

**PHY101**  
**LECTURE 1 TO 22**  
**SUBJECTIVE PART**  
**BY VU BSCS**  
**LEC 1**

**Summary of Lecture 1 – Introduction to Physics**

**1. Science and the Scientific Method:**

- Physics is a science that operates based on the scientific method. This method involves reason, logic, and experimental evidence to distinguish scientifically correct ideas from incorrect ones.
- Discoveries are not accepted just because an authority figure says so; they must be repeatedly verified by different scientists, in various labs, and across different times.
- The strength of science lies in its constant self-challenge and verification.

**2. Universal Laws of Physics:**

- The laws of physics are believed to be the same everywhere, regardless of location or time. This is why experiments carried out by scientists from diverse cultures and times yield the same results.
- Evidence from distant stars shows that the laws of physics were likely the same billions of years ago as they are today, given that atomic spectra have remained consistent over time.

**3. Main Topics in the Course:** The course will cover four main branches of physics:

- **Classical Mechanics:** Focuses on motion under forces, including Newtonian mechanics.
- **Electromagnetism:** Explores how electric charges behave in fields and how charges generate electric and magnetic fields.
- **Thermal Physics:** Studies heat, its effects, and how it interacts with matter.
- **Quantum Mechanics:** Deals with the physics of small-scale objects like atoms, though this will only be covered briefly.

#### 4. Dimensions and Units:

- Physical quantities are expressed in terms of three fundamental dimensions: **Mass (M)**, **Length (L)**, and **Time (T)**.
- Examples of dimensional representations:
  - Speed:  $LT^{-1}$
  - Acceleration:  $LT^{-2}$
  - Force:  $MLT^{-2}$
  - Energy:  $ML^2T^{-2}$
  - Pressure:  $ML^{-1}T^{-2}$
- Quantities with different dimensions cannot be added. For instance, force cannot be added to energy since their dimensions are different.

#### 5. Functions and Dimensional Consistency:

- When using functions like  $f(\theta) = \sin(\theta)$ , the input (in this case,  $\theta$ ) must be dimensionless. A dimensioned value would result in mixing quantities with different dimensions, which is not allowed.

#### 5. Functions and Dimensional Consistency:

- When using functions like  $f(\theta) = \sin(\theta)$ , the input (in this case,  $\theta$ ) must be dimensionless. A dimensioned value would result in mixing quantities with different dimensions, which is not allowed.

#### 6. Units vs. Dimensions:

- **Units** are the specific measures used to quantify physical quantities, while **dimensions** are the fundamental nature of the quantities themselves (like mass, length, time).
- The course uses the **MKS (Meter-Kilogram-Second)** system of units. Conversions between systems must be done systematically.

#### 7. Estimating Orders of Magnitude:

- A good scientist looks at the big picture first and considers the order of magnitude before diving into detailed calculations. The first digit often matters more than the exact decimal places.
- For example, if you calculate the height of a building and get a result like  $4.01219 \times 10^6$  meters, the extra decimal places are irrelevant in this context—what matters is the rough order of magnitude.

#### 8. Dimensional Consistency of Equations:

- Always check if the dimensions on both sides of an equation match.
- For example,  $v^2 = u^2 + 2as$  is dimensionally consistent, but any equation with mismatched dimensions, like  $v^2$  on one side and acceleration on the other, is incorrect.

#### 9. Simplification and Mental Visualization:

- When deriving complicated equations, it's helpful to consider special limits where the equations simplify.
- Imagine extreme cases (e.g., very large or small quantities) and use visual tools like graphs to better understand the behavior of equations.

## Numerical Formula and Example from the Lecture

**Example of Dimensional Consistency:** Suppose we want to check the dimensional consistency of the equation for velocity under constant acceleration:  $v = u + at$  Where:

- $v$  = Final velocity (m/s)
- $u$  = Initial velocity (m/s)
- $a$  = Acceleration (m/s<sup>2</sup>)
- $t$  = Time (s)

**Dimensions:**

- $v$  has dimensions of  $LT^{-1}$
- $u$  has dimensions of  $LT^{-1}$
- $a$  has dimensions of  $LT^{-2}$
- $t$  has dimensions of  $T$

The right side of the equation,  $u + at$ , has dimensions:

The right side of the equation,  $u + at$ , has dimensions:

- $u$  has  $LT^{-1}$
- $at$  has dimensions  $(LT^{-2}) \times T = LT^{-1}$

Since both sides have the same dimensions of  $LT^{-1}$ , the equation is dimensionally consistent.

**Example for Orders of Magnitude:** Let's estimate the time it takes for an object to fall from a height of 10 meters under the influence of gravity. Using the equation for free fall:  $h = \frac{1}{2}gt^2$  Where:

- $h = 10$  m
- $g = 9.8$  m/s<sup>2</sup>
- $t$  is the time in seconds.

Rearranging:  $t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 10}{9.8}} = \sqrt{2.04} \approx 1.43$  seconds

This estimate gives a time of approximately 1.43 seconds for an object to fall from 10 meters, with the order of magnitude being correct even before performing the detailed calculation.

