Lesson 1

1. (i) Explain the use of screw gauge and vernier calliper in measuring smaller distances.

Screw Gauge :

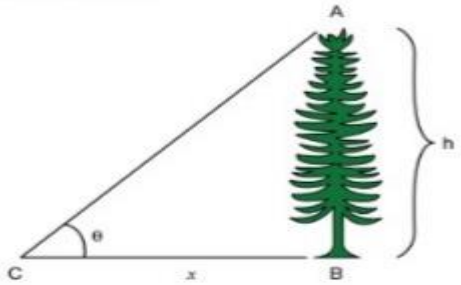
1. Used to measure object dimension about 50 mm.
2. Principle of instrument : i) Linear motion ii) Circular motion
3. Least count of screw gauge is 0.01 mm.

Vernier Calliper :

1. It is a versatile instrument.
2. Used to measure : i) Diameter of hole ii) Depth of hole
3. Least count of vernier is 0.01 cm.

(ii) Triangulation method to measure larger distance

Diagram :



Formula :

$$h = x \tan \theta$$

Theory :

1. Height of the tree AB = h .
2. Base distance BC = x
3. Point of observation is C.
4. Angl e of elevation Θ = < ACB .
5. From triangle ABC ,

$$\tan \theta = \frac{AB}{BC}$$

6. $$\tan \theta = \frac{h}{x}$$

7. $$\frac{h}{x} = \tan \theta$$

8. $$h = x \tan \theta$$

9. By knowing the distance x , θ then h can be determined.

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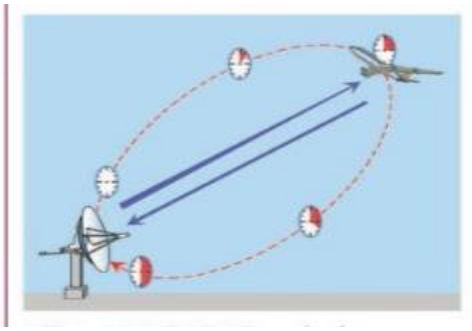
(iii) Radar method to measure larger distance :

Diagram :



Formula :

$$d = \frac{v \times t}{2}$$

Theory :

1. **Radar means " Radio detection and ranging " .**
2. **Used to measure large distance.**
3. **Radio waves send to transmitters .**
4. **Radio waves detect by receiver.**
5. **Distance : $d = \frac{v \times t}{2}$**

---

2. Explain in detail the various types of errors.

Error : **Uncertainty in a measurement is called as error.**

Types of error :

1. Random Error 2. Systematic Error 3. Gross Error

1. Systematic Error :

i) Reproducible Error ii) Inaccuracy Error

Types of systematic error :

1. Instrumental Error : Error due to instrumental manufacture . Example : Meter scale whose end worn out.

2. Imperfection Error : Error due to experiment limitation . Example : Experiment with calorimeter.

3. Personal Error : Error due to personal and individual . Example : Carelessness of individual.

4. External Cause Error: Error due to external cause . Example : Humidity, Pressure .

5. Least Count Error: Smallest value measured by instrument . Example : L.C of screw gauge 0.01 mm.

Random Error: 1. Error due to random condition. 2. Also known as "Chance Error"

Gross Error: 1. Recording wrong observation. 2. Wrong values in calculations.

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3. What do you mean by propagation error? Explain the propagation errors in addition and multiplication.

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The various possibilities of the propagation or combination of errors in maths operation.

1) Error in sum of quantities:

1. **Two quantities ⟶ A , B**
2. **Error in quantities ⟶ ΔA , ΔB**
3. **Sum of quantities ⟶ Z = A + B**
4. **Error in sum ⟶ Δ Z**
5. **Measured value of A = A ± Δ A**
6. **Measured value of B = B ± Δ B**

$$Z = A + B$$

$$Z \pm \Delta A = A \pm \Delta A + B \pm \Delta B$$

$$\boxed{\Delta Z = \Delta A + \Delta B}$$

" The maximum possible errors in the sum of the quantities is equal to the sum of the absolute errors in the individual quantities "

2) Error in multiplication of quantities:

1. **Two quantities ⟶ A , B**
2. **Error in quantities ⟶ ΔA , ΔB**
3. **Sum of quantities ⟶ Z = A B**
4. **Error in sum ⟶ Δ Z**
5. **Measured value of A = A ± Δ A**
6. **Measured value of B = B ± Δ B**

$$Z = A B$$

$$Z \pm \Delta A = (A \pm \Delta A)(B \pm \Delta B)$$

$$Z \pm \Delta A = A B \pm A \Delta B \pm B \Delta A \pm B \Delta B$$

$$\boxed{\frac{\Delta Z}{Z} = \pm \left(\frac{\Delta A}{A} + \frac{\Delta B}{B}\right)}$$

" The maximum fractional error in the product of the quantities is equal to the sum of the fractional errors in the individual quantities "

4.Write a short notes on the following

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a) Unit b) Rounding off c) Dimensionless quantities

a) Unit

An arbitrarily chosen standard of measurement of quantity , which is accepted internationally is called unit of the quantity.

b) Rounding off

1. **Calculators are widely used now a days for calculations.**
2. **Calculators has too many figures.**
3. **Results have more significant figures.**
4. **Numbers containing more than one uncertain number should be round off.**

c) Dimensionless quantities :

Dimensionless variable :

Physical quantity which have no dimension but have variable. Ex : Strain , Specific gravity

Dimensionless constant :

Physical quantity which have constant values but have no dimension. Ex : π , e (Euler's number)

---

5. Explain the principle of homogeneity of dimension . What are its uses ? Give example.

Principle of homogeneity of dimension :

It states that the dimensions of all the terms in physical expression should be same.

Applications / Uses of Principle of homogeneity of dimension :

1. **Convert physical quantity from one system of units to another.**
2. **Check the dimensional correctness of a given physical equation.**
3. **Establish relations among various physical quantities.**

1. Conversion of physical quantity :

Convert the numerical value of physical quantity from one system of unit into other unit.

$$n_1 [M_1^a \; L_1^b \; T_1^c] = n_2 [M_2^a \; L_2^b \; T_2^c]$$

Quantity	Power	One System	Another System
Mass	a	M_1	M_2
Length	b	L_1	L_2
Time	c	T_1	T_2

2. Check the dimensional correctness of physical quantity

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$$V = u + a\,t$$

$$[\,L\,T^{-1}\,] = [\,L\,T^{-1}\,] + [\,L\,T^{-2}\,]\,[\,T\,]$$

$$[\,L\,T^{-1}\,] = [\,L\,T^{-1}\,] + [\,L\,T^{-1}\,]$$

- **Dimension of both sides are equal.**
- **This equation is dimensionally correct.**

3. Establish the relation among physical quantity

1. If the physical quantity Q depends on Q_1 , Q_2 , Q_3

2. Q is proportional to Q_1 , Q_2 , Q_3

- $Q \propto Q_1^a\ Q_2^b\ Q_3^c$
- $Q = K\ Q_1^a\ Q_2^b\ Q_3^c$

K ---------- Dimensionless Constant.

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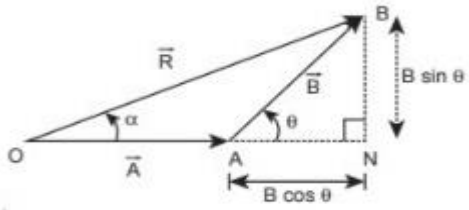
1. Explain in detail the triangle law of addition .

Triangle law of addition :

The vectors $\vec{A}$ and $\vec{B}$ two adjacent sides of triangle then resultant is given by the third side of the triangle.

$$\vec{R} = \vec{A} + \vec{B}$$

Diagram :



From Figure :

$OA = A \quad AB = B \quad OB = R$

$AN = B \cos \Theta \quad BN = B \sin \Theta$

1. Magnitude of resultant vector

Triangle OBN

1. $OB^2 = ON^2 + BN^2$
2. $OB^2 = (OA + AN)^2 + BN^2$
3. $OB^2 = OA^2 + AN^2 + 2\ OA\ .\ AN + BN^2$
4. $R^2 = A^2 + B^2 \cos^2\theta + 2\ A\ B \cos\theta + B^2 \sin^2\theta$
5. $R = \sqrt{A^2 + B^2 + 2\ A\ B \cos\theta}$

2. Direction of resultant vector

Triangle OBN

1. $\tan\alpha = \frac{BN}{ON}$
2. $\tan\alpha = \frac{BN}{OA + AN}$
3. $\tan\alpha = \frac{B \sin \Theta}{A + B \cos \Theta}$

---

2. Discuss the properties of scalar and vector product.

Scalar Product :

1. Product of the magnitudes of both the vectors and cosine of angle between them.

$$\vec{A} . \vec{B} = A\ B \cos \Theta$$

2. Scalar product is commutative $\vec{A} . \vec{B} = \vec{B} . \vec{A}$

3. Distributive law $\vec{A} . (\vec{B} + \vec{C}) = \vec{A} . \vec{B} + \vec{A} . \vec{C}$

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4. Unit Vector : $\hat{i} \cdot \hat{i} = \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1$

5. Orthogonal : $\hat{i} \cdot \hat{j} = \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0$

6. Scalar product is maximum when $\theta = 0^0$ then $\cos\theta = 1$

$$(\vec{A} \cdot \vec{B})_{max} = AB$$

7. Scalar product is minimum when $\theta = 180^0$ then $\cos\theta = -1$

$$(\vec{A} \cdot \vec{B})_{min} = -AB$$

Vector Product :

1. Product of the magnitudes of both the vectors and sine of angle between them.

$$\vec{C} = \vec{A} \times \vec{B} = (AB \sin\theta)\hat{n}$$

2. Vector product is not commutative $\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$

3. Unit Vecor : $\hat{i} \times \hat{i} = \hat{j} \times \hat{j} = \hat{k} \times \hat{k} = 0$

4. Orthogonal : $\hat{i} \times \hat{j} = \hat{k}$; $\hat{j} \times \hat{k} = \hat{i}$; $\hat{k} \times \hat{i} = \hat{j}$;

5. Vector product is maximum when $\theta = 90^0$ then $\sin\theta = 1$

$$(\vec{A} \times \vec{B})_{max} = AB$$

6. Vector product is minimum when $\theta = 0^0$ then $\sin\theta = 0$

$$(\vec{A} \times \vec{B})_{min} = 0$$

7. Self cross product is null vector.

$$\vec{A} \times \vec{B} = AA \sin o^0 \hat{n} = 0$$

---

3. Derive the kinematic equation of motion for constant acceleration.

1. Velocity - Time relation

- $a = \frac{dV}{dt}$
- $dV = a\,dt$
- $\int_u^v dV = a\int_0^t dt$
- $[v]_u^v = a[t]_0^t$
- $v - u = at$
- $v = u + at$

2.Displacement - Time relation

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- $v = \frac{ds}{dt}$
- $ds = v\ dt$
- $ds = (u + at)\ dt$
- $\int_0^s ds = \int_0^t (u + at)\ dt$
- $\int_0^s ds = \int_0^t u\ dt + a\int_0^t t\ dt$
- $S = ut + \frac{1}{2} a t^2$

3. Velocity - Displacement relation :

- $a = \frac{dv}{dt}$
- $a = \frac{dv}{dt} \frac{ds}{ds}$
- $a = \frac{dv}{ds} \frac{ds}{dt}$
- $a = \frac{dv}{ds} v$
- $a\int_0^s ds = \int_u^v v\ dv$
- $as = \frac{v^2 - u^2}{2}$
- $2as = v^2 - u^2$
- $v^2 = u^2 + 2as$

4. $S = ut + \frac{1}{2} a t^2$

- $at = v - u$
- $s = ut + \frac{1}{2} vt - \frac{1}{2} ut$
- $s = \frac{1}{2} ut + \frac{1}{2} vt$
- $S = \frac{(u + v)\ t}{2}$

4.Derive the equation of motion for a particle

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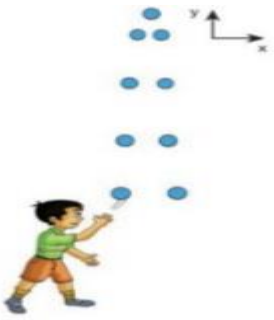
a) Falling vertically b) Projected vertically.

a) Falling Vertically **b) Projected Vertically**



a) Falling vertically

- **Consider an object of mass m falling from a height h.**
- **Let us choose downward direction as positive y – axis.**

Kinematics equation :

- $v = u + at$
- $v^2 = u^2 + 2as$
- $S = ut + \frac{1}{2} a t^2$

Body at rest u = 0

- $v = gt$
- $v^2 = 2gy$
- $y = \frac{1}{2} g t^2$

Particle reach ground t = T and y = h

$v^2 = 2gh$ $v_{ground} = \sqrt{2gh}$

$h = \frac{1}{2} g t^2$ $T = \sqrt{\frac{2h}{g}}$

b) Projected vertically a = - g

- $V = u - gt$
- $V^2 = u^2 - 2gy$
- $S = ut - \frac{1}{2} g t^2$

---

5. Derive the equation of motion , range and maximum height reached by the particle thrown at an oblique angle with

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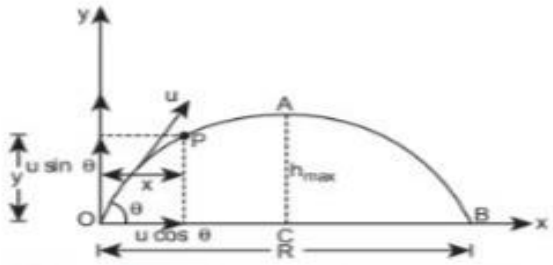
respect to horizontal direction.

Diagram :



Maximum Height : The maximum vertical distance travelled by the projectile during its journey.

Vertical part of motion :

- $V_y^2 = u_y^2 - 2 a_y S$

  $V_y = 0$

  $u_y = u \sin \Theta$

  $a = -g$

  $S = h_{max}$

- $V_y^2 = u_y^2 - 2 a_y S$
- $0^2 = (u \sin \theta)^2 + 2(-g) h_{max}$
- $0 = u^2 \sin^2 \theta - 2 g h_{max}$
- $2 g h_{max} = u^2 \sin^2 \theta$
- $h_{max} = \frac{u^2 \sin^2 \Theta}{2 g}$

Horizontal Range :

The maximum horizontal distance between the point of projection and the point of on the horizontal plane where the projectile hits the ground.

Range = Horizontal component of velocity X Time of flight

$R = u \cos \theta \times \frac{2 u \cos \theta}{g}$

$R = \frac{2 u^2 \sin \theta \cos \theta}{g}$

$R = \frac{u^2 \sin 2\theta}{g}$

---

6. Derive the expression for centripetal acceleration.

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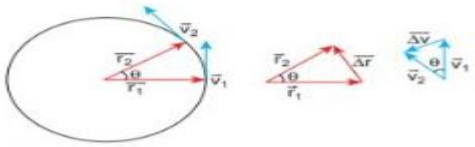
The centripetal acceleration is derived from a simple geometrical relationship between position and velocity vector .

Diagram :



Formula :

$$a = -\frac{v^2}{r}$$

For uniform circular motion

1. **Position Vector** : $r = |\vec{r_1}| = |\vec{r_2}|$
2. **Velocity Vector** : $v = |\vec{v_1}| = |\vec{v_2}|$
3. **Change in position** : $\Delta r = \vec{r_2} - \vec{r_1}$
4. **Change in velocity** : $\Delta v = \vec{v_2} - \vec{v_1}$
5. **Angle** : $= \frac{\Delta r}{r} = -\frac{\Delta v}{v}$
6. **Negative sign implies that Δv points radially inward , towards centre of the circle.**
7. $-\frac{\Delta v}{v} = \frac{\Delta r}{r}$
8. $\Delta v = -\frac{v}{r}\Delta r$
9. $\frac{\Delta v}{\Delta t} = -\frac{v}{r}\frac{\Delta r}{\Delta t}$
10. $a = -\frac{v}{r}v$

$$a = -\frac{v^2}{r}$$

11. **Relation between linear and angular velocity**

$$a = -\frac{r^2\omega^2}{r} = -\omega^2 r$$

$$a = -\omega^2 r$$

---

7. Derive the expression for total acceleration in the non uniform circular motion.

Non Uniform Circular motion :

If the speed of the object in circular motion is not constant , then we have non – uniform circular motion.

For Example :

When the bob attached to a string moves in vertical circle , the speed of the bob is not same at all time.

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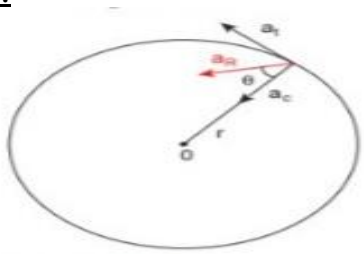
Diagram :



Formula :

1. $a_R = \sqrt{a_t^2 + \left(\frac{v^2}{r}\right)^2}$
2. $\tan\theta = \frac{a_t}{(v^2/r)}$

Acceleration :

1. **Centripetal acceleration :** $a_c = \frac{v^2}{r}$
2. **Tangential acceleration :** a_t
3. **Resultant acceleration :** a_R
4. $a_R^2 = \sqrt{a_t^2 + a_c^2}$
5. $a_R = \sqrt{a_t^2 + a_c^2}$
6. $a_R = \sqrt{a_t^2 + \left(\frac{v^2}{r}\right)^2}$
7. **Angle :** $\tan\theta = \frac{a_t}{a_c}$

$\tan\theta = a_t / (v^2/r)$

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LESSON - 3

1. Prove the law of conservation of linear momentum . Use it to find the recoil velocity of a gun when bullet is fired from it.

Law Of Conservation of Linear Momentum :

1. **If there are no external forces acting on the system , then the total linear momentum of the system ($\vec{p}_{tot}$) is always a constant vector.**
2. **The total linear momentum of the system is conserved in time.**

Explanation :

When two particles interact with each other , they exert equal and opposite forces on each other.

Particle 1 exert force on particle 2 $\longrightarrow \vec{F}_{21}$. Particle 2 exert force on particle 1 $\longrightarrow \vec{F}_{12}$

By Newton's 2nd Law :

$$\vec{F}_{21} = \frac{\vec{dp}_1}{dt} \qquad \vec{F}_{12} = \frac{\vec{dp}_2}{dt}$$

By Newton's 3rd Law :

$$\vec{F}_{21} = -\vec{F}_{12}$$

$$\frac{\vec{dp}_2}{dt} = -\frac{\vec{dp}_1}{dt}$$

$$\frac{\vec{dp}_1}{dt} + \frac{\vec{dp}_2}{dt} = 0$$

$$\frac{d}{dt}(\vec{p}_1 + \vec{p}_2) = 0$$

$$\vec{p}_{tot} = \vec{p}_1 + \vec{p}_2 = \text{Constant}$$

Recoil momentum of gun :

- **Consider the firing of a gun. The system is Gun + Bullet**

Initially

- **Gun and bullet are at rest. Total linear momentum is zero.**

Before Firing

- **Momentum of the bullet is $\vec{p}_1$**
- **Momentum of the gun is $\vec{p}_2$**
- **Total linear momentum is Zero.**
- **$\vec{p}_1 + \vec{p}_2 = 0$**

After Firing

- **Momentum of the bullet is $\vec{p}_1$ to $\vec{p}_1'$**
- **Momentum of the gun is $\vec{p}_2$ to $\vec{p}_2'$**
- **Total linear momentum is Zero.**
- **$\vec{p}_1' + \vec{p}_2' = 0$**

Law of conservation of linear momentum

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1. Total linear momentum has to be zero after the firing also.
2. When the gun is fired , a force is exerted by the gun on the bullet in forward direction.
3. The momentum of the gun is exactly equal , but in opposite direction to the momentum of the bullet.
4. This is the reason after firing , the gun suddenly moves backward with the momentum ($-\vec{p}_2$)
5. It is called as " recoil momentum ".
6. This is an example of conservation of linear momentum.

---

2. What are concurrent forces ? State Lami's theorem.

Concurrent Force :

1. Collection of forces is said to be concurrent if the lines of forces act at a common point.
2. Concurrent forces need not be in the same plane.
3. If they are in same plane , they are concurrent as well as coplanar forces.

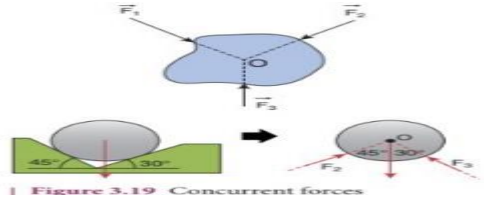


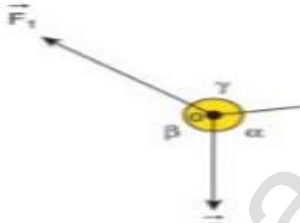
Figure 3.19 Concurrent forces

Lami's Theorem :

" If the system of three concurrent and coplanar forces is in equilibrium , then Lami's theorem states that the magnitude of each force of the system is proportional to the sine of the angle between the other two forces. The constant of proportionality is Same for all three forces ".

1. Let us consider three coplanar and concurrent forces $\vec{F}_1$, $\vec{F}_2$, $\vec{F}_3$ which act at a common point O .

2. If the point is in equilibrium , then according to Lami's theorem



$$|\vec{F}_1| \propto \sin\alpha$$

$$|\vec{F}_2| \propto \sin\beta$$

$$|\vec{F}_3| \propto \sin\gamma$$

$$\frac{|F_1|}{\sin\alpha} = \frac{|F_2|}{\sin\beta} = \frac{|F_3|}{\sin\gamma}$$

Lami's theorem is useful to analyse the forces acting on object which are in static equilibrium.

---

3. Explain the motion of blocks connected by a string in i) Vertical motion ii) Horizontal motion

Motion of connected bodies :

1.When objects are connected by strings and a force F is applied either vertically or horizontally or along an inclined plane.

2. It produces a tension T in the string , which affects the acceleration to an extent.

i) Vertical Motion :

1. Consider two blocks of masses m_1 and m_2 ($m_1 > m_2$)

2. They are connected by a light and inextensible string that passes over a pulley.

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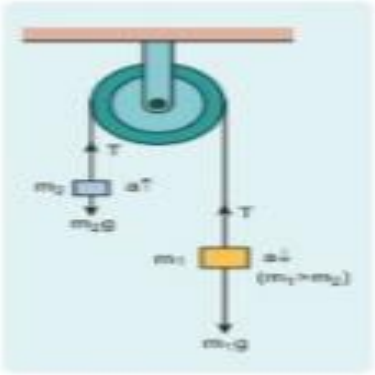
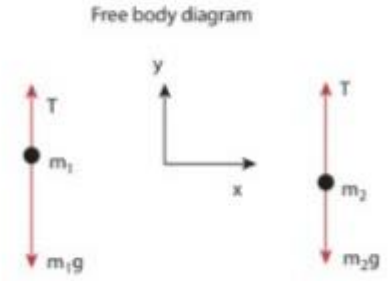
3. When the system is released , both the blocks start moving .
4. m_2 moves vertically upward and m_1 moves downward with same acceleration a .





Derivation :

1. Applying Newton's second law

For mass m_2	For mass m_1
$T\,j - m_2 g\,j = m_2 a\,j$	$T\,j - m_1 g\,j = -m_1 a\,j$
$T - m_2 g = m_2 a$	$T - m_1 g\,j = -m_1 a$
	$m_1 g - T = m_1 a\,j$

2. Adding the above two equations

$$T - m_2 g + m_1 g - T = m_2 a + m_1 a$$

$$m_1 g - m_2 g = m_2 a + m_1 a$$

$$(m_1 - m_2)\, g = (m_2 + m_1)\, a$$

$$(m_2 + m_1)\, a = (m_1 - m_2)\, g$$

$$a = \frac{(m_1 - m_2)\, g}{(m_2 + m_1)}$$

3. Tension acting on the string

$$T - m_2 g = m_2 a$$

Substitute acceleration value in above equation

$$T - m_2 g = m_2 \left(\frac{m_1 - m_2}{m_2 + m_1} \right) g$$

$$T = m_2 g \left(\frac{m_1 - m_2}{m_2 + m_1} \right) + m_2 g$$

$$T = m_2 g \left(1 + \frac{m_1 - m_2}{m_2 + m_1} \right)$$

$$T = m_2 g \left(\frac{m_2 + m_1 + m_1 - m_2}{m_2 + m_1} \right)$$

$$T = m_2 g \left(\frac{2 m_1}{m_2 + m_1} \right)$$

$$\boxed{T = \frac{2 m_1 m_2}{m_1 + m_2} g}$$

ii) Horizontal Motion :

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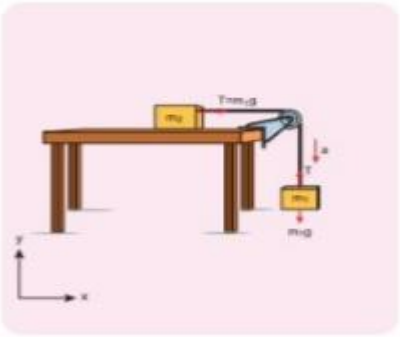
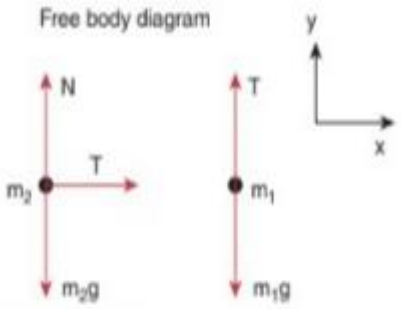
1. In this case mass m_2 is kept on a horizontal table and mass m_1 is hanging through a small pulley .

