SURVIVAL GUIDE FOR ENGINEERING PHYSICS – I

(Semester – I)

For
Diploma Students
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Chapter 1

Units and Measurements

1. What are physical quantities? Distinguish between fundamental and derived quantities.

   Physical quantities are measurable quantities by which laws of physics are described.
   Example: Mass, velocity, force, temperature, current
   Independently defined and directly measurable physical quantities are called fundamental quantities. Fundamental quantities do not depend dimensionally on any other quantities.
   Example: Mass, Length and Time
   Physical quantities which are derived from fundamental quantities are called derived quantities.
   Example: Velocity, area, volume, density, force

2. Define the term unit of a physical quantity. What are fundamental and derived units?

   The standard used for the specification of a physical quantity is called its unit. The units of fundamental quantities are called fundamental or base units and units of derived quantities are called derived units.

3. What is meant by a coherent unit system?

   The complete set of units of physical quantities constitutes a unit system. The essential requirement of a unit system is that it should be coherent. A unit system is said to be coherent if the units of all derived quantities can be obtained as a product or quotient of two or more of its fundamental units.

4. What are the seven fundamental quantities and their units in SI system?

Quantity	**Name of the Unit**	**Symbol**
1. Length	meter	m
2. Mass	kilogram	kg
3. Time	second	s
4. Electric Current	ampere	A
5. Temperature	kelvin	K
6. Amount of Substance	mole	mol
7. Luminous Intensity	candela	cd

5. What are the advantages of SI system?

   (a) SI system is an internationally accepted system.
   (b) SI system is a coherent system.
   (c) SI system is comprehensive (It is possible to define units of all quantities in different branches of science and engineering).
   (d) SI is a metric system (Larger and smaller units can be obtained as multiples or sub multiples of ten).
   (e) SI requires no separate practical unit.

6. List the names of the prefixes and symbols of multiples and sub multiples in SI system (any two of them can be expected in examination).

Multiple	Prefix	Symbol	Sub Multiple	Prefix	Symbol
10	deca	da	10^{-1}	deci	d
10^2	hecto	h	10^{-2}	centi	c
10^3	kilo	k	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	μ
10^9	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f

Chapter 2

Motion in One Dimension

1. Distinguish between scalar quantities and vector quantities.

   Physical quantities having only magnitude are called scalar quantities.
   Example: mass, temperature, current, distance, speed
   Physical quantities having both magnitude and direction are called vector quantities
   Example: displacement, velocity, acceleration, force, momentum

2. Distinguish between distance and displacement.

   The length of the path travelled by a body is called distance. It is a scalar quantity. For a moving body, distance travelled cannot be zero. The straight line distance between the initial position and final position of a body is called its displacement. It is a vector quantity. Displacement of a moving body can be zero if the body returns to its initial position. Displacement is always less than or equal to the distance travelled by the body.

3. Distinguish between speed and velocity.

   Speed is the rate of change of distance travelled by a body. It is equal to the distance travelled by the body in unit time. It is a scalar quantity and its unit is m/s.

$$Speed = \frac{Distance}{Time} = \frac{x}{t}$$
$$Instantaneous\ speed = \frac{dx}{dt}$$

   Velocity of a body is defined as the rate of change of displacement of the body. It is equal to the displacement in unit time. It is a vector quantity and its unit is m/s.

$$Velocity = \frac{Displacement}{Time} = \frac{s}{t}$$
$$Instantaneous\ velocity\ (v) = \frac{ds}{dt}$$

4. What is meant by acceleration of a moving body?

   The rate of change of velocity of a body is called its acceleration. It is a vector quantity and its unit is m/s^2.

$$Acceleration = \frac{Change\ in\ velocity}{Time} = \frac{v-u}{t}$$

where u is the initial velocity and v is the final velocity

$$Instantaneous\ acceleration\ (a) = \frac{dv}{dt} = \frac{d^2s}{dt^2}$$

5. Write down the equations of motion for uniformly accelerated bodies. Write down equations in the case of motion under gravity.

   The equations of motion for a uniformly accelerated body are:

$$v = u + at \tag{1}$$

$$s = ut + \frac{1}{2}at^2 \tag{2}$$

$$v^2 = u^2 + 2as \tag{3}$$

   For motion under gravity, the acceleration is constant called acceleration due to gravity 'g' and is always directed downwards. For upward motion $a = -g$ and for downward motion $a = g$. Displacement is taken as h (height from the reference point)

   Upward motion:

$$v = u - gt$$

$$h = ut - \frac{1}{2}gt^2$$

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

   Downward motion:

$$v = u + gt$$

$$h = ut + \frac{1}{2}gt^2$$

$$v^2 = u^2 + 2gh$$

6. Derive an equation for distance travelled by a particle of mass m and initial velocity u during n^{th} second of its motion.

   Consider a particle moving with initial velocity u and uniform acceleration a. Let S_1 be the distance travelled by the body in n seconds and S_2 be the distance travelled in (n-1) seconds. We have the formula:

$$S = ut + \frac{1}{2}at^2$$

$$S_1 = un + \frac{1}{2}an^2 \qquad \text{(By putting t = n)}$$

$$S_2 = u(n-1) + \frac{1}{2}a(n-1)^2 \qquad \text{(By putting t = n-1)}$$

   Then distance S_n covered during n^{th} second is given by

$$S_n = S_1 - S_2$$

$$S_n = un + \frac{1}{2}an^2 - [u(n-1) + \frac{1}{2}a(n-1)^2]$$

$$S_n = un + \frac{1}{2}an^2 - [un - u + \frac{1}{2}a(n^2 - 2n + 1)]$$

$$S_n = \cancel{un} + \cancel{\frac{1}{2}an^2} - \cancel{un} + u - \cancel{\frac{1}{2}an^2} + an - \frac{1}{2}a$$

$$S_n = u + an - \frac{1}{2}a$$

$$\boxed{S_n = u + a(n - \frac{1}{2})}$$

7. A body is projected upward with a velocity u. Show that time of ascent is equal to time of descent.

Let t_1 be the time of ascent. when the body reaches the maximum height its velocity becomes zero.For upward motion:

$$v = 0; \quad a = -g; \quad u = u; \quad t = t_1$$
$$v = u + at$$
$$0 = u - gt_1$$
$$gt_1 = u$$
$$\boxed{t_1 = \frac{u}{g}} \tag{1}$$

Let h_{max} be the maximum height reached.
Considering upward motion, at maximum height v = 0 ; s = h_{max} and a = -g

$$v^2 = u^2 + 2as$$
$$0 = u^2 - 2gh_{max}$$
$$2gh_{max} = u^2$$
$$\boxed{h_{max} = \frac{u^2}{2g}} \tag{2}$$

Let t_2 be the time of descent. For downward motion

$$u = 0; \quad a = g; \quad s = h_{max}; \quad t = t_2$$
$$s = ut + \frac{1}{2}at^2$$
$$h_{max} = \frac{1}{2}gt_2^2$$

Substituting h_{max} from equation (2)

$$\frac{u^2}{2g} = \frac{1}{2}gt_2^2$$
$$t_2^2 = \frac{u^2}{g^2}$$
$$\boxed{t_2 = \frac{u}{g}} \tag{3}$$

From equation (1) and (3)

$$t_1 = t_2$$

Time of ascent = Time of descent

8. A body moving with uniform acceleration describes 10 m in the 2^{nd} second and 20 m in the 4^{th} second of its motion. Calculate the distance moved by it in the fifth second. (Do similar problems in the same manner)

$$S_n = u + a(n - \frac{1}{2})$$
$$10 = u + a(2 - \frac{1}{2}) \implies 10 = u + 1.5a \tag{1}$$
$$20 = u + a(4 - \frac{1}{2}) \implies 20 = u + 3.5a \tag{2}$$

Subtracting equation (1) from (2)

$$10 = 2a \implies a = 5\ m/s^2$$

Substituting the value of 'a' in equation (1)

$$10 = u + 1.5 \times 5 \implies 10 = u + 7.5 \implies u = 2.5\ m/s$$

$$S_n = u + a(n - \frac{1}{2})$$

$$S_5 = 2.5 + 5(5 - \frac{1}{2}) = 2.5 + 22.5 = 25\ m$$

9. Can a body possess zero velocity and still accelerate? Give example.

   It is possible for a moving body to have zero velocity and a non-zero acceleration at the same time. For example, when a body is thrown vertically up with an initial velocity, at the highest point, the velocity of the body becomes zero. But its acceleration is still the acceleration due to gravity ($g = 9.8\ m/s^2$) acting downwards.

10. A stone is dropped into water from a bridge 44.1 m above the water level. Another stone is thrown vertically downward one second later. Both stones reach the water surface simultaneously. Find the initial downward velocity of the second stone.

    For Dropped stone:

$$u = 0;\ a = 9.8\ m/s^2;\ s = 44.1\ m;\ time = t$$

$$s = ut + \frac{1}{2}at^2$$

$$44.1 = 0 + \frac{1}{2} \times 9.8 \times t^2$$

$$44.1 = 4.9t^2 \implies t^2 = \frac{44.1}{4.9} = 9 \implies t = 3\ s$$

Let the second stone is thrown with an initial velocity u one second later. Then

$$\text{Initial velocity} = u;\quad a = 9.8\ m/s^2;\quad s = 44.1\ m;\quad time = 2\ s$$

$$s = ut + \frac{1}{2}at^2$$

$$44.1 = u \times 2 + \frac{1}{2} \times 9.8 \times 2^2$$

$$44.1 = 2u + 19.6 \implies 2u = 44.1 - 19.6 = 24.5 \implies u = \frac{24.5}{2} = 12.25\ m/s$$

11. A stone is dropped into a well and sound of the splash is heard after 3.91 s. If the depth of the well is 67.6 m , find the velocity of the sound.(Do similar problems in the same way)

Let t_1 be the time taken by the stone to reach the water surface in the well.

$$u = 0;\quad s = 67.6\ m;\quad a = 9.8\ m/s^2;\quad \text{and}\quad t = t_1$$

$$s = ut + \frac{1}{2}at^2$$

$$67.6 = 0 + \frac{1}{2} \times 9.8 \times t_1^2$$

$$t_1^2 = \frac{67.6}{4.9} = 13.8 \implies t_1 = \sqrt{13.8} = 3.71\ s$$

Let t_2 be the time taken by the sound to travel the distance 67.6 m

$$t_2 = \text{total time} - t_1 \implies t_2 = 3.91 - 3.71 = 0.2\ s$$

$$\text{Velocity of the sound,} v = \frac{\text{distance}}{\text{time}}$$

$$v = \frac{67.6}{.20} = 338\ m/s$$

Important Equations to Remember

$$v = u + at$$
$$s = ut + \frac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$
$$\text{Distance travelled during } n^{th} \text{ second, } s_n = u + a(n - \frac{1}{2})$$
$$\text{Upward motion}, a = -g \ \ ; \ \ s = h$$
$$\text{Downward motion}, a = g \ \ ; \ \ s = h$$

Chapter 3

Force and Motion

1. Analyse the statement - Newton's first law defines force while second law provides a means to measure it.

   Newton's first law of motion states that every body continues in its state of rest or of uniform motion along a straight line unless compelled by an external force to change that state. It is clear that first law defines force as that which changes or tends to change the state of rest or of uniform motion of a body. This law does not provide a means to measure the force applied on a body.

   Newton's second law of motion states that the rate of change of momentum of a moving body is directly proportional to the force applied on the body and takes place in the direction of the force. This law provides a quantitative relation between net force and acceleration produce by it. Second law is mathematically expressed as,

   $$\boxed{F = ma}$$

   This equation serves as a means for measuring force.