## LEC 2 TO 5

## Lecture 2 – Kinematics I

### 1. Displacement ( $x(t)$ ):

- Displacement is defined as the position of a body at any time  $t$ .
- If displacement is positive, the body is to the right of the origin; if negative, it is to the left.

Formula:

$x(t)$  (displacement)

Numerical Example:

- If a body moves 5 meters to the right,  $x(t) = 5 \text{ m}$ .

### 2. Average Speed ( $v$ ):

- The average speed over a small time interval  $\Delta t$  is defined as:

$$\text{Average Speed} = \frac{\Delta x}{\Delta t}$$

Numerical Example:

- If a car moves 20 meters in 5 seconds, the average speed is:

$$v = \frac{20 \text{ m}}{5 \text{ s}} = 4 \text{ m/s}$$

### 3. Instantaneous Velocity:

- Instantaneous velocity is the rate of change of displacement at any point in time.

$$v(t) = \frac{x(t + \Delta t) - x(t)}{\Delta t}$$

Numerical Example:

- If a car's position at  $t_1 = 2 \text{ s}$  is 10 meters and at  $t_2 = 3 \text{ s}$  is 15 meters, then the instantaneous velocity at  $t_2$  is:

$$v = \frac{15 \text{ m} - 10 \text{ m}}{3 \text{ s} - 2 \text{ s}} = \frac{5 \text{ m}}{1 \text{ s}} = 5 \text{ m/s}$$

#### 4. Instantaneous Acceleration:

- Instantaneous acceleration is the rate of change of velocity.

$$a(t) = \frac{v(t + \Delta t) - v(t)}{\Delta t}$$

Numerical Example:

- If a car's velocity at  $t_1 = 2 \text{ s}$  is 4 m/s and at  $t_2 = 3 \text{ s}$  is 6 m/s, then:

$$a = \frac{6 \text{ m/s} - 4 \text{ m/s}}{3 \text{ s} - 2 \text{ s}} = \frac{2 \text{ m/s}}{1 \text{ s}} = 2 \text{ m/s}^2$$

#### 5. Motion with Constant Speed ( $x = vt$ ):

- If a body is moving with constant speed, the displacement is related to time as  $x(t) = v \cdot t$ .

Numerical Example:

- A car moving at 5 m/s for 10 seconds:

$$x = v \cdot t = 5 \text{ m/s} \times 10 \text{ s} = 50 \text{ m}$$

## Lecture 3 – Kinematics II

#### 1. Derivative Definition:

- The derivative of a function  $f(x)$  at a point is defined as:

$$\frac{d}{dt}x(t) = \lim_{\Delta t \rightarrow 0} \frac{x(t + \Delta t) - x(t)}{\Delta t}$$

#### 2. Distance Moved with Constant Acceleration:

- If the body has constant acceleration, the displacement is given by:

$$x(t) = x_0 + v_0t + \frac{1}{2}at^2$$

Numerical Example:

- A car starts from rest ( $v_0 = 0$ ) and accelerates at  $2 \text{ m/s}^2$  for 5 seconds:

$$x(t) = 0 + 0 + \frac{1}{2} \times 2 \text{ m/s}^2 \times (5 \text{ s})^2 = 25 \text{ m}$$

3. Final Velocity with Constant Acceleration:

- The final velocity after a time  $t$  is:

$$v_f = v_0 + a \cdot t$$

Numerical Example:

- If a car starts from rest ( $v_0 = 0$ ) and accelerates at  $2 \text{ m/s}^2$  for 5 seconds:

$$v_f = 0 + 2 \text{ m/s}^2 \times 5 \text{ s} = 10 \text{ m/s}$$

## Lecture 4 – Force and Newton's Laws

1. Newton's First Law:

- An object will remain at rest or move with constant velocity unless acted upon by an external force.

2. Newton's Second Law ( $F = ma$ ):

- The force acting on a body is equal to the mass of the body multiplied by its acceleration.

Formula:

$$F = m \cdot a$$

Numerical Example:

- A 2 kg object experiences a force of 10 N:

$$a = \frac{F}{m} = \frac{10 \text{ N}}{2 \text{ kg}} = 5 \text{ m/s}^2$$

3. Newton's Third Law:

- For every action, there is an equal and opposite reaction.

## Lecture 5 – Applications of Newton's Laws – I

### 1. Force and Equilibrium:

- For an object in equilibrium, the sum of forces in every direction must be zero:

$$\sum \mathbf{F} = 0$$

#### Numerical Example:

- A block is at rest on a surface. The forces acting on it are:
  - The weight ( $W = mg$ ) acting downward.
  - The normal force ( $N$ ) acting upward.
- For equilibrium,  $N = mg$ .

### 2. Tension in a Rope:

- If a rope is massless, the tension is the same throughout the rope.

#### Numerical Example:

- A block is at rest on a surface. The forces acting on it are:
  - The weight ( $W = mg$ ) acting downward.
  - The normal force ( $N$ ) acting upward.
- For equilibrium,  $N = mg$ .

### 2. Tension in a Rope:

- If a rope is massless, the tension is the same throughout the rope.

