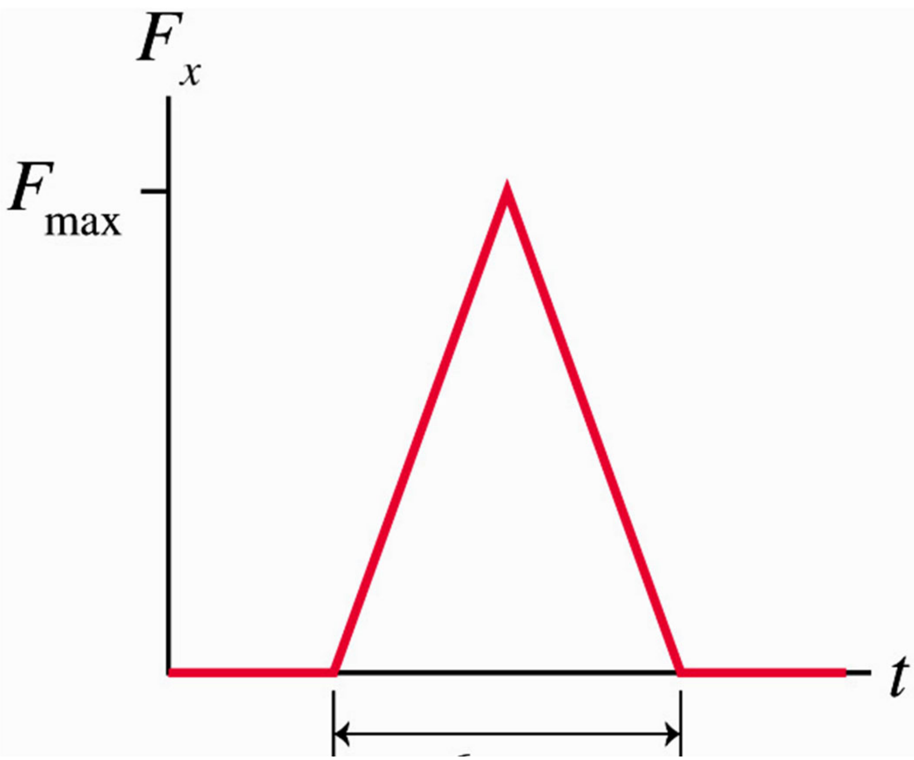
Impulse = Average Force * contact time

What if that force isn't constant?