2. Why Newton's first law of motion is called law of inertia? (Define inertia of a body.)

   Newton's first law of motion states that every body continues in its state of rest or of uniform motion along a straight line unless compelled by an external force to change that state. First law help us to understand an inherent property of all bodies called inertia. Inertia is defined as the inability of a body to change its state of rest or of uniform motion along a straight line by itself. Mass of a body is a numerical measure of inertia of the body. Since Newton's first law defines inertia, it is also called law of inertia.

3. State Newton's second law of motion (State the law which help us to measure force) and derive the equation for force.

   Newton's second law of motion states that the rate of change of momentum of a moving body is directly proportional to the force applied on the body and takes place in the direction of the force.

   Consider a body of mass 'm' moving with a velocity 'u'. Let a force 'F' is acting on the body for a time 't' seconds. Consequently, velocity changes from u to v at the end of t seconds.

   $$\text{Initial momentum} = mu$$
   $$\text{Final momentum} = mv$$

$$\text{Change in momentum} = mv - mu$$

$$\text{Rate of change of momentum} = \frac{mv - mu}{t} = m\frac{(v-u)}{t}$$

$$\text{Since } a = \frac{v-u}{t} \text{ is the acceleration of the body,}$$

$$\text{Rate of change of momentum} = ma$$

According to Newton's second law of motion, force F is directly proportional to the rate of change of momentum.

$$\therefore \quad F \propto ma$$

$$F = kma$$

where k is a constant. The unit of force is selected in such a way that when $m = 1$, and $a = 1$, then $F = 1$. In such a case, $k = 1$.

$$\boxed{F = ma}$$

4. Define the SI unit of force. Find the dimensional formula for force.

The SI unit of force is newton (N). One newton is defined as the force that produces an acceleration of 1 m/s^2 to a mass of 1 kg.

$$\boxed{1\ newton = 1\ kg\ m/s^2}$$

Dimensional formula for the force can be obtained from the equation,

$$F = ma \implies F = m(\frac{v}{t}) \implies F = m(\frac{s}{t^2})$$

$$[F] = [M]\frac{[S]}{[T^2]} = [MLT^{-2}]$$

5. State Newton's third law of motion and law of conservation of momentum. Prove the law of conservation of momentum in the case of collision of two bodies moving in the same direction, using newton's second and third law.

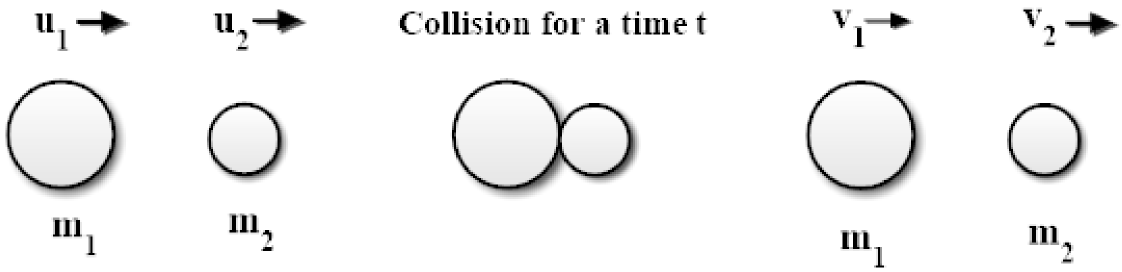
Newton's third law of motion: To every action, there is equal and opposite reaction. If a body B exerts a force on a body A ($\overrightarrow{F_{AB}}$), then the body A exerts a force on body B ($\overrightarrow{F_{BA}}$) of same magnitude, but opposite in direction

$$\boxed{\overrightarrow{F_{AB}} = -\overrightarrow{F_{BA}}}$$

For example, if a man sitting in a boat pushes another boat, the second boat moves forward while the first boat moves backward.

Law of conservation of momentum: Law of conservation of momentum states that in the absence any external force, the total momenta of a system of particles remain constant. Law of conservation of momentum in the case of collision of particles can be stated as when two or more bodies collide, the sum of their momenta before collision is equal to sum of their momenta after collision.

Proof



Consider two bodies of mass m_1 and m_2 moving along a line with velocities u_1 and u_2 respectively. Let them collide for a time 't' seconds and velocities after collision be v_1 and v_2.

$$\text{Change in momentum of } m_2 \text{ in t seconds} = m_2v_2 - m_2u_2$$

$$\text{Rate of change of momentum of } m_2 = \frac{(m_2v_2 - m_2u_2)}{t}$$

According to second law, this change in momentum is caused by the force exerted on mass m_2 by m_1 and let this force be F_{21}.

$$F_{21} = \frac{(m_2v_2 - m_2u_2)}{t} \tag{1}$$

$$\text{Change in momentum of } m_1 \text{ in t seconds} = m_1v_1 - m_1u_1$$

$$\text{Rate of change of momentum of } m_1 = \frac{(m_1v_1 - m_1u_1)}{t}$$

According to second law, this change in momentum is caused by the force exerted on mass m_1 by m_2 and let this force be F_{12}.

$$F_{12} = \frac{(m_1v_1 - m_1u_1)}{t} \tag{2}$$

$$\text{According Newton's third law, } F_{21} = -F_{12}$$

$$\frac{(m_2v_2 - m_2u_2)}{t} = \frac{-(m_1v_1 - m_1u_1)}{t}]$$

$$m_2v_2 - m_2u_2 = -m_1v_1 + m_1u_1$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2 \tag{3}$$

$$\text{Total momenta before collision} = \text{Total momenta after collision}$$

6. Define impulse of a force and give its unit. Show that impulse is equal to change in momentum. Calculate the impulse require to stop a car of mass 2000 kg moving with a speed of 30 m/s.

A large force acting for a short interval time to produce a finite change in momentum is called an impulsive force and the measure of effect of such a force is called impulse. Impulse of a force is defined as the product of force and time for which it acts. Its unit is kg m/s.

$$\text{Impulse} = \text{Force} \times \text{Time}$$

$$I = F \times t$$

$$\text{From Newton's second law, } F = ma = m\frac{(v-u)}{t}$$

$$\therefore\ I = m\frac{(v-u)}{t} \times t$$

$$I = m(v-u)$$

$$I = mv - mu$$

$$\text{Impulse} = \text{Change in momentum}$$

<u>Solution of the Problem</u>

$$\text{Initial momentum} = 2000 \times 30 = 60000\ kgm/s$$

$$\text{Final momentum} = 0$$

$$\text{Impulse } = \text{Change in momentum} = 0 - 60000 = -60000\ kgm/s$$

7. Explain the recoil of a gun and obtain an equation for recoil velocity of a gun by applying law of conservation of momentum.

   When a bullet is fired from a gun, bullet moves forward with a high velocity and the gun moves backward with a velocity. This is called recoil of the gun and the velocity with which gun moves backward is called recoil velocity of the gun. Before firing, both bullet and gun are at rest and total momenta before firing is zero. But after firing, the bullet moves forward with a momentum and in order to conserve the momentum the gun moves backward. Let M and m are the masses and V and v are velocities of the gun and the bullet respectively. By applying the law of conservation of momentum,

$$MV + mv = 0$$
$$MV = -mv$$
$$\boxed{V = \frac{-mv}{M}}$$

8. Calculate the force required to stop a gun within a distance 's'.

   Let M and m are the masses and V and v are velocities of the gun and the bullet respectively. By applying the law of conservation of momentum,

$$MV + mv = 0$$
$$MV = -mv$$
$$\boxed{V = \frac{-mv}{M}}$$

$$\text{Intial velocity of the gun (in the backward direction)} = \frac{mv}{M}$$
$$\text{Final velocity} = 0$$
$$\text{Distance travelled before stopping} = s$$

Let the retardation of the gun be a. Using the formula,

$$v^2 = u^2 - 2as$$
$$0 = (\frac{mv}{M})^2 - 2as$$
$$2as = (\frac{mv}{M})^2$$
$$\text{Retardation } a = \frac{m^2v^2}{2sM^2}$$

If F is the force required to stop the gun, $F = mass \times retardation$

$$F = M \times \frac{m^2v^2}{2sM^2}$$
$$\boxed{F = \frac{m^2v^2}{2sM}}$$

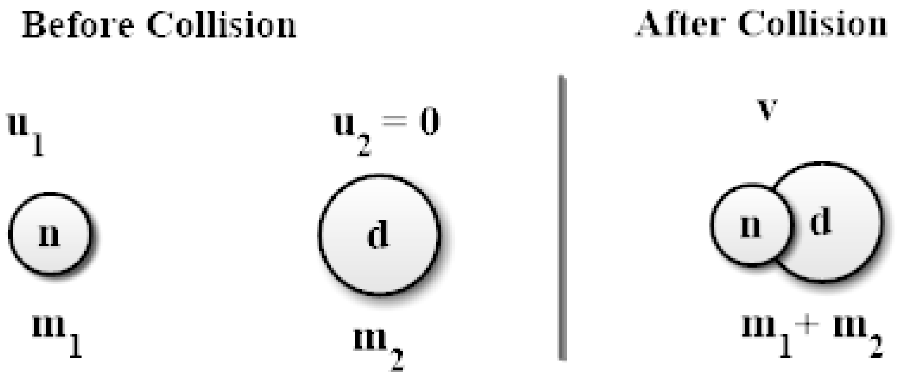
9. Explain the principle of Rocket propulsion.

   Rocket propulsion is based on the principle of conservation of linear momentum. The initial total momentum of the rocket on its launching pad is zero. When the rocket is fired, the hot gases produced by the combustion of the fuel are ejected downward with high velocity. In order to conserve the momentum, the rocket moves upward. This also an application of Newton's third law. The motion of the rocket is an example of a system in which mass is continuously changing. Mass of the rocket decreases as it goes up and as a result its velocity increases considerably. The thrust on the rocket is given by the equation:

$$Thrust = Exhaust\ \ speed\ \times \frac{Change\ \ in\ \ mass}{Change\ \ in\ \ time}$$

$$F = u\ \frac{dm}{dt}$$

10. A neutron having a mass of 1.67×10^{-27} kg and moving at 10^8 m/s collides with a duetron at rest and sticks to it. Calculate the speed of the combination. [Mass of deuteron = 3.34×10^{-27} kg.]



$$m_1 = 1.67 \times 10^{-27}\ kg$$
$$m_2 = 3.34 \times 10^{-27}\ kg$$
$$u_1 = 10^8\ m/s$$
$$u_2 = 0$$
$$v = ?$$

By applying law of conservation of momentum i.e. total momenta before collision is equal to tolal momenta after collision.