#### Numerical Example:

- A rope supports a 10 kg mass. The weight of the mass is:

$$W = m \cdot g = 10 \text{ kg} \times 9.8 \text{ m/s}^2 = 98 \text{ N}$$

- The tension in the rope is  $T = 98 \text{ N}$ .

## 2. Tension in a Rope:

- If a rope is massless, the tension is the same throughout the rope.

### Numerical Example:

- A rope supports a 10 kg mass. The weight of the mass is:

$$W = m \cdot g = 10 \text{ kg} \times 9.8 \text{ m/s}^2 = 98 \text{ N}$$

- The tension in the rope is  $T = 98 \text{ N}$ .

## 3. Frictional Force:

- The frictional force is given by:

$$F_{\text{friction}} = \mu \cdot N$$

### Numerical Example:

- A 5 kg box is resting on a table. The coefficient of friction  $\mu = 0.3$ . The normal force is  $N = mg = 5 \times 9.8 = 49 \text{ N}$ .

$$F_{\text{friction}} = 0.3 \times 49 \text{ N} = 14.7 \text{ N}$$

# LEC 5 TO 9

# 1. Applications of Newton's Laws

## Fluid Resistance (Drag Force)

- Newton's Third Law: The force exerted by a body moving through a fluid is met with an equal and opposite force by the fluid.
  - Drag Force:  $F_{\text{drag}} = kv$  where  $k$  is the drag coefficient and  $v$  is the velocity of the object.

## Terminal Velocity

- When forces balance (gravity and friction), the object reaches terminal velocity:
  - At Terminal Velocity:  $F_{\text{gravity}} = F_{\text{friction}}$
  - $mg = kv_{\text{terminal}}$

## Weight in a Lift

- When the lift accelerates downwards:
  - $N = M(g - a)$
  - If acceleration equals gravity ( $a = g$ ),  $N = 0$  (Weightlessness).

## Friction

- Friction force always acts in the opposite direction to the applied force.
  - $F_{\text{friction}} = \mu N$ , where  $\mu$  is the coefficient of friction and  $N$  is the normal force.

## Force on Hanging Rope (Slipping Condition)

- For a rope partially hanging from a table:
  - $N = mg - mgl/L$
  - $\mu = \frac{mgl}{N}$ , where  $m$  is mass per unit length,  $L$  is total length, and  $l$  is the length hanging.

## 2. Work and Energy

### Work Done by a Force

- General Formula:
  - $W = F \cdot d \cdot \cos(\theta)$  where  $F$  is force,  $d$  is displacement, and  $\theta$  is the angle between force and displacement.

### Kinetic Energy

- Formula:  $KE = \frac{1}{2}mv^2$  where  $m$  is the mass and  $v$  is the velocity of the object.

### Work-Energy Theorem

- The work done on a body equals the change in its kinetic energy:
  - $W = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$

### Power

- Formula:  $P = \frac{W}{t}$ , where  $W$  is work done, and  $t$  is time taken.
- In terms of velocity:  $P = F \cdot v$

## 3. Conservation of Energy

### Potential Energy

- Gravitational Potential Energy:
  - $PE = mgh$ , where  $m$  is the mass,  $g$  is acceleration due to gravity, and  $h$  is height.

### Energy Conservation

- In a frictionless system: Total mechanical energy (KE + PE) remains constant.
  - $KE_1 + PE_1 = KE_2 + PE_2$

### Spring Potential Energy

- Elastic Potential Energy (Spring):
  - $PE_{\text{spring}} = \frac{1}{2}kx^2$ , where  $k$  is the spring constant and  $x$  is the displacement from equilibrium.

## 4. Momentum

### Momentum

- Formula:
  - $p = mv$ , where  $m$  is mass and  $v$  is velocity.
  - Units of momentum:  $\text{kg} \cdot \text{m/s}$ .

### Impulse and Change in Momentum

- Impulse:
  - $J = F \cdot \Delta t$
  - The impulse is equal to the change in momentum:  $\Delta p = F \cdot \Delta t$ .

### Conservation of Momentum

- In a closed system (no external forces):
  - $\Delta p = 0$
  - $p_{\text{initial}} = p_{\text{final}}$

### Example Problems

#### Example 1: Terminal Velocity

A ball bearing of mass 0.5 kg is dropped into oil. If the drag coefficient is  $k = 0.1 \text{ kg/s}$ , calculate the terminal velocity.

- Using  $mg = kv_{\text{terminal}}$ :

$$v_{\text{terminal}} = \frac{mg}{k} = \frac{0.5 \times 9.8}{0.1} = 49 \text{ m/s}$$

#### Example 2: Work Done

You lift a 20 kg object vertically through a distance of 2 meters. Calculate the work done.

- Using  $W = F \cdot d$ :

$$F = mg = 20 \times 9.8 = 196 \text{ N}$$

$$W = F \cdot d = 196 \times 2 = 392 \text{ J}$$

### Example 3: Kinetic Energy

A 12 kg box is pushed to a speed of 1.5 m/s from rest over a distance of 2.4 m.