2. If m_1 moves with an acceleration a downward then m_2 also moves with the same acceleration a horizontally.

Diagram :





Forces acting on mass m_2 :

1. Downward gravitational force ($m_2 g$)
2. Upward normal force exerted by the surface (N)
3. Horizontal tension exerted by the string (T)

Forces acting on mass m_1 :

1. Downward gravitational force ($m_1 g$) 2. Tension acting upwards (T)

Derivation :

1. Applying Newton's second law

For mass m_1	For mass m_2
$T\,j - m_1 g\,j = -m_1 a\,j$	$T\,i = m_2 a\,i$
$T - m_1 g = -m_1 a$	$T = m_2 a$

2. $m_2 a - m_1 g = -m_1 a$

$m_2 a + m_1 a = m_1 g$

$(m_2 + m_1)\, a = m_1 g$

$$a = \frac{m_1 g}{(m_2 + m_1)}$$

Tension in the string :

$$T = \left(\frac{m_1 m_2}{m_1 + m_2}\right) g$$

Tension in string for horizontal motion is half of the tension for vertical motion for same set of masses & strings.

Applications in industries :

The ropes used in conveyor belts (H- motion) work for longer duration than those of cranes and lifts (V- motion)

---

4. Briefly explain the origin of friction . Show that in an inclined plane , angle of friction is equal to angle of repose.

(or) 9. Describe the method of measuring angle of repose .

Origin of friction :

1. The origin of friction is electromagnetic interaction between the atom of the surfaces which are touching each other .

2. It is a very gentle force in the horizontal direction is given to an object at rest on the table , it does not move .

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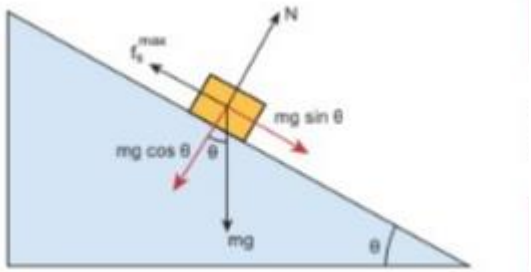
3. It is because of the opposing force exerted by the surface on the object and the surface where its placed.
4. This force is called the frictional force which always opposes the relative motion between an object and the surface where it is placed .
5. If the force applied is increased , the object moves after a certain limit.

Angle of friction equal to angle of repose :

1. Consider an object placed in an inclined plane. Let the angle θ makes with horizontal plane.
2. For small angle of θ , the object may not slide down . As θ is increased for particular value the object begins to slide down . This value is called " Angle of repose ".

Diagram :



Formula :

$$\tan \theta = \mu_s$$

Gravitational Force :

Gravitational force mg resolved into two components

1. Parallel component : mg sin θ 2. Perpendicular component : mg cos θ

Normal Force :

The component of force perpendicular to inclined plane is balanced by the normal force.

$$N = mg \cos \theta \longrightarrow (1)$$

Static Friction :

The component of force parallel to the inclined plane tries to move the object down. When the object just begins to move , the static friction attain its maximum value.

$$f_s^{max} = \mu_s N \longrightarrow (2)$$

Sub eqn (1) in eqn (2)

$$f_s^{max} = \mu_s mg \cos \theta \longrightarrow (3)$$

From Free body diagram :

$$f_s^{max} = mg \sin \theta \longrightarrow (4)$$

Dividing eqn (4) by (3)

$$\frac{f_s^{max}}{f_s^{max}} = \frac{mg \sin \theta}{\mu_s mg \cos \theta}$$

$$1 = \frac{\tan \theta}{\mu_s}$$

$$\tan \theta = \mu_s$$

"Angle of repose is same as the angle of friction "

---

5. State Newton's three laws and discuss their significance .

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Newton's First Law :

Every object continues to be in the state of rest or of uniform motion unless there is external force acting on it.

Newton's Second Law :

The force acting on an object is equal to the rate of change of its momentum. $\vec{F} = \frac{d\vec{p}}{dt} = m\vec{a}$

Newton's Second Law :

For every action there is an equal and opposite reaction. $\vec{F}_{12} = -\vec{F}_{21}$

Discussion on Newton's Laws :

1. Newton's laws are vectors laws. $\vec{F} = m\vec{a}$

$$F_x \hat{i} + F_y \hat{j} + F_z \hat{k} = m a_x \hat{i} + m_y \hat{j} + m a_z \hat{k}$$

1.The acceleration along x direction depends only on the component of force act along x – direction. $F_x = m a_x$
2. The acceleration along y direction depends only on the component of force act along y – direction. $F_y = m a_y$
3. The acceleration along z direction depends only on the component of force act along z – direction. $F_z = m a_z$

4. The acceleration experienced by the body at time t depends on the force which acts on the body at that instant of time. It does not depend on the force which acted on the body before the time t. $\vec{F}(t) = m\vec{a}(t)$

5. In general the direction of a force may be different from the direction of motion.

Case 1 : Force and motion in the same direction

When an apple falls towards the Earth , the direction of motion of the apple and that of force are in same direction.

Case 2 : Force and motion not in the same direction

The moon experiences a force towards the earth. But it actually moves in elliptical orbit. In this case , the direction of the force is different from the direction of motion.

Case 3 : Force and motion in opposite direction

If an object is thrown vertically upward the direction of motion is upward but gravitational force is downward.

Case 4 : Zero net force but there is motion

When raindrop gets detached from the cloud it experiences both downward gravitational force and upward air drag force . As it descends towards the earth , the upward air drag force increases and cancel downward gravity. Then raindrop moves at constant velocity till it touches the surface of the earth. Hence the raindrop comes with zero net force , with zero acceleration but with non zero terminal velocity.

4. If multiple forces $\vec{F}_1, \vec{F}_2, \vec{F}_3 \ldots\ldots \vec{F}_n$ act on the same body , the total force $\vec{F}_{net}$ is equivalent to the vectorial sum of the individual forces.

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots\ldots + \vec{F}_n = m\vec{a}$$

5. Newton's second law can also be written as $\vec{F} = m\frac{d^2\vec{r}}{dt^2}$

The acceleration is the second derivative of position vector of the body.

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7. Briefly explain centrifugal force with suitable examples.

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Centrifugal Force :

1. Centrifugal force is called as " pseudo force " .
2. Pseudo force has no origin.
3. It arises due to the non inertial nature of the frame considered.
4. To use Newton's first and second laws in the rotational frame of reference , we include pseudo force.
5. This centrifugal force appears to act on the object with respect to rotating frames.

Example :

1. Consider the case of a whirling motion of a stone tied to a string.
2. The stone has angular velocity ω in the inertial frame .
3. If the motion of the stone is observed from which is also rotating along with the stone with same angular velocity ω then , the stone appears to be at rest.
4. Inward centripetal force - $m\omega^2 r$.
5. There must be an equal and opposite force that acts on the stone.
6. Outward centripetal force + $m\omega^2 r$.
7. The total force acting on the stone in a rotating frame is equal to zero.
8. $- m\omega^2 r + - m\omega^2 r = 0$
9. This outward force $+ m\omega^2 r$ is called the centrifugal force.
10. The word " centrifugal " means " flee from centre "
11. The centrifugal force appears to act on the particle , only when we analyse the motion from a rotating frame.

---

8. Briefly explain " rolling friction ".

1.One of the important applications is suitcase with rolling on coasters.

2.Rolling wheels makes it easier than carrying luggage .

3.When an object moves on a surface , essentially it is sliding on it.

4. But wheels move on the surface through rolling motion.

5. In rolling motion when a wheel moves on a surface , the point of contact with surface is always at rest .

6. Since the point of contact is at rest , there is no relative motion between the wheel and surface.

7. Hence the frictional force is very less.

8. At the same time if an object without a wheel , there is a relative motion between the object & the surface.

9. As a result frictional force is larger. This makes it difficult to move the object.

10. Ideally in pure rolling , motion of the point of contact with the surface should be at rest, but in practice it is not so.

11. Due to the elastic nature of the surface at the point of contact there will be some deformation on the object at this point on the wheel or surface.

12. Due to this deformation , there will be minimal friction between wheel and surface .

13. It is called " rolling friction ". It is much smaller than kinetic friction.

---

10. Explain the need for banking of tracks.

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Banking of tracks :

1. In a levelled circular road , skidding mainly depends on the co efficient of static friction μ_s .

2. The coefficient of static friction depends on the nature of the surface which has a maximum limiting value.

Diagram :

To avoid the problem :

The outer edge of the road is slightly raised compared to inner edge is called " banking of roads or tracks " and the angle is called " banking angle ".

Theory

1. Let the surface of the road make angle θ with horizontal surface .

2. Then the normal force makes the same angle θ with the vertical.

3. When the car takes a turn , there are two forces acting on the car.

Forces acting on the car :

1. Gravitational force acts downward (mg) 2. Normal force perpendicular to surface (N)

Normal Force :

1. Normal force resolved into two components.

2. N cos θ balances the downward gravitational force mg

3. N sin θ provides the necessary centripetal acceleration.

By using Newton's second law :

$$N \cos\theta = mg \longrightarrow (1)$$

$$N \sin\theta = \frac{m v^2}{r} \longrightarrow (2)$$

Eqn (2) % by (1)

$$\frac{N \sin\theta}{N \cos\theta} = \frac{m v^2}{r} \times \frac{1}{mg}$$

$$\tan\theta = \frac{v^2}{r g}$$

$$v^2 = r g \tan\theta$$

$$\boxed{v = \sqrt{r g \tan\theta}}$$

Banking angle θ and radius of curvature of the road or track determines the safe speed of the car at the turning.

If the speed of car exceeds safe speed

It starts to skid outward but frictional force comes into effect and provides additional centripetal force to prevent the outward skidding .

If the speed of car lesser than safe speed

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It starts to skid inward and frictional force comes into effect which reduces centripetal force to prevent the inward skidding .

<u>If the speed of car greater than correct speed</u>

Then the frictional force cannot stop the car from skidding.

---

6. Explain the similarities and differences of centripetal and centrifugal forces.

S.NO	Centripetal Force	Centrifugal force
1.	It is a real force .	It is a pseudo force or fictitious force.
2.	Real force and has real effects.	Pseudo force but has real effects.
3.	Acts in both inertial and non - inertial frames	Acts only in rotating / non – inertial frame.
4.	Origin of centripetal force is interaction between two objects.	Origin of centrifugal force is inertia. It does not arise from interaction.
5.	It is exerted on the body by the external agencies like gravitational force , tension in the String , normal force etc.	It cannot arise from gravitational force , tension in the String , normal force etc.
6.	It acts towards the axis of rotation or centre of the circle in circular motion.	It acts outwards from the axis of rotation or radially outwards from the centre of the circular motion.
7.	In inertial frames centripetal force has to be included when free body diagrams are drawn.	In inertial frames there is no centrifugal force. In rotating frames , both centripetal and centrifugal force have to be included when free body diagrams are drawn.
8.	$F_{CP} = \frac{m\omega^2 r}{r} = m v^2$	$F_{Cf} = \frac{m\omega^2 r}{r} = m v^2$

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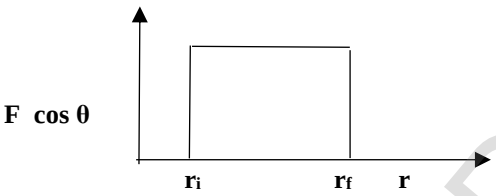
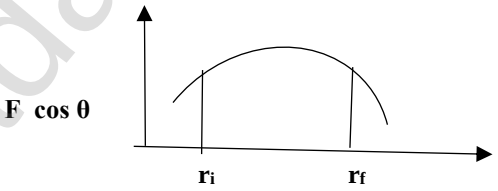
LESSON 4

1.Explain with graphs the difference between work done by a constant force and by a variable force.

Work done by a constant force	Work done by a variable force
1. Constant Force → F	1. Variable Force → F
2. Small work done → d W	2. Small work done → d W
3. Small displacement → d r	3. Small displacement → d r
4. Initial Position → r_i	4. Initial Position → r_i
5. Final Position → r_f	5. Final Position → r_f
6. Work done : $\int_{r_i}^{r_f} dW = F\cos\theta \int_{r_i}^{r_f} d\,r$	6. Work done : $\int_{r_i}^{r_f} dW = \int_{r_i}^{r_f} F\cos\theta\, d\,r$
7. $W = F\cos\theta\,(r_f - r_i)$	7. $W = \int_{r_i}^{r_f} F\cos\theta\, d\,r$
8. Graph : 	8. Graph: 

2.State and explain work energy principle . Mention any three examples for it.

Work Energy principle :

Work done by the force on the body changes the kinetic energy of the body. This is called as work energy theorem.

- **Work and energy are equivalent.**
- **Let us consider a body of mass at rest on frictionless horizontal surface.**

1. Work done : $W = F \cdot s$

2. Constant Force : $F = m\,a$

3. Equation of motion : $v^2 = u^2 + 2\,a\,s$

$$2\,a\,s = v^2 - u^2$$

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

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4. $F = m \left(\frac{v^2 - u^2}{2s} \right)$

5. $W = m \left(\frac{v^2 - u^2}{2s} \right) s$

6. $W = m \left(\frac{v^2 - u^2}{2} \right)$

7. $W = \frac{1}{2} m v^2 - \frac{1}{2} m u^2$

8. $W = \Delta$ K.E

Work done	Kinetic Energy
Positive	Increases
Negative	Decreases
No Work done	No Kinetic energy

---

3. Arrive at an expression for power and velocity.

Work done by a force $\vec{F}$ for a displacement dr is $W = \int \vec{F} . d\vec{r}$

L.H.S : $W = \int dW = \int \frac{dW}{dt} dt$

R.H.S

$$\int \vec{F} . d\vec{r} = \int \left(\vec{F} . \frac{d\vec{r}}{dt} \right) dt = \int \left(\vec{F} . \vec{v} \right) dt$$

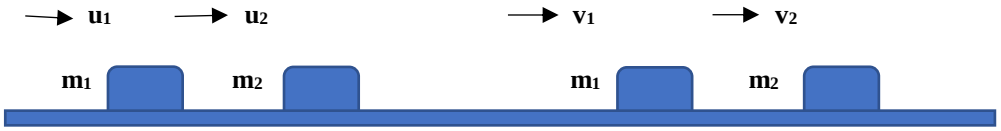
Derivation :

1. $\int \frac{dW}{dt} . dt = \int \left(\vec{F} . \vec{v} \right) dt$
2. $\int \left(\frac{dW}{dt} - \vec{F} . \vec{V} \right) dt = 0$
3. $\int \frac{dW}{dt} - \vec{F} . \vec{v} = 0$
4. $\frac{dW}{dt} = \vec{F} . \vec{v} = P$

---

4. Arrive at an expression for elastic collision in one dimension and discuss various cases.

Diagram:



Theory :

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Consider two elastic bodies of masses m_1 and m_2 moving in a straight line on a frictionless horizontal surface.

Mass and Velocity

Mass	Initial Velocity	Final Velocity
m_1	u_1	v_1
m_2	u_2	v_2

Momentum

Collision	Mass m_1	Mass m_2	Total Momentum
Before Collision	$P_{i1} = m_1 u_1$	$P_{i2} = m_2 u_2$	$P_i = m_1 u_1 + m_2 u_2$
After Collision	$P_{f1} = m_1 v_1$	$P_{f2} = m_2 v_2$	$P_f = m_1 v_1 + m_2 v_2$

Kinetic Energy

Collision	Mass m_1	Mass m_2	Total Kinetic Energy
Before Collision	$K.E_{i1} = \frac{1}{2} m_1 u_1^2$	$K.E_{i2} = \frac{1}{2} m_2 u_2^2$	$K.E_i = \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$
After Collision	$K.E_{f1} = \frac{1}{2} m_1 v_1^2$	$K.E_{f2} = \frac{1}{2} m_2 v_2^2$	$K.E_f = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$

Law Conservation of Momentum :

1. $m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$
2. $m_1 u_1 - m_1 v_1 = m_2 v_2 - m_2 u_2$
3. $m_1 (u_1 - v_1) = m_2 (v_2 - u_2)$ ---------- (1)

For Elastic Collision :

1. $\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$
2. $\frac{1}{2} m_1 u_1^2 - \frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_2 v_2^2 - \frac{1}{2} m_2 u_2^2$
3. $\frac{1}{2} m_1 (u_1^2 - v_1^2) = \frac{1}{2} m_2 (v_2^2 - u_2^2)$
4. $m_1 (u_1 + v_1)(u_1 - v_1) = m_2 (v_2 + u_2)(v_2 - u_2)$ ------- (2)

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Equation (2) % (1)

5. $\frac{m_1 (u_1 + v_1) (u_1 - v_1)}{m_1 (u_1 - v_1)} = \frac{m_2 (v_2 + u_2) (v_2 - u_2)}{m_2 (v_2 - u_2)}$

6. $u_1 + v_1 = v_2 + u_2$

7. $v_2 = u_1 + v_1 - u_2$ ---------- (3)

To find final velocity :

Sub equation (3) in (1)

8. $m_1 (u_1 - v_1) = m_2 (u_1 + v_1 - u_2 - u_2)$

9. $m_1 (u_1 - v_1) = m_2 (u_1 + v_1 - 2u_2)$

10. $m_1 u_1 - m_1 v_1 = m_2 u_1 + m_2 v_1 - 2 m_2 u_2$

11. $m_1 u_1 - m_2 u_1 + 2 m_2 u_2 = m_1 v_1 + m_2 v_1$

12. $(m_1 - m_2) u_1 + 2 m_2 u_2 = (m_1 + m_2) v_1$

Formula :

1. $v_1 = \frac{(m_1 - m_2)}{(m_1 + m_2)} u_1 + \frac{2 m_2}{(m_1 + m_2)} u_2$

2. $v_2 = \frac{2 m_1}{(m_1 + m_2)} u_1 + \frac{(m_2 - m_1)}{(m_1 + m_2)} u_2$

Case 1 : When bodies have same mass $m_1 = m_2$ then $v_1 = u_2$ and $v_2 = u_1$

Case 2 : When bodies have same mass $m_1 = m_2$ but second body is at rest then $v_1 = 0$ and $v_2 = u_2$

Case 3 : First body lighter than second body $m_1 < m_2$: $m_1 / m_2 = 0$; $u_2 = 0$ then $v_1 = - u_1$ and $v_2 = 0$

Case 4 : Second body lighter than First body $m_2 < m_1$: $m_2 / m_1 = 0$; $u_2 = 0$ then $v_1 = u_1$ and $v_2 = 2 u_1$

---

5. What is inelastic collision ? In which way it is different from elastic collision . Mention few examples.

S.NO	Elastic Collision	Inelastic Collision
1.	Total momentum is conserved.	Total momentum is conserved.
2.	Total kinetic energy is conserved .	Total kinetic energy is not conserved .
3.	Forces involved are conservative forces.	Forces involved are non conservative forces.
4.	Mechanical energy is not dissipated.	Mechanical energy is dissipated into heat , light etc.

Total Kinetic Energy

K.E Before Collision - K.E After Collision = Loss in energy during collision = ΔQ

Example : When a clay putty is thrown on moving vehicle , the clay putty sticks to moving vehicle and they move together with same velocity.

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1. Explain the types of equilibrium with suitable examples.

1. Translational Equilibrium :

*** Linear momentum is constant. * Net force is zero.**

2. Rotational Equilibrium :

*** Angular momentum is constant. * Net torque is zero.**

3. Static Equilibrium :

*** Linear momentum and angular momentum are *zero*. * Net force and torque are zero.**

4. Dynamic Equilibrium :

*** Linear momentum and angular momentum are *constant*. * Net force and torque are zero.**

5. Stable Equilibrium :

- **Linear momentum and angular momentum are zero.**
- **The body tries to come back to equilibrium if slightly disturbed and released.**
- **The centre of mass of the body shifts slightly *higher* if disturbed from equilibrium.**
- **Potential energy of the body is minimum and it increases if disturbed.**

6. Unstable Equilibrium :

- **Linear momentum and angular momentum are zero.**
- **The body *cannot* come back to equilibrium if slightly disturbed and released.**
- **The centre of mass of the body shifts slightly *lower* if disturbed from equilibrium.**
- **Potential energy of the body is *not* minimum and it increases if disturbed.**

7. Neutral Equilibrium :

- **Linear momentum and angular momentum are zero.**
- **The body remains at the same equilibrium if slightly disturbed and released.**
- **The centre of mass of the body *does not* shifts slightly higher if disturbed from equilibrium.**
- **Potential energy of the body remains *same* even if disturbed.**

---

2. Explain the method to find the centre of gravity of a irregularly shaped lamina.

Centre of gravity :

The point at which the entire weight of the body acts irrespective of the position and orientation of the body.

Method to find centre of gravity of a irregularly shaped lamina :

Method 1 :

1. The lamina remains horizontal when pivoted at the point where the net gravitational force acts , which is at the centre of gravity.

2. A body is supported at centre of gravity , sum of the torques acts on all point masses of the rigid body becomes zero.

3. The weight is compensated by the normal reaction force exerted by the pivot.

4. The body is in static equilibrium and hence it remains horizontal.

Method 2 :

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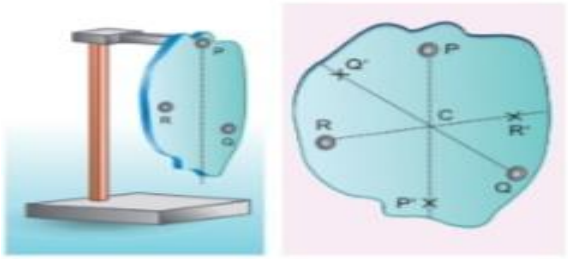


1. There is also another way to determine the centre of gravity of an irregular lamina.
2. If we suspend the lamina from different points like P , Q , R .
3. The vertical lines PP′ , QQ′ , RR′ all pass through the centre of gravity.
4. Reaction force acting at point of suspension and gravitational force acts on the centre of gravity cancel each other.
5. The torques caused by them also cancel each other.

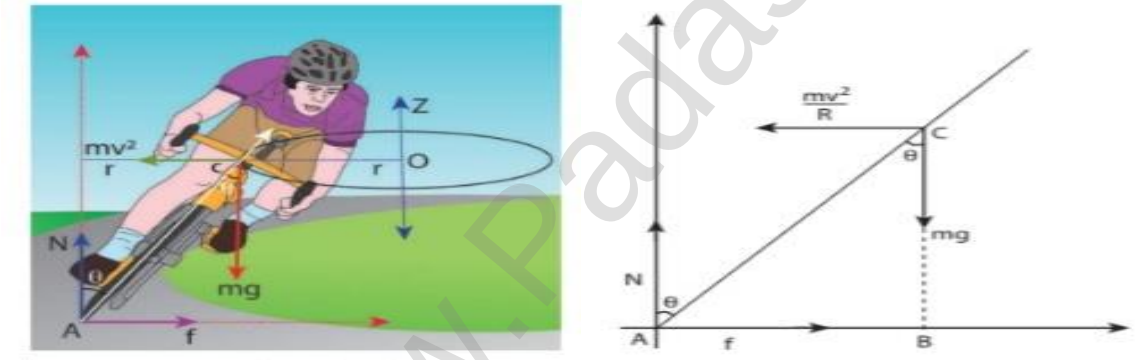
---

3. Explain why a cyclist bends while negotiating a curved road ? Arrive at the expression for angle of bending for a given velocity.

Bending of cyclist

1. Let us consider a cyclist negotiating a circular level road of radius r with a speed v.
2. The cycle and the cyclist are considered as one system with mass m.
3. The centre gravity of the system is C and circle centre is O.

Diagram :



Theory :

1. Let us choose the line OC as X – axis and the vertical line through O as Z – axis.
2. The system as a frame is rotating about Z - axis.
3. The system is at rest in this rotating frame.
4. In rotating frame pseudo force acts on the system
5. This force will act through the centre of gravity.

