ✓ There are concerns with the transmission delays associated with GEO systems, particularly for high-speed data. However, sophisticated echo cancellation and other technologies have permitted GEOs to be used successfully for both voice and high-speed data applications.

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Inclined Orbit

An inclined orbit is used to cover the Polar Regions. It's not a very popular orbit and used not very frequently. The height of the inclined orbit is kept such that it covers the required area of the region of interest. The time for which the satellite is visible to the point on the earth is also controlled. Satellite cannot remain in continuous contact with the point on the earth if rotating in inclined orbit. Sometimes the inclined orbit is also called elliptical inclined orbit.

Polar Orbit

The Polar Orbit is not much suitable for communication purposes because it moved in a different direction than that of direction of earth's rotation. So, the use of Polar satellites depends upon their arrival at a particular point on earth at a particular point. The Polar orbits are used for special applications like navigational satellites.

Altitude of Geostationary Orbit

Concept Notes 11.

- The height of the geostationary orbit is 35786 kilometers above earth
- In Geostationary Orbit, the satellite moves with an orbital speed of 11068 km per hours.
- A minimum of three satellites are needed to cover the entire earth
- Super synchronous orbit is a disposal / storage orbit above GSO. From earth, they would seem **drifting in westerly direction.**
- Sub synchronous orbit is a orbit close to but below GSO and is used for satellites undergoing station, **changes in an eastern direction.**

For circular motion of a planet, the condition is that:

F (Gravitational) = **F** (centripetal)

$$\frac{GMm}{r^2} = m\frac{v^2}{r}$$

V is the speed. Now, we know that the speed v of the planet in its orbit is equal to the circumference of the orbit divided by the time required for one revolution T. so v=2πr/T. So, the above formula becomes as follows:

$$\frac{GMm}{r^2} = m\frac{\left(\frac{2\pi r}{T}\right)^2}{r}$$

From the above formula, we can derive the value of T^2 as follows

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

The above mathematical derivation is suitable for circular as well as elliptical orbits. Now we know that geostationary satellite follows a **circular, equatorial, geostationary** orbit, without any inclination, so we can apply the Kepler's third law to determine the geostationary orbit. Since, the path is circle, its semi-major axis will be equal to the radius of the orbit.

Now, it has already been calculated that Earth completes one rotation on its polar axis in 23 hr 56 min and 4.09 sec, which comes out to be 86164.09 seconds. So, the period of rotation of the Geostationary satellite should be 86164.09 seconds.

This means that

T=86164.09 seconds

Now we use this formula

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$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

$$r^3 = \frac{GM}{4\pi^2}$$

$$r^3 = \frac{6.67x10^{-11}x5.983x10^{24}x86164.09}{4\pi^2}$$

$$r^3 = 7.546x10^{22}$$

$$r = 4.23\ x10^7 \text{ meters}$$

$$r = 42300\ kilometers$$

The above derivation gives the height of the Geostationary orbit. Now, please note that the above height includes radius of Earth which is 6,384 km. When we deduct it from the calculated height we get 35916 Kilometers. The precise height is altitude of 35,786 km (22,236 mi) above ground.

Orbital speed (how fast the satellite is moving through space) is calculated by multiplying the angular speed by the orbital radius:

$$v = \omega r \approx 3.0746 \text{ km/s} \approx 11068 \text{ km/h} \approx 6877.8 \text{ mph}.$$

Orbiting at the height of 22,282 miles above the equator (35,786 km), the satellite travels in the same direction and at the same speed as the Earth's rotation on its axis, taking 24 hours to complete a full trip around the globe. Thus, as long as a satellite is positioned over the equator in an assigned orbital location, it will appear to be "stationary" with respect to a specific location on the Earth.

Clarke Orbit

Please note that a single geostationary satellite can view approximately **one third of the Earth's surface**. If three satellites are placed at the proper longitude, the height of this orbit allows almost the Earth's entire surface to be covered by the satellites. It was first of all conceptualized by world famous science fiction writer Arthur C. Clarke. The arrangement which was suggested by Clarke is shown in the following figure:

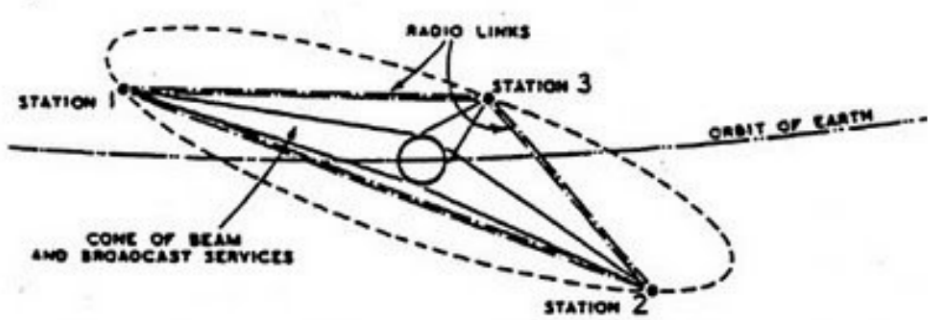

Fig. 3. Three satellite stations would ensure complete coverage of the globe.

The stations would be arranged approximately equidistantly around the earth and the following longitudes appear suitable:

- 30°E - Africa & Europe
- 150°E - China & Oceania

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- 90° W- The Americas

The station chain would be linked by radio or optical beams and thus any broadcast service could be provided. The geostationary orbit is now sometimes referred as the Clarke Orbit or the Clarke Belt in his honor.

Other Orbits

- Super synchronous orbit is a disposal / storage orbit above GSO. From earth, they would seem drifting in westerly direction.
- Sub synchronous orbit is a orbit close to but below GSO and is used for satellites undergoing station, changes in an eastern direction.
- Graveyard orbit is a Supersynchronous orbit where spacecraft are intentionally placed at the end of their operational life.

Low Earth Orbits

A satellite can also be placed in orbits below the Geostationary orbit, however, as we discussed above, to place an orbit below the Geostationary orbit, it will require higher orbital velocity. For example, a satellite which is placed in an orbit at altitude of 200 kilometers will need an orbital velocity of approximately 29000 kilometer per hour. Similarly, a satellite placed in an orbit at around 1730 kilometers will need a speed of 25,400 kilometers per hour.

> The International Space Station is in a LEO that varies from 320 km (199 mi) to 400 km (249 mi) above the Earth's surface

LEO systems fly about 1,000 kilometers above the Earth (between 400 miles and 1,600 miles) and, unlike GEOs, they appear travelling across the sky from earth. A typical LEO satellite takes 1 and half hours to orbit the Earth, which means that a single satellite is "in view" of ground equipment for a only a few minutes. As a consequence, if a transmission takes more than the few minutes that any one satellite is in view, a LEO system must "hand off" between satellites in order to complete the transmission. In general, this can be accomplished by constantly relaying signals between the satellite and various ground stations, or by communicating between the satellites themselves using "inter-satellite links."

> **Orbital Decay**
> The satellites particularly in the LEO are subject to a drag produced by an atmosphere due to frequent collisions between the satellite and surrounding air molecules. The amount of this drag keeps increasing or decreasing depending upon several factors including the solar activity. The more activity heats of the upper atmosphere and can increase the drag. This drag in a long duration causes a reduction in the altitude of a satellite's orbit, which is called orbital decay.
> So, the major cause of the orbital decay is Earth's atmosphere. The result of the drag is increased heat and possible reentry of satellite in atmosphere causing it to burn. Lower its altitude drops, and the lower the altitude, the faster the decay. Apart from Atmosphere, the Tides can also cause orbital decay, when the orbiting body is large enough to raise a significant tidal bulge on the body it is orbiting and is either in a retrograde orbit or is below the synchronous orbit. Mars' moon Phobos is one of the best examples of this.

LEO systems are designed to have more than one satellite in view from any spot on Earth at any given time, minimizing the possibility that the network will lose the transmission. Because of the fast-flying satellites, LEO systems must incorporate sophisticated tracking and switching

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equipment to maintain consistent service coverage. The need for complex tracking schemes is minimized, but not obviated, in LEO systems designed to handle *only short-burst transmissions*.

The advantage of the LEO system is that the satellites' proximity to the ground enables them to transmit signals with no or very little delay, unlike GEO systems. LEO satellites rotate the earth and currently deliver significant voice quality over the Geosynchronous (GEO) satellite systems. Now days, LEO Satellites are used in constellations such as Globalstar and Iridium constellations. In addition, because the signals to and from the satellites need to travel a relatively short distance, LEOs can operate with much smaller user equipment (e.g., antennae) than can systems using a higher orbit. In addition, a system of LEO satellites is designed to maximize the ability of ground equipment to "see" a satellite at any time, which can overcome the difficulties caused by obstructions such as trees and buildings.