- Using  $KE = \frac{1}{2}mv^2$ :

$$KE = \frac{1}{2} \times 12 \times (1.5)^2 = 13.5 \text{ J}$$

## LEC 10 TO 12

### Collisions

1. Elastic Collision (Momentum and Kinetic Energy Conservation):

- Formula for conservation of momentum:

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

where:

- $m_1, m_2$  are the masses.
  - $u_1, u_2$  are the initial velocities.
  - $v_1, v_2$  are the final velocities.
- Formula for relative speed in elastic collisions:

$$(v_1 - v_2) = -(u_1 - u_2)$$

This means the relative speed of approach equals the relative speed of separation in elastic collisions.

- Solving for final velocities: For two bodies colliding elastically:

$$v_1 = \frac{(m_1 - m_2)u_1 + 2m_2u_2}{m_1 + m_2}$$

$$v_2 = \frac{2m_1u_1 + (m_2 - m_1)u_2}{m_1 + m_2}$$

. Inelastic Collision:

- In inelastic collisions, kinetic energy is not conserved. However, momentum is still conserved:

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

For a completely inelastic collision (where the bodies stick together):

$$(m_1 + m_2)v = m_1u_1 + m_2u_2$$

Solving for  $v$  (final velocity):

$$v = \frac{m_1u_1 + m_2u_2}{m_1 + m_2}$$

## Rotational Kinematics

### 1. Angular Displacement:

- Angular displacement  $\phi$  in radians for a circular motion is given by:

$$\phi = \frac{s}{r}$$

where  $s$  is the arc length, and  $r$  is the radius.

### 2. Angular Speed (or Angular Velocity):

- Average angular velocity  $\omega_{\text{avg}}$ :

$$\omega_{\text{avg}} = \frac{\Delta\phi}{\Delta t}$$

Instantaneous angular speed  $\omega$  is the derivative:

$$\omega = \frac{d\phi}{dt}$$

### 3. Angular Acceleration:

- Average angular acceleration  $\alpha_{\text{avg}}$ :

$$\alpha_{\text{avg}} = \frac{\Delta\omega}{\Delta t}$$

Instantaneous angular acceleration  $\alpha$  is the derivative:

$$\alpha = \frac{d\omega}{dt}$$

### 4. Kinematic Equations for Rotational Motion:

- Analogous to linear kinematic equations, for rotational motion with constant angular acceleration:

$$\omega_f = \omega_0 + \alpha t$$

$$\phi_f = \phi_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega_f^2 = \omega_0^2 + 2\alpha\Delta\phi$$

## Physics of Many Particles (Center of Mass)

### 1. Center of Mass:

- For two particles, the center of mass  $r_{\text{cm}}$  is:

$$r_{\text{cm}} = \frac{m_1 r_1 + m_2 r_2}{m_1 + m_2}$$

where  $m_1, m_2$  are the masses and  $r_1, r_2$  are their positions.

### 2. Generalization to $N$ Particles:

- For a system of  $N$  particles, the center of mass is:

$$r_{\text{cm}} = \frac{\sum_{i=1}^N m_i r_i}{\sum_{i=1}^N m_i}$$

### 3. Moment of Inertia (Rotational Inertia):

- The moment of inertia for a point mass is:

$$I = mr^2$$

### 3. Moment of Inertia (Rotational Inertia):

- The moment of inertia for a point mass is:

$$I = mr^2$$

where  $m$  is the mass and  $r$  is the distance from the axis of rotation.

- For a system of particles:

$$I = \sum_i m_i r_i^2$$

where  $m_i$  and  $r_i$  are the mass and distance from the axis for each particle.

### 4. Kinetic Energy in Rotational Motion:

- The total kinetic energy for a rotating rigid body:

$$K = \frac{1}{2} I \omega^2$$

where  $I$  is the moment of inertia and  $\omega$  is the angular velocity.

1. Elastic Collision Example:

- Consider two bodies:  $m_1 = 3 \text{ kg}$ ,  $m_2 = 2 \text{ kg}$ , with initial velocities  $u_1 = 4 \text{ m/s}$ ,  $u_2 = -2 \text{ m/s}$ .

Using the formula for final velocities:

$$v_1 = \frac{(3 - 2) \times 4 + 2 \times (-2)}{3 + 2} = \frac{4 - 4}{5} = 0 \text{ m/s}$$
$$v_2 = \frac{2 \times 3 \times 4 + (2 - 3) \times (-2)}{3 + 2} = \frac{24 + 2}{5} = 5.2 \text{ m/s}$$

So, after the collision,  $v_1 = 0 \text{ m/s}$  and  $v_2 = 5.2 \text{ m/s}$ .

2. Rotational Motion Example:

- A wheel with radius  $r = 0.5 \text{ m}$  and angular acceleration  $\alpha = 2 \text{ rad/s}^2$  starts from rest. Find the angular speed after 5 seconds.