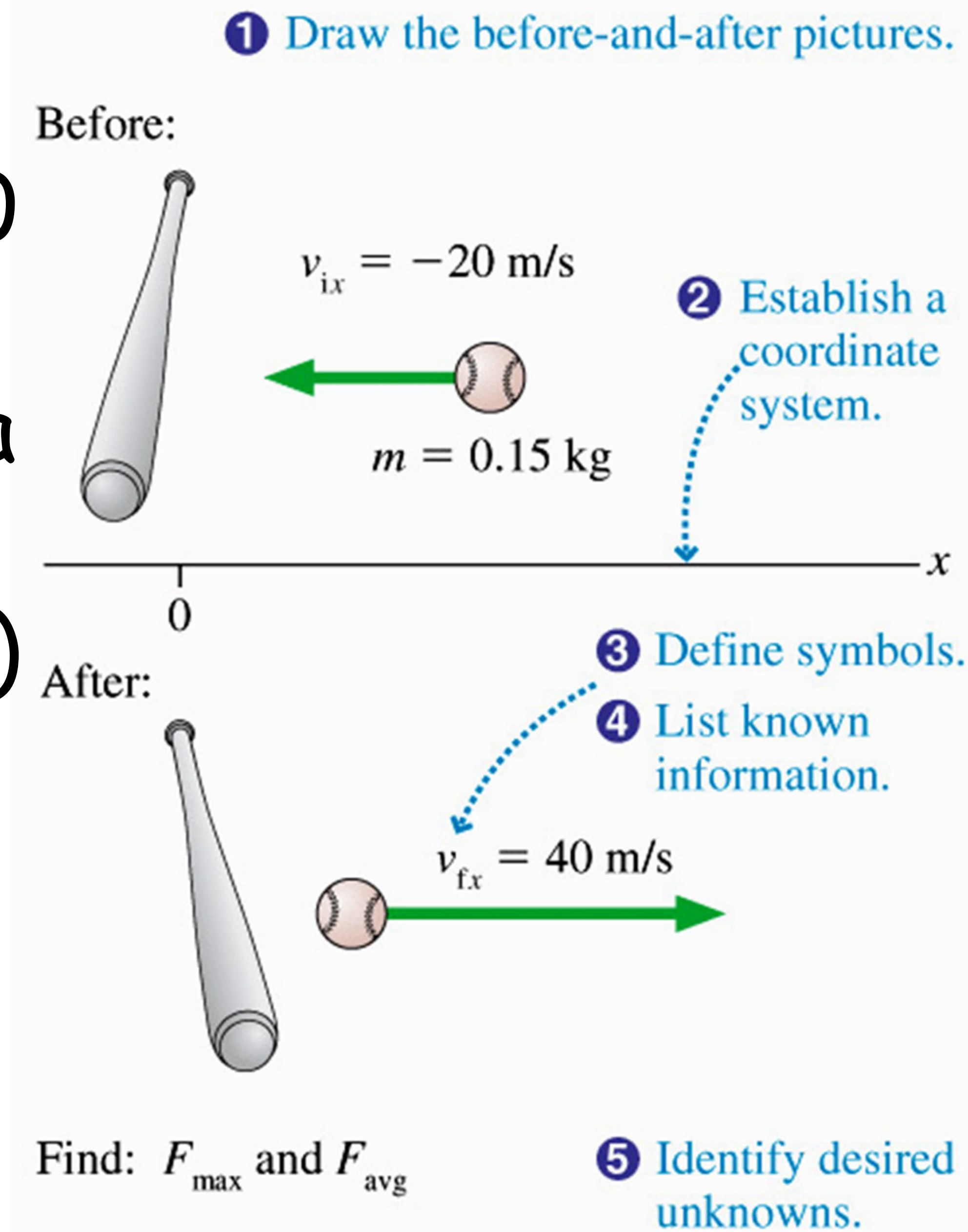


Can you think of an example?

Hitting a Baseball

A 150 g baseball is thrown at a speed of 20 m/s. It is hit straight back to the pitcher at a speed of 40 m/s. (Contact time is 0.006s)

What is the impulse and average force F_{av} that the bat exerts on the ball?

