PHY101H - Mechanics and Introduction to Waves

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September 29, 2024

Contents

1 Kinematics

Kinematics deals with the description of motion. It focuses on understanding how objects move without considering the forces causing that motion.

1.1 Position, Displacement, and Distance

- **Position**: The location of an object in space, usually described using a coordinate system. - **Displacement** $\vec{s}$: A vector quantity that represents the change in position of an object:

$$\vec{s} = \vec{x}_f - \vec{x}_i$$

- **Distance**: A scalar quantity that refers to the total path length traveled by an object.

1.2 Velocity and Speed

- **Velocity** $\vec{v}$: The rate of change of displacement with respect to time. It is a vector:

$$\vec{v} = \frac{d\vec{s}}{dt}$$

- **Speed**: The magnitude of velocity, a scalar quantity:

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

1.3 Acceleration

Acceleration is the rate of change of velocity with time:

$$\vec{a} = \frac{d\vec{v}}{dt}$$

For constant acceleration:

$$v = u + at$$

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

$$v^2 = u^2 + 2as$$

1.4 Free Fall

Free-fall motion is an example of uniformly accelerated motion under gravity, where $g = 9.8\,\mathrm{m/s^2}$. The key equations are:

$$v = u + gt$$

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

where $u = 0$ when the object is dropped from rest.

2 Newton's Laws of Motion

Newton's laws describe the relationship between the motion of an object and the forces acting on it.

2.1 First Law: Inertia

An object will remain at rest or in uniform motion unless acted upon by a net external force.

2.2 Second Law: Force and Acceleration

The net force acting on an object is equal to the mass of the object multiplied by its acceleration:

$$\vec{F} = m\vec{a}$$

This law can also be written as $\sum \vec{F} = m\vec{a}$, where $\sum \vec{F}$ represents the sum of all forces acting on the object.

2.3 Third Law: Action and Reaction

For every action, there is an equal and opposite reaction. If object A exerts a force on object B, then object B exerts an equal force in the opposite direction on object A:

$$\vec{F}_{A\to B} = -\vec{F}_{B\to A}$$

2.4 Example: Forces on an Inclined Plane

For an object of mass m on a frictionless slope inclined at an angle θ, the forces acting on the object include the weight (mg) and the normal force (F_N). The component of the gravitational force acting parallel to the incline is:

$$F_{\text{parallel}} = mg\sin\theta$$

The normal force is:

$$F_N = mg\cos\theta$$

3 Work, Energy, and Power

Energy is the capacity to do work, and power measures the rate at which work is done.

3.1 Work

Work is defined as the force applied to an object multiplied by the displacement in the direction of the force:

$$W = \vec{F} \cdot \vec{s} = Fs\cos\theta$$

where θ is the angle between the force and the displacement.

3.2 Kinetic Energy

Kinetic energy is the energy of an object due to its motion:

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

3.3 Potential Energy

Potential energy is the energy stored in an object due to its position. For gravitational potential energy:

$$P.E. = mgh$$

3.4 Work-Energy Theorem

The work done on an object is equal to the change in its kinetic energy:

$$W = \Delta K.E.$$

3.5 Power

Power is the rate at which work is done:

$$P = \frac{W}{t}$$

4 Momentum and Collisions

Momentum is a measure of an object's motion and is defined as the product of mass and velocity:

$$\vec{p} = m\vec{v}$$

4.1 Conservation of Momentum

In the absence of external forces, the total momentum of a system remains constant:

$$\sum \vec{p}_{\text{initial}} = \sum \vec{p}_{\text{final}}$$

4.2 Elastic and Inelastic Collisions

In an elastic collision, both momentum and kinetic energy are conserved. In an inelastic collision, only momentum is conserved, and some kinetic energy is transformed into other forms of energy.

5 Circular Motion and Gravitation

5.1 Uniform Circular Motion

For an object moving in a circle with constant speed, the centripetal acceleration is directed toward the center of the circle:

$$a_c = \frac{v^2}{r}$$

The corresponding centripetal force is:

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

5.2 Newton's Law of Universal Gravitation

Every point mass attracts every other point mass with a force proportional to the product of their masses and inversely proportional to the square of the distance between them:

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

where G is the gravitational constant ($6.674 \times 10^{-11}\ \text{N m}^2/\text{kg}^2$).

6 Oscillations and Waves

6.1 Simple Harmonic Motion (SHM)

An object exhibits SHM if it experiences a restoring force proportional to its displacement:

$$F = -kx$$

The displacement as a function of time is given by:

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

where A is the amplitude, ω is the angular frequency, and ϕ is the phase constant.

6.2 Wave Motion

Waves transfer energy through oscillations. A wave is characterized by its wavelength λ, frequency f, and speed v:

$$v = f\lambda$$

7 Thermodynamics

7.1 Zeroth Law of Thermodynamics

If two systems are in thermal equilibrium with a third system, then they are in thermal equilibrium with each other.

7.2 First Law of Thermodynamics

The change in the internal energy of a system is equal to the heat added to the system minus the work done by the system:

$$\Delta U = Q - W$$

8 Fluids

8.1 Density and Pressure

Density ρ is the mass per unit volume:

$$\rho = \frac{m}{V}$$

Pressure P is the force per unit area:

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