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$
$$\text{Since } u_2 = 0;$$
$$m_1u_1 = (m_1 + m_2)v$$

$$v = \frac{m_1u_1}{m_1 + m_2}$$
$$= \frac{1.67 \times 10^{-27} \times 10^8}{1.67 \times 10^{-27} + 3.34 \times 10^{-27}}$$
$$= 3.33 \times 10^7\ m/s$$

11. A gun weighing 10 kg fires a bullet of 30 g with a velocity 330 m/s. Calculate the recoil velocity of the gun.

$$\text{Mass of the gun, } M = 10\ kg$$
$$\text{Mass of the bullet, } m = 30\ g = 30 \times 10^{-3}\ kg$$
$$\text{Velocity of the bullet, } v = 330\ m/s$$
$$\text{Recoil velocity of the gun, } V = \frac{-mv}{M}$$
$$= \frac{-30 \times 10^{-3} \times 330}{10}$$
$$= 0.99\ m/s$$

12. If a gun of mass 20 kg fires 4 bullets per second each of mass 35×10^{-3} kg with a velocity 400 m/s, calculate the force required to stop the recoil of the gun.

$$\text{Mass of the gun, } M = 20\ kg$$
$$\text{Mass of the bullet, } m = 35 \times 10^{-3}\ kg$$

$$\text{Velocity of the bullet, } v = 400\ m/s$$

$$\begin{aligned}\text{Recoil velocity of the gun, } V &= \frac{-mv}{M} \\ &= \frac{-35 \times 10^{-3} \times 400}{20} \\ &= 0.7\ m/s \\ F &= Ma\end{aligned}$$

Since 4 bullets are fired per second, acceleration of the gun is obtained as rate of change of velocity of the gun in $\frac{1}{4}$ seconds.

$$a = \frac{(-0.7 - 0)}{\frac{1}{4}} = -2.8\ m/s^2$$

$$\therefore\ F = 20 \times (-2.8) = -56\ N$$

Force required to stop the recoil of the gun $= 56\ N$

13. If two masses 12 kg and 8 kg with velocities 10 m/s and 5 m/s move together after collision, find their common velocity.

$$\begin{aligned} m_1 &= 12\ kg & m_2 &= 8\ kg \\ u_1 &= 10\ m/s & u_2 &= 5\ m/s \\ v_1 &= v & v_2 &= v \end{aligned}$$

By applying law of conservation of momentum i.e. total momenta before collision is equal to tolal momenta after collision.

$$\begin{aligned} m_1u_1 + m_2u_2 &= m_1v_1 + m_2v_2 \\ 12 \times 10 + 8 \times 5 &= 12 \times v + 8 \times v \\ 160 &= 20v \\ \therefore\ v = \frac{160}{20} &= 8\ m/s \end{aligned}$$

Important Equations to Remember

Newton's Second Law of Motion, $F = ma$

Newton's Third Law of Motion, $\overrightarrow{F_{AB}} = -\overrightarrow{F_{BA}}$

Law of conservation of momentum in the case of collision of two bodies, $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Recoil velocity of the gun, $V = \frac{-mv}{M}$

Chapter 4

Statics

1. Distinguish between scalar quantities and vector quantities.

   Physical quantities having only magnitude are called scalar quantities.
   Example: mass, temperature, current, distance, speed
   Physical quantities having both magnitude and direction are called vector quantities
   Example: displacement, velocity, acceleration, force, momentum

2. What are collinear vectors and coplanar vectors?

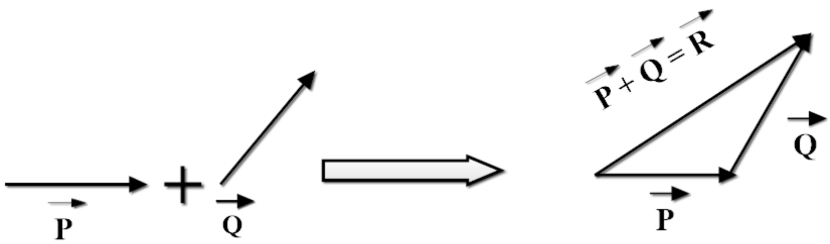
   Vectors that are lying along the same line are called collinear vectors. Vectors that are lying in the same plane are called coplanar vectors.

3. Define Equal vectors and negative of a vector.

   Two vectors of the same kind are said to be equal if they have the same magnitude and the same direction. A vector is said to be the negative of another vector if the two vectors are of equal magnitude, but opposite in direction.

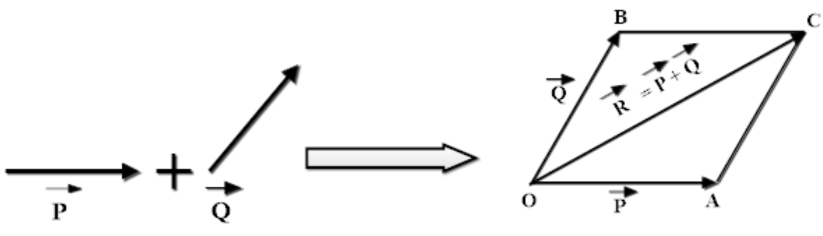
4. State triangular law of vector addition.

   Triangular law of vector addition states that if two vector quantities are represented both in magnitude and direction by the two sides of a triangle taken in order, their resultant is represented by the third side of the triangle taken in reverse the order.



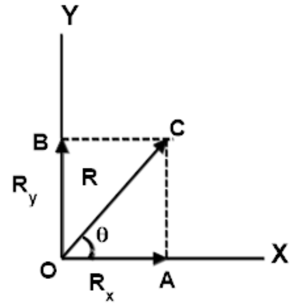
5. State parallelogram law of vector addition.

   Parallelogram law of vector addition states that if two vector quantities are represented both in magnitude and direction by the two adjacent sides of a parallelogram drawn from a point, their resultant is given in magnitude and direction by the diagonal of the parallelogram drawn through the same point.



6. What is meant by the resolution of a vector? What is rectangular resolution?

   The process of splitting a vector into components along any two directions is called resolution of a vector. The resolution of a vector along two mutually perpendicular directions (X-axis and Y-axis) is called rectangular resolution. The components ar called rectangular components (X-component and Y-component).



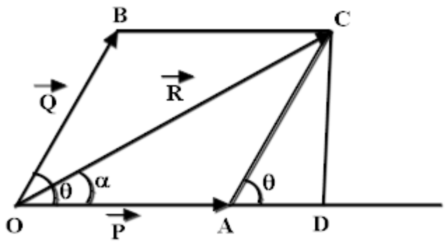
$$\text{X-component:} \quad R_x = Rcos\theta$$
$$\text{Y-component:} \quad R_y = Rsin\theta$$

7. What are concurrent forces?

   Forces whose line of action passes through a common point are called concurrent forces.

8. State parallelogram law of forces. Derive the expressions for magnitude and direction of resultant force using parallelogram law of forces . Discuss the case for $\theta = 0°$ and $\theta = 180°$. (This law and derivation are applicable not only for forces, but for all vectors)

   Parallelogram law of forces states that if two forces acting at a point are represented in magnitude and direction by the two adjacent sides of a parallelogram drawn from the point, their resultant is represented in magnitude and direction by the diagonal of the parallelogram drawn from the same point.



Let OA and OB represents the forces $\overrightarrow{P}$ and $\overrightarrow{Q}$ acting at an angle θ. Complete the parallelogram OACB and draw CD perpendicular to OA. The resultant of the forces, $\overrightarrow{R}$ is represented by the diagonal OC of the parallelogram.

$$\text{From the figure, } OA = |\overrightarrow{P}| = P; \quad OB = AC = |\overrightarrow{Q}| = Q; \quad OC = |\overrightarrow{R}| = R$$

$$\text{From the right angled triangle ODC, } OC^2 = OD^2 + CD^2$$
$$OC^2 = (OA + AD)^2 + CD^2$$
$$OC^2 = OA^2 + 2OA.AD + AD^2 + CD^2$$
$$\text{But from right angled triangle ADC, } AD^2 + CD^2 = AC^2$$
$$\therefore \quad OC^2 = OA^2 + 2OA.AD + AC^2$$
$$\implies \quad R^2 = P^2 + 2P.AD + Q^2$$
$$\text{From right angled triangle ADC, } cos\theta = \frac{AD}{AC}$$
$$AD = ACcos\theta = Qcos\theta$$
$$\therefore \quad R^2 = P^2 + 2PQcos\theta + Q^2$$

$$\text{The magnitude of the resultant is given by, } \boxed{R = \sqrt{P^2 + 2PQcos\theta + Q^2}}$$

$$\text{If the resultant } \overrightarrow{R} \text{ makes an angle } \alpha \text{ with the force } \overrightarrow{P}\text{, then}$$
$$tan\alpha = \frac{CD}{OD} = \frac{CD}{OA + AD}$$

$$\text{From right angled triangle ADC, } sin\theta = \frac{CD}{AC}$$

$$CD = ACsin\theta = Qsin\theta$$

$$AD = Qcos\theta$$

$$\therefore \ tan\alpha = \frac{Qsin\theta}{P + Qcos\theta}$$

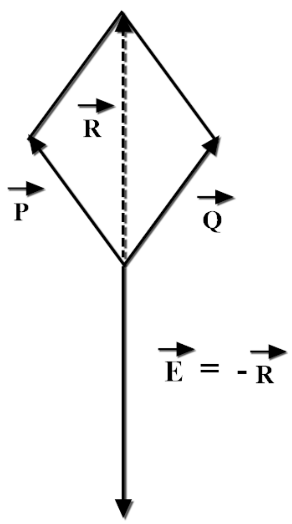
$$\text{The direction of the resultant is given by, } \boxed{\alpha = tan^{-1}\left(\frac{Qsin\theta}{P + Qcos\theta}\right)}$$

$$\text{When } \theta = 0°, \ cos\theta = 1 \quad \therefore \ R = P + Q$$

$$\text{When } \theta = 180°, \ cos\theta = -1 \quad \therefore \ R = P - Q$$

$$\text{When } \theta = 90°, \ cos\theta = 0 \quad \therefore \ R = \sqrt{P^2 + Q^2}$$

9. Distinguish between resultant and equilibrant. (Or Equilibrant of a set of two forces is the negative vector of their resultant. Comment)



The resultant of a set of forces acting on a body is that single force which alone can produce the combined effect of all these forces. The equilibrant of a set of forces acting on a body is that single force which along with the set keeps the body in equilibrium.

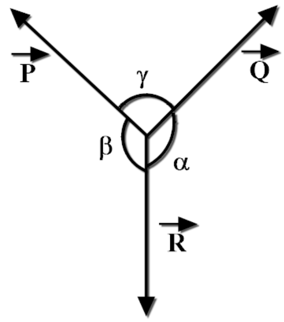
Consider two forces $\vec{P}$ and $\vec{Q}$ acting at a point O. The resultant $\vec{R}$ of $\vec{P}$ and $\vec{Q}$ are determined using parallelogram law as shown in figure. To balance the resultant, an equal and opposite force is required. Thus forces $\vec{P}$ and $\vec{Q}$ are balanced by a single force which is equal in magnitude and opposite in direction to that of the resultant. This single force is called the equilibrant, $\vec{E}$ and it is the negative vector of the resultant.

10. State law of triangle of forces.

Law of triangle of forces state that if three forces acting at a point are represented in magnitude and direction by the sides of a triangle taken in order, they will be in equilibrium.

11. State Lami's theorem.

Lami's Theorem states that if three forces acting on a body keep the body in equilibrium, each force is proportional to the sine of the angle between the other two.



$$P \propto sin\alpha; \quad Q \propto sin\beta; \quad R \propto sin\gamma; \quad \Longrightarrow \boxed{\frac{P}{sin\alpha} = \frac{Q}{sin\beta} = \frac{R}{sin\gamma}}$$

12. What are parallel forces? What is meant by like parallel forces and unlike parallel forces?

    Forces whose line of action are parallel to each other are called parallel forces. Two parallel forces are said to be like when they act in the same direction. Two parallel forces are said to be unlike when they act in anti-parallel direction.

13. Define moment of a force about a point. What is its unit? State the conditions of equilibrium of a body under the action of coplanar parallel forces.

    Moment of a force about a given point is the product of the force and perpendicular distance from the point to the line of action of the force. It is a measure of tendency of the force to rotate the body about the given point. If x is the perpendicular distance A to the line of action of the force F, the moment of the force about the point A is $F.x$. The unit of moment of force is Ns.

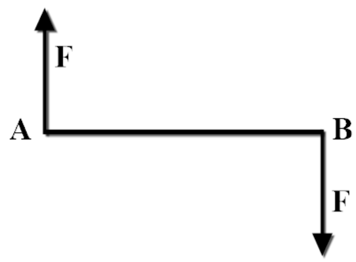
    The conditions for equilibrium of a body under the action of coplanar parallel forces are:

    (a) The algebraic sum of the forces acting on a body should be zero (to prevent translational motion).