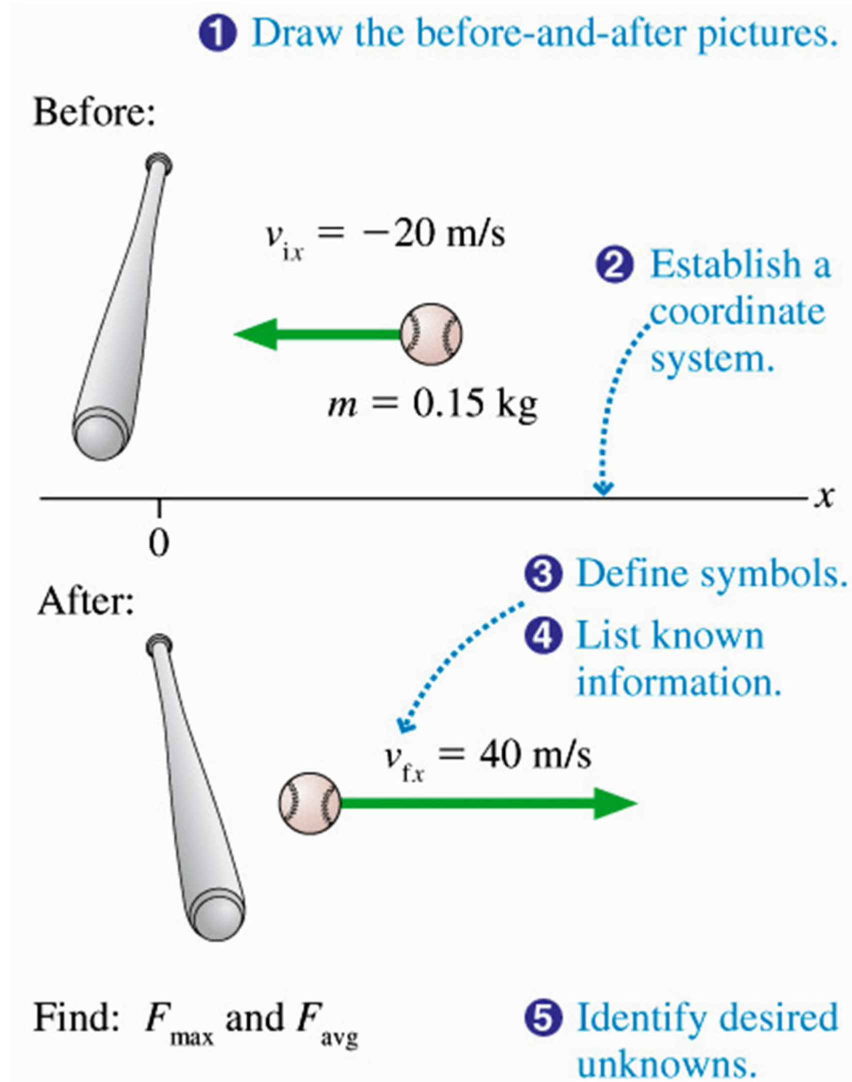


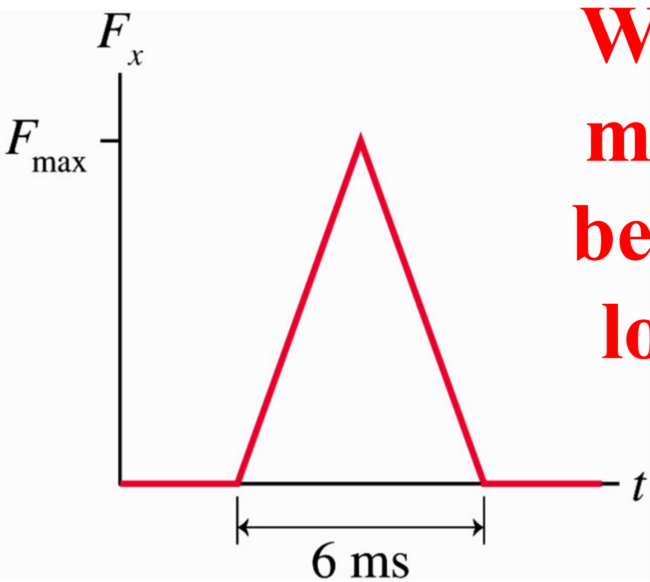
Possible to do this with Chapters 2&4 stuff instead

Hitting a Baseball: Consider just before and just after ball touches bat

$$\Delta p_x = mv_{fx} - mv_{ix} = m(v_{fx} - v_{ix})$$
$$= (0.15\text{ kg})(40\text{ m/s} + 20\text{ m/s})$$
$$= 9.0\text{ kg m/s}$$