LEO systems Pros and Cons

- It requires less energy to place a satellite into a LEO and the LEO satellite needs less powerful amplifiers for successful transmission, LEO is still used for many communication applications.
- However, since these LEO orbits are not geostationary, a network (or "constellation") of satellites is required to provide continuous coverage.
- The transmission delay associated with LEO systems is the lowest of all of the systems.
- Because of the relatively small size of the satellites deployed and the smaller size of the ground equipment required, the LEO systems are expected to cost less to implement than the other satellite systems.
- The small coverage area of a LEO satellite means that a LEO system must coordinate the flight paths and communications hand-offs a large number of satellites at once, making the LEOs dependent on highly complex and sophisticated control and switching systems.
- LEO satellites have a shorter life span than other systems mentioned here. There are two reasons for this: first, the lower LEO orbit is more subject to the gravitational pull of the Earth and second, the frequent transmission rates necessary in LEO systems mean that LEO satellites generally have a shorter battery life than others.

Medium Earth Orbit (MEO)

MEO systems operate at about 8,000-20,000 km above the Earth, which is lower than the GEO orbit and higher than most LEO orbits. The MEO orbit is a compromise between the LEO and GEO orbits. Compared to LEOs, the more distant orbit requires fewer satellites to provide coverage than LEOs because each satellite may be in view of any particular location for several hours. Compared to GEOs, MEOs can operate effectively with smaller, mobile equipment and with less latency (signal delay).

These orbits are primarily reserved for communications satellites that cover the North and South Pole. Although MEO satellites are in view longer than LEOs, they may not always be at an optimal

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elevation. To combat this difficulty, MEO systems often feature significant coverage overlap from satellite to satellite, which in turn requires more sophisticated tracking and switching schemes than GEOs.Typically, MEO constellations have 10 to 17 satellites distributed over two or three orbital planes.Most planned MEO systems will offer phone services similar to the Big LEOs. In fact, before the MEO designation came into wide use, MEO systems were considered Big LEOs. Examples of MEO systems include ICO Global Communications and the proposed Orblink from Orbital Sciences. Unlike the circular orbit of the geostationary satellites, MEO's are placed in an elliptical (oval-shaped) orbit

Polar Orbits

Concept Notes 12.

- Polar orbits are useful in earth mapping
- A satellite in polar orbit would pass over equator on different longitude in successive times.
- No one spot on the Earth's surface can be sensed continuously from a satellite in a polar orbit, however, to make them work on a particular area, they are launched in highly elliptical orbit with its apogee over that area

In a polar orbit, the satellite passes above or nearly above both poles of the earth being orbited on each revolution. So, we can say that the inclination of such orbit is almost 90 degrees to the equator. The Polar orbits are used for earth-mapping, earth observation, and reconnaissance satellites, as well as for some weather satellites. However, Iridium satellite constellation also uses a polar orbit to provide telecommunications services.

Why Polar orbits are used for earth-mapping?

As shown in the diagram, the Polar orbits are in a plane that is a perpendicular to the plane of the equator and so passes over the poles c Earth and then also, Earth rotates from East to West under the satellite instance, if the period of satellite is 6 hours then in one polar revolution, will rotate around 90° westwards. Thus, in a couple of days the whole eart be mapped.

Some important notes about Polar orbits:

- Except for polar geosynchronous orbit, a satellite in a polar orbit will pass over the equator at a different longitude on each of its orbits.
- No one spot on the Earth's surface can be sensed continuously from a satellite in a polar orbit, this is its biggest drawback.
- The polar orbit can be manipulated also. If we want a satellite in polar orbit to remain hovering over a certain area for larger time**, it can be placed in a highly elliptical orbit with its apogee over that area.**

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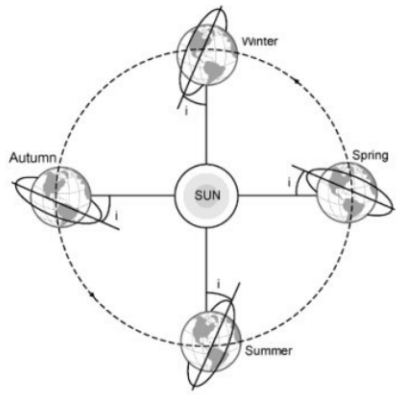
Sun-synchronous orbit

Sun-synchronous orbit or a heliosynchronous orbit very important because of its particular importance to satellites intended for remote sensing and military applications. A sun-synchronous orbit is one that lies in a plane that maintains a fixed angle with respect to the Earth-sun direction. In other words, it combines altitude and inclination in such a way that an object on that orbit ascends or descends over any given point of the Earth's surface at the same local mean solar time.



We can say that the orbital plane in such a case has a fixed orientation with respect to the Earth-sun direction and the angle between the orbital plane and the Earth-sun line remains constant throughout the year. It is shown by the adjacent diagram:

The features of Sun-synchronous satellites are given in the following concept notes

Concept Notes 13. Features of Sun Synchronous Orbits

- The satellite passes over a given location on Earth every time at the same local solar time.
- Thus, it guarantees the same illumination condition, which varies only with seasons.
- The orbit is *Quasi-polar in nature and so ensures coverage of the whole surface of the Earth*
- Every time a sun-synchronous satellite completes one revolution around earth, it traverses a thin strip on the surface of the Earth. During the next revolution it traverses another strip as shown in the diagram.

Frozen Orbits

We all know that Earth is not perfectly round. This means the gravitation is not exactly same at all the places. Apart from that there is gravitational pull from Sun and Moon too, followed by the solar radiation pressure, air drag and so many other forces. In other words, most satellites experience noticeable variations in orbital eccentricity.

But, fortunately, the distorting impacts of these issues can be induced to cancel each other by expert satellite planners. They choose optimum Orbital altitude, inclination, eccentricity and argument of perigee. The satellites whose orbital parameters are controlled by such techniques is said to be in Frozen Orbits.

Thus we can say that:

- Frozen orbit is a Sun-synchronous orbit in which the precession of the orbital plane around the polar axis of the Earth caused by the oblateness of the Earth is utilized to the benefit of the mission by choosing correct orbital parameters.
- The Earth observation satellites ERS-1, ERS-2 and Envisat are all operated in Sun-synchronous "frozen" orbits

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Chapter 5. Surface Tension

Definition and Unit of Surface Tension

Insects like ants, water-spider are able to walk on the surface of water. Mosquitoes sit and move freely on the surface of stagnant water. When we sprinkle water at the roots of trees and shrubs, the sprinkled water gradually rises to their branches upwards. All these observations can be explained on the basis of a property of liquids called surface tension. When we take a clean glass plate and place a very small amount of mercury on the plane surface, we observe that the mercury assumes the form of a spherical drop. However, when we place large amount of mercury on the plane surface, we observe that now mercury assumes ellipsoidal shape. Similarly, when we place a greased sewing needle carefully on a water surface, the sewing needle makes a small depression in the surface and keeps floating even though the density of the needle is very much greater than that of water. A tumbler is filled to the brim with water. Some nails are put inside the water so that water is displaced upwards. A few more nails are added carefully. It is found that water surface rises well above the edge of the tumbler but water does not overflow. This is because the water surface stretches as water is displaced upwards. If a brush is dipped in water its bristles spread out. If it is taken out the bristles come closer and cling together.

The conclusion from the above observations is that there exists a tension on the surface of a liquid which tends to contract the surface to a minimum area. This property of the liquids is known as surface tension. Surface tension of a liquid is defined as the tangential force per unit length acting at right angles on an imaginary line drawn on the surface of the liquid. It's unit is Newton per Metre.

Adhesive and Cohesive Forces

Surface Tension is essentially a molecular phenomenon. There are two types of molecular forces of attraction viz. adhesive force and cohesive force. Forces between molecules of different substances are called **adhesive forces.** The adhesive force is different for different pairs of substances. Gum or glue is an adhesive. The force of attraction between gum and paper is an adhesive force. Forces between molecules of the same substances are called **cohesive forces.** *The cohesive forces are short range forces and therefore they are effective only up to a very small distance*. The adhesion of water to glass is stronger than the cohesion of water. On the other hand, the cohesion of mercury is greater than its adhesion to glass. The maximum distance at which the molecules can attract each other is called molecular range. The molecular range is of the order of 10^{-8} cm.

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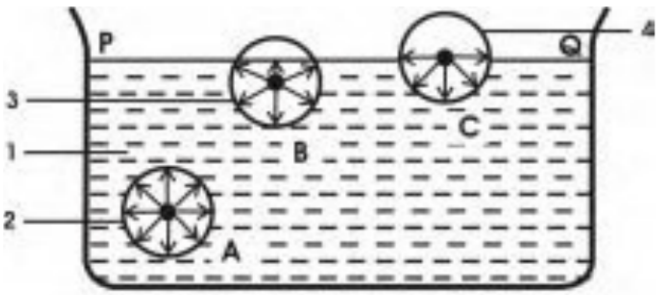
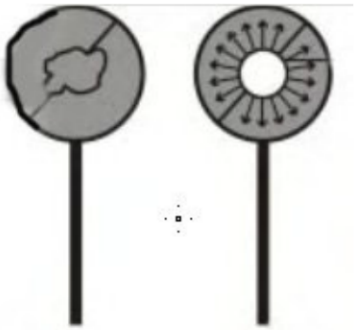
How Surface Tension works?

