Dynamics, Matter Properties, and Impulse

(Mass, Weight, and Density)

Fundamental Dynamics & Newton's Laws

1.1 The Concept of Force

In the previous weeks, we described motion (Kinematics). This week, we explore **Dynamics**, which is the study of the causes of motion—specifically, forces.

- **Force**: An interaction that can change the state of motion or shape of an object.
- **Net Force (∑F)**: The vector sum of all external forces acting on an object.

1.2 Newton's Second Law

Newton's Second Law is the core of dynamics. It states that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

- **The Equation**: {∑F} = m a.
- **Unit**: The SI unit of force is the **Newton (N)**, where 1 N = 1 kg . m/s^2.

Mass, Weight, and Density

2.1 Definition of Mass

Mass is an inherent property of an object.

- **Mass (m)**: A quantitative measure of inertia, which is the resistance of an object to changes in its motion.
- **Property**: Mass is a scalar quantity and remains constant regardless of the object's location in the universe.

2.2 Definition of Weight

Unlike mass, weight dep ends on the local gravitational field.

- **Weight (Fg or W)**: The magnitude of the gravitational force exerted on an object by the Earth.
- **The Equation**: Fg = m g.
- **Gravity (g)**: On Earth, g 9.80m/s^2.

2.3 Definition of Density

Density describes how much mass is contained in a given volume.

- **Density ρ:** The ratio of mass to volume.
- **The Equation**: ρ= m/V.
- **Specific Gravity**: The ratio of the density of a substance to the density of water.

Linear Momentum and Collisions

3.1 Linear Momentum

To understand collisions, we must define momentum.

- **Momentum {p}**: The product of an object's mass and its velocity.
- **The Equation**: {p} = m v.
- **Vector Nature**: Momentum has the same direction as the velocity

3.2 Impulse and the Impulse-Momentum Theorem

When a force acts on an object over a time interval, it creates an "Impulse".

- **Impulse I**: The product of the average force and the time interval of the interaction.
- **The Equation**: I = ∑F \Δt .
- **The Theorem**: The impulse of the net force acting on a particle is equal to the change in momentum of the particle I = Δp

3.3 Collisions

During a collision, the total momentum of an isolated system is conserved.

- **Law of Conservation of Momentum**: $p\ total, i = \ p\ total, f$

Projectile Motion (Extended Analysis)

As per the delivery plan, we apply dynamics to motion in two dimensions.

4.1 Horizontal and Vertical Components

In projectile motion, we assume air resistance is negligible.

- **Horizontal Motion**: There are no horizontal forces, so $ax\ =\ 0$ and horizontal velocity v_x is constant.
- **Vertical Motion**: Gravity is the only force $Fy\ =\ -mg\ , so\ ay\ =\ -g$

4.2 Key Kinematic Equations for Projectiles

- **Horizontal Position**: $x\ =\ xi\ +\ vxi\ t.$
- **Vertical Position**: $yf\ =\ yi\ +\ vyi\ t$ – 1/2 $g\ t$^2.
- **Vertical Velocity**: $vyf\ =\ vyi\ -\ gt$.

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Problem: A 5.0 kg object is pulled along a frictionless horizontal surface by a constant horizontal force of 20 N. Calculate the acceleration of the object.

- **Conceptualize:** A single force acts on a mass on a smooth surface.
- **Categorize:** Particle under a net force (Newton's Second Law).
- **Analyze:**
  - Given: m = 5.0kg , F = 20 N.
  - Formula: a = F/m.
  - Calculation: a = 20 N /5.0 kg = 4.0m/s^2.
- **Finalize:** The units are correct N/kg = m/s^2 , and the magnitude is reasonable.

Problem: A 10 kg box starts from rest and is pushed across a frictionless floor with a constant horizontal force of 30 N. What is the speed of the box after it has traveled 15 meters?

- **Conceptualize:** Use the force to find acceleration, then find the final speed.
- **Categorize:** Combination of Newton's Second Law and Kinematic equations.
- **Analyze:**
  1. **Find Acceleration (a):**
     - $a = F/m = 30N/10\ kg = 3.0\ m/s\text{^}2.$
  2. **Find Final Velocity (vf):**
     - Given: $vi = 0,\ \Delta x = 15m,\ a = 3.0m/s\text{^}2.$
     - Using Kinematic Equation: $vf\text{^}2 = vi\text{^}2 + 2a/\Delta x.$
     - $vf\text{^}2 = 0\text{^}2 + 2(3.0)(15) = 90.$

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- $vf = \sqrt{90} = 9.49\, m/s$.

- **Finalize:** The box speeds up as expected under a constant force

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Problem: A **1500 kg** car moving at **25 m/s** comes to a stop in a distance of **60 meters**. Calculate the magnitude of the constant braking force required.

Conceptualize: Use motion data to find deceleration, then find the force causing it.
Categorize: Particle under constant acceleration followed by Newton's Second Law.

Find Acceleration (a):

- Given: $vi = 25\frac{m}{s}, \quad vf = 0 \quad , \Delta x = 60\, m.$
- $vf\text{^}2 = vi\text{^}2 + 2a\Delta x \rightarrow 0 = (25)\text{^}2 + 2a(60).$
- $0 = 625 + 120a \quad \rightarrow \quad a = -625/120 \; = 5.21\, m/s\text{^}2$

Problem: A 2.0 kg block is released from rest at the top of a 30° incline. The coefficient of kinetic friction is μk = 0.2. If the incline is 5.0 meters long, how long does it take the block to reach the bottom?

Conceptualize: Forces on an incline determine acceleration, which determines time.

Resolve Forces along the Incline (x-axis):

- $Fg\ (parallel)\ =\ mg\ sin\theta.$
- $fk\ =\ \mu k\ n\ =\ \mu k\ (mg\ \ cos\theta).$
- $\sum Fx\ =\ mg\ \ sin\theta\ -\ \mu k\ mg\ \ cos\theta\ =\ ma.$

Calculate Acceleration (a):

- $a\ =\ g\ sin\theta\ -\ \mu k\ cos\theta\ \ =\ 9.8(sin\ 30°\ -\ 0.2\ cos\ 30°).$
- $a\ =\ 9.8(0.5\ -\ 0.173)\ =\ 9.8(0.327)\ \approx\ 3.20\ m/s\text{^}2.$

Find Time (t):

- $Given\ vi\ =\ 0,\quad \Delta x\ =\ 5.0\ m\quad ,a\ =\ 3.20\ m/s\ \text{^}2.$
- $\Delta x\ =\ vi\ t\ +\ ½\ at\text{^}2\qquad \rightarrow\ 5.0\ =\ 0\ +\ ½\ (3.20)t\text{^}2.$
- $5.0\ =\ 1.6t\text{^}2\ \ \rightarrow\ t\text{^}2\ =\ 3.125\ \approx 1.77\ s\ .$

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