Forces acting on the system :

1. Gravitational force (mg)
2. Normal force (N)
3. Frictional force (f)
4. Centrifugal force ($m v^2 / r$)

As the system is in equilibrium :

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In the rotational frame of reference , Net external external force and net external torque must be zero.

Torque due to the gravitational force	Torque due to the Centrifugal force
About the point A is (mg AB)	About the point B is $\left(\frac{m v^2}{r} BC\right)$
It causes clockwise turn.	It causes anticlockwise turn.
And it is taken as negative.	And it is taken as positive.

Derivation :

1. $-mg\ AB + \frac{mv^2}{r} BC = 0$
2. $Mg\ AB = \frac{m v^2}{r} BC \longrightarrow (1)$
3. From Δ A B C
4. $\sin\theta = \frac{AB}{AC}$
5. $AB = AC \sin\theta \longrightarrow (2)$
6. $\cos\theta = \frac{BC}{AC}$
7. $BC = AC \cos\theta \longrightarrow (3)$
8. Sub eqn (2) and (3) in (1)

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

$$mg\ AC \sin\theta = \frac{m v^2}{r} AC \cos\theta$$

9. $\frac{\sin\theta}{\cos\theta} = \frac{v^2}{rg}$
10. $\tan\theta = \frac{v^2}{rg}$

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

---

4. Derive the expression for moment of inertia of a rod about its centre and perpendicular to the rod.

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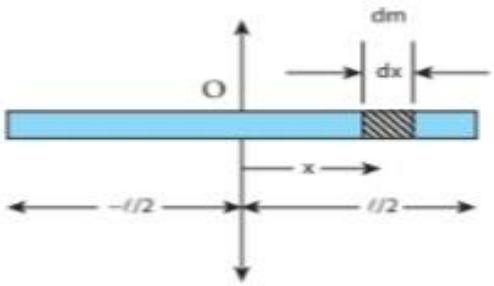
Diagram :



Formula :

$$I = \frac{1}{12} M \ell^2$$

Theory :

1. Let us consider a uniform rod of mass (M) and length (ℓ)
2. The rod about an axis passes through centre of mass and perpendicular to the rod.
3. The rod is along the x - axis and geometric center is O.
4. Infinitesimal small mass (dm) at a distance (x) from the origin.

Moment of inertia of a rod :

1. $dI = (dm)\, x^2 \longrightarrow (1)$
2. Linear mass density = mass per unit length
3. For mass M : $\lambda = \frac{M}{\ell} \longrightarrow (2)$
4. For mass dm : $\lambda = \frac{dm}{dx}$
5. $dm = \lambda\, dx \longrightarrow (3)$
6. Sub eqn (2) in (3)

   $dm = \frac{M}{\ell} dx \longrightarrow (4)$
7. Sub eqn (4) in (1)

   $dI = \left(\frac{M}{\ell}\right) dx \; x^2$
8. $\int dI = \int (dm)\, x^2$
9. $I = \int \frac{M}{\ell} dx \; x^2$
10. $I = \frac{M}{\ell} \int x^2 \, dx$
11. As the mass is distributed on either side of the origin , the limits for integration are $-\ell/2$ to $\ell/2$
12. $I = M \int_{-\ell/2}^{\ell/2} x^2 \, dx$

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ℓ - ℓ / 2

13. $I = \frac{M}{\ell} \left[\frac{x^3}{3} \right]_{-\ell/2}^{\ell/2}$

14. $I = \frac{M}{3\ell} \left[\frac{\ell^3}{2^3} - \frac{\ell^3}{2^3} \right]$

15. $I = \frac{M}{3\ell} \left[\frac{\ell^3}{8} + \frac{\ell^3}{8} \right]$

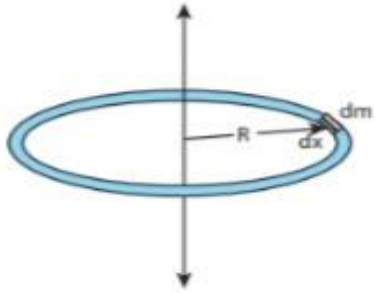
16. $I = \frac{M}{3\ell} \left[\frac{2\ell^3}{8} \right]$

17. $I = \frac{1}{12} M \ell^2$

---

5. Derive the expression for moment of inertia of a ring about an axis passing through the centre and perpendicular to the plane.

Diagram :



Formula :

$$I = M R^2$$

Theory :

1. Let us consider a uniform ring of mass (M) and radius (R).
2. Moment of inertia of the ring about an axis passes through its centre and perpendicular to the plane.
3. Infinitesimal small mass (dm) of length (dx) of the ring.
4. This (dm) is located at a distance R , which is the radius of the ring from the axis.

Moment of inertia of a rod :

1. $dI = (dm) R^2 \longrightarrow (1)$
2. Linear mass density = mass per unit length
3. For mass M : $\lambda = \frac{M}{2\pi R} \longrightarrow (2)$
4. For mass dm : $\lambda = \frac{dm}{dx}$
5. $dm = \lambda \, dx \longrightarrow (3)$
6. Sub eqn (2) in (3)

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$$dm = \frac{M}{2\pi R} dx \longrightarrow (4)$$

7. Sub eqn (4) in (1)

$$\int dI = \int (dm)\, R^2$$

8. $$I = \frac{M}{2\pi R} \int (dx)\, R^2$$

9. $$I = \frac{M R}{2\pi} \int dx$$

10. To cover the entire length of the ring , the limits for integration from 0 to $2\pi R$

11. $$I = \frac{M R}{2\pi} \int_0^{2\pi R} dx$$

12. $$I = \frac{M R}{2\pi} \left[x \right]_0^{2\pi R}$$

13. $$I = \frac{M R}{2\pi} \left(2\pi R - 0 \right)$$

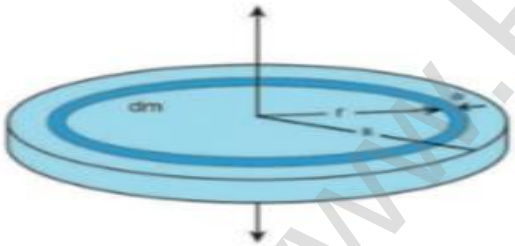
14. $$I = \frac{M R}{2\pi} \left(2\pi R \right)$$

15. $$I = M R^2$$

---

6. Derive the expression for moment of inertia of uniform disc about an axis passing through the center and perpendicular to the plane.

Diagram :



Formula :

$$I = \frac{1}{2} M R^2$$

Theory :

- Let us consider a uniform disc of mass (M) and radius (R)
- This disc is made up of many infinitesimally small rings.
- Infinitesimal small mass (dm) and thickness (dr) and radius (r) .

Moment of inertia of a rod :

1. $dI = (dm)\, r^2 \longrightarrow (1)$
2. Surface mass density = mass per unit area

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3. For mass M : $\sigma = \frac{M}{\pi R^2} \longrightarrow (2)$

4. For mass dm : $\sigma = \frac{dm}{2\pi r\ dr}$

5. Area of the elemental ring = length x thickness = $2\pi r\ dr$

6. $dm = \sigma\, 2\pi r\ dr \longrightarrow (3)$

7. Sub eqn (2) in (3)

$$dm = \frac{M}{\pi R^2} 2\pi r\ dr$$

8. $$dm = \frac{2M}{R^2} r\ dr \longrightarrow (4)$$

9. Sub eqn (4) in (1)

$$\int dI = \int (dm)\ r^2$$

10. $$I = \frac{2M}{R^2} \left(\int (r\, dr)\ r^2 \right)$$

11. $$I = \frac{2M}{R^2} \int r^3\ dr$$

12. The limits fo r integration are taken from 0 to R

13. $$I = \frac{2M}{R^2} \int_0^R r^3\ dr$$

14. $$I = \frac{2M}{R^2} \left(\frac{r^4}{4} \right)_0^R$$

15. $$I = \frac{2M}{4R^2} \left(R^4 - 0 \right)$$

16. $$I = \frac{1}{2} M R^2$$

---

7. Discuss conservation of angular momentum with example .

Conservation of angular momentum :

When no external torque acts on the body , the net angular momentum of a rotating rigid body remains constant. This is known as law of conservation of angular momentum.

Derivation :

1. Angular momentum : $L = I\omega$

2. Torque : $\tau = \frac{dL}{dt}$

3. If $\tau = 0$ then , L = constant

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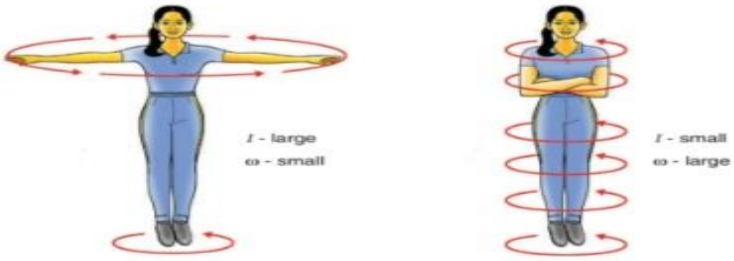
4. **Angular momentum kept as constant.**

5. **If I increases then ω will decreases and vice – versa.**

$$I\ \omega = \text{constant}$$
$$I_i\ \omega_i = I_f\ \omega_f$$

Example :



1. **An ice dancer spins slowly when the hands are stretched out and spins faster when the hands are brought close to the body.**
2. **Stretching of hands away from body resulting in slower spin**
   * **Increases moment of inertia** * **Decreases angular velocity**
3. **Stretching of hands brought close to the body resulting in faster spin**
   * **Decreases moment of inertia** * **Increases angular velocity**

A diver while in air , curls the body close to decrease the moment of inertia , which in turn helps to increase the number of somersaults in air.

---

8. State and prove parallel axis theorem.

Parallel Axis Theorem :

The moment of inertia of a body about any axis is equal to sum of its moment of inertia about a parallel axis through its centre of mass and the product of the mass of the body and the square of the perpendicular distance between the two axes.

$$I = I_C + M d^2$$

Diagram :

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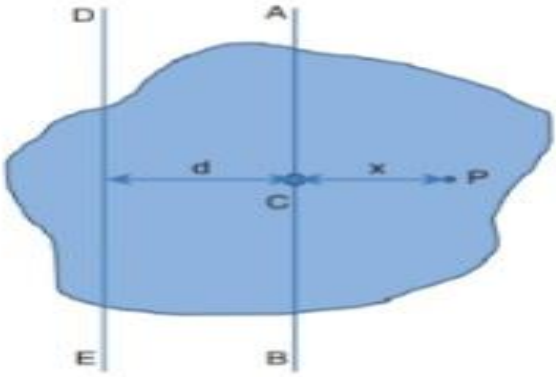

1. I_C is the moment of inertia of the body of mass M about an axis passing through the centre of mass.

2. Moment of inertia I about a parallel axis at a distance d .

Theory :

1. **Let us consider a rigid body .**
2. **Moment of inertia about an axis AB passing through centre mass is I_C.**
3. **Moment of inertia about an axis DE passing through centre mass is I.**
4. **Consider a point mass m on the body at position x from its centre of mass.**
5. **Moment of inertia about a parallel axis at a distance d .**

Derivation :

1. $I = \Sigma m (x + d)^2$
2. $I = \Sigma m (x^2 + d^2 + 2 x d)$
3. $I = \Sigma (m x^2 + m d^2 + 2 m x d)$
4. $I = \Sigma m x^2 + \Sigma m d^2 + 2 d \Sigma m x$
5. **Moment of inertia of the body about centre of mass :** $I_C = \Sigma m x^2$
6. Σm **is the entire mass M of the object :** $\Sigma m = M$
7. $\Sigma m x$ **will be zero.** $\Sigma m x = 0$ **because x can take positive and negative values w.r.t the axis AB.**
8. $I = I_C + M d^2$
9. **Hence , the parallel axis theorem is proved.**

---

9. State and prove perpendicular axis theorem.

Perpendicular Axis Theorem :

The moment of inertia of a plane laminar body about an axis perpendicular to its plane is equal to sum of its moment of inertia about two perpendicular axes lying in the plane of the body such that all the three axes are mutually perpendicular and have a common point.

$$I_Z = I_X + I_Y$$

Diagram :

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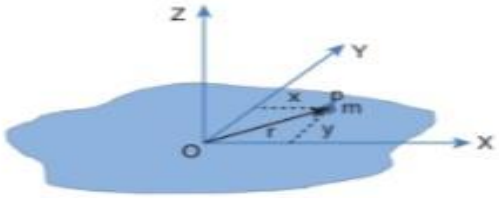


1. Let the X and Y axes lie in the plane and Z – axis perpendicular to the plane of the laminar object.
2. Moment of inertia about X and Y - axes are I_X and I_Y.
3. Moment of inertia about Z - axis is I_Z .
4. The perpendicular axis theorem could be expressed as ,

Theory :

1. Let us consider a plane laminar object of negligible thickness on which lies the origin (O).
2. The X and Y axes lie on the plane and Z - axis is perpendicular to it.
3. The lamina is considered to be made up of a large particles of mass m.
4. Let us choose one such particle at a point P which has coordinates (x , y) at a distance r from O.
5. Moment of inertia of the particle about Z – axis is $m r^2$. ($r^2 = x^2 + y^2$)
6. Moment of inertia of the entire lamina about Z - axis as , $I_Z = \Sigma m r^2$

Derivation :

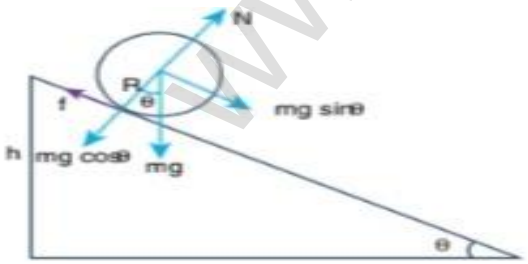
1. $I = \Sigma m r^2$
2. $I = \Sigma m (x^2 + y^2)$
3. $I = \Sigma m x^2 + \Sigma m y^2$
4. Moment of inertia about Y – axis : $I_Y = \Sigma m x^2$
5. Moment of inertia about X – axis : $I_X = \Sigma m y^2$
6. $I = I_X + I_Y$

Thus , the perpendicular axis theorem is proved.

---

10. Discuss rolling on inclined plane and arrive at the expression for the acceleration.

Diagram :



Formula :

$$a = \frac{g \sin \theta}{\left(1 + \frac{K^2}{R^2}\right)}$$

Theory :

1. Let us assume a round object of mass m and radius R.
2. Let it is rolling down an inclined plane without slipping.

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3. There are two forces acting on the object along the inclined plane.

4. One is the component of gravitational force $m\ g \sin\theta$.

5. Other is the static frictional force f .

6. Other is the component of gravitational force $m\ g \cos\theta$.

7. Other is the normal force N exerted by the plane .

8. We can write the equation for motion from the free body diagram of the object.

Derivation :

1. For translational motion , Supporting force → $m\ g \sin\theta$; Opposing force → f

2. $m\ g \sin\theta - f = ma \longrightarrow (1)$

3. For rotational motion , Frictional force → f ; Torque $\tau = R\ f$

4. Relation between torque and angular acceleration

$$\tau = I\ \alpha$$

$$I\ \alpha = R\ f \longrightarrow (2)$$

5. Moment of inertia : $I = m\ K^2$

Angular acceleration : $a = r\ \alpha$

$$\alpha = a / R$$

6. $$R\ f = I\ \alpha$$

$$R\ f = m\ K^2 \left(\frac{a}{R}\right)$$

$$f = m\ K^2 \left(\frac{a}{R^2}\right) \longrightarrow (3)$$

7. Sub eqn (3) in eqn (1)

$$m\ g \sin\theta - f = m\ a$$

$$m\ g \sin\theta - m\ K^2 \left(\frac{a}{R^2}\right) = m\ a$$

$$m\ g \sin\theta - m\ a \left(\frac{K^2}{R^2}\right) = m\ a$$

$$m\ g \sin\theta = m\ a \left(\frac{K^2}{R^2}\right) + m\ a$$

$$m\ g \sin\theta = m\ a \left(\frac{K^2}{R^2} + 1\right)$$

$$a = \frac{g \sin\theta}{\left(1 + \frac{K^2}{R^2}\right)}$$

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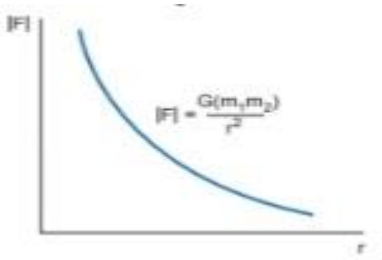
UNIT - 6

1. Discuss the important features of the law of gravitation.

1. As the distance between two masses increases , the strength of the force tends to decreases. Because of *inverse dependence on* r^2 .

- **Planet Uranus experiences less gravitational force from the Sun than the Earth.**
- **Uranus is at large distance from the sun compared to the Earth.**



2. The gravitational forces between two particles constitute an *action - reaction pair.*

- **Gravitational force exerted by the Sun on the Earth is always towards the sun.**
- **The reaction force is exerted by the Earth on the sun.**
- **The direction of this reaction force is towards Earth.**

3. The torque experienced by the Earth due to the gravitational force of the sun is ,

$$\vec{\tau} = \vec{r} \times \vec{F} = \vec{r} \times \left(- \frac{G M_S M_E \hat{r}}{r^2} \right) = 0$$

$$\vec{\tau} = \frac{d\vec{L}}{dt} = 0 \qquad \text{since } \vec{r} = r\,\hat{r} \text{ , } \hat{r} \times \hat{r} = 0$$

- **Angular momentum L is a constant vector.**
- **Angular momentum of the Earth about the sun is constant throughout the motion.**

4. Earth orbits around the sun due to sun's gravitational force , we assumed Earth & sun to be point masses.

$$\vec{F} = - \frac{G M_1 M_2}{r^2} \hat{r}$$

- **Both M_1 and M_2 are treated as point masses.**
- **The distance between two bodies is very much larger than their diameter.**

5. To calculate force of attraction between a hollow sphere of mass M with uniform density and point mass m kept outside the hollow sphere , we can replace the hollow sphere of mass M as equivalent to a point mass M located at the centre of the hollow sphere. If another object of mass m inside this hollow sphere the force experienced by this mass m will be zero.

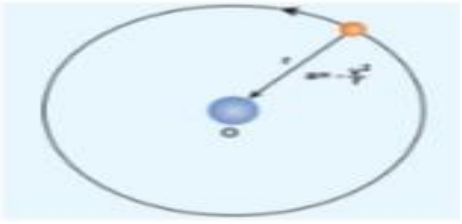
---

2. Explain how Newton arrived at his law of gravitation from Kepler's law.

Newton's inverse square law :

- **Newton considered the orbits of the planets as circular .**
- **For circular orbit of radius r , centripetal acceleration acts towards the centre.**

Diagram :



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Derivation :

1. Centripetal Acceleration : $a = \frac{v^2}{r}$ ---------- (1)

2. Velocity in terms of r and T : $v = \frac{2\pi r}{T}$ ---------- (2)

3. Sub eqn (2) in (1) : $a = \frac{-\left(\frac{2\pi r}{T}\right)^2}{r} = \frac{-4\pi^2 r}{T^2}$

4. From Newton's second law : $F = -\frac{4\pi^2 m r}{T^2}$

5. From Kepler's third law : $\frac{r^3}{T^2} = \frac{k}{r^2}$

$\frac{r}{T^2} = \frac{k}{r^2}$ ---------- (3)

6. Sub eqn (3) in (2) : $F = -\frac{4\pi^2 m k}{r^2}$

7. Negative sign implies that force is attractive and it acts towards the centre.

8. If Earth is attracted by the sun , then the sun must also be attracted by the Earth with the same magnitude of force .

9. Newton equated the constant $4\pi^2 k$ to G M which is the law of gravitation. $F = -\frac{G M m}{r^2}$

10. Negative sign in the above equation implies that the gravitational force is attractive.

---

3. Explain how Newton verified his law of gravitation.

1. Newton verified his law of universal gravitation by comparing the acceleration of a terrestrial object to the acceleration of the moon.

2. He knew that the distance from the centre of earth to the centre of two spheres of known mass at either end of a light rod suspended by a then fibre from the centre of the rod.

3. He had earlier found the small force that was needed to twist the fibre.

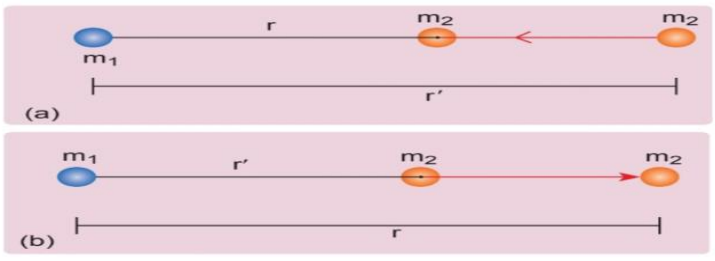
4. By bringing a third sphere close to one of the suspended spheres.

5. He was able to measure the force of gravity between the spheres and gravitation.

---

4. Derive the expression for gravitational potential energy.

Diagram :



Formula :

$$U(r) = -\frac{G m_1 m_2}{r}$$

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Theory :

- Two masses m_1 and m_2 are initially separated by a distance r'.
- Assuming m_1 to be fixed in its position , work must be done on m_2.
- To move mass m_2 from the distance r' to r.
- To move the mass m_2 through an infinitesimal displacement $\vec{dr}$ from $\vec{r}$ to $\vec{r} + \vec{dr}$ work has to be done externally.

Derivation :

1. Infinitesimal Work is given by, $dW = \vec{F}_{ext} \cdot \vec{dr}$ ------- (1)

2. Work is done against the gravitational force $|\vec{F}_{ext}| = |\vec{F}_G| = \frac{G m_1 m_2}{r^2}$ ------- (2)

3. Sub eqn (2) in (1)

$$dW = \frac{G m_1 m_2 \hat{r}}{r^2} \cdot \vec{dr}$$

$$\vec{dr} = \hat{r}\, dr \quad \text{and} \quad \hat{r} \cdot \hat{r} = 1$$

$$dW = \frac{G m_1 m_2 \hat{r} \cdot \hat{r}}{r^2} dr$$

$$dW = \frac{G m_1 m_2 dr}{r^2} \qquad \text{---------- (3)}$$

4. Total work done for displacing the particle r' to r is ,

$$W = \int_{r'}^{r} dW \qquad \int_{r'}^{r} \frac{G m_1 m_2 dr}{r^2}$$

$$W = -\left(\frac{G m_1 m_2}{r^2}\right)_{r'}^{r}$$

$$W = \frac{-G m_1 m_2}{r} + \frac{G m_1 m_2}{r'}$$

$$W = U(r) - U(r')$$

5. Work done gives the gravitational potential energy difference of the system of masses m_1 and m_2 when separation between them are r and r' respectively.

6. Gravitational potential energy :

$$U(r) = -\frac{G m_1 m_2}{r}$$

S.NO	Case 1 : If $r < r'$	Case 2 : If $r > r'$
1.	Object move from r' to r .	Object move from r' to r
2.	Work done is to be negative.	Work done is to be positive.
3.	Work done by the body spend internal energy.	Work is done on the body by external force.