A sphere drawn with the molecule as centre and radius equal to the molecular range is called the sphere of molecular influence. The molecular forces are effective within this sphere of molecular influence. Therefore all the molecules lying within this sphere of molecular influence exert a force of attraction on the molecule at the centre. These molecular forces are responsible for surface tension. On the basis of this, Laplace gave an explanation of the surface tension. In the adjacent diagram, PQ represents the free surface of a liquid in a container. Let A, B and C represent molecules with their spheres of influence drawn around them. The sphere of influence around the molecule A is well within the free surface PQ. Hence it is equally attracted in all directions by the molecules in the sphere of influence. Therefore the resultant force acting on the molecule A is zero.



In the case of molecule B the sphere of influence is partly outside the liquid surface PQ. The number of molecules in the upper half is less than that in the lower half. Thus the resultant force on B acts in the downward direction.

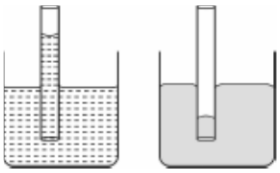
The molecule C is exactly on the free surface PQ. The sphere of influence around the molecule C is exactly half outside and half inside the liquid. **Hence this molecule C is attracted in the downward direction with maximum force.** Thus we conclude that the **molecules in the surface PQ are pulled downwards due to the resultant cohesive force**. This makes the free surface of the liquid at rest behave like a stretched elastic membrane. This force gives rise to the surface tension of the liquid.



To understand this, we can make a circular wire ring in which a loop of thread is attached as shown in the adjacent diagram. The wire and thread are dipped in a soap solution and taken out gently. We see that a film of the soap solution is formed across the ring. The zig-zag loop of the thread lies on the film. If the film inside the loop of thread is punctured with a needle, then the loop takes the shape of a circle due to surface tension. The surface of the liquid film pulls the thread radially outward as shown by the arrows.

Capillary Action

A glass tube with a very fine uniform bore is called a capillary tube. When a capillary tube is dipped vertically into a liquid contained in beaker, the liquid immediately rises or falls in the tube. The rise or fall of a liquid in a very narrow capillary tube is given by



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$$h = \frac{2T\cos\theta}{r\rho g}$$

Where:

- T is the surface tension of the given liquid.
- r is the radius of the capillary tube
- ρ is the density of the liquid
- g is acceleration due to gravity
- θ is the angle of contact for the given pair of solid and liquid

The angle of contact is defined as the angle between the tangent to the liquid surface at the point of contact and the solid surface inside the liquid. The angle can be acute or obtuse. If the angle of contact is acute, the level of liquid inside the capillary tube is higher than that in the beaker. This capillary rise is observed in the case of water. If the angle of contact is obtuse, the level of liquid inside the tube is lower than that in the beaker.

- ✓ This capillary fall is observed in mercury ($\theta \approx 140°$).
- ✓ For water in silver tube, $\theta = 90°$ **and h = 0. The level of liquid remains the same.**
- ✓ For pure water and clear glass $\theta = 0°$

Applications of Capillary Action in daily lives

- ✓ The rise of sap in trees and plants: The Xylem or Bark has such structure that the water rises to reach from roots to leaves via capillary action, although some other theories also persist to explain this. *When the bark of a tree (Xylem) is removed in a circular fashion all around near its base, it gradually dries up and dies because water from soil cannot rise to aerial parts.*
- ✓ The rise of kerosene or oil in the wick of an oil lamp or stove.
- ✓ The absorption of ink in a blotting paper.
- ✓ Sandy soil is gets drier earlier than clay: *The interspaces between the particles of the clay form finer capillaries and water rises to the surface quickly.*
- ✓ *The purpose of applying soap to clothes is to spread it over large area. When soap is dissolved in water the surface tension of water is lowered. Surface tension always opposes the spreading of a liquid. By reducing surface tension we facilitate the liquid to spread over larger surfaces. This is why soap is used for washing.*
- ✓ *For the same reason the paste spreads more freely in the mouth and facilitates cleaning of the mouth.*
- ✓ *When we pour oil on the surface of water it lowers the surface tension of water. Hence the mosquito breed sinks down and perishes.*
- ✓ *In voyage at the high seas, when there are violent waves the sailors pour tins of oil around their boats or ships. Due to oil the surface tension of sea water is reduced thereby the height of water waves is also reduced.*

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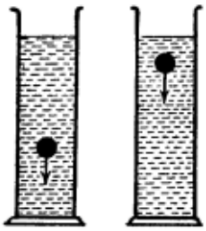
- ✓ *A pen nib is split at the tip to provide the narrow capillary and the ink is drawn upto the tip continuously.*
- ✓ *When molten lead is allowed to fall through the end of a narrow tube, lead drops assume spherical shape due to surface tension. In factories lead shots are manufactured in this way.*
- ✓ *Rain drops assume spherical shape due to surface tension of water.*

Chapter 6. Viscosity

When we move our fingers through any liquid we experience a resistance. This is because liquid offers a frictional force. The resistance offered by fluids (liquids as well as gases) to relative motion between its different layers is called viscous force. This property is called viscosity. The viscous forces are similar to frictional forces which resist relative motion between two bodies in contact. To observe this, we can take two long cylinders, one filled with water while the other filled with glycerine. We take two identical lead shots and drop one in water and the other in glycerine at the same time. We see that the lead shot dropped in water comes down more quickly and the lead shot in glycerine descends slowly. This implies that the viscous force is more in the case of glycerine than that in the case of water.



Flow of liquid through Pipes

There are two types of flows viz. streamlined flow and turbulent flow.

- ✓ If all the particles of the liquid pass across a point with the same velocity, the flow is said to be stream lined. In this flow, a particle follows the same path throughout its motion.
- ✓ If the particles pass across a point with different velocities, the flow is turbulent. In this flow, a particle does not follow the same path throughout its motion.

When a liquid flows slowly and steadily through a pipe, the velocity of the layer of the liquid in contact with the walls of the pipe is zero. As we move towards the axis of the tube, the velocity of the layers gradually increases and reaches a maximum value along the axis of the tube. In the case of streamlined flow of a river, the velocity is maximum for water on the upper layer (surface) of river . The velocity is minimum for water in the bottom most layer. When two parallel layers of a liquid are

moving with different velocities, they experience tangential forces which tend to retard the faster layer and accelerate the slower layer. These forces are (F) called viscous forces.

Newton found that the viscous force is

- ✓ Directly proportional to the common area (A) of the liquid layers in contact.
- ✓ Directly proportional to their relative velocity (v1 - v2)
- ✓ Inversely proportional to the distance (x) between them.

This can be represented by the following formula:

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$$F = \eta A \frac{(v_1 - v_2)}{x}$$

Where η is a constant known as coefficient of viscosity of the liquid and $\frac{(v_1 - v_2)}{x}$ is called the velocity gradient. The unit of coefficient of viscosity is N s m^{-2} or **Poise**. The values of coefficient of viscosity are different for different liquids as shown in the below table:

Fluid	η (poise)
Glycerine	13.4
Castor oil	9.86
Olive oil	0.84
Turpentine	0.015
Water	0.018
Mercury	0.0015
Honey	0.2
Blood	0.0027
Air	0.019×10^{-3}

Applications of Viscosity in Everyday Life

- ✓ The motion of falling raindrops is opposed by the viscous force offered by air. Hence the rain drops falls slowly.
- ✓ The viscosity of sea water makes the waves subside during a storm.
- ✓ The motion of objects in fluids depends upon the viscosity of the fluids. The viscous force of water or air opposes the motion of ships, cars, aeroplane etc., hence their shapes are streamlined in order to minimise the viscous drag on them.

Working of Lubricants

Friction reduces the efficiency of a machine by converting mechanical energy into heat energy and causes much wear and tear of the moving parts. Friction is reduced by using lubricants. A lubricant is a substance used to reduce friction. high molecular weight compounds such as hexanol are added as viscosity index improvers.

The lubricant forms a thin layer between the two surfaces in contact. It also fills the depressions present in the surfaces of contact and reduces friction considerably. In light machinery, thin oils (e.g., clock oil) with low viscosity are used. In heavy and fast moving machinery solids or thick highly viscous oils (e.g., grease) are used. By adding **long chain polymers with lubricating oil, its coefficient of viscosity is kept constant even at high temperatures**.

A good lubricant should have the following properties.

- ✓ It should be able to spread and fill up the minute depressions in the surfaces.
- ✓ It should be chemically inert and should not undergo any decomposition at high temperature.
- ✓ It should be capable of conducting away the heat produced by friction.