    (b) The algebraic sum of the moments of the forces about any point in their plane should be zero (to prevent rotational motion).

14. Explain the term couple and write the equation for moment of a couple. Mention three characteristics of a couple.

    Two equal unlike parallel forces whose lines of action are not the same constitute a couple. The arm of the couple is the perpendicular distance between the lines of action of the forces. In the figure, AB represents the arm of the couple.



The moment of the couple (C) is defined as the product of one of the forces and the arm of the couple.

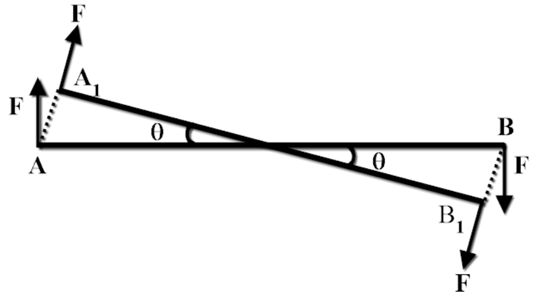
$$C = F.AB$$

(a) Since the algebraic sum of the forces constituting the couple is zero, the effect of the couple is to produce a pure rotation without translation.

(b) The algebraic sum of the moments of the forces constituting a couple about any point in their plane is a constant and equal to the moment of the couple.

(c) Two couples acting in one plane upon a rigid body balance each other if their moments are equal and opposite.

15. Derive an equation for work done by a couple and hence deduce the equation for power. Consider a couple (F, F) acting on a body AB as shown in the figure.



The moment of the couple C is given by

$$C = F.AB \tag{1}$$

Let the couple rotates the body through an angle θ about a point O. When the body rotates through an angle θ, the point of application of the forces are moved through the arcs AA_1 and BB_1. Then work done by the couple is given by

$$W = F.AA_1 + F.BB_1 \tag{2}$$

$$\text{We have, } \theta = \frac{arc\ length}{radius}$$

$$\therefore\ \theta = \frac{AA_1}{AO} \implies AA_1 = AO.\theta$$

$$\theta = \frac{BB_1}{BO} \implies BB_1 = BO.\theta$$

$$\text{Hence, work done by the couple, } W = F.AO\ \theta + F.BO\ \theta$$

$$W = F.(AO + BO)\ \theta$$

$$W = F.AB\ \theta$$

From equation (1), F.AB is the moment of the couple C $\therefore\ \boxed{W = C\theta}$

For a complete revolution, $\theta = 2\pi$

Hence work done for complete revolution is, $W = 2\pi C$

If the body performs N revolutions per second, then Work done per second $= 2\pi NC$

The work done per second is called power. Hence the power developed is given by

$$\boxed{P = 2\pi NC}$$

16. A body is acted upon by two forces 3 N and 10 N. The angle between the forces is 60°. Find out the magnitude and direction of the force to be applied to keep the body in equilibrium.

$P = 3\ N;\ \ Q = 10\ N;\ \ \theta = 60^\circ$

Magnitude of the resultant, $R = \sqrt{P^2 + 2PQcos\theta + Q^2}$

$= \sqrt{3^2 + 2 \times 3 \times 10 \times cos60 + 10^2}$

$= 11.8\ N$

If α is the angle between P and R, then $\alpha = tan^{-1}\left(\frac{Qsin\theta}{P + Qcos\theta}\right)$

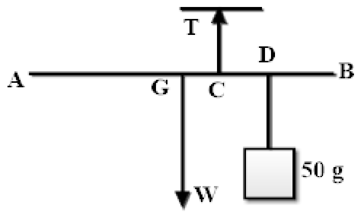
$$= tan^{-1}\left(\frac{10 \times sin60}{3 + 10 \times cos60}\right)$$

$$= 47.3°$$

Magnitude of the equilibrant, $E = R = 11.8\ N$

The angle between P and E $= 180 + 47.3 = 227.3°$

17. A uniform meter scale has width 2.5 cm and thickness 4 mm. The scale is balanced at the 60 cm mark when a weight 50 gm is suspended at 75 cm mark. Calculate the density of the material of the scale.



In the figure, AB is a meter scale of weight W which acts at the centre of gravity G (50 cm mark). The 50 g weight is suspended at D (75 cm mark)and the scale balances at C (60 cm mark). Let T be the tension in the string (in gram weight). Consider the equilibrium of the scale at the point C and applying the conditions for equilibrium,

$$\text{Sum of the downward forces} = \text{Sum of the upward forces}$$

$$W + 50 = T \tag{1}$$

$$\text{Sum of clockwise moments about A} = \text{Sum of anti-clockwise moments about A}$$

$$W \times 50 + 50 \times 75 = T \times 60$$

$$50W + 3750 = (W + 50) \times 60$$

$$50W + 3750 = 60W + 3000$$

$$10W = 750$$

$$W = 75\ g$$

$$\text{Length of the scale} = 1\ m = 100\ cm$$

$$\text{Width of the scale} = 2.5\ cm$$

$$\text{Thickness of the scale} = 4\ mm = 0.4\ cm$$

$$\text{Volume of the scale} = 100 \times 2.5 \times 0.4 = 100\ cm^3$$

$$\text{Density of the scale} = \frac{Mass}{Volume}$$

$$= \frac{75}{100}$$

$$= 0.75\ g/cm^3$$

$$\text{Density of the scale in SI unit} = 0.75 \times 1000 = 750\ kg/m^3$$

18. Two forces 10 N and 15 N act at an angle 60° between them. Find the magnitude of the resultant.

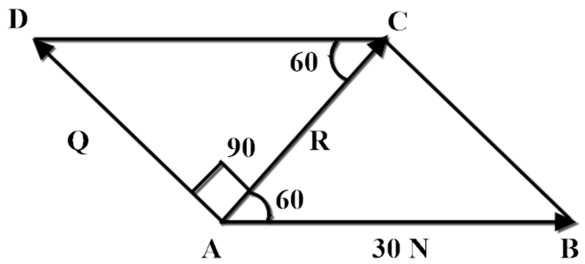
$P = 10\ N;\ \ Q = 15\ N;\ \ \theta = 60°$

Magnitude of the resultant, $R = \sqrt{P^2 + 2PQcos\theta + Q^2}$

$$= \sqrt{10^2 + 2 \times 10 \times 15 \times cos60 + 15^2}$$

$$= 21.8\ N$$

19. Two unequal forces acting at an angle 150° have their resultant perpendicular to the smaller force. The larger force is 30 N. Find the smaller force and resultant.



Let Q and R represent the smaller force and resultant.

$$\text{From the right angled triangle ACD, } sin60 = \frac{AD}{CD} = \frac{AD}{AB}$$

$$\therefore AD = ABsin60 \implies Q = 30 \times sin60 = 26\ N$$

$$\text{Also from the right angled triangle ACD, } \; AC^2 + AD^2 = CD^2$$

$$R^2 + Q^2 = 30^2$$

$$R^2 = 900 - Q^2$$

$$R = \sqrt{900 - 26^2} = 15\ N$$

Important Equations to Remember

$$\text{Magnitude of resultant of two forces P and Q making an angle } \theta: \; R = \sqrt{P^2 + Q^2 + 2PQcos\theta}$$

$$\text{Direction of the resultant}: \; \alpha = tan^{-1}\left(\frac{Qsin\theta}{P + Qcos\theta}\right)$$

$$\text{Lami's theorem}: \; \frac{P}{sin\alpha} = \frac{Q}{sin\beta} = \frac{P}{sin\gamma}$$

Condition for equilibrium (1) : Sum of downward forces = Sum of upward forces

Conditions for equilibrium (2) : Sum of clockwise moments = Sum of ant-clockwise moments

Work done by the couple : $W = c\theta$

Power developed by the couple : $P = 2\pi NC$

Chapter 5

Elasticity

1. Distinguish between deforming force and restoring force.

   Deforming force is the external force applied on a body on account of which a deformation is produced in the body. When deforming forces are applied to an elastic body, forces of reaction come into play internally to restore the original shape of the body. The force with which a body resists deformation is called restoring force. If the body is elastic, the restoring force is equal in magnitude and opposite in direction to the deforming force.

2. Distinguish between stress and strain.

   Stress is defined as the internal restoring force developed per unit area within a body when deforming forces are applied to it. The restoring force is equal in magnitude and opposite in direction to the deforming force. If F is the deforming force acting on an area A of a body, then

   $$stress = \frac{Restoring\ force}{Area} = \frac{Deforming\ force}{Area} = \frac{F}{A}$$

   The unit of stress is N/m^2 or pascal. The unit of stress and pressure are same.

   Strain is the fractional deformation of a body resulting from the application of deforming forces. Strain is defined as a ratio of change in dimension to the original dimension of the body. Strain is a dimensionless quantity and it has no unit.

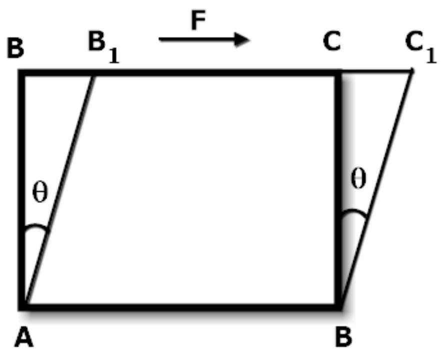
3. Explain various types of strain possible for a solid.

   Three types of strains are possible for an elastic body namely longitudinal strain, shearing strain and volume strain (bulk strain).

   Longitudinal Strain: If the length of the body is changed by the application of a force, the corresponding strain is called longitudinal strain. Longitudinal strain can be defined as the ratio of change in length to the original length of the body. Longitudinal strain may be compressive (decrease in length) or tensile (increase in length).

   $$Longitudinal\ strain = \frac{Change\ in\ length}{Orginal\ length} = \frac{\Delta L}{L}$$

   Shearing Strain: When a body undergoes a change in shape without accompanying a change in volume, the corresponding strain is called shearing strain. The figure below shows the section of a rectangular block sheared by a tangential force F. The face $ABCD$ is distorted to AB_1C_1D.



$$Shearing\ strain = \frac{BB_1}{AB} = \frac{CC_1}{CD} = \theta\ (in\ radian)$$

Thus angular deformation due to shearing stress is called shearing strain.

Volume Strain (Bulk Strain): If the volume of a body is changed by the application of a stress or pressure, the corresponding strain is called volume strain. Volume strain is defined as the ratio of the change in volume to the original volume of the body.

$$Volume\ strain = \frac{Change\ in\ volume}{Orginal\ volume} = \frac{\Delta V}{V}$$

4. State Hooke's Law.

   Hooke's law of elasticity states that within elastic limit, stress is proportional to strain.

$$stress \propto strain$$
$$\frac{stress}{strain} = constant$$

   This constant is called modulus of elasticity. Modulus of elasticity or elastic modulus is defined as the ratio of stress to the strain and its unit is N/m^2 or pascal.

5. Explain and deduce the expressions of three moduli of elasticity . (Or Explain Young's Modulus, Rigidity modulus and Bulk modulus. Derive the equations for each of them).