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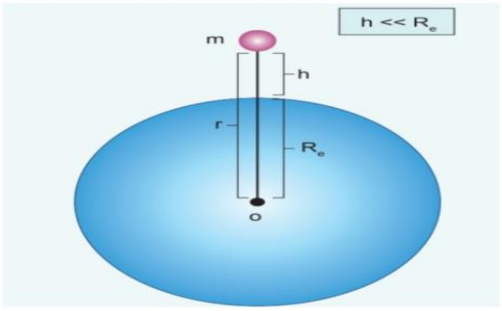
5. Prove that at points near the surface of the Earth, the gravitational potential energy of the object is U = m g h

Diagram :



Formula :

$$U = m\ g\ h$$

Theory :

- **Consider the Earth and mass system with r the distance between the mass m and Earth's centre.**
  - **Mass of the earth → M_e**
  - **Radius of the earth → R_e**
  - **Mass of the object → m**
  - **Height above Earth's surface → h**

Potential Energy :

1. $U = \dfrac{-G M_e m}{r}$

2. $r = R_e + h$

3. $U = -\dfrac{G M_e m}{R_e + h}$

4. **If h < < < R_e then ,**

$$U = -\frac{G M_e m}{R_e\left(\dfrac{R_e + h}{R_e}\right)}$$

5. $$U = -\frac{G M_e m}{R_e\left(1 + \dfrac{h}{R_e}\right)}$$

6. $$U = -\frac{G M_e m}{R_e}\left(1 + \frac{h}{R_e}\right)^{-1}$$

7. **By using Binomial expansion and neglecting the higher order terms we get**

$$U = -\frac{G M_e m}{R_e}\left(1 - \frac{h}{R_e}\right)$$

$$U = -\frac{G M_e m}{R_e} - \frac{G M_e m h}{R_e^2} \quad \text{----------} \quad (1)$$

8. **Acceleration due to gravity**

$$g = \frac{G M_e}{R_e^2}$$

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$$m g R_e = \frac{G M}{R_e} \quad \text{---------- (2)}$$

9. Sub eqn (2) in (1)

$$U = - m g R_e + m g h \quad \text{---------- (3)}$$

10. If the object is taken from height h_1 to h_2 .

Potential energy at h_1 : $U(h_1) = - m g R_e + m g h_1$

Potential energy at h_2 : $U(h_2) = - m g R_e + m g h_2$

11. Potential energy difference between h_1 and h_2

$U(h_2) - U(h_1) = - m g R_e + m g h_2 - (- m g R_e + m g h_1)$

$U(h_2) - U(h_1) = - m g R_e + m g h_2 + m g R_e - m g h_1$

$U(h_2) - U(h_1) = m g h_2 - m g h_1$

$U(h_2) - U(h_1) = m g (h_2 - h_1)$

12. The gravitational potential energy stored in the particle of the mass m at a height h from the surface of the Earth is $U = m g h$

13. On the surface of the Earth , $U = 0$ since h is zero.

---

6. Explain in detail the idea of weightlessness using lift as an example.

Weightlessness :

1. When the lift falls with downward acceleration a = g , the person inside the elevator is in the state of weightlessness or free fall.
2. Freely falling objects experience only gravitational force.
3. As they fall freely , they are not in contact with any surface.
4. Normal force acting on the object is zero.
5. Downward acceleration is equal to acceleration due to gravity of the earth.

$$a = g \text{ then } N = m (g - g) = 0$$

6. This is called the state of " weightlessness ".

---

7. Derive an expression for escape speed.

Escape Speed :

The escape speed is defined as , the minimum speed required by an object to escape from Earth's gravitational field .

$$V_e = \sqrt{2 g R_E}$$

Theory :

1. Consider an object of mass M on the surface of the Earth.
2. When it is thrown up with an initial speed v_i .
3. Initial total energy of the object is,

$$E_i = \frac{1}{2} M v_i^2 - \frac{G M M_E}{R_E}$$

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M_E → Mass of the earth .

R_E → Radius of the earth .

4. Potential energy of the mass M : $U(r) = -\frac{G M M_E}{R_E}$

5. When the object reaches a height far away from Earth and approach infinity.

6. Potential energy becomes zero and kinetic energy becomes zero.

7. Therefore final total energy of the object becomes zero. $E_f = 0$

Derivation :

1. According to the law of energy conservation , $E_i = E_f$

2. $\frac{1}{2} M v_i^2 - \frac{G M M_E}{R_E} = 0$

3. $\frac{1}{2} M v_i^2 = \frac{G M M_E}{R_E}$

4. $\frac{1}{2} v_i^2 = \frac{G M_E}{R_E}$

5. $v_i^2 = \frac{2 G M_E}{R_E}$

6. Hence replace v_i by v_e

$$v_e^2 = \frac{2 G M_E}{R_E}$$

7. Acceleration due to gravity : $g = \frac{G M_E}{R_E^2}$

8. $v_e^2 = 2 g R_E$

9. Escape Speed : $v_e = \sqrt{2 g R_E} = 11.2 \text{ km s}^{-1}$

10. Escape Speed depends on two factors :

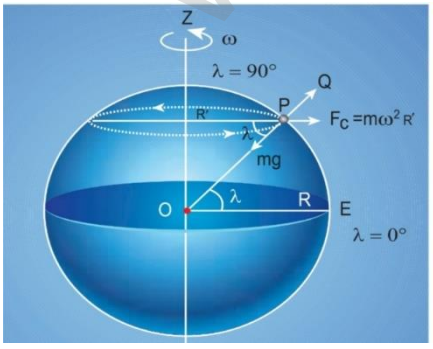
i) Acceleration due to gravity

ii) Radius of the earth R_E = 6400 km

---

8. Explain the variation of g with latitude.

Diagram :



Formula :

$$g' = g - \omega^2 R \cos^2 \lambda$$

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Theory :

1. The motion of objects in *rotating frame* must consider *centrifugal force*.
2. We treat Earth as an *inertial frame* , it is not exactly correct.
3. Because the Earth spins about its own axis.
4. When an object is on the earth surface , it experiences centrifugal force.
5. It depends on the *latitude* of the object on Earth.
6. If the Earth were not spinning , the force on the object is mg.
7. Object experiences an additional centrifugal force due to spinning of the Earth.

Derivation :

1. Centrifugal force = $m \omega^2 R'$

2. Centrifugal acceleration = $\omega^2 R'$

3. Component of centrifugal acceleration experienced by the object in the direction opposite to g.

$$a_{PQ} = \omega^2 R' \cos \lambda \quad \text{------ (1)}$$

4. From figure : $\cos \lambda = \frac{R'}{R}$

$$R' = R \cos \lambda \quad \text{---------- (2)}$$

5. Sub eqn (2) in (1)

$$a_{PQ} = \omega^2 R \cos \lambda \cos \lambda = \omega^2 R \cos^2 \lambda$$

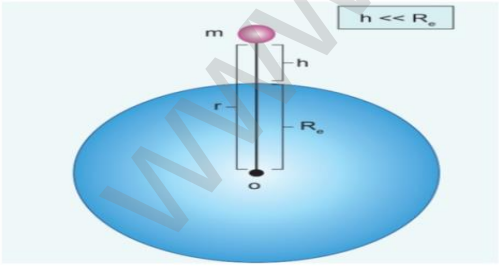
6. Variation of g with latitude : $\boxed{g' = g - \omega^2 R \cos^2 \lambda}$

Case i :	At equator	$\lambda = 0$	$g' = g - \omega^2 R$	Gravity is minimum
Case ii :	At poles	$\lambda = 90^0$	$g' = 0$	Gravity is maximum

---

9. Explain the variation of g with altitude.

Diagram :



Formula :

$$\boxed{g' = g\left(1 - \frac{2h}{R_E}\right)}$$

Theory :

Consider an object of mass m at a height h from the Earth.

- Mass of the Earth → M
- Radius of the Earth → R_E
- Mass of the object → m

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Derivation :

1. Acceleration due to gravity : $g = \frac{GM}{R_E^2}$

2. Gravity with altitude : $g' = \frac{GM}{(R_E + h)^2}$

3. Taking R_E outside : $g' = \frac{GM}{R_E^2\left(1 + \frac{h}{R_E}\right)^2} = \frac{GM}{R_E^2}\left(1 + \frac{h}{R_E}\right)^{-2}$

4. By using Binomial expansion : $g' = \frac{GM}{R_E^2}\left(1 - \frac{2h}{R_E}\right)$

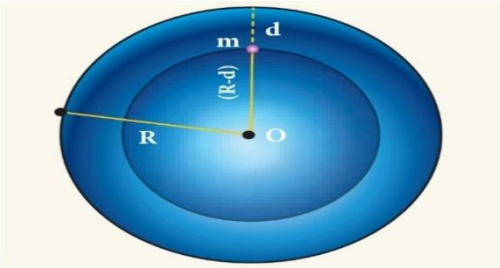
5. Variation of g with altitude : $\boxed{g' = g\left(1 - \frac{2h}{R_E}\right)}$

6. $g' < g$, " Altitude h increases then acceleration due to gravity g decreases "

---

10 . Explain the variation of g with depth from the Earth's surface.

Diagram :



Formula :

$$\boxed{g' = g\left(1 - \frac{d}{R_E}\right)}$$

Theory :

1. Consider a particle of mass m which is in a deep mine on the Earth. Ex : Coal mines in Neyveli
2. Acceleration due to gravity is g .
3. Assume the depth of the mine as d .
4. The part of Earth which is above radius (R_E - d) do not contribute to acceleration.
5. Assuming the density of Earth ρ to be constant .
6. Mass of the Earth → M
7. Volume of the Earth → V

Derivation :

1. $g = \frac{GM}{R_E^2}$ ------- (1)

2. $g' = \frac{GM'}{(R_E - d)^2}$ ------- (2)

3. $\rho = \frac{M}{V} = \frac{M'}{V'}$ -------- (3)

4. $M' = \frac{M}{V} V'$

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5. $M' = \frac{M}{\left(\frac{4}{3}\pi R_E^3\right)} \left(\frac{4}{3}\pi (R_E - d)^3\right)$

6. $M' = \frac{M}{R_E^3} (R_E - d)^3$ ------- (4)

7. Sub eqn (4) in (2)

8. $g' = \frac{G M (R_E - d)^3}{R_E^3 (R_E - d)^2}$

9. $g' = \frac{G M}{R_E^3} (R_E - d)$

10. $g' = \frac{G M}{R_E^2} \frac{(R_E - d)}{R_E}$

11. $g' = \frac{G M}{R_E^2}\left(1 - \frac{d}{R_E}\right)$

$$\boxed{g' = g\left(1 - \frac{d}{R_E}\right)}$$

12. Variation of g with depth :

13. $g' < g$; " As depth increases , g' decreases "

---

11. Derive the time period of satellite orbiting the Earth.

Time Period :

The distance covered by the satellite during one rotation in its orbit is equal to $2\pi (R_E + h)$ and time taken for it , is the time period.

Time Period = $\frac{\text{Distance Travelled}}{\text{Time Taken}}$

Derivation :

1. $v = \frac{2\pi (R_E + h)}{T}$

2. Orbital speed : $v = \frac{G M_E}{\sqrt{(R_E + h)}}$

3. $\sqrt{\frac{G M_E}{(R_E + h)}} = \frac{2\pi (R_E + h)}{T}$

4. $T = \frac{2\pi (R_E + h)}{\sqrt{G M_E (R_E + h)^{1/2}}}$

5. $T = \frac{2\pi}{\sqrt{G M_E}} (R_E + h)^{3/2}$

6. Squaring on both sides

$T^2 = \frac{4\pi^2}{G M_E} (R_E + h)^3$

7. $c = \frac{4\pi^2}{G M_E}$

8. $T^2 = c (R_E + h)^3$

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9. A satellite orbiting the Earth has same relation between time and distance as that of " *Kepler's law of planetary motion* ".

10. For a satellite orbiting near the surface of the Earth , h is negligible compared to the radius of the Earth.

11. $T^2 = \frac{4\pi^2}{G M_E} (R_E + h)^3$

12. $T^2 = \frac{4\pi^2}{G M_E} R_E^3 \quad (h = 0)$

13. $T^2 = \frac{4\pi^2}{\frac{G M_E}{R_E^2}} R_E^3$

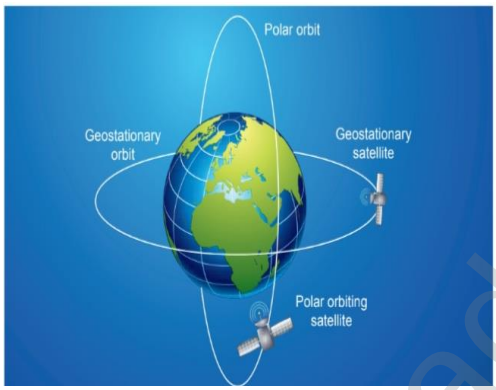
14. $T^2 = \frac{4\pi^2}{g} R_E$

15. $T = 2\pi \sqrt{\frac{R_E}{g}}$

---

13. Explain in detail the geostationary and polar satellite.

Diagram :



Geostationary Satellite :

1. Geostationary satellites appear to be stationary , when seen from Earth.

2. Distance h turns out be 36,000 km.

3. India uses the INSAT group of satellites that are basically geostationary satellite.

4. They are used for purpose of telecommunication.

5. The satellite orbiting the Earth have different time periods corresponding to different orbital radii.

6. Orbital radius of satellite if its time period is 24 hours calculated by Kepler's 3rd law

$$T^2 = \frac{4\pi^2}{G M_E} (R_E + h)^3$$

$$(R_E + h)^3 = \frac{G M_E T^2}{4\pi^2}$$

$$R_E + h = \left(\frac{G M_E T^2}{4\pi^2}\right)^{1/3}$$

7. The time period 24 hrs = 86400 sec , mass and radius of the Earth , h turns out to be 36,000 km . Such satellites are called " Geo - stationary satellite ".

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Polar Satellite :

1. Another type satellite which is placed at a distance of 500 to 800 km.

2. This type satellite that orbits Earth from pole to south pole .

3. The time period of polar satellite is nearly 100 minutes.

4. The satellites completes many revolution in a day.

5. A polar satellite covers small strip of area from pole to pole during one revolution.

6. In the next revolution , it covers different strip of area since the Earth would have moved by a small angle.

7. In this way polar satellite cover the entire surface area of the Earth.

---

14. Explain how geocentric theory is replaced by heliocentric theory using the idea of retrograde motion of planets.

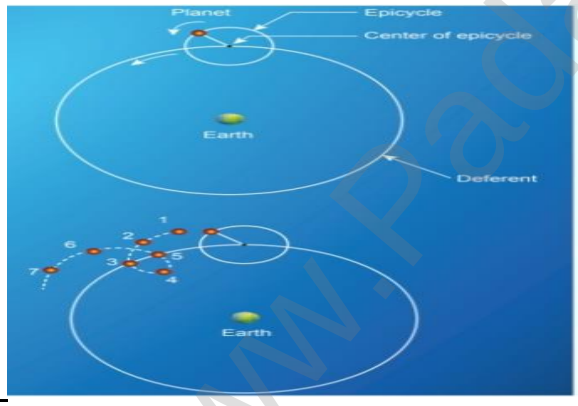
Retrograde Motion :

1. When the motion of the planets are observed in the night sky by naked eyes .
2. The planets move eastwards and reverse their motion for a while and return to eastward motion again.
3. This is called " *retrograde motion* " of the planets.

Examples :

- **The retrograde motion of the planet Mars.**
- **Initially moves eastwards (Feb to June)**
- **Reverse its path & moves backwards (July, Aug , Sep)**
- **It changes its direction of motion once again and continue its forward motion (October onwards)**

Diagram :



Ptolemy Concept :

1. To explain this retrograde motion , Ptolemy introduced the concept of " *epicycle* " in geocentric model.

2. According to this theory , while the planet orbited the Earth it also underwent another circular motion termed as " *epicycle* "

3. A combination of epicycle and circular motion around the Earth gave rise to retrograde motion of the planets with respect to Earth.

4. Ptolemy's model became more and more complex as every planet was found to undergo retrograde motion.

5. In the 15th century , the Polish astronomer Copernicus proposed.

6. The heliocentric model to explain this problem in a simple manner .

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7. According to this model , the sun is at the centre of the solar system and all planets orbited the sun.

8. The retrograde motion of planets with respect to Earth is because of the planet of the relative motion of the planet with respect to Earth.

9. The Earth orbits around the Sun faster than Mars.

10. Because of the relative motion between Mars & Earth appears to move backwards from July to October.

11. The retrograde motion of all other planets was explained successfully by the Copernicus model.

---

15. Explain in detail the Eratosthenes method of finding the radius of Earth.

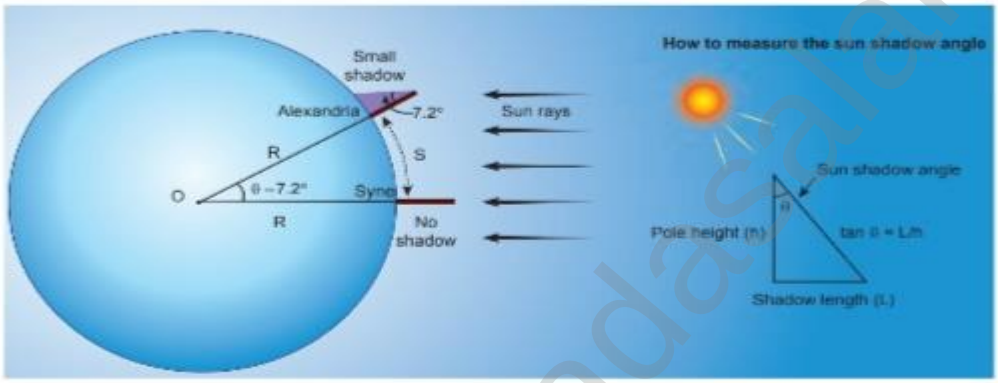
1. During noon time of summer solstice the Sun's rays cast no shadow in the city Syne which was located 500 miles away from Alexandria.

2. At the same day & same time h found that in Alexandria the Sun's rays made 7.2 degree with local vertical .

3. He realized that this differences of 7.2 degree was degree was due to the curvature of the Earth.

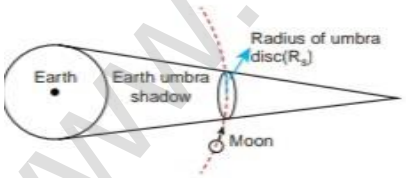
6. The angle 7.2 degree is equivalent to 1 / 8 radian . So $\theta = 1/8$ rad .

Diagram :



Derivation :

If S is the length of the length of arc between the cities of Syne and Alexandria , and if R is radius of Earth.



1. $S = R\theta$
2. $R = \frac{S}{\theta}$
3. S = 500 miles and $\theta = 1/8$
4. $R = \frac{500}{(1/8)}$
5. R = 4000 miles
6. R = 4000 X 1.609 km (1 mile = 1.609 km)
7. R = 6436 km (which is close to correct value 6378 km)

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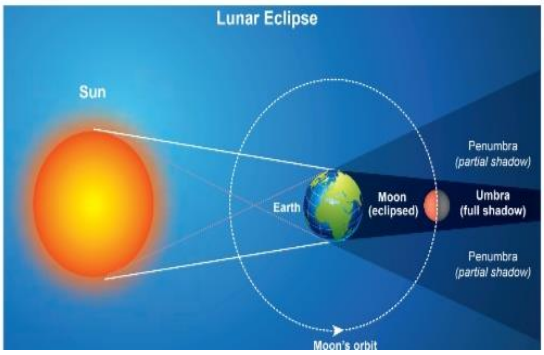
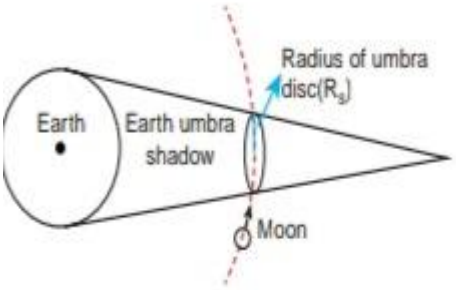
16. Describe the measurement of Earth's shadow (umbra) radius during total lunar eclipse.

Diagram:





1. It is possible to measure the radius of shadow of the Earth at the point where the Moon crosses.

2. When the Moon is inside the umbra shadow , it appears red in colour.

3. As soon as the Moon exits from the umbra shadow , it appears in crescent shape.

4. By finding the apparent radii of the Earth's umbra shadow and the Moon , the ratio of the these radii can be calculated.

Derivation :

1. The apparent radius of Earth's umbra shadow = R_s = 13.2 cm

2. The apparent radius of the Moon = R_m = 5.15 cm

3. The ratio $\frac{R_s}{R_m}$ = 2.56

4. The radius of the Earth's umbra shadow is = R_s = 2.56 X R_m

5. The radius of the moon R_m = 1737 km

6. The radius of the Earth's umbra shadow is R_s = 2.56 X 1737 km = 4446 km

7. The correct radius is 4610 km.

8. The percentage of error in the calculation

$$\frac{4610 - 4446}{4610} \times 100 = 3.5\ \%$$

9. The error will reduce if the pictures taken using a high quality telescope is used.

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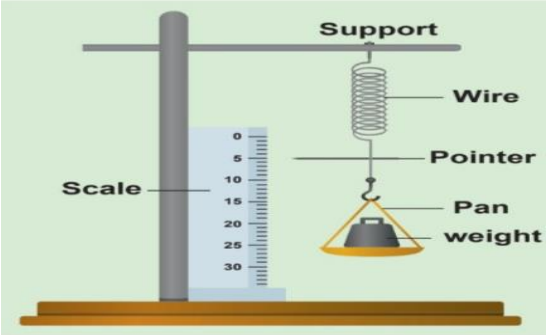
7. Properties of Matter

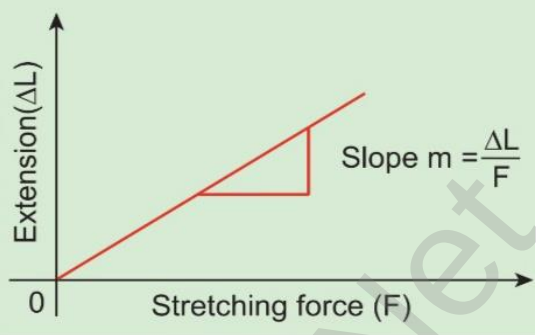
1. State Hooke's law and verify it with the help of an experiment.

Hooke's Law :

"Within the elastic limit , the stress is directly proportional to the strain ".

Diagram :





Theory :

1. Let us consider stretching thin straight wire of length L.
2. And uniform cross – sectional area A suspended from a fixed point O.
3. A pan and a pointer are attached at the free end of the wire.
4. Extension produced on the wire is measured using a vernier scale arrangement.
5. For a given load , the corresponding stretching force is F and elongation is Δ L.
6. It is directly proportional to the original length L and inversely proportional to the area of cross section A.
7. A graph is plotted using F on the X – axis and Δ L on the Y – axis.
8. This graph is a straight line passing through the origin.

Derivation :

1. $\text{Slope} = \frac{\Delta L}{F}$
2. $\Delta L = (\text{slope}) F$
3. Multiplying and dividing by volume $V = A L$
4. $F (\text{slope}) = \frac{A L}{A L} \Delta L$
5. Rearranging , we get

$$\frac{F}{A} = \left(\frac{L}{A (\text{slope})} \right) \frac{\Delta L}{L}$$

6. $\frac{F}{A} \alpha \frac{\Delta L}{L}$
7. $\sigma \alpha \varepsilon$
8. Stress is proportional to the strain with in the elastic limit.

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2. Explain the different types of modulus of elasticity .

Modulus of elasticity :

From Hooke's law , stress α strain ; $\frac{\text{Stress}}{\text{Strain}}$ = constant

SI unit : N m^{-2} or pascal ; Dimension : M L^{-1} T^{-2}

Types of modulus :

1. Young's modulus 2. Rigidity modulus or shear modulus 3. Bulk modulus

1. Young's modulus :

"Ratio between tensile stress and tensile strain is defined as " Young's modulus "

$$\text{Young modulus} = \frac{\text{Tensile stress or compressive stress}}{\text{Tensile strain or compressive strain}}$$

$$Y = \frac{\sigma_t}{\varepsilon_t} \text{ or } \frac{\sigma_c}{\varepsilon_c}$$

2. Bulk modulus :

"Ratio between volume stress and volume strain is defined as " Bulk modulus "

$$\text{Bulk modulus} = \frac{\text{Normal (perpendicular) stress}}{\text{Volume strain}}$$

- **Normal stress or pressure :** $\sigma_n = \frac{F_n}{\Delta A} = \Delta p$
- **Volume strain :** $\varepsilon_v = \frac{\Delta V}{V}$
- $K = \frac{\sigma_n}{\varepsilon_v} = \frac{-\Delta p}{\frac{\Delta V}{V}}$
- **Negative sign implies that when the pressure is applied , its volume decreases.**

2. Rigidity or Shear modulus :

"Ratio between shearing stress and shearing strain is called as Rigidity modulus "

$$\text{Rigidity modulus} = \frac{\text{Shearing stress}}{\text{Shearing strain}}$$

- **Shearing stress :** $\frac{\text{Tangential force}}{\text{Area over which it is applied}}$
- $\sigma_s = \frac{F_t}{\Delta A}$
- **Angle of strain :** $\varepsilon_s = \frac{x}{h} = \theta$
- $\eta_R = \frac{\sigma_s}{\varepsilon_v} = \frac{\frac{F_t}{\Delta A}}{\frac{x}{h}} = \frac{F_t}{\Delta A \theta}$
- **Rigidity modulus is inversely proportional to angle of shear.**

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3. Derive an expression for the elastic energy stored per unit volume a wire.

Elastic Energy :

When a body is stretched , work is done against the restoring force. This work done is stored in the body in the form of " Elastic energy "

Explanation :

Let us consider a unstretched wire.

- **Length of the wire** ⟶ **L**
- **Force on the wire** ⟶ **F**
- **Area of cross section** ⟶ **A**
- **Extension in length** ⟶ l

Derivation :

Work done by the force F is equal to the energy gained by the wire.