Viscosity of Blood

If the arteries and veins of human body contract and become hard, their diameters decrease. Hence the flow of blood is affected due to the viscosity of blood and the blood pressure increases. This

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affects the functioning of heart. When the temperature of human body increases during fever, the coefficient of viscosity of blood decreases. This increases the blood circulation and the normal heart functioning is maintained.

Bernoulli's theorem

When air is blown over the top of a sheet of paper, the paper rises in the air stream. This happens because the pressure falls above the paper where the air is moving faster. We take a table tennis ball and place in a funnel and hold it with the mouth sloping upwards. When we blow it, we can blow the ball out. Similarly, two balls are suspended side by side and air is blown up through the space between them. As the air flows through the narrow space between the balloons, the pressure falls. The atmospheric pressure from the sides brings the balls together.

The above observations lead us to conclude that **there is a relation between pressure and velocity of air**. Bernoulli's equation is a fundamental relation in fluid mechanics. It can be derived from the work-energy theorem. The work-energy theorem says that the work done by the resultant force acting on a system is equal to the change in kinetic energy of the system. Any moving liquid has three kinds of energies:

1. Kinetic energy by virtue of its motion
2. Potential energy by virtue of its position
3. Pressure energy when it is subject to pressure

The work-energy theorem states that the work done by the resultant force acting on a system is equal to the **change in kinetic energy of the system.** Let **m** be mass of the liquid and v be its velocity in motion.

Then its kinetic energy will be

$$= \frac{1}{2}mv^2$$

The kinetic energy per unit mass will be:

$$= \frac{1}{2}v^2$$

Similarly, Let h be the height of the liquid above the earth's surface.

Then its potential energy = **mgh**

Potential energy per unit mass = gh

Similarly, Let p be the hydrostatic pressure exerted by a liquid, r be its density and V be its volume.

Then its pressure energy = PV

$$= P\left(\frac{m}{\rho}\right)$$

Pressure energy per unit mass $=\frac{P}{\rho}$

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These three types of energies possessed by a liquid under flow are mutually convertible one into another. Bernoulli's theorem says that the *sum of the energies possessed by a flowing, non-viscous, incompressible liquid at any point throughout its flow is constant* ***when the flow is streamlined***.

This implies that:

Pressure Energy + Kinetic Energy + Potential Energy = Constant

For a unit mass of liquid:

$$\frac{p}{\rho} + \frac{1}{2}v^2 + gh = \text{constant}$$

If the pipe is horizontal, then h also is constant so:

$$\therefore \frac{P}{\rho} + \frac{v^2}{2} = \text{constant.}$$

The above equation makes it clear that when the velocity of the fluid increases, the pressure of the fluid decreases and vice versa. This principle can be illustrated by numerous demonstrations.

Everyday applications of Bernoulli's Theorem:

- Bernoulli's principle is used in venturimeter to find the rate of flow of a liquid.
- It is used in a carburettor to mix air and petrol vapour in an internal combustion engine.
- Bernoulli's principle is used in an atomiser and filter pump.

Wings of Aeroplane

Wings of an aeroplane are made tapering. The upper surface is made convex and the lower surface is made concave. Due to this shape of the wing, the **air currents at the top have a large velocity than at the bottom**. Consequently the pressure above the surface of the wing is less as compared to the lower surface of the wing. This difference of pressure is helpful in giving a vertical lift to the plane.

How storms blow off the roofs?

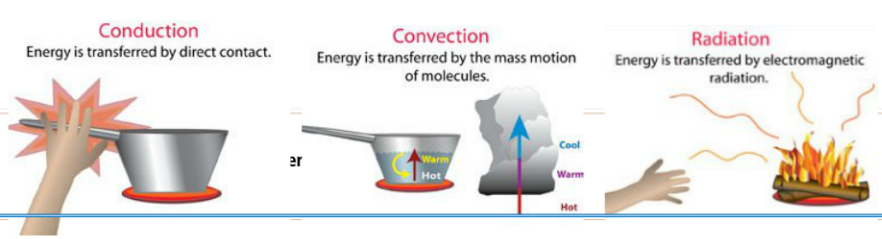
Due to strong wind, storm or cyclone, the roofs are blown off. When a strong wind blows over the roof, there is lowering of pressure on the roof. As the pressure on the bottom side of the roof is higher, roofs are easily blown off without damaging the walls of the building.

How a moving train attracts a person standing nearby on a platform?

A suction effect is experienced by a person standing close to the platform at railway station when a fast train passes the person. This is because the fast moving air between the person and train produces a decrease in pressure and the excess air pressure on the other side pushes the person towards the train

Chapter 7. Heat

Heat is the most common form of energy.



Heat can be transferred from one place to another by means of **conduction, convection and radiation**. It can be converted into other forms of energy.

We all know that Sun is the main source of heat energy for Earth. Fuels such as wood, petrol, coal and gas are other sources of heat energy. For the survival of all living things, heat energy is essential.

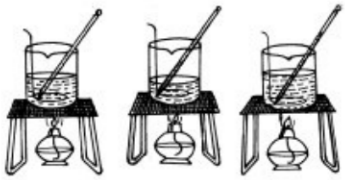
The temperature of a body is a measure of its hotness or coldness. It is a measure of the kinetic energy of the particles of the body.

Change in temperature, change of state and thermal expansion in a body, are some of the main observable physical effects of heat energy. Heat energy plays a major role in determining the climatic and weather conditions.

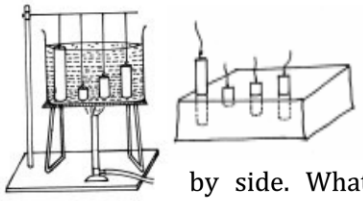
Specific Heat Capacity

Observations

- We take three identical glass beakers and fill them with equal mass of water, kerosene and coconut oil. We first note down their initial temperatures and then heat them one by one by same lamp for 5 minutes each; we find that the rise in temperature of each of them is different.



- We take four cylindrical blocks of aluminium, lead, copper and iron of equal mass having the same area of cross section. Now, we suspend the cylindrical blocks fully inside boiling water. After few minutes, take out the blocks simultaneously and place them on a thick paraffin cake side by side. What we observe is that depths of sink is different for different materials.



- We take a stone and water of same mass. Place them in the hot sun for about half an hour. Now touch the stone with one hand and water with the other hand. What we observe is that the stone is hotter than water.

When a substance is heated, it absorbs heat energy and its temperature rises. The **amount of heat energy absorbed** by the substance (Q) is directly proportional to mass of the substance (m) and the change in temperature (Δ t)

$$Q = m s \Delta t$$

Here s is a constant called Specific Heat Capacity. The value of the specific heat capacity depends on the nature of the substance. In the above equation, If m = 1 kg and Δt = 1 K then Q = s. This implies that:

The specific heat capacity of a substance is the amount of heat energy required to raise the temperature of 1 kg mass of the substance by 1 K. Its unit is J kg^{-1} K^{-1}. **It is a measure of thermal inertia of a substance.**

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The heat capacity of a substance is defined as the amount of heat required to raise the temperature of the substance through 1 K.

Thus:

Heat capacity = mass x specific heat capacity.

Its unit is J/K.

The following table shows the specific Heat Capacity of some common materials.

Sr. No.	Substance	Specific Heat Capacity ($J\ kg^{-1}\ K^{-1}$)
1.	Lead	128
2.	Mercury	138
3.	Copper	386
4.	Aluminium	899
5.	Wood	1755
6.	Kerosene	2090
7.	Ice	2130
8.	Water	4180
9.	Paraffin Wax	2900

Among the liquids, the specific heat capacity is maximum for water, hence water is used as a coolant in radiators of automobile engines and mercury is used as a thermometric liquid.

Thermal Expansion

Thermal expansion takes place in all states of matter. The gases expand more than liquids and liquids expand more than solids for the same amount of heat. Thermal expansion plays an important role in many engineering applications.

- When an object is heated its **molecules vibrate more violently because they have more kinetic energy**. They also need more space around them. This causes the material to expand.

Increase in length due to heating is called **linear expansion**. Increase in area as **superficial expansion** and that of volume as **volume expansion or cubical expansion**. The thermal expansion is **different for different substances.**

Every day applications of thermal expansion of solids

- If we find difficult to remove the stopper from a glass bottle, we can heat the neck of the bottle. Now the neck of the bottle expands and the stopper comes out easily.
- The principle of thermal expansion is used in fixing iron rim with the wooden wheel firmly.
- Rivets are used to hold steel plates together very tightly. A very hot rivet is pushed through the two plates and its end is hammered over. When the rivets cools down it pulls the two plates together very tightly.
- To avoid bursting of soft drink bottles containing gas, due to thermal expansion, their walls are made very thick.