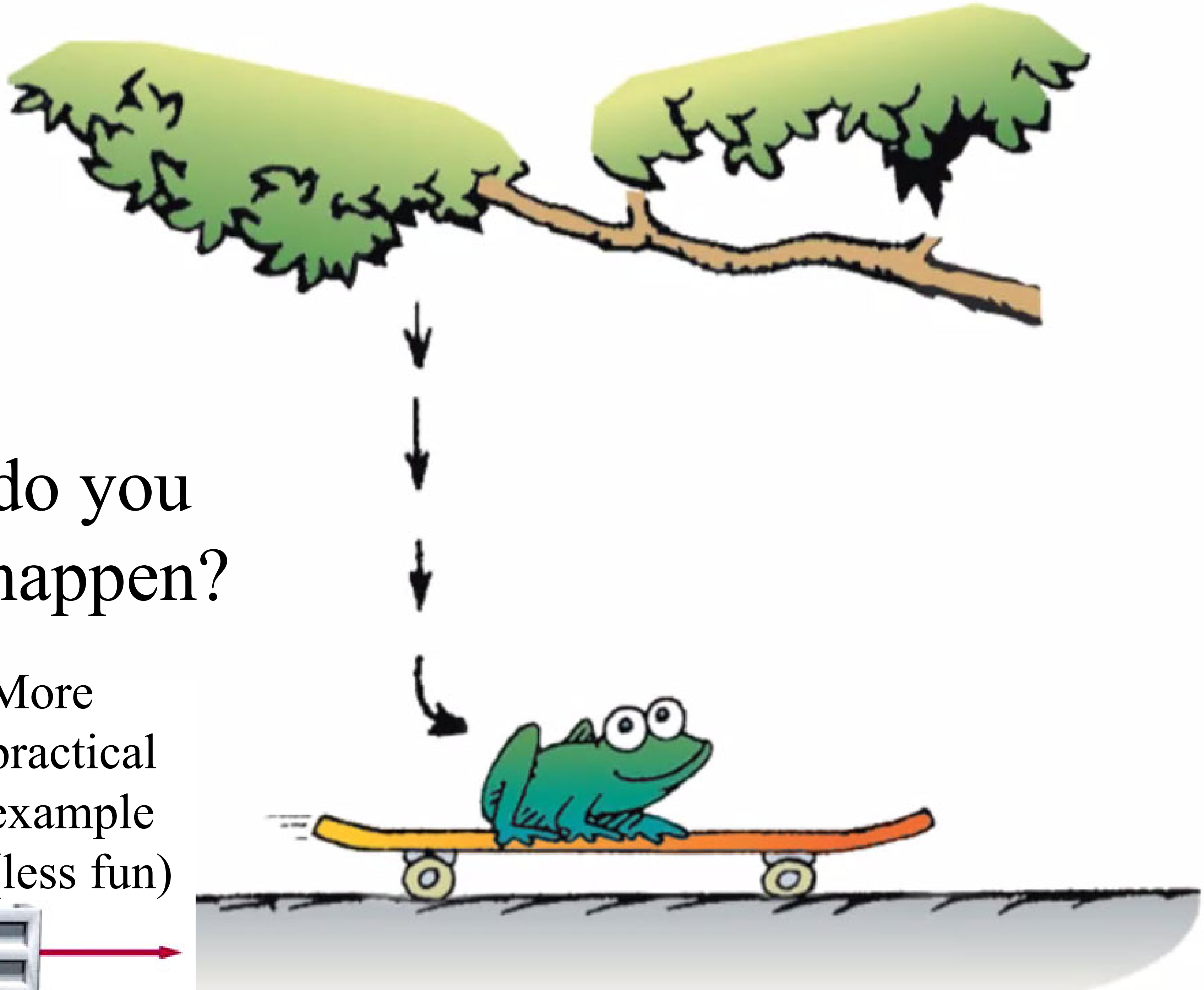
$$F_{av} = \frac{\Delta p_x}{\Delta t} = \frac{(9.0\text{ kg m/s})}{(.006\text{ s})} = 1{,}500\text{ N}$$



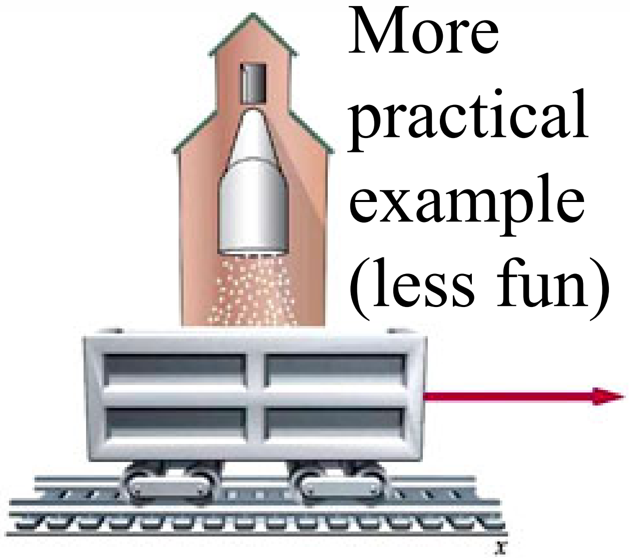


What would the maximum force be if force graph looks like this?