1. **Work done : W** $= \int_0^{l} F\, dl$

2. **Young's Modulus :** $Y = \frac{F}{A} \times \frac{L}{l}$

3. **Force :** $F = \frac{Y A l}{L}$

4. **Work done :** $W = \int_0^{l} \frac{Y A l}{L}\, dl$

5. $W = \frac{Y A}{L} \int_0^{l} l\, dl$

6. $W = \frac{Y A}{L} \left(\frac{l}{2}\right)^2$

7. $W = \frac{1}{2} \frac{Y A}{L} l\ l$

8. $W = \frac{1}{2} F l$

9. **Work done = Elastic potential energy**

10. **Energy Density : Energy per unit volume**

$$\text{Energy Density} = \frac{\text{Elastic potential energy}}{\text{Volume}}$$

$$u = \frac{1}{2} \frac{F}{A} \frac{l}{L}$$

$$u = \frac{1}{2} \times \text{Stress} \times \text{Strain}$$

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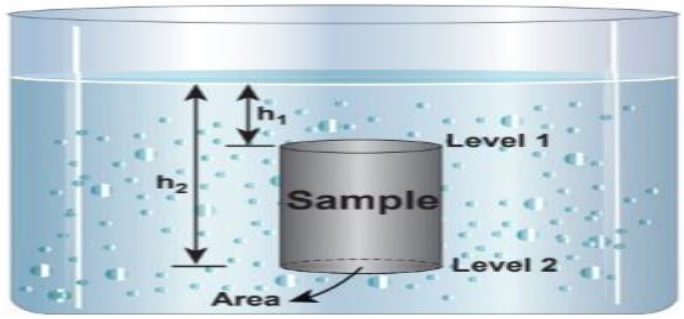
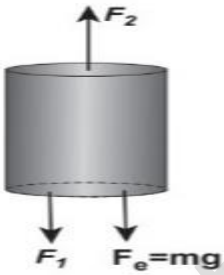
4. Derive an equation for the total pressure at a depth " h " below the liquid surface.

Consider a water sample of cross sectional area in the form of cylinder.

Diagram :





Theory :

1. Cross sectional Area ⟶ A
2. Depth at Level 1 ⟶ h_1
3. Depth at Level 2 ⟶ h_2
4. Force acts downward ⟶ $F_1 = P_1 A$
5. Force acts upward ⟶ $F_2 = P_2 A$
6. Gravitational Force ⟶ F_G

Derivation :

1. Under equilibrium condition , Total upward force (F_2) balanced by total downward force (F_1)

$$F_2 = F_1 + F_G \longrightarrow (1)$$

2. Gravitational force :

$$F_G = m g$$

$$F_G = V \rho g$$

$$F_G = A (h_2 - h_1) \rho g \longrightarrow (2)$$

3. Sub eqn (2) in (1)

$$F_2 = F_1 + F_G$$

$$P_2 A = P_1 A + A (h_2 - h_1) \rho g$$

$$P_2 \cancel{A} = [P_1 - (h_2 - h_1) \rho g] \cancel{A}$$

$$P_2 = [P_1 - (h_2 - h_1) \rho g]$$

4. If we choose the level 1 at the surface of the liquid and level 2 at a depth h below the surface.

h_1 becomes zero then $P_1 = P_a$
h_2 becomes h then $P_2 = P$

$$P = P_a + h \rho g$$

5. If the atmospheric pressure is ignored then $P = h \rho g$

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5. State and prove Pascal's law in fluids.

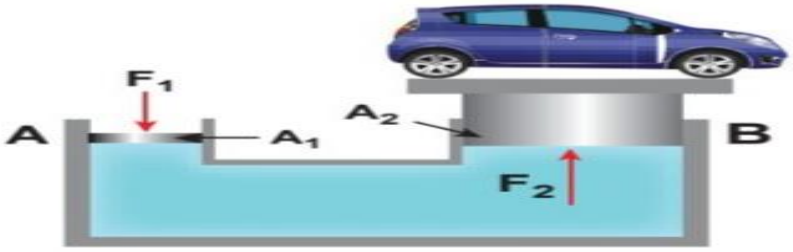
Pascal's Law :

" If the pressure in a liquid is changed at a particular point , the change is transmitted to the entire liquid without being diminished in magnitude".

Application of Pascal's Law :

1. A practical application of Pascal's law is *Hydraulic lift* .
2. It is used to lift heavy load with small force. 3. It is a Force multiplier.

Diagram :



Construction :

1. Consists of two cylinders A and B.
2. They are connected to each other.
3. Horizontal pipe is filled with liquid.
4. They are fitted with frictionless piston.
5. Cross sectional areas are A_1 and A_2 . ($A_2 > A_1$)

Working :

1. Downward force F_1 is applied on the smaller piston.
2. Pressure of the liquid under this piston increases to P . ($P = F_1 / A_1$)
3. Increased pressure is exerted on piston B is F_2 .

According to Pascal's Law :

$$F_2 = P \times A_2$$

$$F_2 = \frac{F_1}{A_1} \times A_2$$

$$\boxed{F_2 = \frac{A_2}{A_1} \times F_1}$$

Mechanical advantage of lift :

1. The factor A_2 / A_1 is called mechanical advantage of lift.

2. Changing force on smaller piston A , force on the piston B increased by the factor A_2 / A_1.

---

6. State and prove Archimedes principle.

Archimedes principle :

It states that when a body is partially or wholly immersed in a fluid , it experiences an upward thrust equal to weight of the fluid displaced by it and its upthrust acts through the centre of gravity of the liquid displaced.

Upthrust or Buoyant force = Weight of liquid displaced

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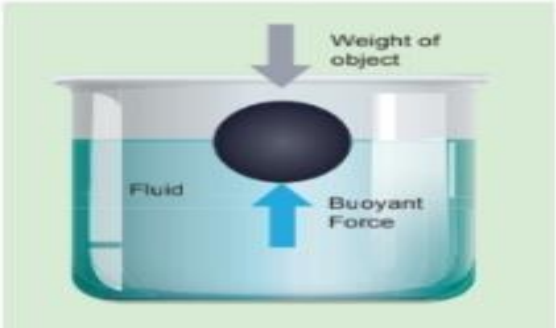
Diagram :



Buoyancy :

The upward force exerted by a fluid that opposes the weight of an immersed object in a fluid is called upthrust or buoyant force and the phenomenon is called " buoyancy ".

Law of flotation :

A body will float in a liquid if the weight of the liquid displaced by the immersed part of the body equals the weight of the body.

Example :

A wooden object 300 kg (about 3000 N) floats in water displaces 300 kg of water.

7.Derive the expression for the terminal velocity of a sphere moving in a high viscous fluid using stokes force.

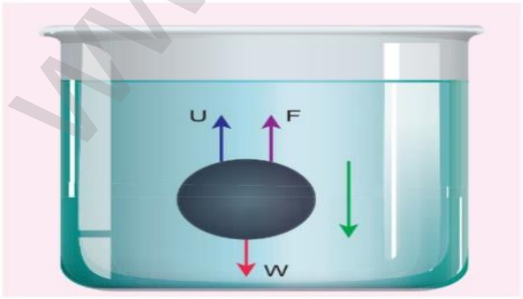
Consider a sphere which falls freely through highly viscous liquid.

1. **Radius of the sphere ⟶ r**
2. **Density of the sphere ⟶ ρ**
3. **Density of the liquid ⟶ σ**
4. **Coefficient of viscosity ⟶ η**

Derivation :

Downward Force = Upward force [F_G = U + F]

Diagram :



1. Gravitational Force :

$$F_G = m\,g = V\,\rho\,g$$

$$F_G = \frac{4}{3}\,\pi\,r^3\,\rho\,g$$

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2. Upthrust : $U = \frac{4}{3} \pi r^3 \sigma g$

3. Viscous Force : $F = 6 \pi \eta r v_t$

4. $F_G = U + F$

$$\frac{4}{3} \pi r^3 \rho g = \frac{4}{3} \pi r^3 \sigma g + 6 \pi \eta r v_t$$

$$6 \pi \eta r v_t = \frac{4}{3} \pi r^3 \rho g - \frac{4}{3} \pi r^3 \sigma g$$

$$6 \pi \eta r v_t = \frac{4}{3} \pi r^3 (\rho - \sigma) g$$

$$3 \eta v_t = \frac{2}{3} r^2 (\rho - \sigma) g$$

$$v_t = \frac{2}{9} \frac{r^2 (\rho - \sigma) g}{\eta}$$

Terminal speed of the sphere is directly proportional to the square of its radius $v_t \alpha r^2$

---

8. Derive Poiseuille's formula for the volume of a liquid flowing per second through a pipe under streamlined floor.

- Consider a liquid flowing steadily through horizontal capillary tube.
- Let volume of the liquid flowing out per second (v = V / t) through a capillary tube.

Quantity and Dimension :

S.NO	Quantity	Dimension
1.	v = V / t	$L^3 T^{-1}$
2.	H	$M L^{-1} T^{-1}$
3.	P / l	$M L^{-2} T^{-2}$
4.	R	L

1. Coefficient of viscosity (η)
2. Radius of the tube (r)
3. Pressure Gradient (P / ℓ)
4. $v \alpha \eta^a r^b \left(\frac{P}{\ell} \right)^c$
5. $v = k \eta^a r^b \left(\frac{P}{\ell} \right)^c \longrightarrow (1)$

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6. $\left[L^3 T^{-1} \right] = K \left[M L^{-1} T^{-1} \right]^a \left[L \right]^b \left[M L^{-2} T^{-2} \right]^c$

7. $M^0 L^3 T^{-1} = K M^a L^{-a} T^{-a} L^b M^c L^{-2c} T^{-2c}$

8. $M^0 L^3 T^{-1} = K M^{a+c} L^{-a+b-2c} T^{-a-2c}$

Power of M : $a + c = 0$

Power of L : $-a + b - 2c = 3$

Power of T : $a - 2c = -1$

After solving these equations we get $a = -1$, $b = 4$, $c = 1$ sub in eqn (1)

$$v = k \eta^a r^b \left[\frac{P}{l} \right]^c$$

$$v = k \eta^{-1} r^4 \left[\frac{P}{l} \right]^1$$

$$v = \frac{\pi r^4 P}{8 \eta l}$$

Experimentally the value of $k = \pi / 8$ then

---

9. Obtain an expression for the excess of pressure inside i) liquid drop ii) soap bubble iii) air bubble.

i . Liquid drop :

- Consider a liquid drop of radius R having surface tension T.
- Let P_1 and P_2 be the pressures outside and inside the bubble.

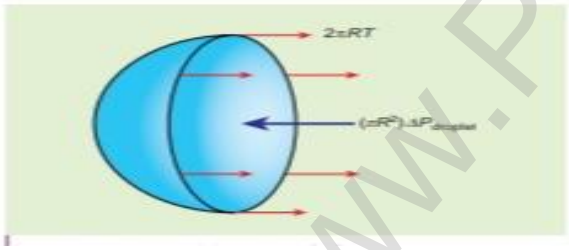
The various forces acting on the liquid drop are ,

i) Force due to surface tension $F_T = 2 \pi R T$

ii) Force due to outside pressure $F_{P1} = P_1 \pi R^2$

iii) Force due to outside pressure $F_{P2} = P_2 \pi R^2$

Diagram :



As the drop is in equilibrium ,

$$F_{P2} = F_T + F_{P1}$$

$$P_2 \pi R^2 = 2 \pi R T + P_1 \pi R^2$$

$$P_2 \pi R^2 - P_1 \pi R^2 = 2 \pi R T$$

$$(P_2 - P_1) \pi R^2 = 2 \pi R T$$

$$P_2 - P_1 = \frac{2T}{R}$$

$$\text{Excess Pressure} = \Delta P = \frac{2T}{R}$$

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ii Soap Bubble :

- **Consider a soap bubble of radius R having surface tension T.**
- **Let P_1 and P_2 be the pressures outside and inside the bubble.**

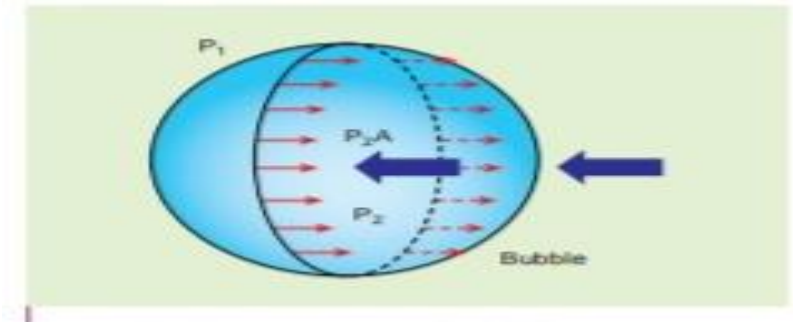
The various forces acting on the liquid drop are ,

i) Force due to surface tension $F_T = 4 \pi R T$

ii) Force due to outside pressure $F_{P1} = P_1 \pi R^2$

iii) Force due to outside pressure $F_{P2} = P_2 \pi R^2$

Diagram :



As the drop is in equilibrium ,

$$F_{P2} = F_T + F_{P1}$$

$$P_2 \pi R^2 = 4 \pi R T + P_1 \pi R^2$$

$$P_2 \pi R^2 - P_1 \pi R^2 = 4 \pi R T$$

$$(P_2 - P_1) \pi R^2 = 4 \pi R T$$

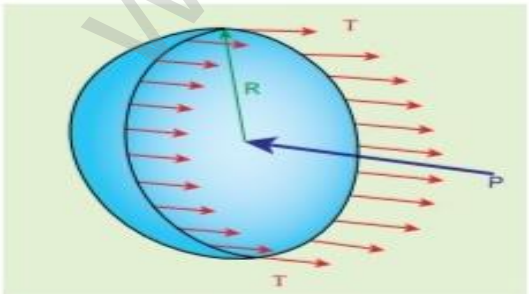
$$P_2 - P_1 = \frac{4T}{R}$$

Excess Pressure = $\Delta P = \frac{4T}{R}$

iii . Air Bubble :

- **Consider a air bubble of radius R having surface tension T.**
- **Let P_1 and P_2 be the pressures outside and inside the bubble.**

Diagram :



The various forces acting on the liquid drop are ,

i) Force due to surface tension $F_T = 2 \pi R T$

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ii) Force due to outside pressure $F_{P1} = P_1 \pi R^2$

iii) Force due to outside pressure $F_{P2} = P_2 \pi R^2$

As the drop is in equilibrium ,

$$F_{P2} = F_T + F_{P1}$$

$$P_2 \pi R^2 = 2 \pi R T + P_1 \pi R^2$$

$$P_2 \pi R^2 - P_1 \pi R^2 = 2 \pi R T$$

$$(P_2 - P_1) \pi R^2 = 2 \pi R T$$

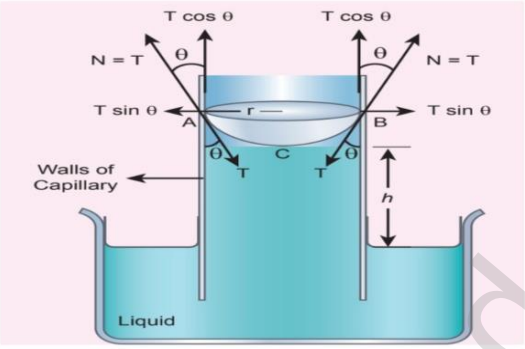
$$P_2 - P_1 = \frac{2T}{R}$$

Excess Pressure = $\Delta P = \frac{2T}{R}$

---

10. What is capillarity ? Obtain an expression for the surface tension of a liquid by capillary rise method .

Diagram :



Theory :

Consider a capillary tube which is held vertically in a beaker containing water.

- **Capillary rise → h**
- **Angle of contact → θ**
- **Surface Tension → T**
- **Horizontal component → T sin θ**
- **Vertical component → T cos θ**

Derivation :

1. **Total upward force = Downward weight liquid**
2. $2 \pi r T \cos \theta = m g$
3. $2 \pi r T \cos \theta = V \rho g \longrightarrow (1)$
4. **Volume of liquid = (Volume of liquid column of radius r height h) +**
   (Volume of liquid radius r & height r - Volume of hemisphere of radius r)
5. $V = \pi r^2 h + (\pi r^2 \times r - \frac{2}{3} \pi r^3)$

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6. $V = \pi r^2 h + \frac{\pi r^3}{3}$

7. If the capillary is very fine tube of radius is very small then $r/3$ can be neglected.

8. $V = \pi r^2 h \longrightarrow (2)$

9. Sub eqn (2) in (1)

$$2 \pi r T \cos\theta = \pi r^2 h \rho g$$

$$2 T \cos\theta = r h \rho g$$

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

10. Smaller radius have greater capillarity. h is inversely proportional to r^2.

---

11. Obtain an equation of continuity for a flow of liquid on the basis of conservation of mass.

Assumption :

Mass flow rate through a pipe depends on following ,

1. Flow of fluid is *steady* .
2. Velocity of fluid particle remains *constant* wrt time.
3. Path taken by the fluid particle is a *streamline.*

Construction :

1. Consider a pipe AB of varying cross sectional area a_1 & a_2 . ($a_1 > a_2$)
2. A non - viscous and incompressible liquid flows through the pipe.
3. Let v_1 and v_2 velocities of the liquid flows through the pipe.
4. Let m_1 and m_2 mass of fluid through the pipe.

Diagram :

Derivation :

1. Mass of fluid flowing through section A in time Δt : $m_1 = (a_1 v_1 \Delta t)\rho$
2. Mass of fluid flowing through section B in time Δt : $m_2 = (a_2 v_2 \Delta t)\rho$
3. For an incompressible liquid , mass is conserved $a_1 v_1 \Delta t \rho = a_2 v_2 \Delta t \rho$

$$a_1 v_1 = a_2 v_2$$

$$\boxed{a\ v = \text{constant}}$$

- It is called the equation of continuity.
- It is conservation of mass in the flow of fluid.

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12. State and prove Bernoulli's theorem for a flow of incompressible, non – viscous and streamlined flow of fluid.

Bernoulli's theorem :

The sum of pressure energy , kinetic energy and potential energy , kinetic energy and potential energy per unit mass of an incompressible non – viscous fluid in a streamlined flow remains a constant.

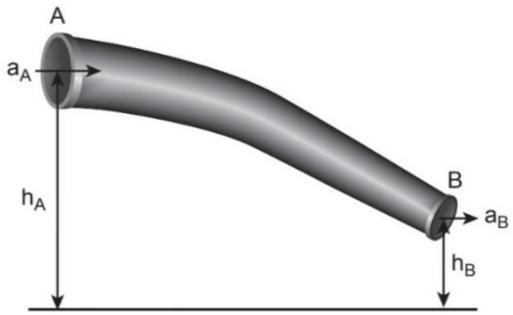
$$\frac{P}{\rho} + \frac{1}{2} v^2 + g h = \text{constant}$$

Flow of liquid through a pipe AB

1. Let us consider a flow of liquid through a pipe AB.

2. Let V be the volume of the liquid , when it enters A in a time t which is equal to liquid leaving from B.

Diagram :



S.NO	Quantity	Section A	Section B
1.	Velocity	V_A	V_B
2.	Height	h_A	h_B
3.	Area of cross section	a_A	a_B

Pressure Energy :

Pressure Energy = Work done

$$E_P = W = F\ d$$

$$E_P = P\ A\ d$$

$$E_P = P\ V$$

$$E_P = \frac{P}{\rho} m$$

Kinetic Energy :

$$K.E = \frac{1}{2} m v^2$$

Potential Energy :

$$P.E = m g h$$

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S.NO	Energy	Section A	Section B
1.	Pressure Energy	$\frac{P_A}{\rho}$ m	$\frac{P_B}{\rho}$ m
2.	Kinetic Energy	$\frac{1}{2}$ m V_A^2	$\frac{1}{2}$ m V_B^2
3.	Potential Energy	m g h_A	m g h_B

Total Energy at A

$$E_A = \frac{P_A}{\rho} m + \frac{1}{2} m V_A^2 + m g h_A$$

Total Energy at B

$$E_A = \frac{P_B}{\rho} m + \frac{1}{2} m V_B^2 + m g h_B$$

Law of conservation of energy $E_A = E_B$

$$\frac{P_A}{\rho} m + \frac{1}{2} m V_A^2 + m g h_A = \frac{P_B}{\rho} m + \frac{1}{2} m V_B^2 + m g h_B$$

Divide both sides by m

$$\frac{P_A}{\rho} + \frac{1}{2} V_A^2 + g h_A = \frac{P_B}{\rho} + \frac{1}{2} V_B^2 + m g h_B$$

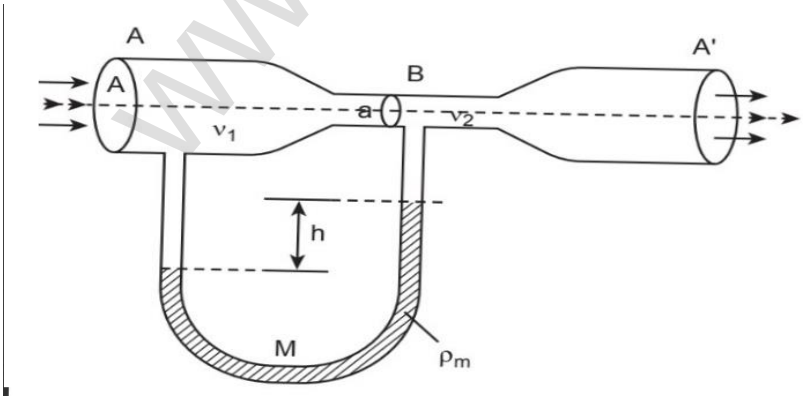
Bernouli's Equation $\frac{P}{\rho} + \frac{1}{2} v^2 + g h = \text{constant}$

---

13. Describe the construction and working of venturi meter and obtain an equation for the volume of liquid flowing per second through a wider entry of the tube.

Venturi meter

A device is used to measure the rate of flow of incompressible fluid flow through a pipe. It works on the principle of " Bernoulli's theorem ".



Construction :

1. It consists of two wider tubes A and A and connected by narrow tube B.

2. A manometer in the form of U – tube is attached between wide and narrow tube.

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3. Let us assume the fluid of density ρ flows from the pipe .

4. According to Bernoulli's equation , increase in speed is by decrease in pressure.

5. By measuring the height difference between surfaces of the manometer liquid.

S.NO	Quantity	Section A	Section B
1.	Pressure	P_1	P_2
2.	Velocity	V_1	V_2
3.	Area	A	a

From Equation of continuity

$$a_1 v_1 = a_2 v_2$$

$$A v_1 = a v_2$$

$$V_2 = \frac{A}{a} v_1 \longrightarrow (1)$$

Using Bernoulli's equation

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

Multiply by ρ

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

$$P_1 + \frac{1}{2} \rho v_1^2 = P_2 + \frac{1}{2} \rho v_2^2 \longrightarrow (2)$$

Sub eqn (1) in (2)

$$P_1 + \frac{1}{2} \rho v_1^2 = P_2 + \frac{1}{2} \rho \left(\frac{A}{a}\right) v_1^2$$

$$P_1 + \rho \frac{v_1^2}{2} = P_2 + \rho \frac{A}{a^2} \frac{v_1^2}{2}$$

$$P_1 - P_2 = \rho \frac{A}{a^2} \frac{v_1^2}{2} - \rho \frac{v_1^2}{2}$$

$$\Delta P = \rho \frac{v_1^2}{2} \left(\frac{A^2}{a^2} - 1\right)$$

$$\Delta P = \rho \frac{v_1^2}{2} \left(\frac{A^2 - a^2}{a^2}\right)$$

$$V_1^2 = \frac{2 (\Delta P) a^2}{\rho (A^2 - a^2)}$$

$$\boxed{V_1 = a \sqrt{\frac{2 (\Delta P)}{\rho (A^2 - a^2)}}}$$

Volume of liquid flow per sec

$$V = \frac{v}{t} = A v_1$$

$$\boxed{V = a A \sqrt{\frac{2 (\Delta P)}{\rho (A^2 - a^2)}}}$$

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UNIT -8

1.Explain the working of heat and work with suitable examples.

1. When hands are rubbed against each other the temperature of the hands increases. Some work is done on hands by rubbing.

2. The temperature of the hands increases due to this work. Now if the hands are placed on the chin , the temperature of the chin increases. This is because the hands are at higher temperature than the chin.

3. The temperature of hands is increased due to work and temperature of the chin is increased due heat transfer from the hands to the chin.

4. By doing work on the system , the temperature in the system will increase and sometimes may not. Like heat , work is also not a quantity and through the work energy is transferred to the system.

5. Either the system can transfer energy to the surrounding or the surrounding may transfer energy to the system by doing work on the system.

6. For the transfer of energy from one body to another body through the process of work , they need not be at different temperatures.

---

2. Discuss the ideal gas laws.

1. Boyle's Law :

$$P \propto \frac{1}{V}$$

When the gas is kept at constant temperature , the pressure of the gas is inversely proportional to the volume.

