PHYS 101

Momentum

Goals

- Build a conceptual understanding of momentum and impulse
- Discuss momentum as a conserved quantity within isolated systems
- Describe how momentum changes

What's going on?

- Conservation of energy alone <u>cannot</u> explain the behavior of Newton's Cradle.
- The interactions have a <u>symmetric</u> nature
- What other symmetric behavior have we discussed in class?





Clicker Question

What other law or principle have we discussed in class that has symmetric properties?

- A. Galileo's Law of Inertia
- B. Newton's 2nd Law
- C. Newton's 3rd Law
- **D**. Newton's Law of Universal Gravity

Remember Newton's 3rd Law

If Object 1 and Object 2 interact, the force that Object 1 exerts on Object 2 (F_{12}) is equal and opposite to the force Object 2 exerts on Object 1 (F_{21})



Forces always Come in Pairs: You Push on a Wall the Wall Pushes Back

$$\vec{F}_{1\to 2} = -\vec{F}_{2\to 1}$$

Suppose two objects form an <code>isolated</code> system. The only forces are $\rm F_{12}$ and $\rm F_{21}$

$$\begin{aligned} \mathsf{3^{rd} Law}: \ \vec{F_{1\to 2}} &= -\vec{F_{2\to 1}} & & & \\ \mathsf{m_2} \, \vec{a_2} &= -\mathsf{m_1} \, \vec{a_1} \\ \\ \mathsf{m_2} \, \mathsf{m_2} \, \vec{a_2} &= -\mathsf{m_1} \, \vec{a_1} \\ \\ \vec{a_2} &= \frac{\vec{F_{1\to 2}}}{\mathsf{m_2}} & \vec{a_1} &= \frac{\vec{F_{2\to 1}}}{\mathsf{m_1}} \end{aligned}$$

Suppose these objects interact for a time period *t* during which the acceleration is constant

$$\vec{v}_1 = \vec{v}_{1_0} + \vec{a}_1 t$$

 $\vec{v}_2 = \vec{v}_{2_0} + \vec{a}_2 t$

$$m_2\left(\frac{\vec{v}_2 - \vec{v}_{2_0}}{t}\right) = -m_1\left(\frac{\vec{v}_1 - \vec{v}_{1_0}}{t}\right)$$

$$m_1 \vec{v}_1 + m_2 \vec{v}_2 = m_1 \vec{v}_{10} + m_2 \vec{v}_{20}$$

Linear Momentum

For this class, we define linear momentum as the product of an object's mass and its linear velocity

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



Problem

A softball pitcher claims she can throw a 190 g softball with as much momentum as a 3.00 g bullet travelling a 1500 m/s

How fast must the pitcher through her softball to have the same momentum?





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$$\vec{p}_{\rm b} = {\rm m}_{\rm b} \vec{v}_{\rm b} = (0.003 \text{ kg})(+1500 \text{ m/s}) = +4.50 \text{ kg m/s}$$

$$\vec{p}_{s} = (0.190 \text{ kg})\vec{v}_{b}$$

 $\vec{v}_{s} = \frac{+4.50 \text{kg m/s}}{0.190 \text{ kg}} = +23.7 \text{ m/s}$







Prediction Question

A softball pitcher claims she can throw a 190 g softball with as much momentum as a 3.00 g bullet travelling a 1500 m/s

Which object has the greater kinetic energy?

- A. softball
- B. bullet
- C. they have the same amount of KE
- D. no idea





Prediction Question

A softball pitcher claims she can throw a 190 g softball with as much momentum as a 3.00 g bullet travelling a 1500 m/s

$$K_{\rm b} = \frac{1}{2} {\rm m}_{\rm b} v_{\rm b}^2 = \frac{1}{2} (0.003 \text{ kg}) (1500 \text{ m/s})^2 =$$

$$K_{\rm s} = \frac{1}{2} (0.190 \text{ kg}) (23.7 \text{ m/s})^2$$





Conservation of Momentum

In a closed, isolated system, momentum is conserved

$$\sum \vec{F}_{\text{ext}} = 0 \quad \rightarrow \quad \Delta \vec{p}_{\text{tot}} = 0$$

Closed isolated system : a system of objects that does not experience any net external force from outside the system

Problem

Two objects, Object 1 with mass M and Object 2 with mass 2M are initially stuck together. At t=0, the combined object "explodes" - causing the objects to move away from each other in opposite directions. Determine the velocity of Object 1 with respect to Object 2's velocity Assume the motion is in the horizontal direction

- Draw your initial and final state of your system
- Determine if external forces are acting on it. If not, momentum is conserved.
- Determine the initial and final momentum

Consider one object in the interaction

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

Let's assume during a small period of time, Δt , that its momentum has change by Δp

$$\frac{\Delta \vec{p}}{\Delta t} = m \left(\frac{\Delta \vec{v}}{\Delta t}\right) = m \vec{a}_{ave} \qquad \Delta t \to 0 \text{ so that}$$
$$F_{net} = \frac{\Delta \vec{p}}{\Delta t}$$

 $\vec{a}_{\rm ave} \rightarrow \vec{a}$

Impulse

Impulse is a vector representing the effect of an applied net force acting on an object over a given time

If the force is constant during the time interval

$$\vec{I} = \vec{F}_{\rm net} \Delta t = \Delta \vec{p} = \mathbf{m} \Delta \vec{v}$$

Problem 0: A 75.0-kg person is riding in a car moving at 20.0 m/s when the car runs into a bridge abutment.

(a) Calculate the average force on the person if he is stopped by a padded dashboard that compresses an average of 1.00 cm. [assume constant acceleration]

(b) Estimate the compression time

(c) Calculate the average force on the person if he is stopped by an airbag that compresses an average of 15.0 cm.

(d) Estimate the compression time due to the airbag