Note that the impulse is the area under this curve! (Area of triangle = ½ height * width)



What do you expect happen?



More practical example (less fun)

Main Ideas in Class Today

After today's class, you should be able to:

- Understand what a "system" is and determine whether it is isolated
- Apply Conservation of Linear Momentum to determine a final velocity in one or two dimensions

Extra Practice: 6.21, 6.25, 6.27, 6.65

What is a System?

A system is a set of objects interacting with each other

(set of pool balls, ball/bat, cars colliding)

How does the total momentum change during a fender bender?

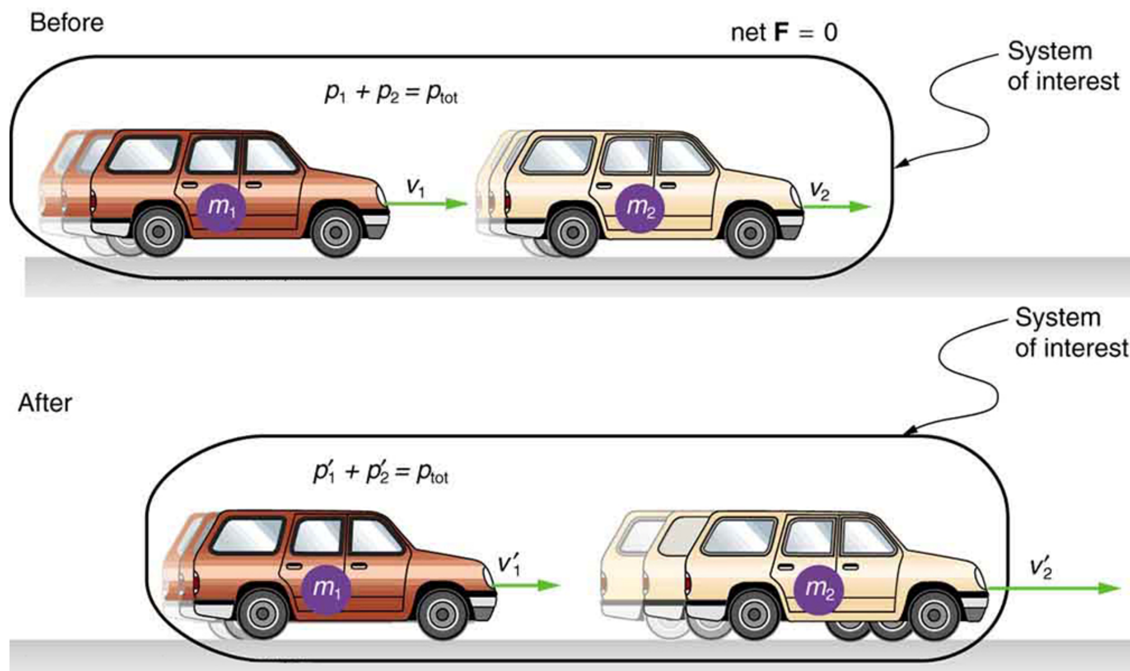
From the definition of impulse, we know:

$$\Delta \mathbf{p}_1 = \mathbf{F}_1 \Delta t$$

$$\Delta \mathbf{p}_2 = \mathbf{F}_2 \Delta t$$

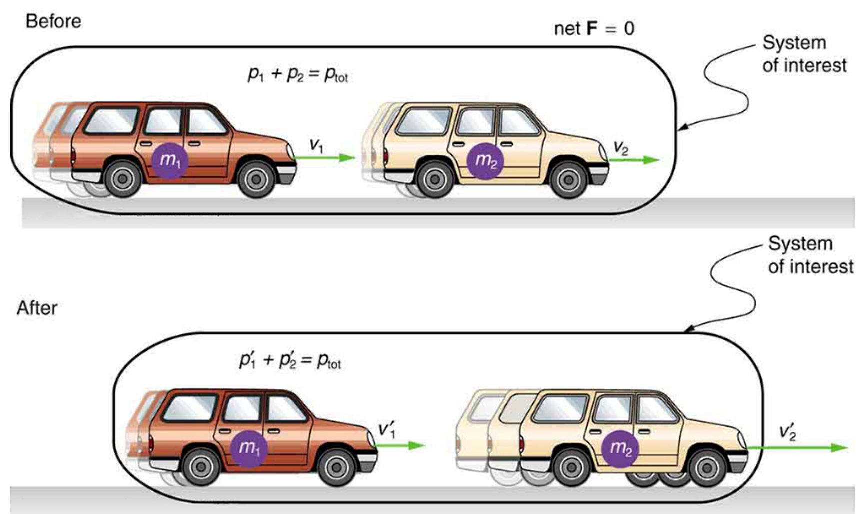
Newton's Third Law implies

$$\mathbf{F}_2 = -\mathbf{F}_1$$



How does the total momentum change during a fender bender?

So $\Delta \mathbf{p}_2 = -\mathbf{F}_1 \Delta t = -\Delta \mathbf{p}_1$



Which means

$\Delta \mathbf{p}_1 + \Delta \mathbf{p}_2 = 0$

Or $(\mathbf{p}_{1f} - \mathbf{p}_{1i}) + (\mathbf{p}_{2f} - \mathbf{p}_{2i}) = 0$

Rearranged to be: $\mathbf{p}_{1i} + \mathbf{p}_{2i} = \mathbf{p}_{1f} + \mathbf{p}_{2f}$

The total momentum <u>of the system</u> is the same before and after the collision!!!

Recoil

A rifle with a **weight ($W=mg$)** of 20 **N** fires a 4.0 g bullet with a speed of 280 m/s.

(a) Find the recoil speed of the rifle.

(b) If a 725 N man holds the rifle firmly against his shoulder, find the recoil speed of the man and rifle.

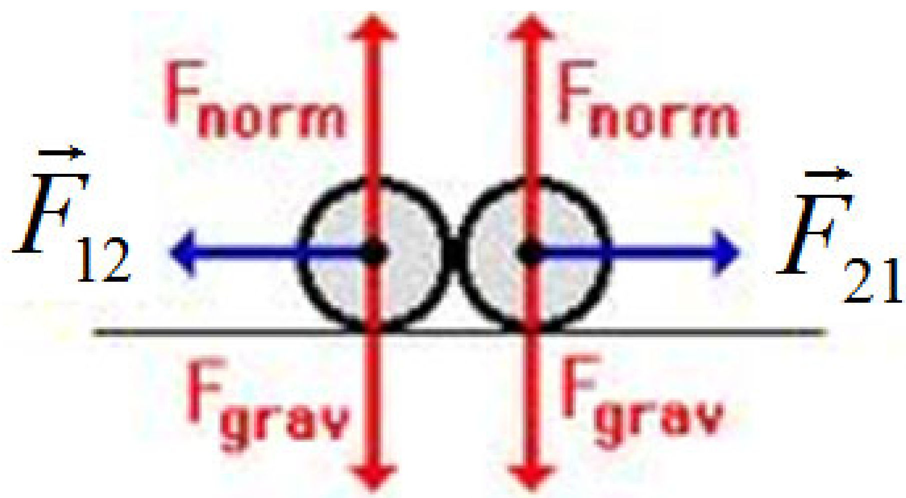
What is the system?

What is a System?

A system is a set of objects interacting with each other

(set of pool balls, ball/bat, students in this room)

An **isolated system** has **no unbalanced external forces**, meaning no unbalanced forces outside the system (e.g., normal/gravity)



The collision between two billiard balls on a friction-free surface occurs in an isolated system

Isolated System?

Ignore air resistance (small effect).

A. Yes.
B. No.

If yes, then no forces external to the system play a big role in the motion.