2. Charle's Law :

When the gas is kept at constant pressure , the volume of the gas is directly proportional to the absolute temperature.

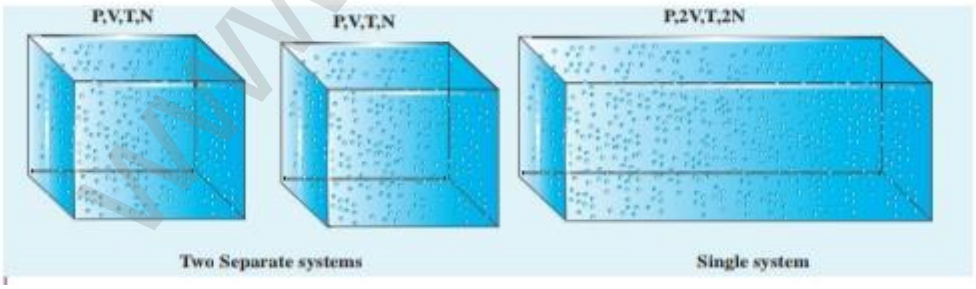
$$V \propto T$$

3. By combining these two equations : $P V = C T$

- The constant C as k times the number of particles N.

4. If we take containers of same type of gas with same volume V , same pressure P , same temperature T then the gas in each container obeys the equation $P V = C T$.

5. If two containers of gas is considered as a single system , then the pressure and temperature of this combined system will be same but volume will be twice & number of particles will also double.



6. For this combined system , V becomes 2 V so C should also double to match with the ideal gas equation

$$\frac{P\,(2\,V)}{T} = 2\,C$$

7. It implies that C must depend on the number of particles in the gas , also should have the dimension

$$\left(\frac{P\,V}{T}\right) = J\,K^{-1}$$

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8. We can write the constant C and k times the number of particles N.

- K is the Boltzmann constant 1.381 X 10^{-23} J K^{-1}.
- Ideal Gas Law : P V = N k T

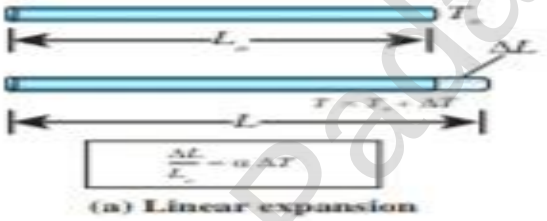
---

3. Explain in detail the thermal expansion.

1. The tendency of matter to change in shape , area and volume due to a change in temperature.
2. All three states of matter (solid , liquid and gas) expand when heated.
3. When solid is heated , its atoms vibrate with higher amplitude about their fixed points.
4. The relative change in the size of solids is small.
5. Railway tracks are given small gaps so that in the summer , the tracks expand and do not buckle . Railroad tracks and bridges have expansion joints to allow them to expand and contracts freely with temperature changes.
6. Liquids have less intermolecular forces than solids and hence they expand more than solids. This is the principle behind the mercury thermometers.
7. In the case of gas molecules , the intermolecular forces are almost negligible and hence they expand much more than solids.
8. The increase in dimension of body due to the increase in its temperature is called "*thermal expansion* ".
9. Unit of coefficient of linear , area and volumetric expansion of solid is ^{o}C or K^{-1}.

Linear Expansion :

In solids ,small fractional change in length ($\Delta L / L_0$) is directly proportional to ΔT



$$\frac{\Delta L}{L_0} = \alpha_L \Delta T$$

$$\alpha_L = \frac{\Delta L}{L_0 \Delta T}$$

Coefficient of linear expansion → α_L

Change in length → ΔL

Original length → L_0

Change in temperature → ΔT

Area Expansion :

In solids , small fractional change in area ($\Delta A / A_0$) is directly proportional to ΔT

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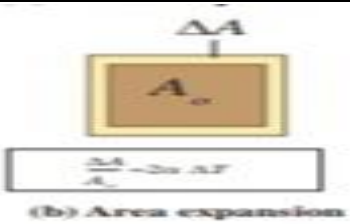


(b) Area expansion

$$\frac{\Delta A}{A_0} = \alpha_A \Delta T$$

$$\alpha_A = \frac{\Delta A}{A_0 \Delta T}$$

Coefficient of area expansion → α_A

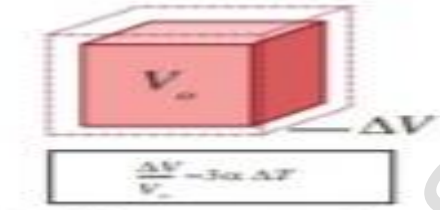
Change in area → ΔA

Original area → A_0

Change in temperature → ΔT

Volume Expansion :

In solids , small fractional change in volume ($\Delta V / V_0$) is directly proportional to ΔT



(c) Volume expansion

$$\frac{\Delta V}{V_0} = \alpha_V \Delta T$$

$$\alpha_V = \frac{\Delta V}{V_0 \Delta T}$$

Coefficient of volume expansion → α_V

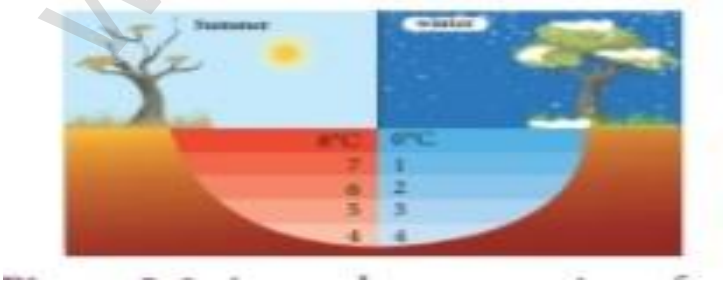
Change in volume → ΔV

Original volume → V_0

Change in temperature → ΔT

---

4. Describe the anomalous expansion of water . How is it helpful in our lives ?



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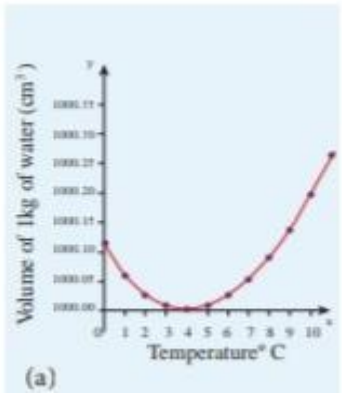
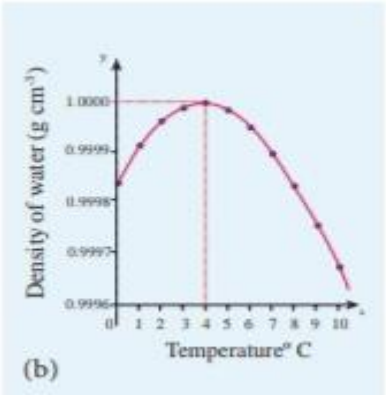




1. Liquids expand on heating and contract on cooling moderate temperatures . But water exhibits an anomalous behaviour. It contracts on heating between 0^0C & 4^0 C.

2. The volume of the given amount of water decreases as it is cooled from room temperature , until it reach 4^0 C.

3. Below 4^0 C the volume increases and so the density decreases. This means that the water has a maximum density at 4^0 C . This behaviour of water is called anomalous expansion of water.

4. In cold countries during the winter season , the surface of the lakes will be at lower temperature than the bottom.

5. Since the solid water (ice) has lower density than its liquid form ,below 4^0 C , the frozen water will be on the top surface above the liquid water.

6. This is due to the anomalous expansion of water. As the water in lakes and ponds freeze only at the top the species living in the lakes will be safe at the bottom.

---

6. Explain Calorimetry and derive an expression for final temperature when two thermodynamics systems are mixed.

Calorimetry :

1. Calorimetry means the measurement of the amount of heat released or absorbed by thermodynamic system during the heating process.

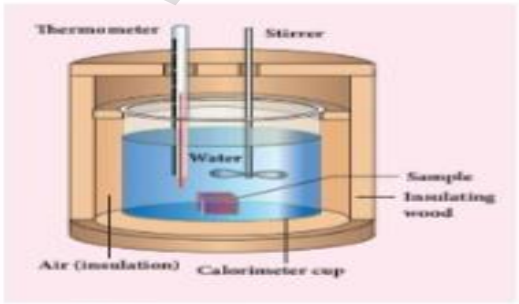
2. When a body at higher temperature is brought in contact with another body at lower temperature , the heat lost by the cold body.

3. No heat is allowed to escape to the surroundings .

4. Heat gained or lost is measured with a calorimeter.

5. Usually the calorimeter is an insulated container of water .

Diagram :



Formula :

$$Q_{gain} = - Q_{lost}$$

$$Q_{gain} + Q_{lost} = 0$$

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Experiment :

- A sample is heated at high temperature (T_1) and immersed into water at room temperature (T_2) in calorimeter .
- After some time both sample & water reach a final equilibrium temperature T_f
- Since the calorimeter is insulated , heat given by the hot sample is equal to heat gained by water.
- The heat lost is denoted by negative sign and heat gained is denoted as positive.

Working :

1. $Q_{gain} = m_2 s_2 (T_f - T_2)$
2. $Q_{lost} = m_1 s_1 (T_f - T_1)$
3. $m_2 s_2 (T_f - T_2) = - m_1 s_1 (T_f - T_1)$
4. $m_2 s_2 T_f - m_2 s_2 T_2 = - m_1 s_1 T_f + m_1 s_1 T_1$
5. $m_2 s_2 T_f + m_1 s_1 T_f = m_1 s_1 T_1 + m_2 s_2 T_2$
6. $(m_2 s_2 + m_1 s_1) T_f = m_1 s_1 T_1 + m_2 s_2 T_2$

Final Temperature :

$$T_f = \frac{m_1 s_1 T_1 + m_2 s_2 T_2}{m_1 s_1 + m_2 s_2}$$

---

6. Discuss various modes of heat transfer .

1. Conduction :

The process of direct transfer of heat through matter due to temperature difference. When two objects are in direct contact with one another , heat will be transferred from the hotter object to the colder one.

2. Convection :

The process in which heat transfer is by actual movement of molecules in fluids such as liquids and gases. In convection , molecules move freely from one place to another.

3.Radiation :

It is a form of energy transfer from one body to another by electromagnetic waves. Radiation does not require medium to transfer energy from one object to another.

Examples :

1. Solar energy from the sun
2. Radiation from room heater.

---

7. Explain in detail Newton's law of cooling .

1. Newton's law of cooling states that the rate of loss of heat of a body is directly proportional to the difference in the temperature between that body & its surroundings .

$$\frac{dQ}{dt} \alpha - (T - T_S)$$

2. The negative sign indicates that the quantity of heat lost by liquid goes on decreasing with time .

- Temperature of the object → T

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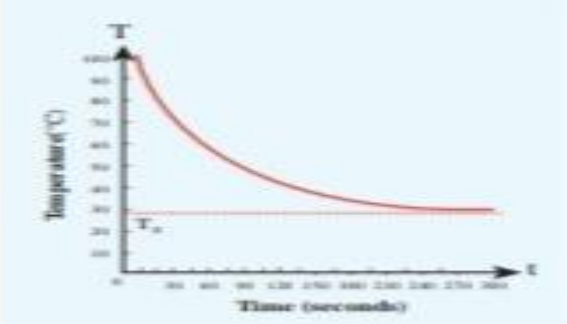
- **Temperature of the surrounding → T_S**

3. From the graph , the rate of cooling is high initially and decreases with falling temperature.



4. Let us consider an object of mass m and specific heat capacity at temperature T. Let T_S be the temperature of the surroundings . If the temperature falls by a small amount d T in time d t , then the amount of heat lost is calculated.

Derivation :

1. $dQ = m\,s\,dT$
2. Dividing both sides by d t

$$\frac{dQ}{dt} = \frac{m\,s\,dT}{dt} \quad \text{------- (1)}$$

3. From Newton's law of cooling

$$\frac{dQ}{dt} \propto -(T - T_S)$$

4. $$\frac{dQ}{dt} = -a(T - T_S) \quad \text{----- (2)}$$

5. Sub eqn (1) in (2)

$$\frac{m\,s\,dT}{dt} = -a(T - T_S)$$

$$\frac{dT}{T - T_S} = -\frac{a}{m\,s}\,dt$$

6. Integrating above eqn

$$\int \frac{dT}{T - T_S} = -\frac{a}{m\,s}\int dt$$

7. $$\ln(T - T_S) = \frac{a}{m\,s}t + b_1$$

8. Taking exponential on both sides

$$T - T_S = b_2\, e^{a/ms\,t}$$

9. $$b_2 = e^{b_1} = \text{constant}$$

10. $$T = T_S + b_2\, e^{a/ms\,t}$$

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8. Explain Wien's law and why our eyes sensitive only to visible rays ?

1. Wien's law states that wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the body.

$$\lambda_m \alpha \frac{1}{T}$$

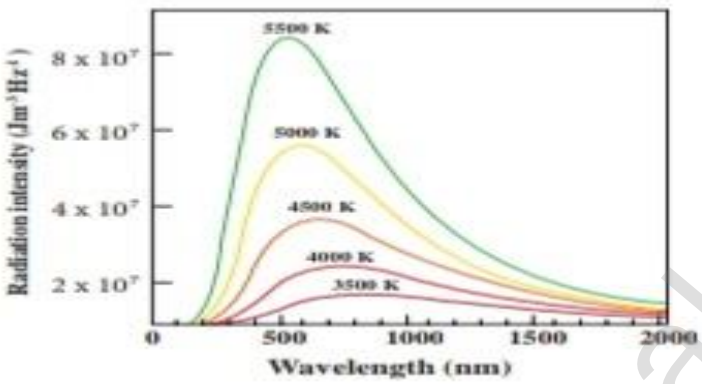
$$\lambda_m = \frac{b}{T}$$

b is known as Wien's constant .

b = 2.898 X 10^{-3} m K .

2. The sun is approximately taken as a black body. Since any object above 0 K will emit radiation , sun also emits radiation . Its surface temperature is about 5700 K.

$$\lambda_m = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{5700} = 508 \text{ nm}$$



3. It is the wavelength at which maximum intensity is 508 nm . Since the sun's temperature is around 5700 k , the spectrum of radiations emitted by sun lie between 400 n m and 700 nm which is the visible part of the spectrum.

4. The humans evolved under sun by receiving its radiations . The human eye is sensitive only in the visible not in infrared or X - ray ranges in the spectrum.

5. Suppose if humans had evolved in a planet near the star Sirius (9940 K) , then they would have had the ability to see the ultraviolet rays.

---

9. Discuss the following a) Thermal equilibrium b) Mechanical equilibrium

c) Chemical equilibrium d) Thermodynamic equilibrium

a) Thermal Equilibrium :

Two systems are said to be in thermal equilibrium with each other if they are at the same temperature , which will not change with time.

b) Mechanical equilibrium :

1. Consider a gas container with piston . When some mass is placed on the piston , it will move downward due to downward gravitational force and after certain humps and jumps the piston will come to rest at a new position.

2. When the downward gravitational force given by the piston is balanced by the piston is balanced by the upward force exerted by the gas , the system is said be in mechanical equilibrium .

3. A system is said to be in mechanical equilibrium if no unbalanced force acts on the thermodynamics system or on the surrounding by thermodynamic system.

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c) Chemical Equilibrium :

If there is no net chemical reaction between two thermodynamics systems in contact with each other then it is said to be in chemical equilibrium.

d) Thermodynamic Equilibrium :

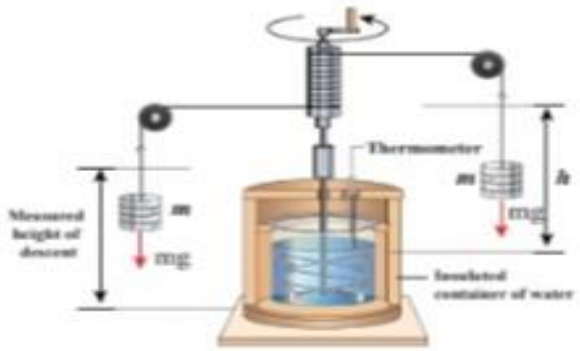
1. If two systems are said to be in thermodynamic equilibrium , then the systems are at thermal , mechanical and chemical equilibrium with each other.

2. In a state of thermodynamic equilibrium the macroscopic variables such as pressure , volume and temperature will have fixed values and do not change with time.

---

10. Explain Joule's experiment of the mechanical equivalent of heat.

Diagram :



1. Joule showed that mechanical energy can be converted into internal energy . In his experiment , two masses were attached with a rope and a paddle wheel.

2. When these masses fall through a distance h due to gravity , both the masses lose potential energy equal to 2 m g h.

3. When the masses fall , the paddle wheel turns . Due to the turning of wheel inside water , frictional force comes in between the water and paddle wheel.

4. This cause a rise in temperature of the water. This implies that gravitational potential energy is converted to internal energy of water.

5. The temperature of water increases due to the work done by the masses . Joule was able to show that the mechanical work has the same effect as giving heat.

6. He found that to raise 1 g of an object by 1^0 C , 4 .1 8 6 J of energy is required. In earlier days the heat was measured in calorie.

1 Cal = 4 .1 8 6 J

- **This is called Joule's mechanical equivalent of heat.**

---

11. Derive the expression for the work done in a volume change in a thermodynamics system.

1. Consider a gas contained in the cylinder fitted with a movable piston.

2. Suppose the gas is expanded quasi statically by pushing the piston by a small distance dx.

3. Since the expansion occurs quasi - statically the pressure , temperature and internal energy will have unique values at every instant. The small work done by the gas on the piston d W = F d x

4. The force exerted by the gas on the piston F = P A . Here A is area of the piston and P is pressure exerted by the gas on the piston.

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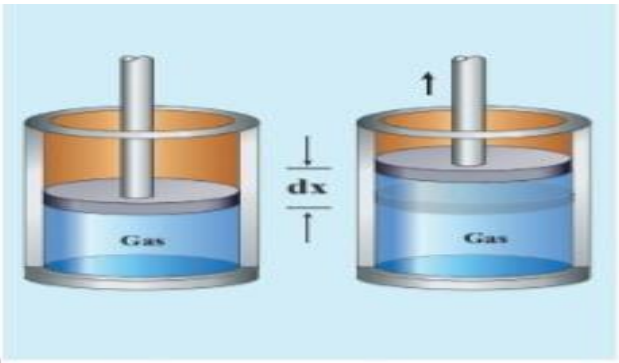
Diagram :



Derivation :

1 $dW = F\,dx$

2. $F = P\,A$

3. $dW = P\,A\,dx$

4. $\int dW = \int_{V_i}^{V_f} P\,dV$

5. $W = \int_{V_i}^{V_f} P\,dV$

6. Work is done by the system then $V_i < V_f$ then W is positive.

7. Work is done on the system then $V_i > V_f$ then W is negative.

---

12. Derive Mayer's relation for an ideal gas.

1. Consider μ mole of an ideal gas in a container with volume V , pressure P and temperature T.

2. When the gas is heated at constant volume the temperature increases by d T.

3. As no work is done by the gas , the heat that flows into the system will increase only the internal energy . Let the change in internal energy by d U.

4. If C_V is the molar specific heat capacity at constant volume.

$$dU = \mu C_V\,dT \quad \text{----------} \quad (1)$$

5. The gas is heated at constant pressure so that the temperature increases by d T . If ' Q ' is the heat supplied in this process and 'd V ' the change in volume of the gas.

$$Q = \mu C_P\,dT \quad \text{----------} \quad (2)$$

6. If W is the work done by the gas $W = P\,d\,V$ ---------- (3)

7. First law of thermodynamics $Q = dU + W$ ---------- (4)

8. Sub eqn (1) , (2) , (3) in (4)

$$\mu C_P\,dT = \mu C_V\,dT + P\,d\,V \quad \text{----------} \quad (5)$$

9. For mole of ideal gas equation , $P\,V = \mu\,R\,T$

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10. Diff the above eqn $P\,dV + V\,dP = \mu R\,dT$

11. Since the pressure is constant , $dP = 0$ then $P\,dV = \mu R\,dT$ ----- (6)

12. Sub eqn (6) in (5) ➔ $\mu C_P\,dT = \mu C_V\,dT + \mu R\,dT$

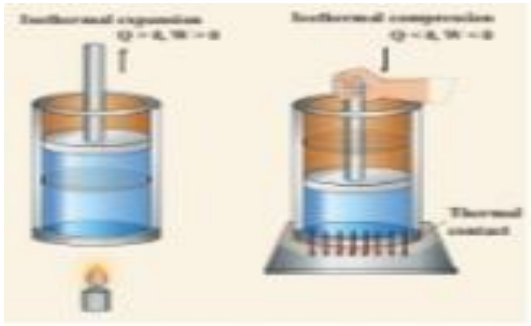
13. $\mu C_P\,dT - \mu C_V\,dT = \mu R\,dT$

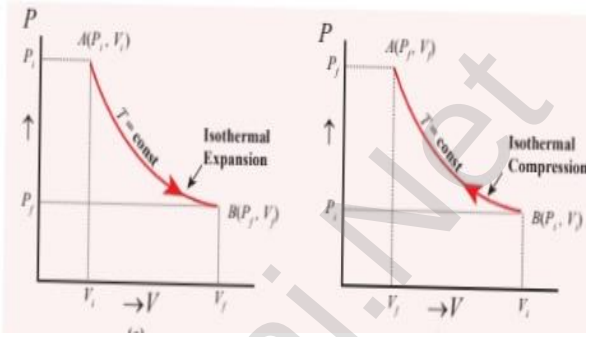
14 . $\mu (C_P - C_V)\,dT = \mu R\,dT$

15. $C_P - C_V = R$ " Mayer's Relation "

---

13. Explain in detail the isothermal process.





1. It is a process in which the temperature remains constant.

2. But the pressure and volume of thermodynamic system will change.

3. Equation of state for isothermal process : PV = constant

4. If the gas goes from one equilibrium state (P_1 , V_1) to another equilibrium state (P_2 , V_2) then

$$P_1 V_1 = P_2 V_2$$

5. P V graph is *hyperbola* . P V diagram is also called *isotherm*.

6. Temperature is constant , internal energy is also constant . $\Delta U = 0$

7. First law of thermodynamics , $Q = W$

8. Isothermal expansion and compression takes place.

9. The isothermal compression takes place when the piston of the cylinder is pushed.

10. This will increase the internal energy which will flow out of the system through thermal contact.

---

14. Derive the work done in an isothermal process.

1. Consider an ideal gas which is allowed to expand quasi - statically at constant temperature from initial state (P_i , V_i) to the final state (P_f , V_f) .

2. Work done by the gas , $W = \int_{V_i}^{V_f} P\,dV$ ➔ (1)

3. Ideal gas equation $PV = \mu R T$ then $P = \frac{\mu R T}{V}$ ➔ (2)

4. Sub eqn (2) in (1) $W = \int_{V_i}^{V_f} \mu \frac{R T}{V}\,dV$

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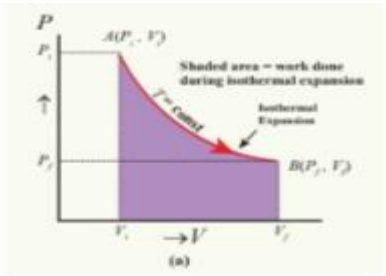
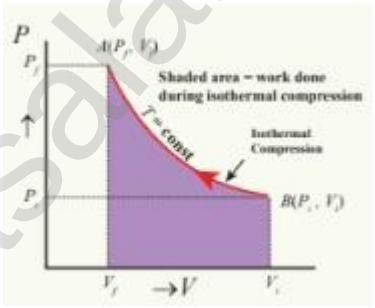
5. $W = \mu R T \int_{V_i}^{V_f} \frac{dV}{V}$

6. $W = \mu R T \ell n \left(\frac{V_f}{V_i} \right)$

S.NO	Isothermal Expansion	Isothermal Compression
1.	$\frac{V_f}{V_i} > 1$	$\frac{V_f}{V_i} < 1$
2.	$\ell n \left(\frac{V_f}{V_i} \right) > 0$	$\ell n \left(\frac{V_f}{V_i} \right) < 0$
3.	Work done by the gas is positive	Work done by the gas is negative
4.		