   Young's Modulus: The ratio of longitudinal stress to longitudinal strain is called Young's modulus (Y). It is a measure of length elasticity of a body. Consider a wire of length L and cross sectional area A is elongated by amount ΔL under a stretching force F, then

$$\text{Young's Modulus} = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}}$$
$$Y = \frac{(\frac{F}{A})}{(\frac{\Delta L}{L})}$$
$$Y = \frac{FL}{A\Delta L}$$

   If the wire has a circular cross section with radius r, then

$$A = \pi r^2$$
$$\therefore\ Y = \frac{FL}{\pi r^2 \Delta L}$$

   Rigidity Modulus: The ratio of shearing stress to shearing strain is called Rigidity modulus (η). Consider a body undergoes a change in shape without a change in volume by the application of a tangential force F acting on an area A of the body. The shearing stress is the angular deformation, θ of the body. Then,

$$\text{Rigidity modulus} = \frac{\text{Shearing stress}}{\text{Shearing strain}}$$
$$\eta = \frac{(\frac{F}{A})}{\theta}$$
$$\eta = \frac{F}{A\theta}$$

Bulk Modulus: The ratio of volume stress to volume strain is called Bulk modulus (B). Consider a body of volume V is being pressed by a normal force F acting on a area A so that the change in volume of the body is ΔV. But the normal force acting per unit area (volume stress) is called pressure (P).

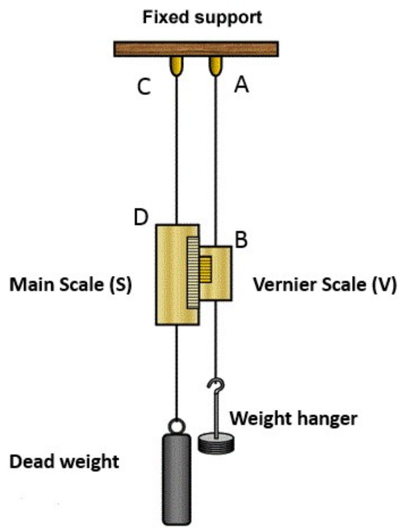
$$\text{Bulk modulus} = \frac{\text{Volume stress}}{\text{Volume strain}}$$
$$B = \frac{P}{(\frac{\Delta V}{V})}$$
$$B = \frac{PV}{\Delta V}$$

6. What is meant by compressibility?.

   The reciprocal of bulk modulus of a body is called compressibility (K).

$$K = \frac{1}{B} = \frac{\Delta V}{PV}$$

7. Describe Searle's mthod to find the Young's modulus of a wire.



The given material is taken in the form of a long wire AB of length about 3 m and diameter about 1 mm. One end of the wire is rigidly fixed to a ceiling and a weight hanger is attached to the other end. A similar wire CD is fixed by the side of AB as a reference wire. A scale (S) graduated in millimetre is fixed to the reference wire CD and a vernier scale (V) is attached to the wire AB. A dead weight is added to the reference wire and initial reading C_0 is observed by noting main scale reading and coinciding vernier scale division. A weight of 1 kg is is placed in the weight hanger and new reading C_1 is noted. The difference in reading $(C_1 - C_0)$ gives the extension for 1 kg. The wire is then loaded with 2 kg, 3 kg and 4 kg and corresponding readings are noted. The loads are then removed one by one noting the readings once again in each case. The mean reading corresponding to each load is found out and the extension ΔL for each load M is calculated. The average value of $\frac{M}{\Delta L}$ is found out. The radius r of the wire is found out using a screw gauge and length L by a meter scale. The Young's modulus is calculated using the formula:

$$Y = \frac{MgL}{\pi r^2 \Delta L}$$
$$Y = \frac{gL}{\pi r^2}(\frac{M}{\Delta L})$$

8. Why springs are made of steel and not of copper?

   The steel is more elastic than copper. Steel has high value of Young's modulus and breaking stress compared to copper. Therefore steel can regain its original shape for a comparably high stress. This is the reason why springs are made of steel and not of copper.

9. Distinguish between elasticity and plasticity.

   Elasticity is the property of a body by virtue of which it tends to regain its original size and shape when deforming forces are removed. The materials showing elasticity are called elastic materials.
   Examples: Rubber, Steel, Copper

   Plasticity is the property of a body by virtue of which it tends to remain in the distorted state without showing any tendency to regain its original size and shape when deforming forces are removed. The materials showing plasticity are called plastic materials.
   Examples: Clay, mud, Wax

10. What is meant by elastic limit?

    Elastic materials retain its elastic property upto a limit called elastic limit, when the applied force on it is increased. Elastic limit is the maximum stress within which the body regains its original size and shape when the deforming force is removed.

11. What is meant by breaking stress? What is the difference between the elastic behaviour of ductile and brittle materials?

    The maximum stress a material can withstand before breaking is called breaking stress. For a ductile material, a large deformation takes place between elastic limit and fractional state (large plastic region). But in the case of brittle material, it breaks soon after elastic limit (very small plastic region).

12. Explain elastic fatigue.

    The failure of an elastic body to withstand large fluctuations of stress is defined as elastic fatigue. In many applications, elastic materials are required to withstand varying loads which causes fluctuation in stresses. The crank shaft of an engine and springs of auto mobiles are often subjected to varying stresses. Due the fluctuation in stresses, fracture may occur at a stress much below the normal breaking stress under static load condition.

Important Equations to Remember

$$\text{Youngs Modulus, } Y = \frac{(\frac{F}{A})}{(\frac{\Delta L}{L})}$$

$$Y = \frac{FL}{A\Delta L}$$

$$\text{If the wire has a cross section with radius r, } Y = \frac{FL}{\pi r^2 \Delta L}$$

$$\text{If the wire is stretched by a load of mass M, } Y = \frac{MgL}{\pi r^2 \Delta L}$$

$$\text{Rigidity Modulus, } \eta = \frac{F}{A\theta}$$

$$\text{Bulk Modulus, } B = \frac{P}{(\frac{\Delta V}{V})} = \frac{PV}{\Delta V}$$

Chapter 6

Flow of Fluids

1. Distinguish between streamline flow and turbulent flow.

   The flow of a fluid is said to be a streamline flow or steady flow if every particle of the fluid follows the path of its preceding particle with exactly the same velocity. In steady flow, the velocity of all the particles of the fluid crossing a particular point does not change with time. But the velocity of the particles at different points may not be the same. Steady flow is usually achieved at very low flow speeds.

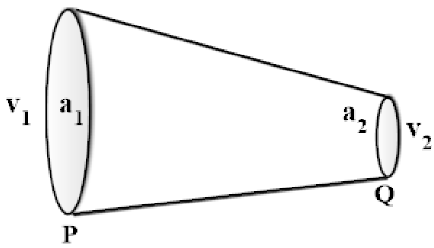
   When a liquid flows with a velocity greater than its critical velocity, the motion of the particles of the fluid become irregular or turbulent. Such a fluid flow is called turbulent flow. In turbulent flow, the velocities of the fluid particles vary erratically from point to point as well as from time to time.

2. Explain the term critical velocity in the case of fluid flow and state the factors on which it depends.

   Critical velocity of a fluid can be defined as the limiting value of velocity of flow of the fluid below which the fluid flow remains steady and above which fluid flow becomes turbulent. The critical velocity depends on the coefficient of viscosity, density of the fluid and diameter of the tube through which it flows.

3. Explain the equation of continuity in the case of fluid flowing through a pipe of varying cross section.

   The principle of continuity is a statement of conservation of mass in the case of flowing fluids. According to this principle, when there is a steady flow of an incompressible and non-viscous fluid through a tube of non uniform cross section, the product of the area of cross section and the velocity of flow remains constant at every point in the tube.



   Consider a portion of a pipe PQ of cross sections a_1 and a_2 at the points P and Q respectively. If v_1 and v_2 are the velocities of the liquid crossing the areas a_1 and a_2, then according to equation of continuity:

$$a_1 v_1 = a_2 v_2$$
$$av = constant$$

4. Explain different forms of energy associated with fluid flow.

   A flowing fluid has three types of energies associated with it. These energies are kinetic energy, potential energy and pressure energy.

   Kinetic Energy: Kinetic energy is due to the velocity of flow of the fluid. If a mass m of the fluid flows with a velocity v, then

$$\text{Kinetic energy of the fluid } = \frac{1}{2}mv^2$$
$$\therefore \text{ Kinetic energy per unit mass of the fluid } = \frac{1}{2}v^2$$

Potential Energy: If a mass m of the fluid situated at a height h above a reference level, then

$$\text{Potential energy of the fluid} = mgh$$
$$\therefore \text{ Potential energy per unit mass of the fluid} = gh$$

Pressure Energy:The energy possessed by a fluid by virtue of its pressure is called pressure energy. If m is the mass of the fluid of density d under a pressure P, then

$$\text{Pressure energy of the fluid} = \frac{mP}{d}$$
$$\therefore \text{ Pressure energy per unit mass of the fluid} = \frac{P}{d}$$

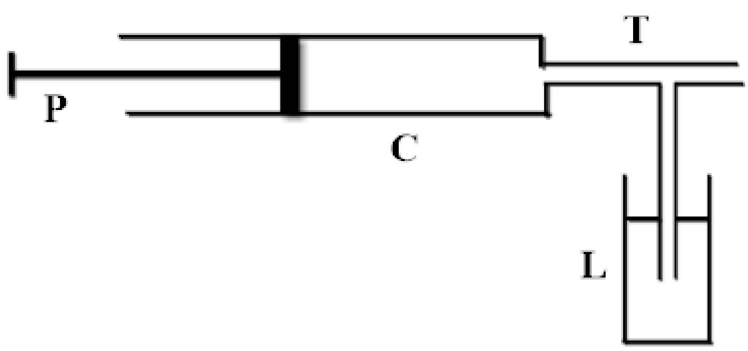
5. State Bernoulli's theorem.

   Bernoulli's theorem is a restatement of law of conservation of energy in the case of flowing fluids. Bernoulli's theorem states that the sum of the kinetic energy, potential energy and pressure energy of an incompressible and non-viscous fluid in steady flow remains constant throughout the flow.

$$\text{Kinetic Energy} + \text{Potential Energy} + \text{Pressure Energy} = \text{constant}$$
$$\frac{1}{2}v^2 + gh + \frac{P}{d} = \text{constant}$$
$$\frac{1}{2}v_1^2 + gh_1 + \frac{P_1}{d} = \frac{1}{2}v_2^2 + gh_2 + \frac{P_2}{d}$$

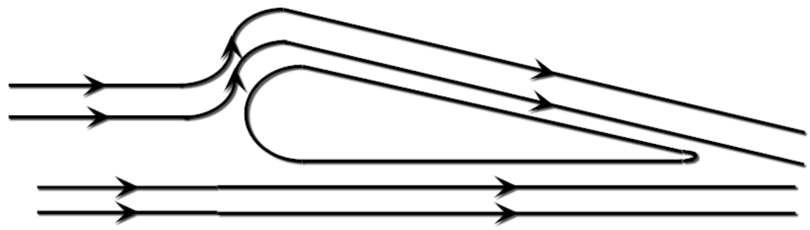
6. Explain the working of an atomiser with a neat diagram.

   Atomiser is an application of Bernoulli's theorem. According to Bernoulli's principle, when a fluid passes through a region at high speed, pressure decreases in that region.



   The figure shows the essential parts of an atomiser. C is a cylindrical barrel which terminates in a small tube T. T is connected to a vessel L containing the liquid to be sprayed. When air in the barrel is pushed by the piston P, the speed of the air increases considerable in tube T. According to Bernoulli's principle, this causes a reduction in pressure. As a result, the liquid in the vessel rushes up and mix with high speed air to form a fine spray.

7. Explain the principle behind an aerofoil (air foil). Or Explain the lift of an air craft wing using Bernoulli's principle.



An aero foil or air foil is a device which is shaped in such a way as to cause a force at right angles to the direction of motion through air. The upper surface of the air foil is more curved and hence longer than the lower surface as shown in figure. Because of this shape, air moves faster over the upper surface compared to the bottom surface. According to Bernoulli's principle, when a fluid passes through a region at high speed, pressure decreases in that region. Hence, the pressure under the air foil increases while above it decreases. This pressure difference cause an upward force which provides a substantial part of the lift on the wing.