Bimetallic Strip

A **bimetallic strip** consists of two different metals such as brass and iron joined together. At normal temperature the bimetallic strip is straight. As it is heated the brass expands more than the

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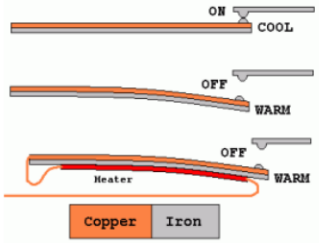
iron. So the brass forms the outside of a curve with the iron on the inside. Such a bimetallic strip can be used in a thermostat to break an electrical circuit. A thermostat is used to maintain a steady temperature in a system. As the temperature increases the strip bends and breaks electrical contact in the heater circuit. When the temperature decreases, the bimetallic strip returns to its original position and shape. Thus contact is restored.



Some of the problems created by thermal expansion is the changing of shape and dimensions of objects such as doors, Wall collapsing due to bulging, cracking of glass tumbler due to heating and bursting of metal pipes carrying hot water or steam.

Thermal Expansion and Railway Lines

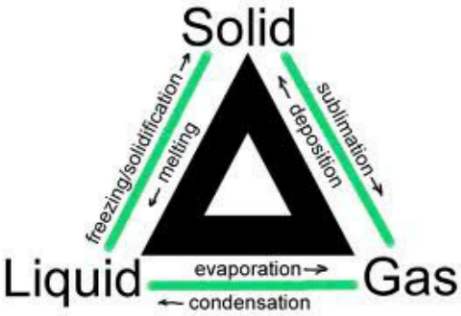
Rails are made of steel which expands on heating and contracts on cooling. A gap is left between two ends of the rails at the joint. If no gaps are left, due to expansion in summer the rails get distorted causing derailment. For the same reason, gaps are left in the concrete slabs of bridges and Highways.

Clock Pendulums

The period of oscillation of a pendulum in a clock depends on its length. When the temperature changes, the length also changes. Hence the clock loses time in summer and gains it in winter. This can be compensated by using a bimetallic pendulum against the effect of thermal expansion.

Change in state of mater

Matter exists in three states viz., solid, liquid and gas. The change from one state to another can be brought about by the application or withdrawal of heat. The water can be in the form of solid ice or liquid water or gaseous steam. The process in which a solid changes into liquid on heating is called melting. For example, ice changes into water. The change of a liquid into a solid on cooling is known as freezing. The process in which a liquid changes into vapour on heating is called vaporisation. e.g., water changes into water vapour or steam. Some materials may change directly from a solid to a gas. This is called sublimation. Solid carbon dioxide changes to carbon dioxide gas as it warms up. Another substance which sublimes is Iodine. When vapour condenses to form a liquid the change of state is called condensation. Steam changes to water as it condenses.



Latent Heat

The latent heat of a substance is defined as the amount of heat absorbed by a unit mass of the substance to change its state without change of temperature. The heat absorbed during the change

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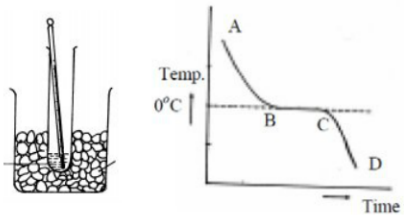
of state of a substance is used to overcome the force of attraction between the molecules of a substance. The kinetic energy of the molecules does not increase and hence there is no raise in temperature during the change of state of the substance. Two of the more common forms of latent heat (or enthalpies or energies) encountered are latent heat of fusion (melting or freezing) and latent heat of vaporization (boiling or condensing). These names describe the direction of energy flow when changing from one phase to the next: from solid to liquid, and to gas.

Cooling due to evaporation

- When we put a little ether or petrol at the back of our hand and wave it around, we observe that the spirit evaporates rapidly and our hand feels very cold. The sprit takes the heat of vaporization from our hand. The hand loses heat and gets cooled. Similarly, water vaporizing from the leaves of the trees cools the surrounding air.
- A liquid evaporates when it changes into gas. Evaporation occurs at the surface of a liquid. During evaporation, only high energy molecules overcome the attraction of their neighbouring molecules and leave the liquid. In this way, the liquid loses its most energetic molecules, while the less energetic molecules are left behind.
- The average kinetic energy of the remaining molecules is therefore, reduced. This results in a fall of temperature of the liquid which gets cooled. The rate of evaporation of a liquid depends on its surface area, temperature and the amount of vapour already present in the surrounding air.
- On a rainy day, wet clothes take longer time to dry, because large amount of vapour already present in the air, slows down the evaporation. Similarly, during high fever, a cloth soaked in cold water is kept on the forehead the water evaporates rapidly and takes heat from the head and the body.
- Dogs keep their tongue usually out in summer. Water evaporates from the tongue and keeps it cool. Water in an earthen pot remains cool in summer. Water comes out of the pores of the vessel and evaporates. Therefore water remains cool in an earthen vessel by evaporation. After sometimes, when the pores get blocked by the dissolved material in water, the earthen pot becomes useless.
- Evaporation of sweat or perspiration from our skin causes a cooling effect.

Fusion of Ice Experiment

We take a test tube with clean water and a thermometer is placed in the test tube. The test tube is placed in a freezing mixture bath. The water level in the test tube is well below the level of the freezing mixture. While stirring water slightly and carefully, the thermometer readings for every 30 seconds are recorded till the temperature falls a few degrees below 0o C. A graph is drawn by taking time along



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the X-axis and temperature long the Y axis. The portion AB represents the liquid state. At B the change of state takes place from liquid to ice at 0o C. At C entire liquid is changed to ice. Here during the change of state the temperature remains constant. Below C it is in the solid state (ice). The flat portion of the graph represents the time during which the water solidifies. Here both solid and liquid states exist together. This is the melting or freezing point. During this time heat continues to be lost from the substance as it changes from liquid to solid but there is no fall in temperature.

When water changes into solid; its volume increases. When a substance melts, heat is gained. When it freezes, heat is lost

Working of Refrigerators

When a liquid evaporates it takes in heat energy and cools its surroundings. When the gas condenses back to a liquid, the latent heat is released. This is used to take heat from inside a fridge, and release it outside. A liquid which evaporates easily is called volatile liquid. Freon is a volatile liquid used in most fridges. The liquid evaporates in the coils around the ice box or cold plate inside the fridge. This causes cooling. The Freon gas formed is pumped away and pressurised in the condenser on the back of the fridge. Here the Freon gas condenses back into liquid. As it condenses it releases the heat energy it has taken in. So heat energy has been taken from food and other things inside the fridge and released outside it.

If we leave the fridge door open, the pump has to work hard and more heat will be released into the kitchen which will eventually become hotter.

Freezing Mixtures

A mixture of compounds that produces a low temperature is called freezing mixture. A freezing mixture consists of powdered ice, common salt and ammonium nitrate. Temperatures lower than 0° C can be produced by mixing certain salts such as Sodium Chloride, Ammonium Chloride, Magnesium Sulphate etc. with ice. When salt is mixed with ice, some ice melts taking heat from the salt. The temperature of the mixture decreases. Now salt gets dissolved in the water formed. The necessary heat for this is extracted from the mixture itself and consequently the temperature of mixture falls below zero. With the freezing mixture of salt and ice in the ratio 1 : 3, temperatures as low as -13°C can be obtained

Latent heat of fusion

The latent heat of fusion of a substance is the quantity of heat required to convert unit mass of the solid at its melting point to the liquid state at the same temperature. The S.I unit of Latent heat is J kg-1.

Ice at 0°C is more effective in cooling a substance than water at 0°C. This is due to the fact that for melting at 0°C each kilogram of ice takes its latent heat of 3.34×10^5 J from the substance and hence cools the substance more effectively. On the other hand water at 0°C cannot take latent heat from the substance. This concept is valid for most of the liquids and their solids.

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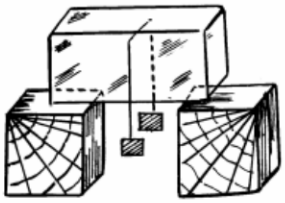
Latent heat of vaporization

Latent heat of vaporization of a liquid is the amount of heat required to convert unit mass of a liquid at its normal boiling point into vapour at the same temperature.

The burns caused by steam are much more severe than those caused by boiling water though both of them are at the same temperature of 100°C. This is due to the fact that steam contains more heat in the form of latent heat (2.26×10^6 J/kg) than boiling water. Here we note that the latent heats of fusion is maximum for ice and latent heat is maximum for steam. Hence steam and ice can be considered to be the best source and sink of heat respectively in a heat engine.

Impact of pressure Melting Points



When we take two pieces of ice and apply pressure and release them; we observe that the two pieces freeze together. This implies that melting point of a substance can be lowered by applying pressure. We take a slab of ice is and a put a metal wire over it. Two equal weights (5 kg) are fixed to its ends. The wire passes through ice slab due to the load applied to it. Just below the wire, ice melts at a lower temperature due to increase in pressure. When the wire has passed, the water above the wire freezes again. Thus the wire passes through the slab and the slab does not split. This phenomenon of refreezing is called **regelation**.