Cars crashing on ice
(ignore friction, small)

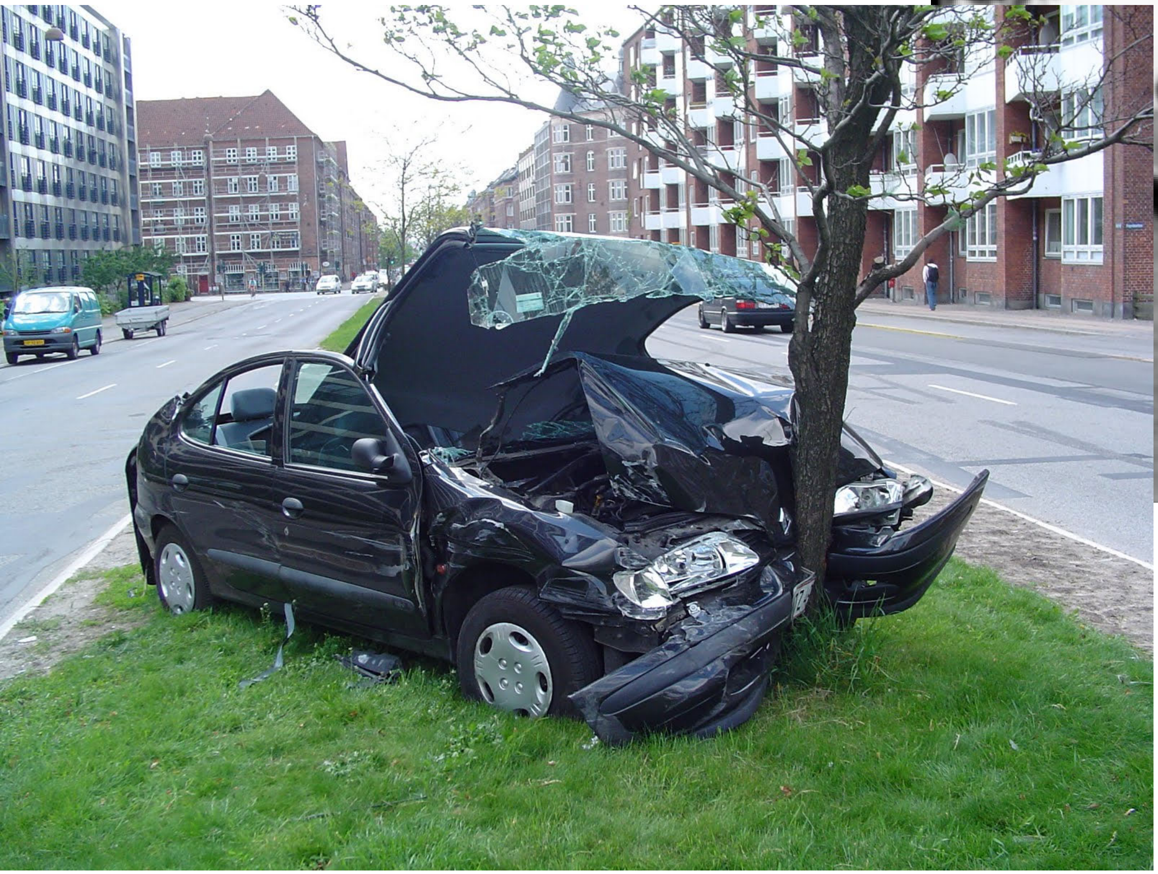
Jumping guy hits soccer ball in air

Two boats crashing

Q72-74

Isolated System?