Using  $\omega = \omega_0 + \alpha t$ , and  $\omega_0 = 0$ :

$$\omega = 0 + 2 \times 5 = 10 \text{ rad/s}$$

## LEC 13 TO 15

## Lecture 13: Angular Momentum

### 1. Definition of Angular Momentum:

- The angular momentum ( $L$ ) of a particle with respect to an origin is given by:

$$\mathbf{L} = \mathbf{r} \times \mathbf{p}$$

where:

- $\mathbf{r}$  is the position vector,
- $\mathbf{p} = m\mathbf{v}$  is the linear momentum,
- $m$  is the mass of the particle,
- $\mathbf{v}$  is the velocity of the particle.

### 2. Angular Momentum in terms of components:

- If  $\mathbf{r} = (x, y, z)$  and  $\mathbf{p} = (p_x, p_y, p_z)$ , then:

$$\mathbf{L} = (yp_z - zp_y, zp_x - xp_z, xp_y - yp_x)$$

### 3. Rate of Change of Angular Momentum (Torque):

- The time derivative of angular momentum is the torque:

$$\frac{d\mathbf{L}}{dt} = \boldsymbol{\tau}$$

where  $\boldsymbol{\tau}$  is the torque.

### 4. Relation between Force and Torque:

- Torque can be calculated using the cross-product of the position vector and the force vector:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$

where  $\mathbf{F}$  is the force acting on the particle.

### 5. Projectile Motion and Angular Momentum:

- For a projectile launched at an angle  $\theta$  from the ground:

$$\mathbf{v}_x = v_0 \cos(\theta), \quad \mathbf{v}_y = v_0 \sin(\theta) - gt$$

where  $v_0$  is the initial velocity,  $g$  is the acceleration due to gravity, and  $t$  is the time.

5. **Projectile Motion and Angular Momentum:**

- For a projectile launched at an angle  $\theta$  from the ground:

$$\mathbf{v}_x = v_0 \cos(\theta), \quad \mathbf{v}_y = v_0 \sin(\theta) - gt$$

where  $v_0$  is the initial velocity,  $g$  is the acceleration due to gravity, and  $t$  is the time.

6. **Fundamental equation:**

- The time rate of change of angular momentum is equal to the net torque acting on the system:

$$\frac{d\mathbf{L}}{dt} = \tau$$

## Lecture 14: Equilibrium of Rigid Bodies

1. **Conditions for Equilibrium:**

- A rigid body is in equilibrium if both:
  - The sum of the forces acting on the body is zero:
$$\sum \mathbf{F} = 0$$
  - The sum of the torques (moments) acting on the body is zero:
$$\sum \tau = 0$$

2. **Example of Equilibrium in a Beam:**

- For a beam resting on supports, the forces on the beam are balanced both vertically and horizontally. The torque about any point must also sum to zero.

3. **Static Equilibrium of a Beam:**

- The forces acting on the beam (vertical components  $F_1, F_2$ ) are balanced:

$$F_1 + F_2 = Mg$$

where  $M$  is the mass of the beam, and  $g$  is acceleration due to gravity.

## 2. Example of Equilibrium in a Beam:

- For a beam resting on supports, the forces on the beam are balanced both vertically and horizontally. The torque about any point must also sum to zero.

## 3. Static Equilibrium of a Beam:

- The forces acting on the beam (vertical components  $F_1, F_2$ ) are balanced:

$$F_1 + F_2 = Mg$$

where  $M$  is the mass of the beam, and  $g$  is acceleration due to gravity.

## 4. Torque Balance for Static Equilibrium:

- The torque balance condition about a point is:

$$F_1 \cdot L_1 = F_2 \cdot L_2$$

where  $L_1$  and  $L_2$  are the distances from the pivot point to the forces.

# Lecture 15: Oscillations

## 1. Simple Harmonic Motion (SHM):

- The equation for a mass attached to a spring is:

$$F = -kx$$

where:

- $k$  is the spring constant,
- $x$  is the displacement from equilibrium.
- The motion of the mass is described by the differential equation:

$$m \frac{d^2x}{dt^2} = -kx$$

which is the equation of motion for simple harmonic oscillation (SHO).

## 2. Angular Frequency:

- The angular frequency  $\omega$  for simple harmonic motion is given by:

$$\omega = \sqrt{\frac{k}{m}}$$

where:

- $m$  is the mass,
- $k$  is the spring constant.

## 3. Period and Frequency of SHM:

- The period  $T$  (time for one complete cycle) is:

$$T = \frac{2\pi}{\omega}$$

- The frequency  $f$  (number of cycles per second) is:

$$f = \frac{1}{T} = \frac{\omega}{2\pi}$$

## 4. Energy in SHM:

- The total mechanical energy  $E$  in simple harmonic motion is constant and given by:

$$E = \frac{1}{2}kA^2$$

where  $A$  is the amplitude of the oscillation.

## 5. Displacement as a function of time:

- The displacement of a mass undergoing simple harmonic motion is given by:

$$x(t) = A \cos(\omega t + \phi)$$

where:

- $A$  is the amplitude,
- $\omega$  is the angular frequency,
- $\phi$  is the phase constant.