Important Equations to Remember

$$\text{Equation of continuity : } a_1 v_1 = a_2 v_2$$
$$\text{Bernoulii's theorem : Kinetic Energy + Potential Energy + Pressure Energy = constant}$$
$$\frac{1}{2}v^2 + gh + \frac{P}{d} = \text{constant}$$
$$\frac{1}{2}v_1^2 + gh_1 + \frac{P_1}{d} = \frac{1}{2}v_2^2 + gh_2 + \frac{P_2}{d}$$
$$\text{Pressure difference b/w top and bottom of the aeroplane wing (Air foil) : } P_2 - P_1 = \frac{d}{2}[v_1^2 - v_2^2]$$
$$\text{Upward lift on the wing } = \text{Pressure difference } \times \text{ Area}$$

Chapter 7

Viscosity

1. Explain the term viscosity. On what factors does the viscous force acting tangentially on layer depends?.

   The property of a fluid by virtue of which it tends to resist the relative motion between the layers of the fluid is called viscosity. The viscous force (F) acting between two layers of the liquid depends on area of either layer (A) and velocity gradient between the layers (v_2 - v_1 / d).

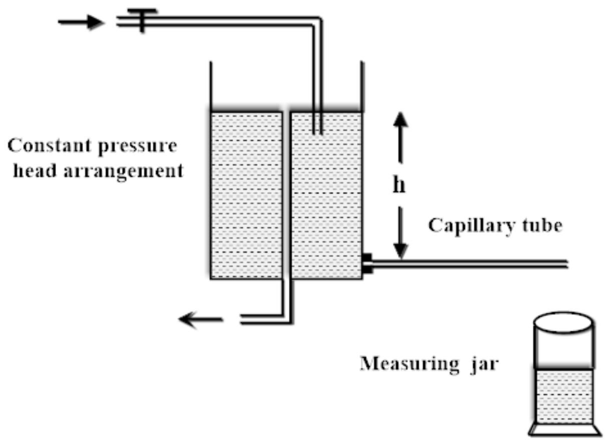
2. Define the coefficient of viscosity. What is its SI and CGS units?.

   The property of a fluid by virtue of which it tends to resist the relative motion between the layers of the fluid is called viscosity. The viscous force (F) acting between two layers of the liquid depends on area of either layer (A) and velocity gradient between the layers (v_2 - v_1 / d). It is experimentally found that F/A is proportional to the velocity gradient.

$$\frac{F}{A} \propto \frac{(v_2 - v_1)}{d}$$
$$\boxed{F = \eta A \frac{(v_2 - v_1)}{d}}$$

The constant of proportionality η is called coefficient of viscosity. In the above equation, if A = 1 and v_2 - v_1 / d = 1 , then F = η. Hence coefficient of viscosity can be defined as the tangential force required per unit area to maintain unit velocity gradient between two layers. The SI unit of coefficient of viscosity is $kgm^{-1}s^{-1}$. The CGS unit of coefficient of viscosity is $gcm^{-1}s^{-1}$ and it is known as poise. 1 poise = $\frac{1}{10}$ SI unit.

3. Explain the experimental method (Poiseuille's method) to determine the coefficient of viscosity of water (low viscous liquid).



A uniform capillary tube nearly 50 cm long and about 1 mm in diameter is chosen. The tube is attached horizontally to a constant pressure head arrangement as shown in figure. The level of the water is always kept the same in the reservoir thereby attaining a constant pressure head h. The amount of water Q flowing through the tube for a known time t is collected in a measuring jar. The volume V flowing per second is calculated as $V = \frac{Q}{t}$. The radius of the tube is accurately measured using a travelling microscope with a vernier arrangement. The length l of the capillary tube is measured using a meter scale. According to Poiseuille's formula,

$$V = \frac{\pi P r^4}{8 l \eta} \quad \Longrightarrow \therefore \quad \eta = \frac{\pi P r^4}{8 l V}$$

If h is the height of the water column above the tube, then pressure $P = hdg$ where d is the density of water and g is the acceleration due to gravity. Hence coefficient of viscosity can be calculated using the equation

$$\boxed{\eta = \frac{\pi h d g r^4}{8 l V}}$$

4. Describe the motion of a small sphere through a viscous fluid and deduce the expression for coefficient of viscosity of a highly viscous liquid. Consider a sphere of mass m, density ρ and radius r falls vertically downwards through a highly viscous medium of density d. When a body moves through a viscous medium three types of forces act on it:

   (i) Weight of the body acting downwards

   $$\text{Gravitational force, } F_g = mg = \frac{4}{3}\pi r^3 \rho g \tag{1}$$

   (ii) Upward thrust due to the displaced liquid (buoyant force) which according to Archimedes' principle is equal to the weight of the fluid displaced by the sphere.

   $$\text{Upward thrust or buoyant force, } F_b = \frac{4}{3}\pi r^3 d g \tag{2}$$

(iii) Motion of the sphere through the viscous medium causes relative motion between the layers of the liquid and hence motion of the sphere is influenced by the viscosity of the medium. The viscous force act in a direction opposite to the direction of motion of the sphere and Stokes derived a formula for viscous force acting on a sphere of radius r falling through a liquid of coefficient of viscosity η given by

$$\text{Viscous force, } F_v = 6\pi\eta r v \tag{3}$$

Here v is the terminal velocity of the sphere. Terminal velocity of a body is the constant velocity attained by the body moving through a viscous medium when upward forces on it is balanced by the downward force. Therefore, when the sphere attains terminal velocity

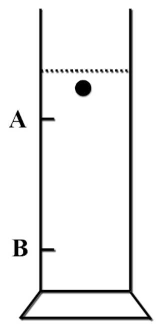
$$\begin{aligned}
\text{Gravitational force } &= \text{Upthrust} + \text{Viscous force} \\
F_g &= F_b + F_v \\
\frac{4}{3}\pi r^3 \rho g &= \frac{4}{3}\pi r^3 d g + 6\pi\eta r v \\
\frac{4}{3}\pi(\rho - d) r^3 &= 6\pi\eta r v \\
\eta &= \frac{\frac{4}{3}\pi(\rho - d) r^3}{6\pi r v} \\
\boxed{\eta = \frac{2r^2(\rho - d)g}{9v}}
\end{aligned}$$

5. What is terminal velocity? Using Stoke's law, obtain an expression for terminal velocity of a sphere falling through a viscous liquid.

   Terminal velocity of a body is the constant velocity attained by the body moving through a viscous medium when upward forces on it is balanced by the downward force. (Derivation is same as above except the final equation which should be written as given below):

$$\boxed{\textit{Terminal velocity } v = \frac{2r^2(\rho - d)g}{9\eta}}$$

6. Explain the experimental method (Stokes's method) to determine the coefficient of viscosity of a highly viscous liquid.



The coefficient of viscosity of a highly viscous liquid can be determined using Stoke's formula. The liquid is taken in a tall glass cylinder. A small metal sphere is taken and its radius is measured using a screw gauge. The sphere is gently dropped into the cylinder containing the liquid. The terminal velocity is determined by noting the time required for the sphere to travel a known distance through the liquid. For this, two marks A and B are made on the cylinder, one little below the surface of the liquid and the other above the bottom. If s is the distance between the marks and t is the time taken to travel the same,

$$v = \frac{s}{t}$$

By changing the positions of the marks and by noting the time in each case, the terminal velocity is calculated as an average of several trials. If ρ and d are the densities of the sphere and the liquid respectively, the coefficient of viscosity is calculated using the formula

$$\boxed{\eta = \frac{2r^2(\rho - d)g}{9v}}$$

7. Discuss the variation of viscosity with temperature.

The viscosity of a liquid is found to decrease with temperature. In the case of pure liquids, the coefficient of viscosity η_t at temperature $t°C$ is related to that at $0°C$ by the formula

$$\eta_t = \frac{\eta_0}{1 + at + bt^2}$$

Here a and b are positive constants.

The viscosity of a gas is found to increase with temperature. Using kinetic theory of gases, Sutherland deduced a formula connecting viscosity and temperature of a gas.

$$\eta_t = \frac{\eta_0 A\sqrt{T}}{1 + \frac{B}{T}}$$

Here $T = 273 + t$ represents the absolute temperature. A and B are called Sutherland constants.

Important Equations to Remember

Viscous force acting between the layers of the liquid : $F = \eta A\frac{(v_2 - v_1)}{d}$

Poiseuille's formula for volume of the liquid flowing per second through a capillary tube : $V = \frac{\pi P r^4}{8l\eta}$

Coefficeient of viscosity by Poiseuille's method : $\eta = \frac{\pi h d g r^4}{8lV}$

Viscous force acting on a sphere moving through a viscous medium : $F = 6\pi\eta r v$

Coefficeient of viscosity by Stoke's method : $\eta = \frac{2r^2(\rho - d)g}{9v}$

Chapter 8

Periodic Motion and Waves

1. Define simple harmonic motion (State the two conditions for a periodic motion to be simple harmonic). Write the differential equation for simple harmonic motion. Give examples of simple harmonic motion.

   A particle is said to execute simple harmonic motion if acceleration at any instant is directed towards a fixed point and is directly proportional to the displacement from the fixed point. The fixed point is called equilibrium position of the particle. If the displacement of the particle at any time t is y, then

$$\text{Acceleration, } a = \frac{d^2y}{dt^2}$$

$$\text{According to the definition of SHM, } \frac{d^2y}{dt^2} \propto -y$$

$$\frac{d^2y}{dt^2} = -\omega^2 y$$

$$\boxed{\frac{d^2y}{dt^2} + \omega^2 y = 0}$$

   This is the differential equation for simple harmonic motion. Here ω^2 is a constant of proportionality.

   <u>Examples of simple harmonic motion</u>

   (a) Oscillations of a simple pendulum.

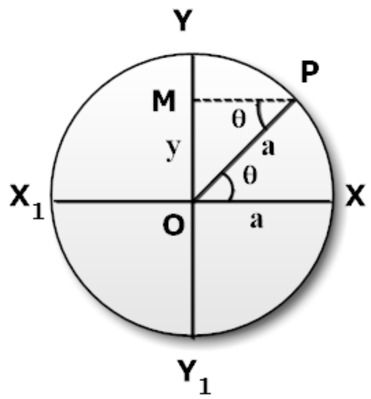
   (b) Vertical oscillations of a loaded spring.

   (c) Oscillations of water contained in a U tube when the column in one limb is slightly depressed and released.

   (d) Oscillations of a freely suspended magnet in earth's magnetic field.

2. Discuss the relation between simple harmonic motion and uniform circular motion. (Or Show that simple harmonic motion is the projection of uniform circular motion along a diameter of the circle).

   Consider a particle moving along the circumference of a circle of radius a and centre O with uniform velocity ω.



XX_1 and YY_1 are two mutually perpendicular diameters of the circle. Let the particle be at point X when time, t = 0. After a time t the particle comes to the position P describing an angle $\theta = \omega$t. Now PM is drawn perpendicular to the diameter YY_1. When P moves once around the circle, the foot of the perpendicular M moves to and fro along the diameter YY_1 with point O as equilibrium position. Hence, simple harmonic motion can be defined as the projection of uniform circular motion along a diameter of the circle.

From the figure, the displacement y of the point M during the time t is OM. From the triangle OMP,

$$\sin\theta = \frac{OM}{OP} \quad \implies OM = OP\sin\theta$$

$$\text{But, } OP = a,\ OM = y \text{ and } \theta = \omega t$$

$$\therefore \quad \boxed{y = a\sin\omega t}$$

This is the equation for simple harmonic equation.

