Studio 7: Impulse and Conservation of Momentum

(and some energy too)

Warm-Up Activity

Momentum is conserved when...

(A) The kinetic energy is zero.

(B) The net external work is zero.

(C) The net force is zero.

(D) There is no change in potential energy.

S7-1: Ejector Seat

- A stationary stunt car driver has an ejector seat that rests on a compressed vertical spring.
- When the spring is released, the seat with its passenger is launched out of the car and into the air.
  - Explain why you might want to include the Earth and the spring in your system.
- Consider three instants in time: (1) just before the seat is released, (2) when the spring is at equilibrium, and (3) the person reaches maximum height.
  - Write a qualitative description of how the energy of the system transforms through these three instants.
- For each instant:
  - Draw a physical diagram.
  - Construct an energy bar chart.
  - Write each energy symbolically.
- How high does the person go?
- What is the person's speed when the ejector seat leaves the spring?
  - Don't forget to make sense of your answers!

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Impulse and Momentum

We rewrote Newton's 2nd law in a new way, which we will call the impulse-momentum theorem.

$$\text{Impulse} = \text{Change in Momentum}$$
$$\vec{J}_{net} = \Delta\vec{p}$$
$$\int_{t_i}^{t_f} \vec{F}^{net} dt = m\vec{v}_f - m\vec{v}_i$$

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A Deeper Model for Interactions

- Quantities
  - Energy E
  - Work $W = \int_{r_i}^{r_f} \vec{F} \cdot d\vec{r}$
  - Kinetic Energy $K = \frac{1}{2}mv^2$
  - Potential Energy $U =$ depends on interaction
    You have to tell everyone where zero PE is!
    * Gravity $U_g = mgy$
    * Spring $U_{sp} = \frac{1}{2}kx^2$
  - Momentum $\vec{p} = m\vec{v}$
  - Impulse $\vec{J}_{net} = \int_{t_i}^{t_f} \vec{F}^{net} dt$
- Laws
  - Work-energy theorem $W_{\text{net,ext}} = \Delta E_{\text{total}}$
  - Impulse-momentum theorem $\vec{J}_{net} = \Delta\vec{p}$

S7-2: The Ball and the Ground I

- You drop a 0.05 kg tennis ball from rest and it takes 0.5 s to hit the ground.
- Use the impulse-momentum theorem to find the velocity of the ball just before impact with the ground.

S7-2: The Ball and the Ground II

- You drop a 0.05 kg tennis ball from rest and it takes 0.5 s to hit the ground.
- The tennis ball rebounds from the ground with the same speed as impact. The collision takes 0.01 s.
- Find the average net force on the tennis ball.

$^2\hat{y}$.

Conservation of Momentum

If the net force on a system is zero, then the impulse is zero.

$$\vec{J} = \Delta \vec{p}$$
$$\vec{0} = \Delta \vec{p}$$

Under this condition, we say that the momentum of the system is *conserved*—it does not change!

S7-3: Two Rocks Collide

- A small rock (mass m) is moving to the right on a frictionless table with speed v.
- It hits a second rock (mass M) that is initially at rest on the table. The rocks do not stick together.
  - Is momentum conserved? For what system?
  - Is energy conserved? For what system?
- Our goal is to find the final speed of each rock, but don't try to solve it yet.
  - Instead, what special cases do you want to think about for this situation? What makes these special cases easier to think about than the general problem?

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Energy and Collisions

- Collisions where kinetic energy is conserved are known as *elastic collisions.*
- Collisions where the energy of the system decreases are known as *inelastic collisions.*
  - When two things stick together, this is a *perfectly inelastic collision.*
- Collisions where the energy of the system increases are known as *superelastic collisions.*
  - Think explosions.

Main Ideas

- Momentum and impulse are useful quantities for solving dynamics problems.
- The impulse is always equal to the change in momentum for a system.
- When the impulse is zero (because the net force is zero), the momentum of the system is constant—it is *conserved*.