Here, we have to note down that if a substance contracts on melting, as in the case of Ice, its melting point is lowered by an increase of pressure. If a substance expands on melting, as in the case of a paraffin wax, its melting point is raised by an increase of pressure.

Skates, Sledges and Snowballs

Since the edges of the skates are fine, the pressure applied on ice is sufficient to melt it. Water thus formed due to melting acts as a lubricant and enables the skates to move freely over ice. Due to regelation the water formed is again converted into ice. Thus free motion of skates with good grip is achieved. The same explanation holds good for sledges and snow balls.

Impact of impurities on Melting Points

We put some salt or other impurity into a beaker of water and heat it until it boils. Measure the boiling point and observe that it is above 100°C. It shows that the boiling point of liquid is raised by adding impurities. Again, we take some pieces of ice in a beaker and sprinkle some salt on the ice. Stir until the ice melts and measure its temperature. We observe that it is less than 0°C. The presence of impurity lowers the melting point.

Impact of Pressure on Boiling Points

Cooking food in a pressure cooker has various advantages apart from cooking in short time, such as:

1. Cooking in Pressure cooker retains vitamins and minerals better
2. Cooking in Pressure cooker prevents oxidation of food material

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3. Cooking in Pressure cooker is easier in high altitudes

Which among the above statements is / are correct?

Answer: [4]

The boiling point of a liquid is lowered under reduced pressure and increased under increased pressure. The atmospheric pressure is less on the top of a mountain and therefore water boils at a lower temperature. This temperature is too low to cook food properly. It means that a longer time is required for cooking in hill stations. The time required for cooking vegetables and other foods can be greatly reduced if the boiling point of water is raised. This can be done by the use of a pressure cooker. A pressure cooker consists of a strong vessel of an aluminium alloy or stainless steel sealed so tightly that steam can be confined inside it with a pressure of about 2 atmospheres. The boiling point of water at this pressure will be about 120°C. When foods are cooked under these conditions there is a considerable saving of fuel and time. Since the cooking time is reduced the food value (vitamins and minerals) is retained better. Any possible oxidation of food material is also prevented because cooking takes place in an atmosphere of steam instead of air. The pressure cooker solves cooking problems at high altitudes also.

Chapter 8. Humidity and Relative Humidity

Humidity is the amount of water vapour present in atmosphere. The amount of water vapour in atmosphere changes with time and weather. The air containing water vapour is called humid air. The amount of vapour present per unit volume of air is called the humidity of air. Humidity is generally measured in kg/m^3.

The knowledge of humidity helps us to predict weather. When the amount of water vapour in the air is small, the air appears to be dry and the humidity is low. When the amount of water vapour in the air is large, the air appears to be wet and the humidity is high. The degree of wetness of air is expressed in terms of its relative humidity.

Relative Humidity

The ratio of the mass of water vapour actually present in certain volume of air (m) to the mass of water vapour (M) required to saturate the same volume of air at the same temperature is called relative humidity (R.H)

$$\text{Relative humidity} = \frac{m}{M} \times 100\%$$

If the air contains the maximum amount of water vapour its R.H is 100%. In such a case, water on earth cannot vaporate at all. If the relative humidity is less than 100% but still high, the rate of evaporation will be slow and the clothes do not dry up easily in such weather. The relative humidity varies from season to season. During rainy season, as the amount of water vapours in air increases,

[4] All are correct statements.

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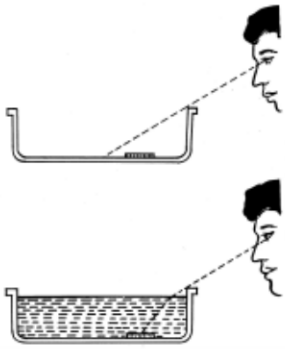
the relative humidity becomes more (R.H = 100%) More R.H is a permanent feature of coastal areas. Due to more R.H perspiration from our body does not evaporate and we feel sultry.

Chapter 9. Light

Refraction of light

When we place a pencil in a beaker containing water, we observe that the pencil appears to be bent at the point where it just enters water. Again, when we put a coin in the bottom of an empty cup and position our head so that the coin is just off sight, we can bring it into our view without moving head or the cup, by just pouring water in the cup.

The above two observations lead us to conclude that the ray of light bends at the boundaries of air and water medium. The phenomenon of bending of light as it passes from one medium to another is known as the refraction of light.



Refraction is the change in direction of a wave **due to a change in its medium**. It is essentially a surface phenomenon.

The phenomenon is mainly in governance to the law of conservation of energy and momentum. Due to change of medium, the **phase velocity of the wave is changed but its frequency remains constant**. Refraction of light is the most commonly observed phenomenon, but any type of wave can refract when it interacts with a medium, for example when sound waves pass from one medium into another or when water waves move into water of a different depth. Refraction is described by Snell's law, which states that for a given pair of media and a wave with a single frequency, the ratio of the sines of the angle of incidence θ1 and angle of refraction θ2 is equivalent to the ratio of phase velocities (v1 / v2) in the two media, or equivalently, to the opposite ratio of the indices of refraction (n2 / n1):

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}.$$

An easy way to remember Snell's law is that

$$\begin{pmatrix}\text{refractive index}\\ \text{of the medium}\end{pmatrix} \times \begin{pmatrix}\text{sine of the angle}\\ \text{in the medium}\end{pmatrix} = \text{constant}$$

The refractive index of the medium with respect to air (or vacuum) is called the absolute refractive index of the material. The refractive index for light going from first medium to second is equal to the reciprocal of the refractive index for light going from second to first medium.

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$$_1\mu_2 = \frac{1}{_2\mu_1}$$

The refractive index of glass with respect to water is equal to the ratio of refractive index of glass and refractive index of water with respect to air.

$$_{water}\mu_{glass} = \frac{_{air}\mu_{glass}}{_{air}\mu_{water}}$$

Similarly, the refractive index of water with respect to glass is:

$$_{glass}\mu_{water} = \frac{_{air}\mu_{water}}{_{air}\mu_{glass}}$$

The refractive index of the medium gives the light bending ability of that medium. Glass has higher refractive index than air. So more bending of light rays take place in glass. Glass is said to be optically denser medium and air is an optically rarer medium. The adjacent table shows the refractive index of some common materials with respect to air or vacuum:

Substance	Refractive Inde
Air	1.0029
Ice	1.3
Water	1.33
Ethanol	1.35
Sulphuric acid	1.43
Kerosene	1.44
Quartz	1.46
Glycerine	1.48
Benzene	1.5
Crown glass	1.52
Flint glass	1.65
Canadian balsm	1.53
Sodium chloride	1.54

Measuring Refractive Index

The simplest way to measure the refractive index of a liquid is to measure its apparent depth and its real depth. We can place a scale inside a glass beaker containing liquid. Take another scale and hold it outside of the beaker by stand. View the scale from the top and adjust the outside scale until the bottom ends of both scales appear to be at the same level. Measure the heights h1 and h2 of the level of water surface on both scales. h1 and h2 are the real and apparent depth respectively. The refractive index of the liquid with respect to air.

$$_{air}\mu_{water} = \frac{\text{realdepth}}{\text{apparent depth}} = \frac{h_1}{h_2}$$

The apparent depth of an object seen through a glass slab of refractive index 1.5 is 4 cm. The actual depth is __:

A. 5 cm
B. 6 cm
C. 8 cm
D. 4 cm

Answer: [5]

Total Internal Reflection

When a ray of light passes from an optically denser medium into a rarer medium; the refracted ray is bent away from the normal. A ray of light incident normal to the surface passes without any

[5] Refractive index of glass, μ = 1.5; Apparent depth = 4 cm; Actual depth = ?. μ = Actual depth / Apparent depth. 1.5=?/4. ?=6 cm

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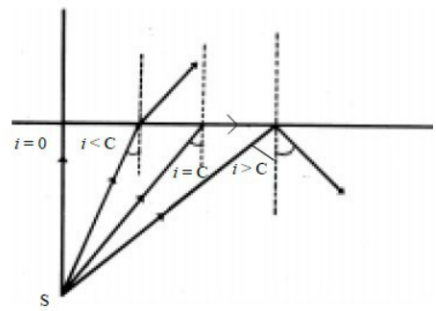
deviation. As the angle of incidence increases, the angle of refraction also increases and at a certain angle of incidence the refracted ray just grazes surface of water. This angle of incidence within a denser medium for which angle of refraction becomes 90° is called the critical angle. If the angle of incidence is increased beyond the critical angle, the ray bends inside the denser medium. This is called total internal reflection.