3. Explain the characteristics of simple harmonic motion. (OR Explain the term frequency, period, amplitude and phase of simple harmonic motion).

   Period (T): Period is the time taken for one complete vibration.

   Frequency (f): Frequency is the number of vibrations produced per second. Period T and frequency f are related by the equation $f = \frac{1}{T}$

   Amplitude (a): Amplitude is the maximum displacement of the particle executing simple harmonic motion.

   Phase: The phase of a vibrating particle at any instant can be defined as the stage of vibration through which particle is passing at that time. Phase gives an idea regarding the position of the particle at that time. Phase can be indicated in terms of an angle or as a fraction of the time period.

4. Distinguish between longitudinal waves and transverse waves. Derive the relation connecting wave velocity, wavelength and frequency of a wave.

   Wave motion is the propagation of disturbance from one place to another in a regular and organized way, with or without the help of a medium. Generally waves are classified into two types - longitudinal waves and transverse waves.

   Longitudinal waves: A wave motion is said to be longitudinal if the particles of the medium vibrate in a direction parallel to the direction of propagation of the wave. Longitudinal waves require a medium for propagation. Longitudinal waves travels in the form of compressions and rarefactions. Longitudinal waves cannot polarise. Sound is an example of a longitudinal wave.
   Transverse waves: A wave motion is said to be transverse if the particles of the medium vibrate in a direction perpendicular to the direction of propagation of the wave. Transverse waves can propagate with or without the help of a medium. Transverse waves travels in the form of crests and troughs. Transverse waves can polarise. Light is an example of a transverse wave.

   Relation between v, f and λ

   The wave velocity (v) of a wave is the distance travelled by the wave in unit time. If T is the period of the wave, then the wave travels a distance equal to its wavelength (λ) during that time.

$$\text{Velocity} = \frac{\text{Distance travelled}}{\text{Time taken}} \implies v = \frac{\lambda}{T}$$

$$\text{But, } f = \frac{1}{T} \quad \therefore \quad \boxed{v = \lambda f}$$

5. Explain four characteristics of wave motion (Define wavelength, wave velocity, frequency and amplitude of a wave).

Wavelength (λ): Wavelength is defined as the distance between any two nearest particles of the medium which are in the same state of vibration. In the case of longitudinal waves, it is the distance between two consecutive compressions or two consecutive rarefactions. In the case of transverse waves, it is the distance between two consecutive crests or two consecutive troughs.
Wavevelocity (v): Wave velocity is defined as the distance travelled by the wave in unit time.

Frequency (f): Frequency of a wave is defined as the number of waves produced in one second. Frequency is related to time period (T) of a wave by the equation:

$$\boxed{f = \frac{1}{T}}$$

Amplitude (a): Amplitude of a wave is the maximum displacement of the particles of a medium during a vibration cycle.

6. Explain free vibration, forced vibration and resonance.

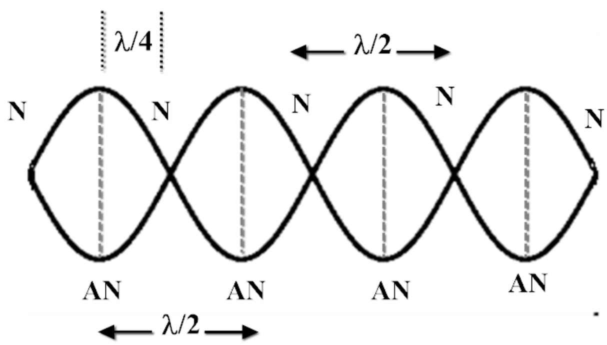
   Free vibration: Free vibration of a body is the natural vibration of the body and frequency of the vibration depends only on the inherent properties of the body. The frequency of free vibration is called natural frequency of the body.
   Eg: Oscillations of a simple pendulum, vibrations of a tuning fork.

   Forced vibration: A body can be set into vibration by imposing on it the free vibration of another body. This kind of vibration is called forced vibration. Eg: Vibration of a table when a vibrating tuning fork is pressed on it

   Resonance: Resonance is the phenomenon of vibration of a body with maximum amplitude by the influence of another vibrating body of same natural frequency as that of the first. Resonance takes place only when the two bodies have exactly the same frequency.

7. What are stationary waves? What are the characteristics of stationary waves?

   Waves which travel outward from a source and transmit energy from one point to another are called progressive waves. When two progressive waves propagating in opposite directions superimpose on each other, interference takes place and the resultant wave is called a stationary wave or standing wave. These waves are called stationary waves since they do not transmit energy from one point to other.



   Characteristics of Stationary Waves

   (a) In a stationary wave, the particles of the medium do not oscillate at certain points. These points are called nodes (denoted as N in the figure).
   (b) In a stationary wave, the particles of the medium oscillate with maximum amplitude at certain points. These points are called antinodes (denoted as AN in the figure).
   (c) Distance between a node and nearest antinode is $\lambda/4$.
   (d) Distance between two consecutive nodes or antinodes is $\lambda/2$.

(e) The standing wave system can vibrate only in special patterns called normal modes. The lowest mode is called fundamental mode and its frequency is called fundamental frequency. Higher modes are called overtones.

8. What is the principle behind musical instruments like clarinet, flute, and nadaswaram. What are the two types of pipes used in musical instruments?.

   Longitudinal stationary waves can be produced in a tube containing air. This is the basic principle of musical instruments like clarinet, flute, and nadaswaram which employ the vibrations of air columns.Two types of pipes are commonly used in musical instruments:

   (a) Closed pipe (Pipe closed at one end)
   (b) Open pipe (Pipe open at both ends)

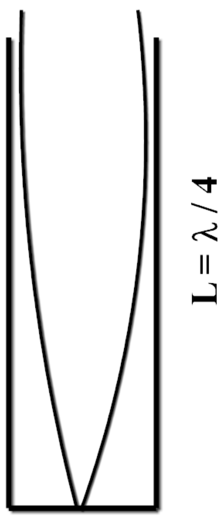
9. What are the two boundary conditions satisfied by the standing waves formed in a pipe containing air?.

   (a) A node is always produced at the closed end because the air column is not free to vibrate at the closed end.
   (b) The open end is always act as an antinode because the air is free to move near the open end.

10. Discuss the modes of vibration of air column in a closed pipe with suitable diagrams.

    Consider a closed pipe of uniform cross section enclosed by air. The pipe is open at one end and closed at other end. Let the length of the pipe be L. When vibrations are produced by blowing air into the pipe or by holding a tuning fork of appropriate frequency, air column begins to vibrate. The longitudinal waves propagates through the pipe and gets reflected at the closed end.

    First mode of vibration



In the first mode of vibration, a stationary wave will have a node at closed end and the next antinode at the open end. The frequency of this vibration f can be calculated in terms of the velocity of the sound v and length L of the pipe.The frequency is related to velocity and wavelength by the relation:

$$f = \frac{v}{\lambda}$$

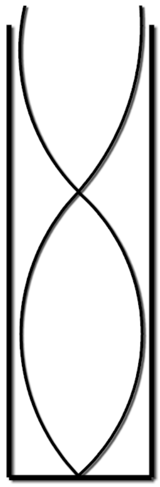
Since the distance between the node and next antinode is $\lambda/4$,

$$\frac{\lambda}{4} = L \implies \lambda = 4L$$

$$\text{Hence, } \boxed{f = \frac{v}{4L}} \tag{1}$$

This is the lowest frequency of vibration of the air column in the pipe and it is called fundamental frequency of vibration. The tone of the sound produced is called fundamental note or first harmonic.

Second mode of vibration



In this mode, two nodes and two antinodes are developed satisfying boundary conditions. Let the new wavelength be λ_1. The frequency of this mode is

$$f_1 = \frac{v}{\lambda_1}$$

The length of the pipe in terms of wavelegth is then,

$$L = \frac{\lambda_1}{4} + \frac{\lambda_1}{4} + \frac{\lambda_1}{4}$$

$$L = \frac{3\lambda_1}{4} \implies \lambda_1 = \frac{4L}{3}$$

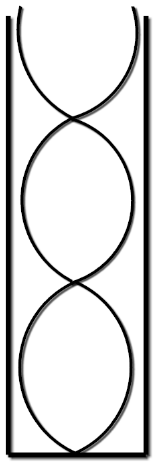
$$\therefore \quad f_1 = \frac{v}{\left(\frac{4L}{3}\right)} = \frac{3v}{4L}$$

$$\text{But the fundamental frequency,} \quad f = \frac{v}{4L}$$

$$\text{Hence,} \quad f_1 = 3f$$

This frequency is called first overtone or third harmonic.

Third mode of vibration



In this mode, three nodes and three antinodes are developed satisfying boundary conditions. Let the new wavelength be λ_2. The frequency of this mode is

$$f_2 = \frac{v}{\lambda_2}$$

The length of the pipe in terms of wavelegth is then,

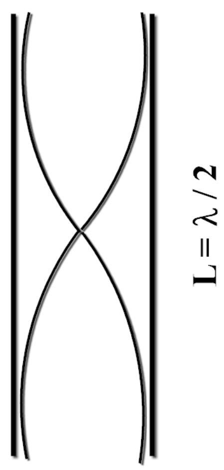
$$L = \frac{5\lambda_2}{4} \quad \Longrightarrow \lambda_2 = \frac{4L}{5}$$
$$\therefore \quad f_2 = \frac{v}{\left(\frac{4L}{5}\right)} = \frac{5v}{4L}$$
$$\text{But the fundamental frequency,} \quad f = \frac{v}{4L}$$
$$\text{Hence,} \quad f_3 = 5f$$

This frequency is called second overtone or fifth harmonic. Similar calculations show that the frequencies possible in the case of a closed pipe are f, 3f, 5f, 7f ...etc. The overtones will be less intense than the fundamental.

11. Discuss the modes of vibration of air column in an open pipe with suitable diagrams.

Consider a uniform pipe of length L open at both ends. When a sound wave is propagating along the length of the tube, it is actually bounded by an infinite quantity of air from outside. Due to the inertial property of the surrounding air, the waves gets reflected from the ends of the tube. The incident and reflected waves interfere producing stationary wave in the pipe,satisfying boundary conditions.

First mode of vibration



In the first mode of vibration, two antinodes are formed at the open ends and a node at the centre of the tube. The frequency of this vibration f can be calculated in terms of the velocity of the sound v and length L of the pipe.The frequency is related to velocity and wavelength by the relation:

$$f = \frac{v}{\lambda}$$

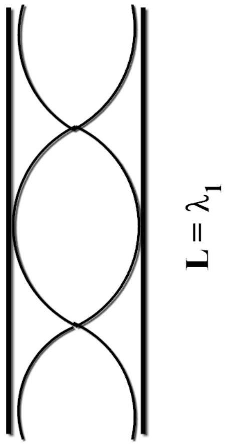
Since the distance between two consecutive antinodes is $\lambda/2$,

$$\frac{\lambda}{2} = L \quad \Longrightarrow \lambda = 2L$$

$$\text{Hence,} \quad \boxed{f = \frac{v}{2L}} \tag{1}$$

This is the lowest frequency of vibration of the air column in the pipe and it is called fundamental frequency of vibration. The tone of the sound produced is called fundamental note or first harmonic.