## Key Points for Numerical Problems

1. **Angular Momentum:** Use  $\mathbf{L} = \mathbf{r} \times \mathbf{p}$  and calculate torque using  $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$ .
2. **Equilibrium:** For static equilibrium problems, ensure that the forces and torques sum to zero. Use the equations for force balance and torque balance to solve for unknowns.
3. **Oscillations:** For SHM, solve the equation  $m \frac{d^2x}{dt^2} = -kx$  and apply the formulas for frequency, period, and amplitude. Use energy conservation to solve for unknown quantities in oscillatory motion.

## LEC 16 TO 18

## 1. Simple Harmonic Oscillator (SHO)

- Restoring Force for SHO:

$$F = -mg \sin \theta \approx -mg\theta \quad (\text{small angle approximation})$$

- Oscillation Frequency (for small angles):

$$\omega = \sqrt{\frac{g}{L}} \quad (\text{where } L \text{ is the length of the string})$$

- Moment of Inertia and Angular Acceleration:

$$\tau = I\alpha = -Mgd \quad (\text{torque for angular oscillations}) \quad \omega = \sqrt{\frac{g}{l}} \quad (\text{angular frequency for rotational motion})$$

## 2. Composition of Harmonic Motions

- Sum of Two Simple Harmonic Motions (same period):  $x(t) = A_1 \sin(\omega t + \phi_1) + A_2 \sin(\omega t + \phi_2)$  Using trigonometric identities, it simplifies to:  $x(t) = R \sin(\omega t + \phi)$  where  $R = \sqrt{A_1^2 + A_2^2}$  and  $\tan \phi = \frac{A_2}{A_1}$

## 3. Damped Harmonic Motion

- Damped Motion Equation:

$$m \frac{d^2x}{dt^2} + b \frac{dx}{dt} + kx = 0$$

- Solution (for underdamped case):

$$x(t) = Ae^{-\gamma t} \cos(\omega' t + \phi) \quad \text{where: } \omega' = \sqrt{\omega_0^2 - \gamma^2} \quad \text{and} \quad \gamma = \frac{b}{2m}$$

## 4. Forced Oscillations and Resonance

- Resonance Frequency:

$$\omega_0 = \sqrt{\frac{k}{m}} \quad (\text{natural frequency})$$

- Resonance Condition (maximum amplitude occurs when driving frequency  $\omega$  matches  $\omega_0$ ).

## 5. Elasticity and Hooke's Law

- Hooke's Law for Stretching:

$$F = k\Delta x$$

- Young's Modulus:

$$Y = \frac{F/A}{\Delta x/L} = \frac{FL}{A\Delta x}$$

- Bulk Modulus:

$$B = \frac{P}{\Delta V/V}$$

- Shear Modulus:

$$\eta = \frac{\text{Shear Stress}}{\text{Shear Strain}} = \frac{F/A}{\Delta x/L}$$

## 6. Fluid Mechanics

- Pressure in Fluids (depth dependence):

$$p = p_0 + \rho gh \quad (\text{pressure at depth } h)$$

- Continuity Equation (fluid flow conservation):

$$A_1 v_1 = A_2 v_2 \quad (\text{where } A \text{ is cross-sectional area and } v \text{ is velocity})$$

- Bernoulli's Equation (steady flow of incompressible fluid):  $p_1 + \frac{1}{2}\rho v_1^2 + \rho gh_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$

**LEC 19 TO 22**

## 1. Physics of Sound (Lecture 19)

- Sound Waves:
  - Sound waves are longitudinal waves, where particles oscillate in the same direction as the wave travels.
  - The density of the medium oscillates as the wave moves through it, resulting in compression and rarefaction regions.
- Intensity of Sound:
  - The intensity of sound is proportional to the square of the amplitude ( $A^2$ ).
  - Formula for sound intensity:

$$I \propto A^2$$

- Decibel Scale:
  - The sound intensity level in decibels (dB) is calculated using the formula:

$$L = 10 \log_{10} \left( \frac{I}{I_0} \right)$$

where:

- $L$  is the sound level in decibels (dB)
  - $I$  is the intensity of the sound
  - $I_0$  is the reference intensity ( $10^{-12} \text{ W/m}^2$ , the threshold of hearing).
- Speed of Sound:
    - For a wave traveling in a medium, the equation can be written as:

$$\rho(x, t) = \rho_0 \sin \left( \frac{2\pi}{\lambda} (x - vt) \right)$$

where:

- $\rho(x, t)$  is the density at position  $x$  and time  $t$
- $v$  is the speed of sound in the medium
- $\lambda$  is the wavelength
- $\rho_0$  is the equilibrium density.

- **Doppler Effect:**
  - The observed frequency when the source or observer is moving is different from the emitted frequency.
  - **Formula for moving observer (source at rest):**

$$f' = f \left( \frac{v + v_o}{v} \right)$$

where:

- $f'$  is the observed frequency
- $f$  is the emitted frequency
- $v$  is the speed of sound in the medium
- $v_o$  is the speed of the observer.