Relation between critical angle and refractive index

We know that

$$_{w}\mu_{a} = \frac{1}{_{a}\mu_{w}}$$

$$\frac{\sin C}{\sin 90^{o}} = \frac{1}{_{a}\mu_{w}}$$

$$\sin C = \frac{1}{_{a}\mu_{w}} \quad (\because \sin 90^{o} = 1)$$

$$_{a}\mu_{w} = \frac{1}{\sin C}$$

The above implies that refractive index of any medium with respect to air is the reciprocal of the sine of the critical angle.

Example:

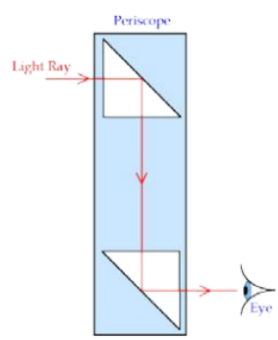
The critical angle of diamond is 24.4°. so C= 24.4° and μ=?

$_{air}\mu_{diamond}$ = 1/sinC

$_{air}\mu_{diamond}$ = 1/sin 24.4° = 2.42

Periscope

There are two essential conditions for Total Internal Reflection. One is that the light must proceed from denser medium to a rarer medium. Second is that the angle of incidence in the denser medium must be greater than the critical angle. For example, a prism having an angle of 90° between its two refracting surfaces and the other two angles each equal to 45° is called a totally reflecting prism, because 45° is greater than the critical angle for glass (42°). Totally reflecting prisms are used in the construction of periscope. Periscope is used in the submarines to see objects above the surface of water.



Optical Fibres

An optical fibre is a device based on total internal reflection by which a light signal can be transmitted from one place to other with negligible loss of energy. An optical fibre is a long glass rod of only a few millimeters thick and it

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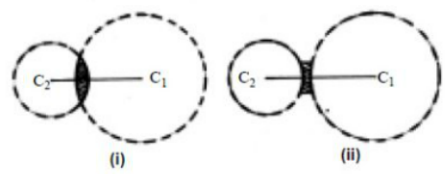
is quite flexible. The fibre glass consists of a cylindrical inner core that carries light and an outer concentric shell called cladding. The refractive index of inner core (m = 1.7) is relatively greater than that of cladding (m = 1.5). The rays of light travelling along the fibre cannot escape because they are totally reflected from the core-cladding interface. So the fibre of solid glass can be used as a light pipe.

Optical fibres can carry light round bents. This allows doctor to see inside our body. (endoscopy). Optical fibres can also carry information in the form of a digital code of light pulses with minimum loss. They carry telephone messages and computer data. Fibre optics technique is used to destroy tumours in solid organ like liver.

Lenses

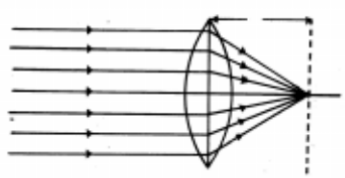
A lens is a thin piece of a transparent material bounded by two spherical surfaces or by one spherical and other plane surface. The width or diameter of a lens is called the **aperture of the lens**. The geometric centre of a lens is known as its **optic centre** (O). The centre of curvature (C) is the centre of the sphere of which its surface forms a part. The radius of curvature (R) of a surface is the radius of the sphere of which the surface forms a part. The line passing through the centres of curvature of the two surfaces and optic centre of a lens is called the **principal axis.**



Radius and Centres of curvature of lenses
(i) Convex lens (ii) Concave lens

When we place a comb in between the torch light and the convex lens and adjust the lens, we observe that the light rays converge at a point. In the case of concave lens, the rays appear to diverge from a point.

A beam of rays parallel to the principal axis after refraction through the lens actually converges at a point on the principal axis. This point is called **principal focus of a convex lens**.



A beam of rays parallel to the principal axis after refraction through a concave lens appear to diverge from a point on the principal axis. This point is called **principal focus of a concave lens**.

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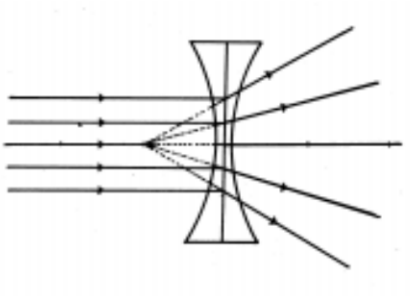
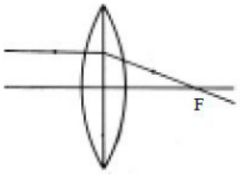


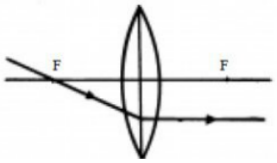
The focal length of a lens is the distance between optic centre and principal focus of the lens

Behaviour of Rays in Convex Lens

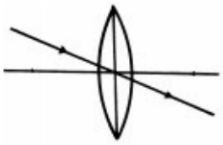
- An incident ray which is parallel to the principal axis, after refraction, passes through the principal focus on the other side of the lens.



- An incident ray which passes through the principal focus, after refraction, emerges parallel to the principal axis

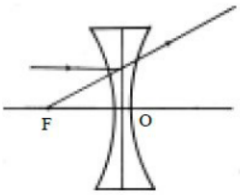


- An incident ray which passes through the optic centre goes straight without deflection.



Behaviour of Rays in Concave Lenses

An incident ray which is parallel to the principal axis, after refraction, appears to diverge from the principal focus on the same side of the lens as the incident light.



An incident ray which proceeds towards the principal focus, after refraction, emerges parallel to the principal axis.

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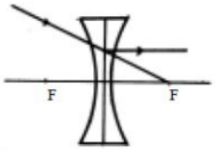
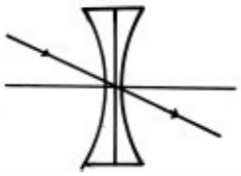


An incident ray which passes through the optic centre goes straight without deflection.



Real Images and Virtual Images

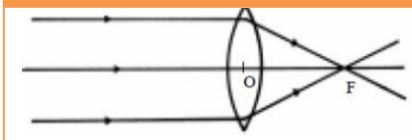
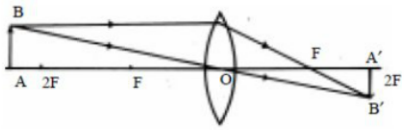
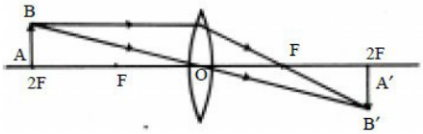
The image formed by the actual intersection of refracted rays through a lens is called the real image. The real images can be caught on the screen and they are inverted.

The images that appear without actual intersection of the refracted rays are called virtual images.

Position and nature of images at various positions of object in case of convex lens

As the object is moved closer to the lens, the image distance increases and the image size increases. At 2F, the object distance

equals the image distance. As the object distance approaches one focal length, the image distance and size approach infinity. When the object distance is one focal length, there is no image. When the object distance is less than one focal length, the images are virtual erect and located on the same side of the object. Finally, if the object distance approaches zero, the image distance also becomes zero. The image size ultimately becomes equal to the object size.

Ray Diagram	Position of Object	Position of Image	Nature and Size of Image	Practical Application
	at infinity	at F	real, point-sized	Telescope objective lens
	beyond 2F	between F and 2F	real, diminished inverted	Camera
	at 2F	at 2F	real, same sized, inverted	Terrestial telescope invert the image so that it is upright.

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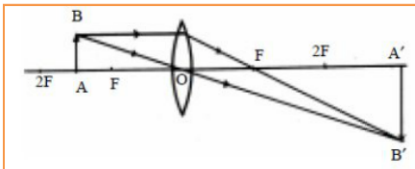
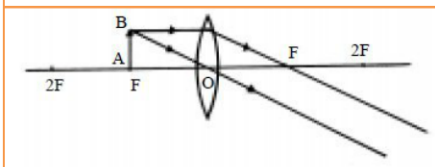
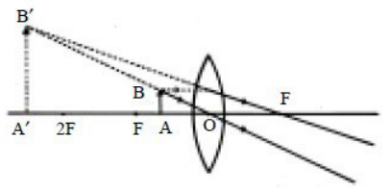
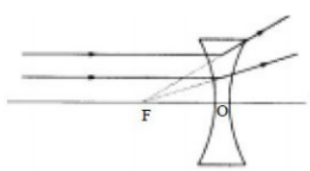
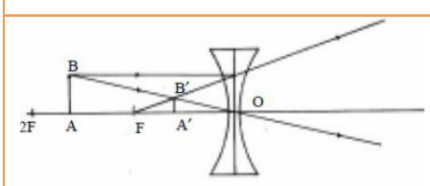
	Between 2F and F	beyond 2F	real, enlarged inverted	Projector
	at F	at infinity	real, infinitely large, inverted	Spotlights
	between F and O	on the side of the object	virtual, enlarged, erect	Magnifying Glass

Position and nature of images at various positions of object in case of concave lens

When an object is moved closer to the concave lens, the image distance decreases and the image size increases with respect to that of previous image. As the object approaches the lens, its virtual image on the same side of the lens also approaches the lens and image size increases. If the object is placed at the optic centre, the virtual erect image of same size will be formed at the optic centre itself.

