



# Classical Mechanics

## First stage

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**Lecture** 9

## 1- Linear Momentum

### Definition of Linear Momentum, $\vec{p}$

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

SI unit:  $\text{kg} \cdot \text{m/s}$

Momentum is a vector; its direction is the same as the direction of the velocity

## 2- Momentum and Newton's Second Law

- Newton's second law, as we wrote it before:

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

is only valid for objects that have constant mass. Here is a more general form, also useful when the mass is changing:

**Newton's Second Law**

$$\sum \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$

### 3- Impulse

**Definition of Impulse,  $\vec{I}$** 

$$\vec{I} = \vec{F}_{av} \Delta t$$

$$\text{SI unit: } \text{N} \cdot \text{s} = \text{kg} \cdot \text{m/s}$$

- Impulse is a vector, in the same direction as the average force.

- We can rewrite

$$\vec{F}_{av} \Delta t = \Delta \vec{p}$$

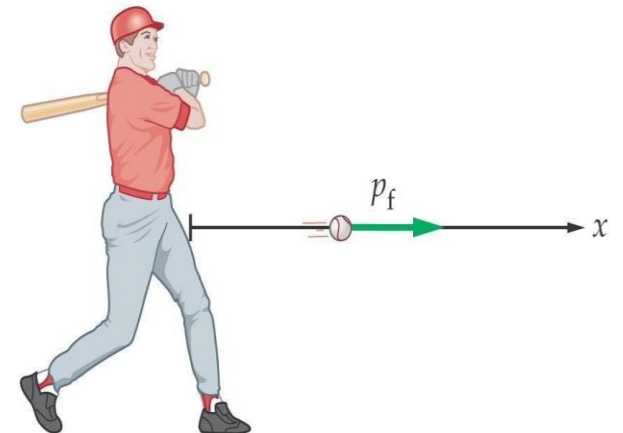
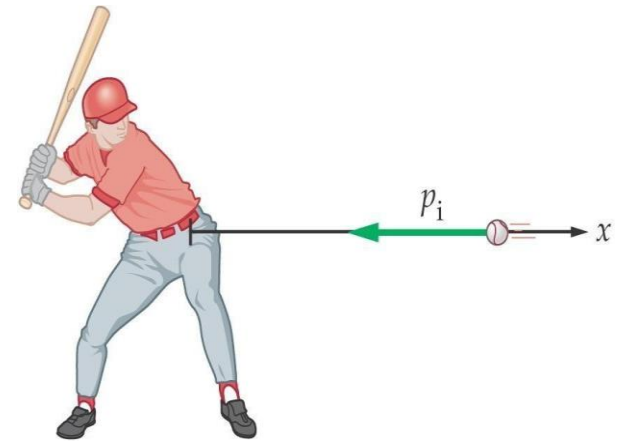
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So we see that

$$\vec{I} = \vec{F}_{av} \Delta t = \Delta \vec{p}$$

- The impulse is equal to the change in momentum.

- Therefore, the same change in momentum may be produced by a large force acting for a short time, or by a smaller force acting for a longer time.



## Example

- An object of mass 3.0 kg is allowed to fall from rest under the force of gravity for 3.4 seconds. What is the change in momentum? Ignore air resistance.

**Want  $\Delta \mathbf{p} = m\Delta \mathbf{v}$ .**

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

$$\Delta \mathbf{v} = -g\Delta t = -33.3 \text{ m/sec}$$

$$\Delta \mathbf{p} = m\Delta \mathbf{v} = -100 \text{ kg m/s (downward)}$$

### Example

- What average force is necessary to bring a 50.0-kg sled from rest to 3.0 m/s in a period of 20.0 seconds? Assume frictionless ice.

$$\Delta \mathbf{p} = \mathbf{F}_{\text{av}} \Delta t$$

$$\mathbf{F}_{\text{av}} = \frac{\Delta \mathbf{p}}{\Delta t} = \frac{m \Delta \mathbf{v}}{\Delta t}$$

$$F_{\text{av}} = \frac{(50.0 \text{ kg})(3.0 \text{ m/s})}{20.0 \text{ s}} = 7.5 \text{ N}$$

The force will be in the direction of motion.

## 4- Conservation of linear momentum

- The net force acting on an object is the rate of change of its momentum:

$$\sum \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$

- If the net force is zero, the momentum does not change:

### Conservation of Momentum

If the net force acting on an object is zero, its momentum is conserved; that is,  
 $\vec{p}_f = \vec{p}_i$

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- **Internal Versus External Forces:**

- **Internal forces** act between objects within the system.
- As with all forces, they occur in action-reaction pairs. As all pairs act between objects in the system, **the internal forces always sum to zero:**

$$\sum \vec{F}_{\text{int}} = 0$$

- Therefore, the **net force** acting on a system is **the sum of the external forces** acting on it.
  - Furthermore, internal forces cannot change the momentum of system  
may change.
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## Example

- A rifle has a mass of 4.5 kg and it fires a bullet of 10.0 grams at a muzzle speed of 820 m/s. What is the recoil speed of the rifle as the bullet leaves the barrel?

As long as the rifle is horizontal, there will be no net external force acting on the rifle-bullet system and momentum will be conserved.

$$\mathbf{p}_i = \mathbf{p}_f$$

$$0 = m_b v_b + m_r v_r$$

$$v_r = -\frac{m_b}{m_r} v_b = -\left(\frac{0.01 \text{ kg}}{4.5 \text{ kg}}\right) 820 \text{ m/s} = -1.82 \text{ m/s}$$