## 2. Wave Motion (Lecture 20)

- **Types of Waves:**
  - **Longitudinal Waves:** Oscillations occur in the direction of wave motion (e.g., sound).
  - **Transverse Waves:** Oscillations occur perpendicular to the wave direction (e.g., light, radio waves).
- **Amplitude and Power:**
  - **Amplitude:** The height of the wave, denoted as  $A$ .
  - Power in a wave is proportional to the square of the amplitude:

$$P \propto A^2$$

- **Wave Equation:**
  - The general wave equation for a sinusoidal wave:

$$y(x, t) = A \sin(kx - \omega t + \phi)$$

where:

- $A$  is the amplitude
- $k$  is the wavenumber,  $k = \frac{2\pi}{\lambda}$
- $\omega$  is the angular frequency,  $\omega = 2\pi f$
- $\phi$  is the phase constant.

- **Wave Speed:**

- For a wave traveling in a medium, the wave speed is:

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

where:

- $v$  is the speed of the wave
- $\lambda$  is the wavelength
- $f$  is the frequency.

### 3. Gravity (Lecture 21)

- **Newton's Law of Gravitation:**

- The gravitational force between two masses is given by:

$$F = \frac{Gm_1m_2}{r^2}$$

where:

- $G$  is the gravitational constant ( $G = 6.674 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$ )
- $m_1$  and  $m_2$  are the masses of the two objects
- $r$  is the distance between the centers of the two masses.

- **Acceleration Due to Gravity:**

- The acceleration due to gravity at the Earth's surface is:

$$g = \frac{GM}{R^2}$$

where:

- $M$  is the mass of the Earth
- $R$  is the radius of the Earth (approximately 6400 km).

- **Escape Velocity:**

- The minimum velocity required for an object to escape the gravitational field of the Earth is given by:

$$v_{\text{escape}} = \sqrt{\frac{2GM}{R}}$$

For Earth, this is approximately 11.2 km/s.

- **Gravitational Potential Energy:**

- The gravitational potential energy at a distance  $r$  from the center of a mass  $M$  is:

$$U = -\frac{GMm}{r}$$

where  $m$  is the mass of the object.

## Numerical Example:

### 1. Intensity of Sound:

- If the intensity of a sound is  $I = 10^{-10} \text{ W/m}^2$ , the sound level in decibels is:

$$L = 10 \log_{10} \left( \frac{10^{-10}}{10^{-12}} \right) = 10 \log_{10}(100) = 10 \times 2 = 20 \text{ dB}$$

### 2. Escape Velocity:

- For Earth, using  $G = 6.674 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$ ,  $M = 5.97 \times 10^{24} \text{ kg}$ , and  $R = 6.4 \times 10^6 \text{ m}$ , the escape velocity is:

$$v_{\text{escape}} = \sqrt{\frac{2 \times (6.674 \times 10^{-11}) \times (5.97 \times 10^{24})}{6.4 \times 10^6}} = 11.2 \text{ km/s}$$

# LEC 1 TO 22 SOLVED EXAMPLES

## Lecture 2: Kinematics – I

- Key Concepts:
  - Motion in one dimension (position, velocity, acceleration)

- Important Formulas:

- Velocity ( $v$ ):

$$v = \frac{\Delta x}{\Delta t}$$

- Acceleration ( $a$ ):

$$a = \frac{\Delta v}{\Delta t}$$

- Kinematic Equations:

$$v = v_0 + at$$

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

- **Example:**

- A car accelerates from rest with a constant acceleration of  $2 \text{ m/s}^2$ . Find the velocity after 5 seconds and the distance traveled.

- Given:  $v_0 = 0 \text{ m/s}$ ,  $a = 2 \text{ m/s}^2$ ,  $t = 5 \text{ s}$ .

- Velocity after 5 seconds:

$$v = v_0 + at = 0 + 2 \times 5 = 10 \text{ m/s}$$

- Distance traveled:

$$x = x_0 + v_0t + \frac{1}{2}at^2 = 0 + 0 \times 5 + \frac{1}{2} \times 2 \times 5^2 = 25 \text{ m}$$

### Lecture 3: Kinematics – II

- Key Concepts:

- Motion in two dimensions (Projectile motion, Relative velocity)

- Important Formulas:

- Projectile Motion (horizontal and vertical components):

- Horizontal motion:

$$x = v_0 \cos \theta \cdot t$$

- Vertical motion:

$$y = v_0 \sin \theta \cdot t - \frac{1}{2}gt^2$$

where  $g$  is the acceleration due to gravity.

- **Example:**

- A projectile is fired with a speed of  $20 \text{ m/s}$  at an angle of  $30^\circ$ . Find the time of flight, maximum height, and range.

- Given:  $v_0 = 20 \text{ m/s}$ ,  $\theta = 30^\circ$ ,  $g = 9.8 \text{ m/s}^2$ .

- Time of flight:

$$t = \frac{2v_0 \sin \theta}{g} = \frac{2 \times 20 \times \sin 30^\circ}{9.8} = 2.04 \text{ s}$$

- Maximum height:

$$H = \frac{(v_0 \sin \theta)^2}{2g} = \frac{(20 \times \sin 30^\circ)^2}{2 \times 9.8} = 5.1 \text{ m}$$

- Range:

$$R = \frac{v_0^2 \sin 2\theta}{g} = \frac{20^2 \sin 60^\circ}{9.8} = 34.64 \text{ m}$$

## Lecture 4: Force and Newton's Laws

- Key Concepts:
  - Newton's three laws of motion: Inertia,  $F = ma$ , and action-reaction.