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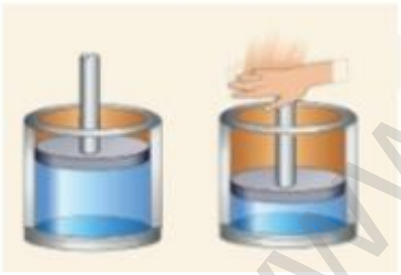
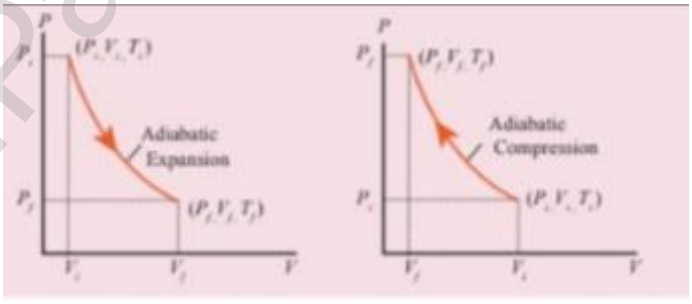
15. Explain in detail an adiabatic process.





1. This is a process in which no heat flows into or out of the system (Q = 0)

2. The pressure , volume and temperature of the system may change .

3. Equation of state for adiabatic process : $P V^{\gamma}$ = constant --------- (1)

4. Adiabatic exponent $\gamma = C_P / C_V$

5. If the gas goes from one equilibrium state (P_i , V_i) to another equilibrium state (P_f , V_f) then

$$P_i V_i^{\gamma} = P_f V_f^{\gamma}$$

6. P V diagram is also called *adiabat.*

7. First law of thermodynamics : $\Delta U = Q - P \Delta V$

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8. Ideal gas equation $P V = \mu R T$ then $P = \frac{\mu R T}{V}$ ----- (2)

9. Sub eqn (2) in (1)

$$\frac{\mu R T}{V} V^{\gamma} = \text{Constant}$$

10. $T V^{\gamma - 1} = \text{Constant}$

11. $T^{\gamma} P^{1-\gamma} = \text{Constant}$

---

16. Derive the work done in an adiabatic process.

1. Consider μ moles of an ideal gas enclosed in a cylinder having perfectly non – conducting walls and base.

2. A frictionless and insulating piston of cross - sectional area A is fitted in the cylinder.

3. Let W be the work done when the system goes from the initial state (P_i , V_i , T_i) to the final state (P_f , V_f , T_f) adiabatically.

4. Work done by the gas , $W = \int_{V_i}^{V_f} P\, dV$ ➔ (1)

5. Adiabatic equation $P V^{\gamma} = \text{Constant}$ then $P = \frac{\text{Constant}}{V^{\gamma}}$ ➔ (2)

6. Sub eqn (2) in (1)

$$W_{adia} = \int_{V_i}^{V_f} \frac{Constant}{V^{\gamma}}\, dV$$

$$W_{adia} = \text{Constant} \int_{V_i}^{V_f} V^{-\gamma}\, dV$$

$$W_{adia} = \text{Constant} \left(\frac{V^{-\gamma+1}}{-\gamma+1} \right)_{V_i}^{V_f}$$

$$W_{adia} = \frac{\text{Constant}}{1 - \gamma} \left(\frac{1}{V_f^{\gamma - 1}} - \frac{1}{V_i^{\gamma - 1}} \right)$$

$$W_{adia} = \frac{1}{1 - \gamma} \left(\frac{\text{Constant}}{V_f^{\gamma - 1}} - \frac{\text{Constant}}{V_i^{\gamma - 1}} \right) \text{ ➔ (3)}$$

7. $P_i V_i^{\gamma} = P_f V_f^{\gamma} = \text{Constant}$ ➔ (4)

8. Sub eqn (4) in (3)

$$W_{adia} = \frac{1}{1 - \gamma} \left(\frac{P_f V_f^{\gamma}}{V_f^{\gamma - 1}} - \frac{P_i V_i^{\gamma}}{V_i^{\gamma - 1}} \right)$$

9. $W_{adia} = \frac{1}{1 - \gamma} \left(P_f V_f - P_i V_i \right)$

10. From ideal gas eqn , $P_f V_f = \mu R T_f$ and $P_i V_i = \mu R T_i$

11. $W_{adia} = \frac{\mu R}{1 - \gamma} (T_f - T_i)$

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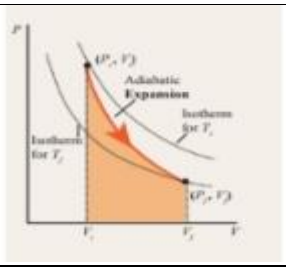
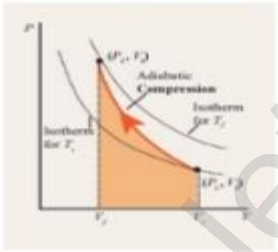
S.NO	Adiabatic Expansion	Adiabatic Compression
1.	$T_i > T_f$	$T_i < T_f$
2.	W_{adia} is positive .	W_{adia} is negative .
3.	Work done by the gas is positive	Work done by the gas is negative
4.		

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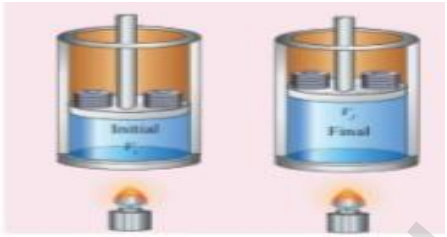
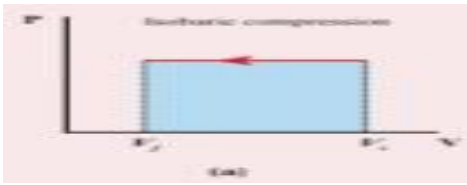
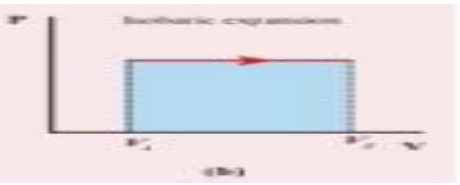
17. Explain the isobaric process and derive the work done in this process.

Diagram :



Isobaric Process :

1. This is a process that occurs at constant pressure .
2. The temperature , volume and internal energy are not constant.
3. Equation of state for isobaric process : $V \alpha T$; $\frac{V}{T}$ = Constant
4. V - T graph is a straight line .
5. If the gas goes from one equilibrium state (V_i , T_i) to another equilibrium state (V_f , T_f) then $\frac{T_f}{V_f} = \frac{T_i}{V_i}$

S.NO	Isobaric Expansion	Isobaric Compression
1.	ΔV is positive	ΔV is negative
2.	W_{adia} is positive	W_{adia} is negative
3.	Work done by the gas is positive	Work done by the gas is negative
4.		

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Work done in a isobaric process :

1. Work done by the gas , $W = \int_{V_i}^{V_f} P\,dV$ ➔ (1)

2. $W = P \int_{V_i}^{V_f} dV$

3. $W = P (V_f - V_i) = P \Delta V$ ➔ (2)

4. From ideal gas eqn $P V = \mu R T$ and $V = \frac{\mu R T}{P}$

5. $V_f = \frac{\mu R T_f}{P}$ and $V_i = \frac{\mu R T_i}{P}$ ➔ (3)

6. Sub eqn (3) in (2)

$$W = P\left(\frac{\mu R T_f}{P} - \frac{\mu R T_i}{P} \right)$$

$$W = \mu R \left(T_f - T_i \right)$$

$$W = \mu R T_f \left(1 - \frac{T_i}{T_f} \right)$$

7. First law of thermodynamics : $\Delta U = Q - P \Delta V$

---

18. Explain in detail the isochoric process.

1. This is a thermodynamics process in which volume of the system is kept constant.

2. But pressure , temperature and internal energy are variables.

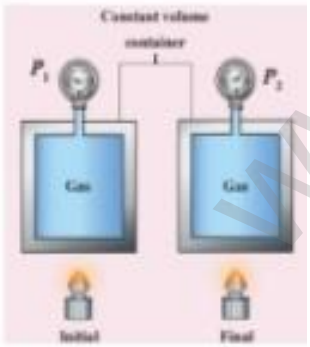
3. Equation of state for isochoric process : $P \propto T$; $\frac{P}{T}$ = Constant

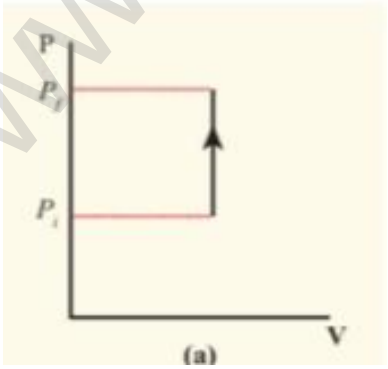
4. V - T graph is a straight line .

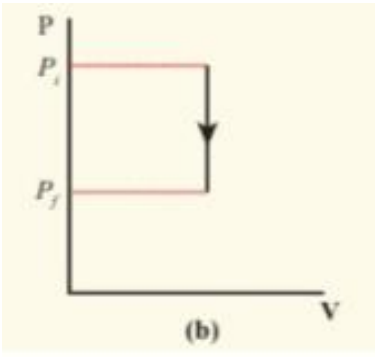
5. If the gas goes from one equilibrium state (P_i , T_i) to another equilibrium state (P_f ,T_f) then $\frac{P_i}{T_i} = \frac{P_f}{T_f}$

6. For an isochoric process $\Delta V = 0$ and $W = 0$

7. First law of thermodynamics : $\Delta U = Q$







8. Heat supplied is used to increase only the internal energy . As a result the temperature increases and pressure also increases.

9. Suppose a system loses heat to the surroundings through conducting walls by keeping the volume constant then its internal decreases. As a result the temperature decreases , the pressure also decreases.

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19. What are the limitations of the first law of thermodynamics ?

Limitations of the first law of thermodynamics :

The first law of thermodynamics explains the inter convertibility of heat and work . But it does not indicate the direction of change.

Example :

1. **When a hot object is in contact with a cold object , heat always flows from the hot object to cold object but not in the reverse direction.**
2. **According to first law , it is possible for the energy to flow from hot object to cold object or from cold object to hot object.**
3. **But in nature the direction of heat flow is always from higher to lower temperature.**
4. **When brakes are applied , car stops due to friction and the work done against friction is converted into heat.**
5. **But this heat is not reconverted to the kinetic energy of the car. So the first law is not sufficient to explain many of natural phenomena.**

---

20. Explain the heat engine and obtains its efficiency.

Heat Engine :

Heat engine is a device which takes heat as input & converts this heat into work by undergoing a cyclic process.

Parts of Heat Engine :

1. Hot Reservoir 2. Working Substance 3. Cold Reservoir

1. Hot Reservoir (or) Source :

It supplies heat to the engine. It is always maintained at a high temperature T_H.

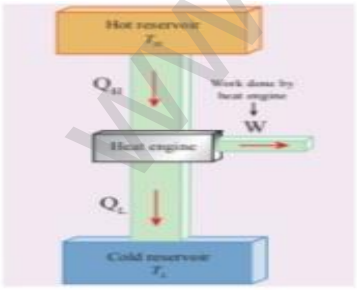
2. Working Substance :

It is a substance like gas or water . It converts the heat supplied into work.

3. Cold Reservoir (or) Sink :

Heat engine ejects some amount of heat Q_L into cold reservoir after it doing work . It is always maintained at a low temperature T_L .

Diagram :



Formula :

$$\eta = 1 - \frac{Q_H}{Q_L}$$

Working :

1. **The heat engine works in a cyclic process .**
2. **After a cyclic process it returns to the same state .**
3. **Since the heat engine returns to the same state after it ejects heat , the change in the internal energy of the heat engine is zero.**

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Efficiency :

The efficiency of the heat engine is defined as the ratio of the work done (output) to the heat absorbed (input) in one cyclic process.

- **Working substance absorb heat → Q_H**
- **Working substance reject heat → Q_L**
- **Input heat = Work done + Ejected heat**
- $Q_H = W + Q_L$
- $\eta = \frac{\text{Output}}{\text{Input}}$
- $\eta = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$
- $Q_L < Q_H$, η **less than 1.**
- **This implies that heat absorbed is not completely converted into work.**

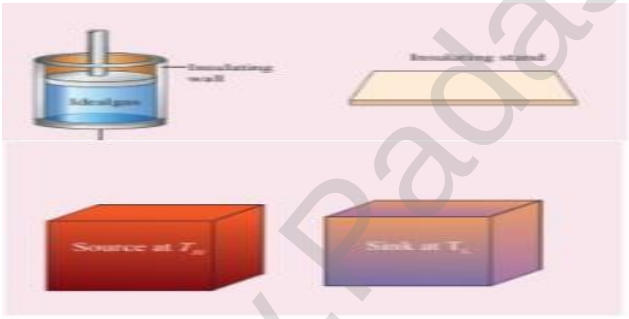
---

21. Explain in detail Carnot heat engine.

Carnot Engine :

A reversible heat engine operating in a cycle between two temperatures in a particular way is called Carnot engine.

Parts of Carnot engine :



1.Source :

- **It is the source of heat maintained at constant high temperature T_H .**
- **Any amount of heat can be extracted from it , without changing its temperature.**

2. Sink :

It is a cold body maintained at a constant low temperature T_L . It can absorb any amount of heat .

3. Insulating Stand :

It is made of perfectly non - conducting material . Heat is not conducted through this stand.

4. Working Substance :

1. It is an ideal gas enclosed in cylinder with perfectly non - conducting walls & perfectly conducting bottom.

2. A non - conducting and frictionless piston is fitted in it.

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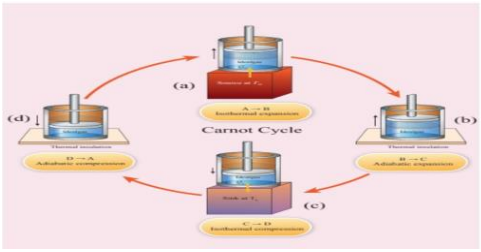
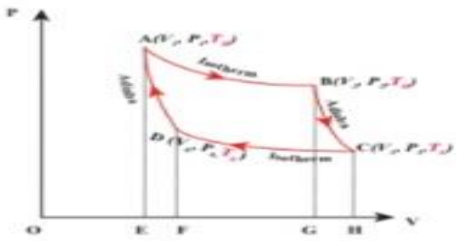
Carnot Cycle :





1. Step A to B :

1. Quasi – static isothermal expansion from (P_1 , V_1 , T_H) to (P_2 , V_2 , T_H)
2. Cylinder is placed on the source .
3. Heat (Q_H) flows from source to the working substance.
4. Volume of gas expands from V_1 to V_2 .
5. Pressure decrease from P_1 to P_2.
6. P - V diagram along the path AB.

$$W_{A\to B} = \int_{V_1}^{V_2} P\,dV = \mu R T_H \ell n \left(\frac{V_2}{V_1}\right) = \text{Area under the curve AB}$$

2. Step A to B :

1. Quasi – static adiabatic expansion from (P_2 , V_2 , T_H) to (P_3 , V_3 , T_L)
2. Cylinder is placed on the insulating stand .
3. Temperature falls to T_L.
4. Volume of gas expands from V_2 to V_3 .
5. Pressure decrease from P_2 to P_3.
6. P - V diagram along the path BC.

$$W_{B\to C} = \int_{V_2}^{V_3} P\,dV = \left(\frac{\mu R}{\gamma - 1}\right)[T_H - T_L] = \text{Area under the curve BC}$$

3. Step C to D :

1. Quasi – static isothermal compression from (P_3 , V_3 , T_L) to (P_4 , V_4 , T_L)
2. Cylinder is placed on the sink .
3. Heat (Q_H) flows from source to the working substance.
4. Volume of gas become V_4 .
5. Pressure of gas P_4.
6. P - V diagram along the path CD.

$$W_{C\to D} = \int_{V_3}^{V_4} P\,dV = \mu R T_L \ell n \left(\frac{V_4}{V_3}\right) = -\text{Area under the curve CD}$$

4. Step D to A :

1. Quasi – static adiabatic compression from (P_4 , V_4 , T_L) to (P_1 , V_1 , T_H)
2. Cylinder is placed on the insulating stand .
3. Temperature rise to T_H.

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4. Volume of gas attains V_1.

5. Pressure of gas attains P_1.

6. P - V diagram along the path DA.

$$W_{D\to A} = \int_{V_4}^{V_1} P\,dV = \left(\frac{\mu R}{\gamma - 1}\right)[T_L - T_H] = \text{Area under the curve DA}$$

---

22. Derive the expression for Carnot engine efficiency .

Efficiency :

The ratio of work done by the working substance in one cycle to the amount of heat extracted from the source.

$$\eta = \frac{\text{Work done}}{\text{Heat Extracted}} = \frac{W}{Q_H}$$

1. From the first law of thermodynamics $W = Q_H - Q_L$

2. Efficiency : $\eta = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$ -------- (1)

3. Applying isothermal conditions

$$Q_H = \mu R T_H \ell n\left(V_2 / V_1\right)$$

$$Q_L = \mu R T_L \ell n\left(V_3 / V_4\right)$$

4. $$\frac{Q_L}{Q_H} = \frac{\mu R T_L \ell n\left(V_3 / V_4\right)}{\mu R T_H \ell n\left(V_2 / V_1\right)}$$

5. $$\frac{Q_L}{Q_H} = \frac{T_L \ell n\left(V_3 / V_4\right)}{T_H \ell n\left(V_2 / V_1\right)}$$ -------- (2)

6. Applying adiabatic conditions

$$T_H V_2^{\gamma - 1} = T_L V_3^{\gamma - 1}$$

$$T_H V_1^{\gamma - 1} = T_L V_4^{\gamma - 1}$$

7. $$\frac{T_H V_2^{\gamma - 1}}{T_H V_1^{\gamma - 1}} = \frac{T_L V_3^{\gamma - 1}}{T_L V_4^{\gamma - 1}}$$

8. $$\left(\frac{V_2}{V_1}\right)^{\gamma - 1} = \left(\frac{V_3}{V_4}\right)^{\gamma - 1}$$

9. $$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$ -------- (3)

10. Sub eqn (3) in (2)

$$\frac{Q_L}{Q_H} = \frac{T_L \ell n\left(V_3 / V_4\right)}{T_H \ell n\left(V_3 / V_4\right)}$$

11. $$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$ -------- (4)

12. Sub eqn (4) in (1)

$$\boxed{\eta = 1 - \frac{T_L}{T_H}}$$

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23. Explain the second law of thermodynamics in terms of entropy.

1. **Quantity Q / T is called entropy.**

2. **It is a very important thermodynamic property.**

3. **It is also a state variable.**

4. **Q_H / T_H is the entropy received by the Carnot engine from hot reservoir.**

5. **Q_L / T_L is the entropy given out by the Carnot engine to cold reservoir.**

6. **For reversible engines both entropies should be same.**

7. **The change in entropy of the Carnot engine in one cycle is zero.**

8. **For all practical engines like diesel and petrol engines which are not reversible engines , they satisfy the relation Q_L / T_L > Q_H / T_H.**

9. **" For all the process that occur in nature , the entropy always increases . For reversible process entropy will not change " .**

10. **Entropy determines the direction in which natural process should occur.**

11. **Entropy increases when heat flows from hot object to cold object. If heat flow from cold to hot object , entropy decreases leading to violation of second law of thermodynamics.**

12. **Entropy is also called " measure of disorder " . All natural process occur such that the disorder should always increases.**

EX :

A drop of ink diffusing into water . Once the drop of ink spreads , its entropy is increases its entropy is increased. The diffused ink can never become a drop again. So the natural processes occur in such a way that entropy should increase for all irreversible process.

---

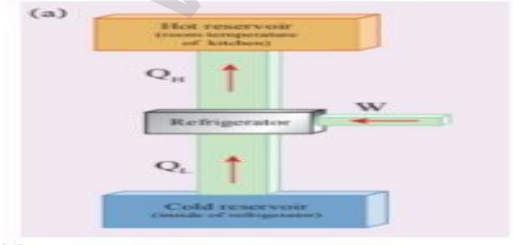
24 . Explain in detail the working of a refrigerator.

A refrigerator is a Carnot's engine working in the reverse order.

Working Principle :

1. **The working substance (gas) absorb a quantity of heat Q_L from the cold body (sink) at lower temperature T_L .**
2. **A certain amount of work W is done on the working substance by the compressor.**
3. **A quantity of heat Q_H is rejected to the hot body (source) at T_H .**
4. **When you stand beneath of refrigerator , you can feel warmth air.**
5. **From the first law of thermodynamics : $Q_L + W = Q_H$**
6. **As a result the cold reservoir (refrigerator) further cools down and the surroundings kitchen gets hotter.**

Diagram :



$$COP = \beta = \frac{Q_L}{W}$$

Coefficient of performance :

It is defined as the ratio of heat extracted from the cold body to the external from the cold body to the external work done by the compressor .

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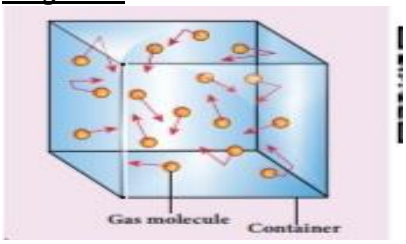
9 . Kinetic theory of gases

1. Write down the postulates of kinetic theory of gases

1. All molecules of a gas are identical elastic spheres.
2. The molecules of different gases are different.
3. The molecules of a gas are in a state of continuous random motion.
4. The molecules obey Newton's laws of motion even though they move randomly.
5. The molecules collide with one another and also with the walls of the container.
6. These collision are perfectly elastic there is no loss of kinetic energy during collision.
7. Between two successive collisions , molecule moves with uniform velocity.

2.Derive the expression of pressure exerted by the gas on the walls of the container.

Diagram :



Formula :

$$P = \frac{1}{3} n m \bar{v}^2$$

Theory :

Consider a monoatomic gas inside a cubical container.

- Mass of the molecule → m
- Velocity of the molecule → v
- Number of the molecule → N

Pressure exerted by the gas molecule

1. Molecules of gas are in random motion.
2. They collide with each other and with container walls.
3. There is no loss of kinetic energy.
4. Change in momentum occurs.
5. Due to momentum , experiences force.
6. Force per unit area determines pressure exerted by the gas molecules.

Derivation :

1. Component of velocity : v_x , v_y , v_z
2. Momentum of the molecule :

Before collision = $m v_x$

After collision = $- m v_x$

Change in momentum = $- m v_x - m v_x = - 2 m v_x$

3. Law of conservation of momentum = $2 m v_x$

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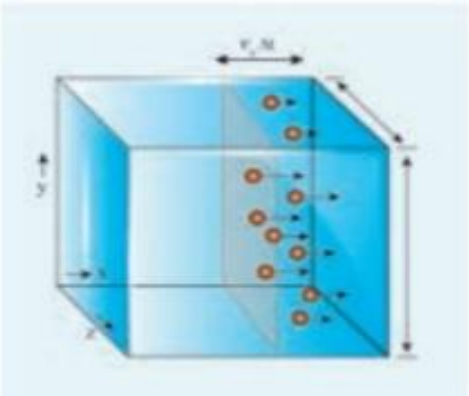

4. Number of molecules hit right side wall $= \frac{n}{2} A v_x \Delta t$

5. Total momentum transfer by molecule $\Delta p = \frac{n}{2} A v_x \Delta t \times 2 m v_x = A v_x^2 nm \Delta t$

6. Newton's second law : $F = \frac{\Delta p}{\Delta t} = n m A v_x^2$

7. Pressure exerted by gas molecule : $P = \frac{F}{A} = n m v_x^2$

8.The molecules do not have same speed . so we can replace the term v_x^2 **by the average** $\overline{v_x}^2$

$$P = n m \overline{v_x}^2$$

9.The molecules have same average speed.

$$\overline{v_x}^2 = \overline{v_y}^2 = v_z^2$$

$$\overline{v}^2 = \overline{v_x}^2 + \overline{v_x}^2 + \overline{v_x}^2 = 3\overline{v_x}^2$$

$$\overline{v_x}^2 = \frac{1}{3}\overline{v}^2$$

10. $P = \frac{1}{3} n m \overline{v^2} = \frac{1}{3}\frac{N}{V} m v^2$ ($n = N / V$)

---

3. Explain in detail the kinetic interpretation of temperature.

1. Microscopic Origin of temperature

$$P = \frac{1}{3}\frac{N}{V} m \overline{v^2}$$

$$P V = \frac{1}{3} N m \overline{v^2}$$

2. Ideal gas equation $P V = N K T$

$$N K T = \frac{1}{3} N m \overline{v^2}$$

$$K T = \frac{1}{3} m \overline{v^2}$$

3. Multiply both sides by 3 / 2

$$\frac{3}{2} K T = \frac{3}{2}\frac{1}{3} m \overline{v^2}$$

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$\frac{3}{2} K T = \frac{1}{2} m \overline{v^2}$

$\frac{1}{2} m \overline{v^2} = \frac{3}{2} K T$

4. Average kinetic energy per molecule $\overline{K.E} = \frac{3}{2} K T$

5. Average K.E directly proportional to temperature.

6. Average K.E depends only on temperature not on mass of the molecule.

7. Internal energy of ideal gas $U = N \left(\frac{1}{2} m \overline{v^2} \right) = \frac{3}{2} N K T$

---

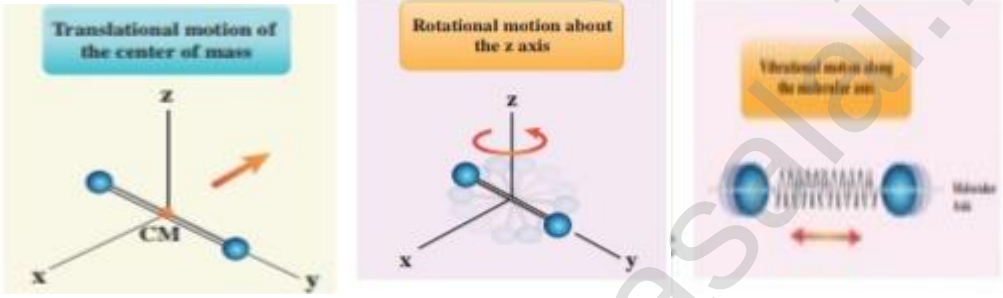
4. Describe the total degrees of freedom for monoatomic molecule , diatomic molecule and triatomic molecule.

