PHYS11 CH8: Linear Momentum & Collisions

Understanding Motion Through Conservation Laws

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Learning Objectives

- Define and calculate linear momentum
- Understand impulse and its relationship to force
- Apply conservation of momentum in various scenarios
- Analyze elastic and inelastic collisions
- Solve problems involving two-dimensional collisions
- Understand basic rocket propulsion principles

Chang'e-5

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Saturn V Launch

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Saturn V Launch Example

Initial Acceleration Calculation

[Insert Saturn V rocket momentum diagram]

Saturn V Facts

- Largest and most powerful rocket ever successfully operated
- Used in Apollo moon missions
- Height: 111 meters (363 feet)
- Thrust at liftoff: 34.5 million newtons

Example 8.8: Saturn V Initial Acceleration

Problem Setup

Given Values

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Strategy

Use rocket acceleration equation:

$$a = \frac{v_e}{m}\frac{\Delta m}{\Delta t} - g$$

Example 8.8: Solution

Step-by-Step Calculation

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$$a = \frac{v_e}{m}\frac{\Delta m}{\Delta t} - g$$

$$= \frac{2.40 \times 10^3 \text{ m/s}}{2.80 \times 10^6 \text{ kg}}$$

Example 8.8: Solution

Step-by-Step Calculation

$$a = \frac{v_e}{m}\frac{\Delta m}{\Delta t} - g$$

$$= \frac{2.40 \times 10^3 \text{ m/s}}{2.80 \times 10^6 \text{ kg}} \times (1.40 \times 10^4 \text{ kg/s}) - 9.80 \text{ m/s}^2$$

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Step-by-Step Calculation

$$a = \frac{v_e}{m}\frac{\Delta m}{\Delta t} - g$$

$$= \frac{2.40 \times 10^3 \text{ m/s}}{2.80 \times 10^6 \text{ kg}} \times (1.40 \times 10^4 \text{ kg/s}) - 9.80 \text{ m/s}^2$$

$$= 12.0 \text{ m/s}^2 - 9.80 \text{ m/s}^2$$

Example 8.8: Solution

Step-by-Step Calculation

$$
\begin{aligned}
a &= \frac{v_e}{m}\frac{\Delta m}{\Delta t} - g \\
&= \frac{2.40 \times 10^3 \text{ m/s}}{2.80 \times 10^6 \text{ kg}} \times (1.40 \times 10^4 \text{ kg/s}) - 9.80 \text{ m/s}^2 \\
&= 12.0 \text{ m/s}^2 - 9.80 \text{ m/s}^2 \\
&= 2.20 \text{ m/s}^2
\end{aligned}
$$

Example 8.8: Discussion

Analysis of Results

- Initial acceleration seems small: $2.20\ \mathrm{m/s^2}$

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- Initial acceleration seems small: 2.20 m/s^2
- Acceleration increases as fuel burns because:
  - Mass (m) decreases
  - Exhaust velocity (v_e) remains constant
  - Fuel burn rate ($\Delta m / \Delta t$) remains constant

Key Insight

The seemingly small initial acceleration is sufficient because it continuously increases as fuel is consumed.

discussion time

Linear Momentum

Definition

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

- Vector quantity with direction same as velocity
- SI units: kgm/s
- Proportional to both mass and velocity

$$\text{Total Momentum} = \sum_i m_i \vec{v}_i$$

8.1 Linear Momentum and Force

Key Definition

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

- Linear momentum is fundamentally defined as mass $\times$ velocity
- SI Units: kg·m/s
- Newton's Second Law in momentum form:

$$\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t}$$

- $\vec{F}_{\text{net}}$ is net external force
- $\Delta \vec{p}$ is change in momentum
- Δt is time interval

Impulse

Key Equation

$\vec{J} = \vec{F}\Delta t = \Delta\vec{p}$

- Measures change in momentum
- Can reduce force by increasing time
- Applications:
  - Airbags
  - Sports equipment
  - Safety padding

Impulse Egg Drop

Show impulse egg drop video

8.2 Impulse

Key Concept

Impulse equals change in momentum

$$\begin{aligned}\vec{J} &= \vec{F}_{\text{net}}\Delta t \\ &= \Delta\vec{p}\end{aligned}$$

- Impulse is the product of force and time interval
- Forces typically vary over time
- Area under force-time curve equals impulse

8.3 Conservation of Momentum

Conservation Principle

In an isolated system: $\vec{p}_{\text{tot}} = \text{constant}$

- An isolated system has zero net external force
- $\vec{p}_{\text{initial}} = \vec{p}_{\text{final}}$
- Conserved in systems with:
  - No external forces
  - During projectile motion (horizontal direction)
  - In particle systems

Elastic Collisions

- Conserves kinetic energy
- Conserves momentum
- Final velocities calculable from initial conditions

Inelastic Collisions

- Kinetic energy not conserved
- Momentum conserved
- Perfectly inelastic: objects stick together

Applications

Sports science, safety systems, particle physics

8.6 Two-Dimensional Collisions

Key Strategy

Break motion into perpendicular components

- Choose x-axis parallel to incoming velocity
- For mass 2 initially at rest:
  - x-axis:
  - $m_1 v_1 = m_1 v_1' \cos\theta_1 + m_2 v_2' \cos\theta_2$
  - y-axis:
  - $0 = m_1 v_1' \sin\theta_1 + m_2 v_2' \sin\theta_2$
- Point masses cannot rotate or spin

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8.7 Rocket Propulsion

Rocket Acceleration

$$a = \frac{v_e}{m}\frac{\Delta m}{\Delta t} - g$$

- Based on Newton's Third Law
- Acceleration depends on:
  1. Exhaust velocity (v_e)
  2. Fuel burn rate ($\Delta m/\Delta t$)
  3. Rocket mass (m)
- Greater acceleration with:
  - Higher exhaust velocity
  - Faster fuel consumption
  - Lower rocket mass