Ray Diagram	Position of Object	Position of Image	Nature and Size of Image
	at infinity	at F	virtual, point-sized
	between infinity and O	between F and O	virtual, erect and diminished

Lens Formula & Power of the Lens

The relationship between the object distance (u), the image distance (v) and the focal length (f) of the lens is called lens formula.

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

From the above formula, Focal length of a lens is obtained as follows:

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

The power of a lens is the measure of its ability to produce convergence or divergence of a parallel beam of light. The power of a lens depends on its focal length. The power of a lens is defined as the reciprocal of its focal length in metres. The unit of power of a lens is dioptre (D).

If two lenses of focal length f_1 and f_2 are in contact, then:

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

And

$$P = P_1 + P_2$$

For example, if a lens has a focal length of 40 cm, its power would be: $1/40 \times 10^{-2} = 100/4 = 2.5D$

Twinkling of Stars

Heat energy radiated by the earth changes the density of the atmospheric layers continuously. This changing density of the air layers near the ground affects its refractive index. Due to the refraction of light rays from the star, path of these rays goes on varying. Hence the eye some times receives more light with the result that the star appears brighter and sometimes it receives only a few rays or no rays which make the star appear fainter. The brighter and fainter appearance of the star with varying time is called the twinkling of the stars.

Mirage

A mirage is an optical illusion observed in deserts or over hot extended surfaces like a coal tarred road. During hot days the lower layers of air near the earth's surface are hotter and lighter than the upper layers away from the earth's surface. Cold air is more dense than warm air and has therefore a greater refractive index. As light passes from colder air across a sharp boundary to significantly warmer air, the light rays bend away from the direction of the temperature gradient. When light rays pass from hotter to cooler, they bend toward the direction of the gradient. If the air near the ground is warmer than that higher up, the light ray bends in a concave, upward trajectory. Hence light from an object (say the top of a tree) undergoes a series of refraction and total internal reflections and bends upwards. Once the rays reach the viewer's eye, the visual cortex interprets it as if it traces back along a perfectly straight "line of sight". This line is however at a tangent to the path the ray takes at the point it reaches the eye. The result is that an "inferior image" of the sky above appears on the ground. The viewer may incorrectly interpret this sight as water which is reflecting the sky, which is, to the brain, a more reasonable and common occurrence. In the case where the air near the ground is cooler than that higher up, the light rays curve downward, producing a "superior image". **Superior Image is common in polar areas, which is known as Looming.**

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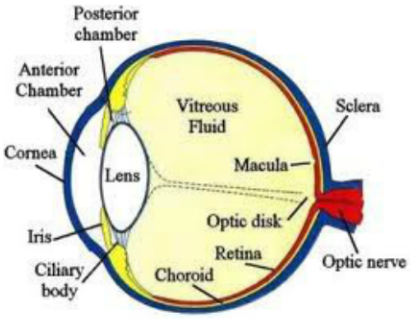
Due to the mirage, a traveller sees shimmering pond of water some distance ahead of him. This optical illusion is called mirage. Thus, *Mirage is due to the combination of Refraction as well as Total Internal Reflection of light.*

Human Eye & Eye Defects

Our eyeball is nearly spherical with white outer layer called the sclera. The light enters the eye through a curved transparent tissue called **Cornea**. In humans, the refractive power of the cornea is approximately **43 dioptres**. While the cornea contributes most of the eye's focusing power, its **focus is fixed**. The curvature of the lens, on the other hand, can be adjusted to "tune" the focus depending upon the object's distance. *The cornea has no blood supply; it gets oxygen directly through the air. Oxygen first dissolves in the tears and then diffuses throughout the cornea to keep it healthy.*



Behind the cornea, is a circular diaphragm called iris which has a central hole called pupil. The size of the pupil aperture is adjusted by muscle action and controls the amount of light entering the eye. The converging crystalline lens composed of glassy fibres is situated behind the iris. The shape and curvature of the crystalline lens is controlled by ciliary muscles. The images are formed on the retina by adjusting and changing the curvature of the lens. This is called accommodation of the eye. The eye ball contains a fluid in front of the lens and a gelatinous material in the space behind it. The retina of the eye consists of two types of photo sensitive rods and cones. *The more numerous rods have a greater sensitivity to light, but do not respond to colour. Rods work well when the light is dim. The cones are sensitive to bright light and colour. They are helpful to us to see things in colour.* Special optical nerves carry the messages from retina to the brain which interprets the images as erect images. The functioning of the eye is similar in many ways to that of a camera. Both have a lens but eyes are advanced because curvature of the camera lens cannot be changed.

The points between which the eye can see distinctly are called far point and near point. The far point is normally without limit (infinity) and near point depends on the accommodation of the crystalline lens. When we move a pencil slowly towards our nose. At some points, we observe that the pencil appears blurred. This is the near point. For a normal human eye, the near point is 25 cm from the eye.

The near point increases with the age as shown below:

Age (yr)	Near point (cm)
10	10
20	12
30	15
40	25
50	40
60	100

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Short-sightedness or Myopia

The inability to see the distant objects clearly and distinctly is called short sightedness. This defect arises when the image is formed infront of the retina. A short sighted person can see near objects clearly. This may arise due to either excessive curvature of the cornea or elongation of the eyeball. This defect is corrected by wearing glasses with a concave lens.

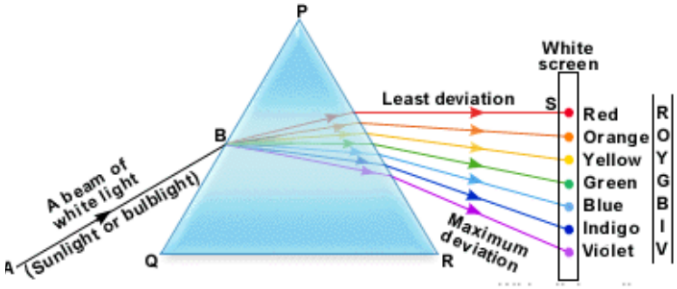
Long sightedness (or) Hypermetropia

The inability to see near objects clearly and distinctly is called long sightedness. This defect arises when the image is formed behind the retina. This defect may arise due to shortening of eye ball. A long sighted person can see the distant objects clearly. This defect is corrected by wearing spectacles with convex lens (converging) of appropriate focal length. A converging lens will correct this defect by converging the incoming rays so that the image is formed on the retina.

Longsightedness occurs naturally with age. As we grow old, our ciliary muscles weaken, and the crystalline lens looses its elasticity or hardens which limits the eye's accommodation. Some persons may have both Longsightedness and short sightedness defects. They should wear glasses consisting of both converging and diverging lenses on the same piece of glass. This is called bifocal glass. The bifocal lens was invented by Benjamin Franklin.

Dispersion of Light

When a beam of white light is passed through a prism, white light splits up into different colours. Consequently a coloured pattern is obtained on the screen. This splitting of white light into its constituent colours is called dispersion of light. The coloured patent obtained on the screen is called a spectrum. The colours are not in strips but change gradually through many different shades of colour. The colours of the spectrum of white light are violet, indigo, blue, green, yellow, orange and red (VIBGYOR). The white light is a mixture of different colours. Each colour is associated with light of a particular wavelength. Red light has longer wavelengths than the blue light. The angle of deviation by a prism is not the same for all the wavelength (colours) of light. Hence the prism disperses white light into its constituent colours. **<u>The red is deviated least and the violet most.</u>**



Color	wavelength
Violet	400 - 440
Indigo	440 - 460
Blue	460 - 500
Green	500 - 570
Yellow	570 - 590
Orange	590 - 620

Color of Objects

The colour of an object depends upon the colour of light it reflects. If all colours are reflected the object appears white. If some colours are reflected, the object appears coloured. The colour seen by the eye is the colour of the reflected light. A ball appears red when it is seen through a piece of red

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glass. White objects reflect all colour and black objects absorb all colours. Red objects reflect red only and absorb other colours.

Primary Colors, Secondary colors and Complimentary Colors

Primary colours are sets of colours that can be combined to make a useful range of colours. For human applications, three primary colours are usually used, since human colour vision is trichromatic. For additive combination of colours, as in overlapping projected lights or in CRT displays, the primary colours normally used are red, green, and blue. For subtractive combination of colours, as in mixing of pigments or dyes, such as in printing, the primaries normally used are cyan, magenta, and yellow, though the set of red, yellow, blue is popular among artists. The colours obtained by mixing of any two primary colours are called secondary colours. Two colors are called complementary if, when mixed in the proper proportion, they produce a neutral color (grey, white, or black). The common complimentary colors are:

- red + green + blue
- yellow + blue
- magenta + green
- cyan + red

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