1.Monoatomic Molecule

It has three translational degrees of freedom. $f = 3$

Example : He , Ne , Ar

2.Diatomic Molecule :



At Normal Temperature	At High Temperature
Translational : f = 3	Translational : f = 3
Rotational : f = 2	Rotational : f = 2
Degrees of freedom : f = 5	Vibrational : f = 2
	Degrees of freedom : f = 7

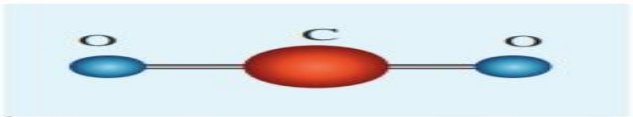
3 .Triatomic Molecule :

i) Linear Triatomic molecule

i i) Non - Linear Triatomic molecule

i) Linear Triatomic molecule

Two atoms lie on either side of central atom. Example : Carbon di oxide



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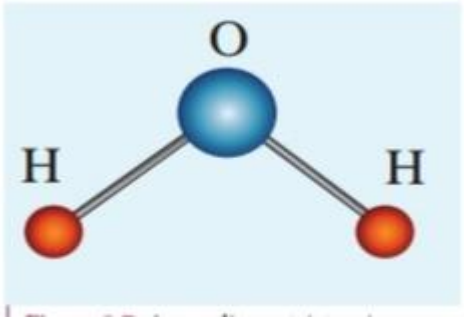
At Normal Temperature	At High Temperature
Translational : f = 3	Translational : f = 3
Rotational : f = 2	Rotational : f = 2
Degrees of freedom : f = 5	Vibrational : f = 2
	Degrees of freedom : f = 5

i i) Non - Linear Triatomic molecule

Three atoms lie at the vertices of triangle. Example : H_2O



Translational : f = 3
Rotational : f = 3
Degrees of freedom : f = 6

---

5. Derive the ratio of two specific heat capacities of monoatomic , diatomic and triatomic molecules.

1. Total energy of a one mole of gas : $U = \frac{3}{2} RT$

2. Mayer's relation of specific heat : $C_p = C_V + R$

3. Ratio between two specific heats : $\gamma = \frac{C_P}{C_V}$

i . Monoatomic Molecule

1. $C_V = \frac{dU}{dT} = \frac{d}{dT}\left[\frac{3}{2} RT\right] = \frac{3}{2} R$

2. $C_p = C_V + R = \frac{3}{2} R + R = \frac{5}{2} R$

3. $\gamma = \frac{C_P}{C_V} = \frac{5/2\ R}{3/2\ R} = \frac{5}{3} = 1.67$

ii . Diatomic Molecule

1. At Low Temperature

1. $C_V = \frac{dU}{dT} = \frac{d}{dT}\left[\frac{5}{2} RT\right] = \frac{5}{2} R$

2. $C_p = C_V + R = \frac{5}{2} R + R = \frac{7}{2} R$

3. $\gamma = \frac{C_P}{C_V} = \frac{7/2\ R}{5/2\ R} = \frac{7}{5} = 1.4$

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2. At High Temperature

1. $C_V = \frac{dU}{dT} = \frac{d}{dT}\left[\frac{7}{2} R T\right] = \frac{7}{2} R$

2. $C_p = C_V + R = \frac{7}{2} R + R = \frac{9}{2} R$

3. $\gamma = \frac{C_P}{C_V} = \frac{9/2\ R}{7/2\ R} = \frac{9}{7} = 1.28$

iii .Triatomic Molecule

1. Linear Molecule :

1. $C_V = \frac{dU}{dT} = \frac{d}{dT}\left[\frac{7}{2} R T\right] = \frac{7}{2} R$

2. $C_p = C_V + R = \frac{7}{2} R + R = \frac{9}{2} R$

3. $\gamma = \frac{C_P}{C_V} = \frac{9/2\ R}{7/2\ R} = \frac{9}{7} = 1.28$

2. At High Temperature

1. $C_V = \frac{dU}{dT} = \frac{d}{dT}\left[\frac{6}{2} R T\right] = 3 R$

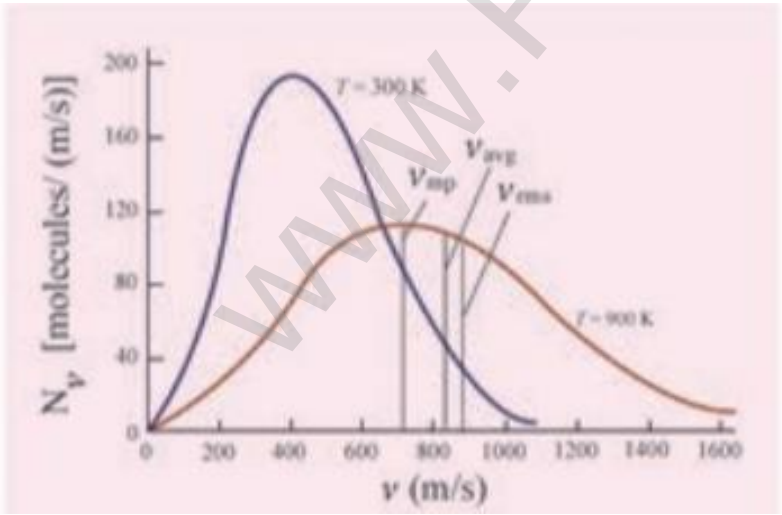
2. $C_p = C_V + R = 3R + R = 4R$

3. $\gamma = \frac{C_P}{C_V} = \frac{4R}{3R} = \frac{4}{3} = 1.33$

---

6. Explain in detail the Maxwell Boltzmann distribution function.

Maxwell Boltzmann distribution function:



1. **In a class room , the air molecules are moving in random directions.**
2. **The speed of each molecule is not the same.**
3. **Difficult to calculate the speed of each molecule.**

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4. **Each molecule collide with every other molecule.**
5. **And the molecules exchanges their speed.**
6. **We can calculate the RMS speed of each molecule.**
7. **Gas molecules have range of speed from v to v + dv.**

Formula :

$$N_v = 4\pi N \left(\frac{m}{2\pi KT}\right)^{3/2} v^2 e^{-m v^{2/2KT}}$$

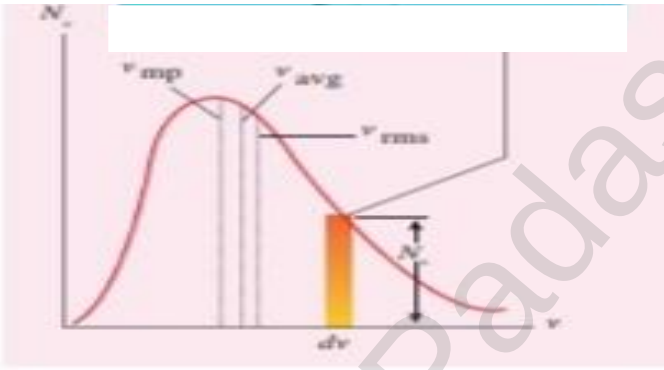
- **Number of molecules having lower speed**

  i) Increases parabolically (v^2)

  ii) Decreases exponentially ($e^{-m v^{2/2KT}}$)

- **The rms speed, average speed and most probable speed are calculated.**
- **The rms speed is greater among the three.**
- **Area under each graph is same since it represents total number of gas molecules.**

Graph:



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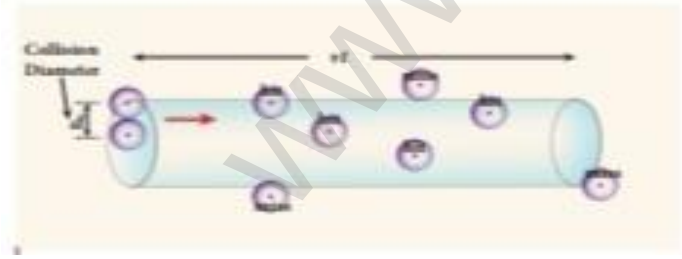
7. Derive the expression for mean free path of the gas.

Diagram :



Formula :

$$\lambda = \frac{1}{\sqrt{2}\, n \pi d^2}$$

Theory :

- **Consider only one molecule is in motion.**
- **All others are at rest in an imaginary cylinder.**

Explanation :

1. **Number of molecule** ⟶ **n**
2. **Diameter of molecule** ⟶ **d**

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3. Speed of molecule → v

4. Time taken by molecule → t

5. Distance travel by molecule → v t

6. Area of the cylinder → πd^2

7. Volume of the cylinder → $\pi d^2 v t$

8. Number of collision → $n \pi d^2 v t$

Derivation:

$$\text{Mean free path} = \frac{\text{Distance travelled}}{\text{Number of collisions}}$$

$$\lambda = \frac{v t}{n \pi d^2 v t} = \frac{1}{n \pi d^2} = \frac{1}{\sqrt{2}\, n \pi d^2}$$

Case I :

1. $\lambda = \frac{1}{\sqrt{2}\, n \pi d^2}$

2. $\lambda = \frac{1}{\sqrt{2}\, n \pi d^2} \times \frac{m}{m}$

3. $\lambda = \frac{m}{\sqrt{2}\, \pi d^2 n m}$

4. $\lambda = \frac{1}{\sqrt{2}\, \pi d^2 \rho}$

Case ii :

1. $P V = N K T$

2. $P = \frac{N}{V} K T$

3. $P = n K T$

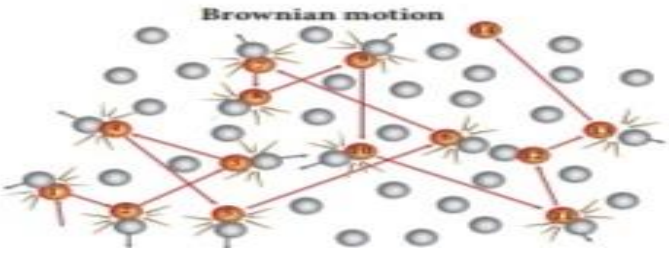
4. $n = \frac{P}{K T}$

5. $\lambda = \frac{K T}{\sqrt{2}\, \pi d^2 P}$

---

8. Describe the Brownian motion.

Diagram:



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Robert Brown

- **Grains of pollen in a liquid moves randomly .**
- **Pollen in a liquid moves in Zig – zag path.**
- **It is called as " Brownian Motion "**

Wiener Gouy

- **Brownian motion is due to the bombardment of particles of molecules in fluid.**

Einstein

- **Brownian motion based on the kinetic theory.**
- **Deduce average size of molecule.**

Reason for Brownian motion:

- **Any particle in a liquid bombarded from all the directions .**
- **Mean free path is almost negligible.**
- **It leads the particle motion in zig – zag.**

Factors affect Brownian motion

- **Brownian motion increases with increasing temperature.**
- **Brownian motion decreases with particle size , high viscosity and density.**

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10. Oscillations

1. What is meant by simple harmonic oscillations ? Give examples and explain SHM is a periodic motion.

S H M :

S H M means that Simple Harmonic Motion . It is a special type of oscillatory motion.

Acceleration :

- **Acceleration on the particle is directly proportional to its displacement.**

$$a_x \ \alpha \ x \ ; \quad a_x = - b x$$

- **x ⟶ Displacement**
- **a_x ⟶ Acceleration**
- **b ⟶ Acceleration per unit displacement**

Force :

From Newton's second law

- **Force on the particle is directly proportional to its displacement.**
- **$F_x \ \alpha \ x \ ; \quad F_x = - k x$**
- **k → Force Constant = Force per unit displacement**

Displacement :

- **Force towards left of equilibrium position x takes positive value.**
- **Force towards right of equilibrium position x takes negative value.**

Restoring force :

Particle execute SHM to restore its original position or equilibrium position.

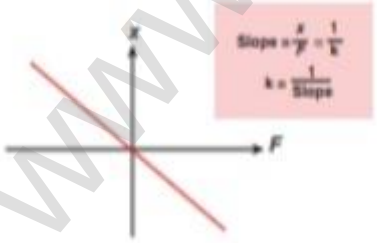
In vector notation :

$$\vec{F} = = K \vec{r}$$

- **r → Displacement of the particle from the origin**
- **Force and displacement have linear relationship.**

Graph :

Graph between force and displacement is straight line.



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3. What is meant by angular harmonic oscillation ? Compute the time period of angular harmonic oscillation ?

1. Angular Oscillation : When a body is allowed to rotate freely about a given axis , it is angular oscillation.

2. Mean Position : The point at which the resultant torque acting on the body is taken to be zero.

3.Torque : Torque is directly proportional to the angular displacement.

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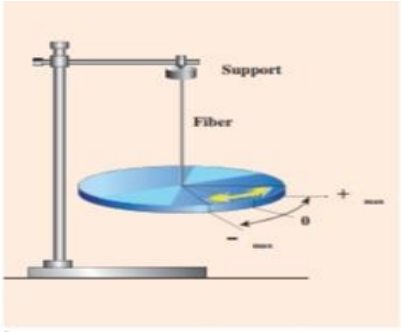
Diagram :



Derivation :

1. $\tau \propto \theta$
2. $\tau = -k\theta$
3. $\tau = I\alpha$
4. $I\alpha = -k\theta$
5. $\alpha = -\frac{k}{I}\theta$
6. $\frac{d^2\theta}{dt^2} = -\frac{k}{I}\theta$
7. $-\omega^2\theta = -\frac{k}{I}\theta$
8. $\omega^2 = \frac{k}{I}$
9. $\omega = \sqrt{\frac{k}{I}}$
10. $2\pi f = \sqrt{\frac{k}{I}}$
11. $f = \frac{1}{2\pi}\sqrt{\frac{k}{I}}$
12. $T = 2\pi\sqrt{\frac{I}{k}}$

---

4. Difference between simple harmonic motion and angular simple harmonic motion.

S.NO	Simple Harmonic Motion	Angular Harmonic Motion
1.	Linear displacement of the particle $\vec{r}$	Angular displacement of the particle $\vec{\theta}$
2.	Acceleration of the particle : $\vec{a} = -\omega^2 \vec{r}$	Acceleration of the particle : $\vec{\alpha} = -\omega^2 \vec{\theta}$
3.	Force : $\vec{F} = m\vec{a}$	Torque : $\vec{\tau} = I\vec{\alpha}$
4.	Restoring Force : $\vec{F} = -k\vec{r}$	Restoring Torque : $\vec{\tau} = -k\vec{\theta}$
5.	Angular Frequency : $\omega = \sqrt{\frac{k}{m}}$	Angular Frequency : $\omega = \sqrt{\frac{k}{I}}$

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5. Describe about simple pendulum in detail.

1. **It exhibits periodic motion.**
2. **It has a bob with mass m.**
3. **It is suspended by a long string.**
4. **Length of the pendulum is l.**
5. **At equilibrium , The pendulum not oscillate.**
6. **The bob of pendulum displaced from mean position , it executes to and fro motion.**

7. **Force acts on the bob is classified as two types.**

i) Gravitational Force $\vec{F}$ ii) Tensional Force $\vec{T}$

8. Component of gravitational force :

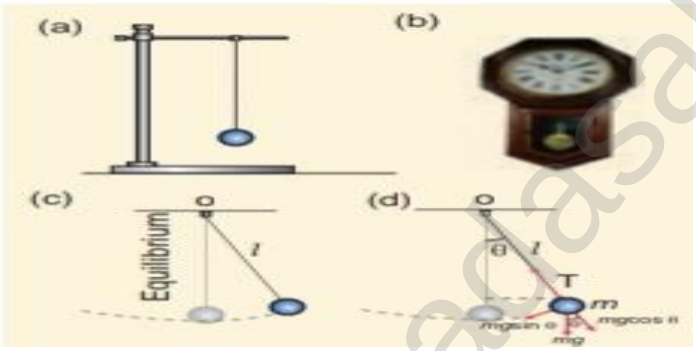
i) Normal Component : $F_{as} = mg\cos\theta$ ii) Tangential Component : $F_{ps} = mg\sin\theta$

9. $T - F_{as} = ma$

$$T - mg\cos\theta = m\frac{v^2}{l}$$

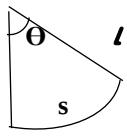
10. $$m\frac{d^2s}{dt^2} + F_{ps} = 0$$

Diagram :



Derivation :

1. $$m\frac{d^2s}{dt^2} = -F_{ps}$$
2. $$m\frac{d^2s}{dt^2} = -mg\sin\theta$$
3. $$\frac{d^2s}{dt^2} = -g\sin\theta$$
4. $$l\frac{d^2\theta}{dt^2} = -g\sin\theta$$
5. $$\frac{d^2\theta}{dt^2} = -\frac{g}{l}\sin\theta$$
6. $$-\omega^2\theta = -\frac{g}{l}\theta$$
7. $$\omega^2 = \frac{g}{l}$$
8. $$\omega = \sqrt{\frac{g}{l}}$$



$s = l\theta$ $\quad \frac{d^2s}{dt^2} = l\frac{d^2\theta}{dt^2}$

$\sin\theta = \theta$

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9. $2\pi f = \sqrt{\frac{g}{l}}$

10. $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$

11. $T = 2\pi\sqrt{\frac{l}{g}}$

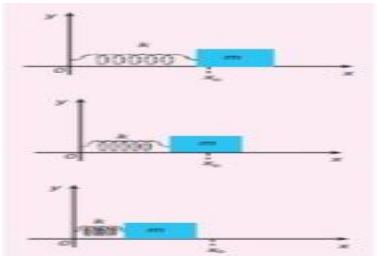
---

6. Explain the horizontal oscillations of a spring.

Theory :

1. Consider a block of mass m.
2. Equilibrium position or mean position x_0 .
3. Small displacement of mass is x.
4. Restoring force be F.
5. Stiffness constant or force constant be k.

Diagram :



Formula :

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Derivation :

1. $F \alpha x$
2. $F = -kx$
3. $ma = -kx$
4. $m\frac{d^2x}{dt^2} = -kx$
5. $\frac{d^2x}{dt^2} = -\frac{k}{m}x$
6. $-\omega^2 x = -\frac{k}{m}x$
7. $\omega^2 = \frac{k}{m}$
8. $\omega = \sqrt{\frac{k}{m}}$
9. $2\pi f = \sqrt{\frac{k}{m}}$
10. $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$
11. $T = 2\pi\sqrt{\frac{m}{k}}$

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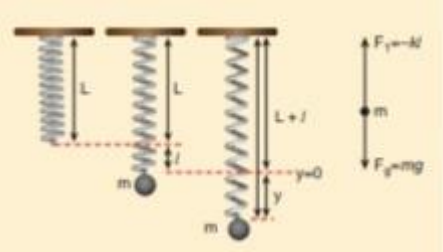
7. Explain the vertical oscillations of a spring.

Diagram:



Theory :

1. **Consider a block of mass m.**
2. **Length of a spring before loading L.**
3. **Length of a spring after loading l.**
4. **Restoring force due to stretched spring F_1.**
5. **Small external force applied is F_2.**

Derivation :

1. $F_1 + m g = 0$
2. $F_1 \alpha l$
3. $F_1 = - K l$
4. $- K l + m g = 0$
5. $m g = k l$
6. $F_2 \alpha y + l$
7. $F_2 = - k (y + l)$
8. $F_2 = - k y - k l$
9. $F = F_2 + m g$
10. $F = - k y - k l + k l$
11. $F = - k y$
12. $m \frac{d^2 y}{d t^2} = - k y$
13. $- \omega^2 y = - k y$
14. $\omega^2 = \frac{k}{m}$
15. $\omega = \sqrt{\frac{k}{m}}$
16. $2 \pi f = \sqrt{\frac{k}{m}}$
17. $f = \frac{1}{2 \pi} \sqrt{\frac{k}{m}}$

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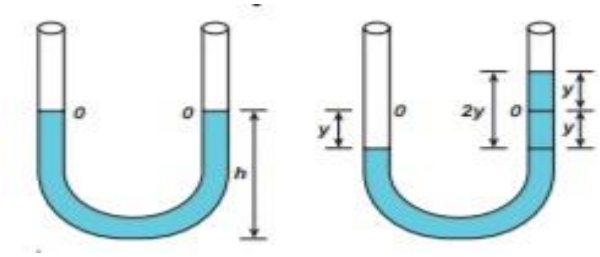
18. $T = 2\pi \sqrt{\frac{m}{k}}$

19. $g = 4\pi^2 \left(\frac{\ell}{T^2}\right)$

---

8. Oscillations of liquid column in U – tube.

Diagram :



Theory :

1. Consider U-shaped glass tube.
2. Consists of yow open arms.
3. Let us pour non- viscous incompressible liquid.
4. Density of the liquid is P.
5. Length of liquid column ℓ

Working :

1. If the tube is not disturbed, is in Equilibrium position.
2. By blowing air at one arm, the liquid gets disturbed.
3. Pressure difference cause the liquid to oscillate.
4. After short duration of time finally comes to rest.
5. Time period of oscillation:

$$T = 2\pi \sqrt{\frac{\ell}{2g}} \text{ sec}$$

---

9. Energy in simple harmonic motion.

Potential Energy :

1. $F = -\frac{dU}{dx}$

2. $-kx = -\frac{dU}{dx}$

3. $dU = k\,x\,dx$

4. $\int dU = K \int x\,dx$

5. $U = k\,\frac{x^2}{2}$

6. $U = \frac{1}{2} m\,\omega^2 x^2 \quad (k = m\,\omega^2)$

7. $U = \frac{1}{2} m\,\omega^2 A^2 \sin^2 \omega t \quad (x = A \sin \omega t)$

Kinetic Energy :

1. $x = A \sin \omega t$

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2. $v_x = \frac{dx}{dt} = A\omega \cos \omega t$

3. $K.E = \frac{1}{2} m v_x^2$

4. $K.E = \frac{1}{2} m \left(\frac{dx}{dt}\right)^2$

5. $K.E = \frac{1}{2} m A^2 \omega^2 \cos^2 \omega t = \frac{1}{2} m A^2 \omega^2 (1 - \sin^2 \omega t)$

6. $K.E = \frac{1}{2} m A^2 \omega^2 \left(1 - \frac{x^2}{A^2}\right)$

7. $K.E = \frac{1}{2} m \omega^2 (A^2 - x^2)$

Total Energy :

1. $E = U + K.E$

2. $E = \frac{1}{2} m \omega^2 x^2 + \frac{1}{2} m \omega^2 (A^2 - x^2)$

3. $E = \frac{1}{2} m \omega^2 A^2$

Another method :

1. $E = \frac{1}{2} m \omega^2 A^2 \sin^2 \omega t + \frac{1}{2} m \omega^2 A^2 \cos^2 \omega t$

2. $E = \frac{1}{2} m \omega^2 A^2$

---

10. Explain in detail the four different types of oscillations.

1. Free Oscillations :

When oscillator is allowed to oscillate by displacing its position from equilibrium position, its oscillations with frequency equal to natural frequency . Ex: Vibration of tuning fork.

2. Damped Oscillations :

Due to the pressure of function and air drag

- **Amplitude of oscillation decreases.**
- **Energy of SHM decreases.**
- **Energy lost is absorbed by surrounding.**
- **Damping (resistive) force proportional to velocity of the oscillations.**
  Ex: Electromagnetic oscillations in tank circuit.

3. Maintained Oscillations :

1. **While playing in swing, due to damping oscillation will stop.**
2. **To avoid damping, to supply push to sustain oscillation.**
3. **By supplying energy, amplitude made constant.**
   Ex: Vibration of tuning fork getting energy from battery.

4. Forced Oscillation :

Any oscillation by an external periodic agency to overcome the damping is known as forced oscillation or drawn oscillator. Ex: Sound boards.

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