Second mode of vibration



In this mode, two nodes and three antinodes are developed satisfying boundary conditions. Let the new wavelength be λ_1. The frequency of this mode is

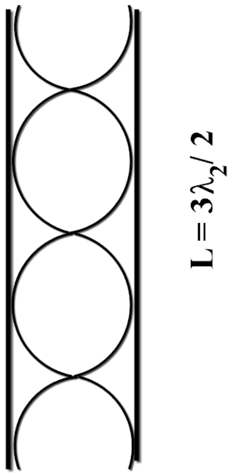
$$f_1 = \frac{v}{\lambda_1}$$

The length of the pipe in terms of wavelegth is then,

$$L = \frac{\lambda_1}{2} + \frac{\lambda_1}{2} = \lambda_1$$
$$\therefore \quad f_1 = \frac{v}{L}$$
$$\text{But the fundamental frequency,} \quad f = \frac{v}{2L}$$
$$\text{Hence,} \quad f_1 = 2f$$

This frequency is called first overtone or second harmonic.

Third mode of vibration



In this mode, three nodes and four antinodes are developed satisfying boundary conditions. Let the new wavelength be λ_2. The frequency of this mode is

$$f_2 = \frac{v}{\lambda_2}$$

The length of the pipe in terms of wavelegth is then,

$$L = \frac{3\lambda_2}{2} \implies \lambda_2 = \frac{2L}{3}$$
$$\therefore \quad f_2 = \frac{v}{\left(\frac{2L}{3}\right)} = \frac{3v}{2L}$$
$$\text{But the fundamental frequency,} \quad f = \frac{v}{2L}$$
$$\text{Hence,} \quad f_3 = 3f$$

This frequency is called second overtone or third harmonic. Similar calculations show that the frequencies possible in the case of an open pipe are f, 2f, 3f, 4f, 5f ...etc. The overtones will be less intense than the fundamental.

12. Show that a closed pipe can produce only odd harmonics where as an open pipe can produce all harmonics. Illustrate your answer with diagrams.

    Ans: Combine answers of Question No.10 and Question No.11 of this chapter

13. Show that the frequency of fundamental note of an open pipe is twice the frequency of the fundamental note in a closed pipe of the same length

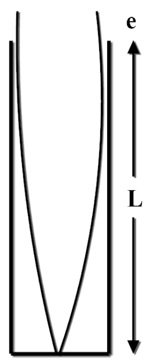
    Ans: Refer to answers of Question No.10 and Question No.11 of this chapter and derive only expressions for the fundamental frequencies in both closed and open pipe. If an open and closed pipe have the same length L, fundamental frequency of the open pipe ($f = v/2L$) is twice the fundamental frequency of the closed pipe ($f = v/4L$.)

14. Why the sound produced by an open pipe is richer in frequencies than that produced in a closed pipe. (Or Why open pipes are preferred to closed pipes in musical instruments?.)

    If f is the fundamental frequency of vibration, it can be shown by calculation that a closed pipe can produce only odd harmonics (f, 3f, 5f, 7f etc) whereas an open pipe can produce all harmonics (f, 2f, 3f ,4f, 5f etc). Since all harmonics are present in an open pipe, the sound is richer in frequencies than that produced in closed pipes. Hence,open pipes are preferred to closed pipes in musical instruments.

15. What is end correction as applied to vibration of air column contained in pipes? Derive the expression for fundamental frequency of vibration produced in a close pipe by taking end correction into account.

    Experiments and theoretical calculations show that the antinode is not formed exactly at the open end of a pipe, but a little distance beyond it. The distance between the open end and the position of the antinode is called end correction (e). Lord Rayleigh has theoretically shown that for a pipe of circular cross section, the end correction is about 30 percent of the internal diameter d of the pipe. Thus, end correction $\boxed{e = 0.3d}$



In the case of fundamental mode for a pipe closed at one end, the geometrical length L is not exactly $\lambda/4$ if we take the end correction into account. Then we have,

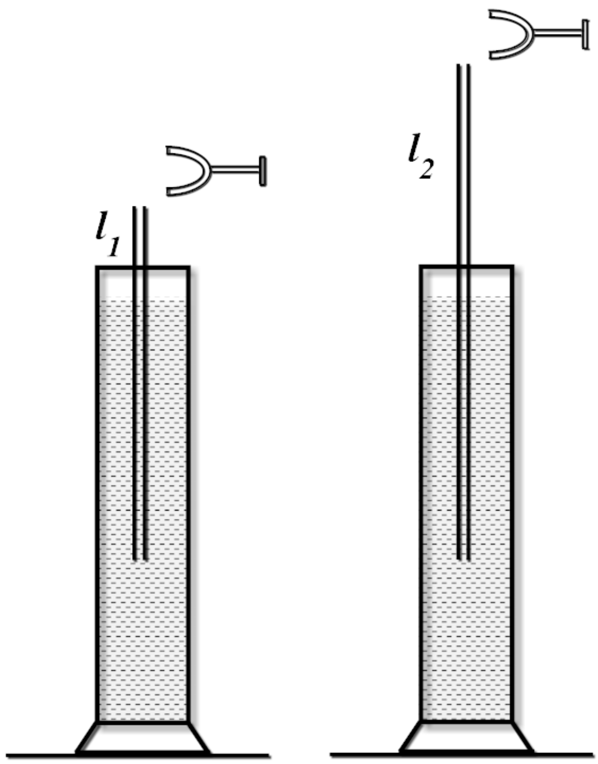
$$(L+e) = \lambda/4 \quad \Longrightarrow \quad \lambda = 4(L+e)$$

$$\text{Fundamental frequency is given by,} \quad f = \frac{v}{\lambda} = \frac{v}{4(L+e)}$$

Thus actual frequency of vibration is slightly smaller if we consider end correction into account.

16. Discuss the resonance column experiment to determine the velocity of sound in air at room temperature. How can we determine the velocity of sound in air at 0^0C using resonance column method.

A hollow uniform metal tube of length about 75 cm and internal diameter about 3 cm is clamped vertically in a tall jar containing water leaving 5 to 10 cm of the tube above water level. Now the tube acts like a pipe closed at one end. A tuning fork of known frequency (say 512 Hz) is sounded over the upper end of the tube. The tube is unclamped and raised slowly until a position is reached where resonance occurs and a large sound is heard. At this point the frequency of the tuning fork is equal to the frequency of the air column in the tube. It is then clamped and length l_1 of the air column above water level is measured using a meter scale.



Since l_1 is the shortest resonant length for frequency f, the wave length is obtained from the relation,

$$(l_1+e) = \lambda/4 \tag{1}$$

$$\lambda = 4(l_1+e) \tag{2}$$

$$\text{Velocity of sound in air,} \quad v = f\lambda = 4f(l_1+e) \tag{3}$$

Here e is the end correction. The internal diameter of the tube can be measured using a vernier and the value of e can be calculated using the formula $e = 0.3d$. The end correction can be eliminated if the second resonant length l_2 is also measured. The tube is unclamped and raised until a large sound is heard corresponding to the second resonance with same tuning fork. The new resonance length l_2 is measured. The length l_2 is related to wavelength λ by the relation,

$$(l_2 + e) = 3\lambda/4 \tag{4}$$

$$\text{Subtracting equation (1) from equation (4),} \quad (l_2 - l_1) = \lambda/2$$

$$\lambda = 2(l_2 - l_1) \tag{5}$$

$$\text{Velocity of sound in air at room temperature,} \quad v = f\lambda = 2f(l_2 - l_1) \tag{6}$$

Velocity of sound in air at 0^0 C can be evaluated using the relation,

$$v_0 = v_t \frac{\sqrt{273}}{\sqrt{(273 + t)}} \tag{7}$$

The experiment can be repeated with tuning forks of different frequencies and the average value of velocity can be calculated.

17. Derive an expression for velocity of sound in air at a temperature t^0 C in terms of velocity at 0^0 C. (Discuss the variation of velocity of sound in air with temperature).

    The velocity of sound in air varies with temperature. It is observed that velocity of sound in air is directly proportional to the square root of absolute temperature. If v_{T1} and v_{T2} are the velocities at absolute temperatures T_1 and T_2 then,

$$\frac{v_{T1}}{v_{T2}} = \frac{\sqrt{T_1}}{\sqrt{T_2}}$$

Here $T_1 = (273 + t_1)$ and $T_2 = (273 + t_2)$ where t_1 and t_2 are the corresponding temperatures in Celsius. If velocity at temperature t^0 C is v_t and velocity at 0^0 C is v_0, then

$$\frac{v_t}{v_0} = \frac{\sqrt{(273 + t)}}{\sqrt{273}}$$

$$v_t = v_0 \frac{\sqrt{(273 + t)}}{\sqrt{273}}$$

$$\text{Or} \quad v_0 = v_t \frac{\sqrt{273}}{\sqrt{(273 + t)}}$$

18. Explain why the frequency of an organ pipe is higher on a hot summer day.

    The velocity of sound in air varies with temperature. It is observed that velocity of sound in air is directly proportional to the square root of absolute temperature. As the temperature increases, velocity of sound in air also increases. Frequency of sound is related to velocity by the relation $v = f\lambda$. Hence, as the velocity increases, frequency also increases. Therefore the frequency of an organ pipe is higher on a hot summer day.

19. Explain two methods (Magnetostriction method and Piezoelectric method) to produce ultrasonic sound.

    Ultrasonics are sound waves of frequencies beyond the upper limit of hearing (beyond 20 kHz). Ultrasonics are generated mainly by two methods - magnetostriction method and piezoelectric method.

    Magnetostriction method: When a ferromagnetic material (iron rod) is placed in a magnetic field, it undergoes a small change in length. This is known as magnetostriction effect. If the rod is subjected to an alternating magnetic field, it undergoes alternate contractions and elongations resulting in a longitudinal vibration of the rod. Ultrasonic waves are generated in this way. Frequency of the wave produced depends on the length of the rod.

Piezoelectric method: When a potential difference is applied across the opposite faces of certain crystals like quartz, tourmaline and Rochelle salt, a mechanical contraction or expansion is produced in the crystal. If the polarity of the electric field is reversed contraction changes into expansion and vice versa. Hence, if an alternating voltage is applied across the opposite faces of a thin quartz crystal, it will set into mechanical vibration producing ultrasonic waves. Usually, an electrical oscillator is used to supply alternating voltage of any desired frequency.

20. List the applications of ultrasonic waves

    (a) Sound navigation ranging (SONAR) or echo sounding used for estimating the depth of the sea under the ship and locating underwater objects like submarines.
    (b) Ultrasonic signalling
    (c) Emulsification of immiscible liquids
    (d) Metal testing
    (e) Underwater communication
    (f) Metallurgical uses such as alloying of many metals
    (g) Medical and biological uses (Ultra sound scanning, removal of kidney stones, tooth cleaning etc.)
    (h) Ultrasonic cleaners

Important Equations to Remember

$$\text{Equation for SHM : } y = asin(wt + \phi)$$
$$\text{Relation between f and T : } f = \frac{1}{T}$$
$$\text{Relation between v, } \lambda \text{ and f : } v = \lambda f$$
$$\text{Fundamental frequency in closed pipe: } \lambda = 4L \ ; \ f = \frac{v}{4L}$$
$$\text{Harmonics in closed pipe: } f, 3f, 5f, 7f, etc.$$
$$\text{Fundamental frequency in open pipe: } \lambda = 2L \ ; \ f = \frac{v}{2L}$$
$$\text{Harmonics in open pipe: } f, 2f, 3f, 4f, etc.$$
$$\text{End correction: } e = 0.3d$$
$$\text{Fundamental frequency in closed pipe with end correction: } \lambda = 4(L+e) \ ; \ f = \frac{v}{4(L+e)}$$
$$\text{Velocity of sound in air (Resonance column exp.): } v = 2f(l_2 - l_1)$$
$$\text{Variation of velocity of sound with temperature: } v_t = v_0 \frac{\sqrt{(273+t)}}{\sqrt{273}}$$