- Important Formulas:

- Newton's Second Law:

$$F = ma$$

- Gravitational Force (Weight):

$$F_g = mg$$

where  $g = 9.8 \text{ m/s}^2$ .

- Example:

- A block of mass 10 kg is resting on a horizontal surface. Find the force required to accelerate the block at  $2 \text{ m/s}^2$ .
  - Given:  $m = 10 \text{ kg}$ ,  $a = 2 \text{ m/s}^2$ .
  - Force required:

$$F = ma = 10 \times 2 = 20 \text{ N}$$

## Lecture 7: Work and Energy

- Key Concepts:
  - Work done by a force, kinetic and potential energy.

- Important Formulas:

- Work (W):

$$W = F \cdot d \cdot \cos \theta$$

- Kinetic Energy (KE):

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

- Potential Energy (PE):

$$PE = mgh$$

- Kinetic Energy (KE):

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

- Potential Energy (PE):

$$PE = mgh$$

- Work-Energy Theorem:

$$W = \Delta KE$$

Example:

- A 5 kg object is lifted to a height of 10 m. Calculate the work done.
  - Given:  $m = 5 \text{ kg}$ ,  $g = 9.8 \text{ m/s}^2$ ,  $h = 10 \text{ m}$ .
  - Work done:

$$W = mgh = 5 \times 9.8 \times 10 = 490 \text{ J}$$

## Lecture 9: Momentum

- Key Concepts:
  - Conservation of momentum, impulse.
- Important Formulas:
  - Momentum (p):

$$p = mv$$

- Impulse (J):

$$J = F \cdot \Delta t = \Delta p$$

- Conservation of Momentum:

$$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2$$

- Example:

- Two objects of masses 2 kg and 3 kg collide. The first object has a velocity of 4 m/s and the second is stationary. Calculate the final velocity after collision, assuming no external forces.
  - Given:  $m_1 = 2 \text{ kg}$ ,  $v_1 = 4 \text{ m/s}$ ,  $m_2 = 3 \text{ kg}$ ,  $v_2 = 0 \text{ m/s}$ .
  - Using conservation of momentum:

$$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2$$

Assuming an elastic collision:

$$2 \times 4 + 3 \times 0 = 2v'_1 + 3v'_2$$

Solve for  $v'_1$  and  $v'_2$ .

## Lecture 19: Physics of Sound

- Key Concepts:
  - Sound waves, Doppler effect, intensity.
- Important Formulas:
  - Doppler Effect (moving observer):

$$f' = f \left( \frac{v + v_o}{v} \right)$$

- Intensity of Sound:

$$I = \frac{P}{A}$$

where  $P$  is power and  $A$  is area.

- Example:
  - A source emits a sound at 500 Hz. If the observer is moving towards the source at 20 m/s, and the speed of sound is 340 m/s, calculate the observed frequency.
  - Given:  $f = 500$  Hz,  $v = 340$  m/s,  $v_o = 20$  m/s.
  - Observed frequency:

$$f' = f \left( \frac{v + v_o}{v} \right) = 500 \left( \frac{340 + 20}{340} \right) = 500 \times 1.1176 = 558.8 \text{ Hz}$$

## Lecture 21: Gravitation

- Key Concepts:
  - Gravitational force, potential energy, escape velocity.
- Important Formulas:
  - Gravitational Force:

$$F = \frac{Gm_1m_2}{r^2}$$

- Escape Velocity:

$$v_{\text{escape}} = \sqrt{\frac{2GM}{R}}$$

- Example:
  - Calculate the escape velocity from the Earth's surface.
  - Given:  $G = 6.674 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$ ,  $M = 5.97 \times 10^{24} \text{ kg}$ ,  $R = 6.4 \times 10^6 \text{ m}$ .
  - Escape velocity:

$$v_{\text{escape}} = \sqrt{\frac{2 \times 6.674 \times 10^{-11} \times 5.97 \times 10^{24}}{6.4 \times 10^6}} = 11.2 \text{ km/s}$$

## Lecture 22: Electrostatics – I

- Key Concepts:
  - Coulomb's Law, Electric field, Electric potential.
- Important Formulas:
  - Coulomb's Law:

$$F = \frac{k_e q_1 q_2}{r^2}$$

where  $k_e = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$ .

- Electric Field (E):

$$E = \frac{F}{q}$$

- Example:
  - Two charges of  $2 \mu\text{C}$  and  $3 \mu\text{C}$  are placed 0.5 m apart. Calculate the force between them.
  - Given:  $q_1 = 2 \times 10^{-6} \text{ C}$ ,  $q_2 = 3 \times 10^{-6} \text{ C}$ ,  $r = 0.5 \text{ m}$ .
  - Force between charges:

$$F = \frac{k_e q_1 q_2}{r^2} = \frac{8.99 \times 10^9 \times (2 \times 10^{-6}) \times (3 \times 10^{-6})}{(0.5)^2} = 2.16 \text{ N}$$

**EFFORT BY VU BSCS (M.TAQD)**