Car and Tree



Car and Zombie moving with constant velocity (before or after hitting each other)

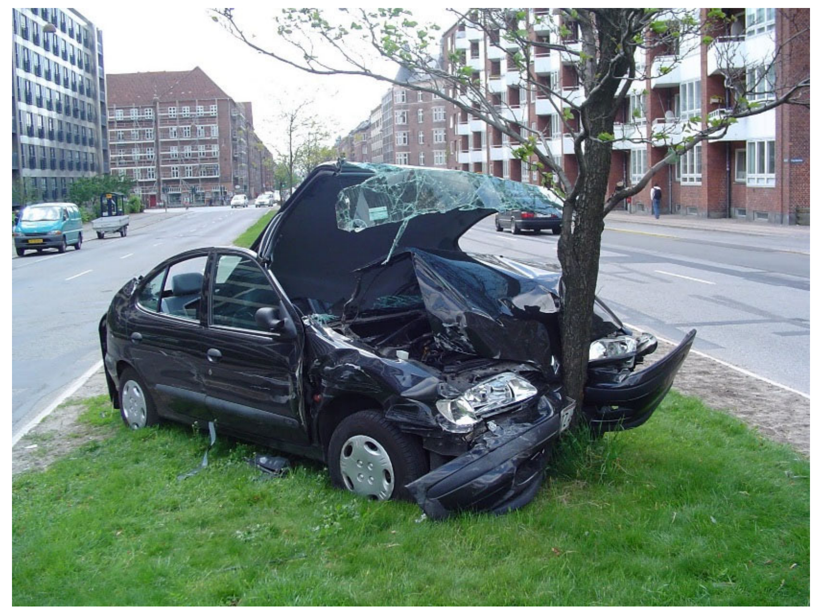
A. Yes.

B. No.

Q75-76

Even if a system isn't isolated, sometimes we can approximate it as isolated by only considering just before and after the instant of the collision (other forces don't have much time to act)

Would work fine



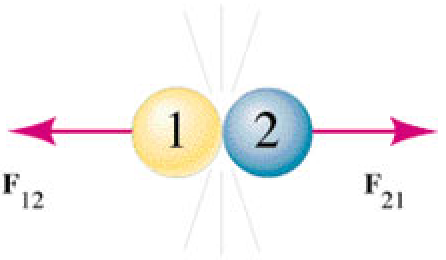
Would not work here (external force has a large impact on the result)

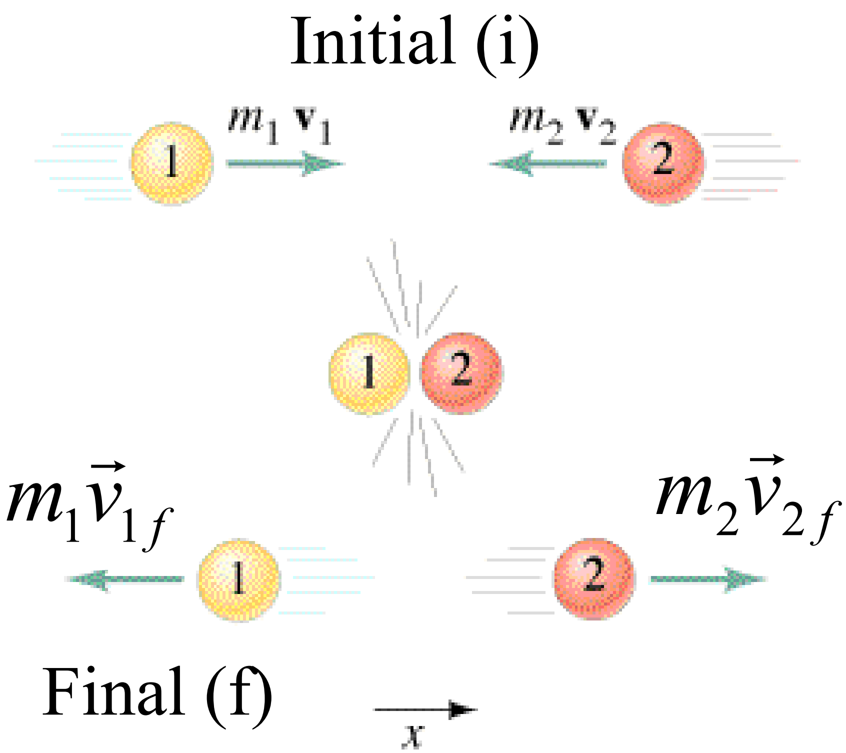
There is Conservation of Linear Momentum in Isolated Systems.

$$\vec{p}_{f,system} = \vec{p}_{i,system}$$

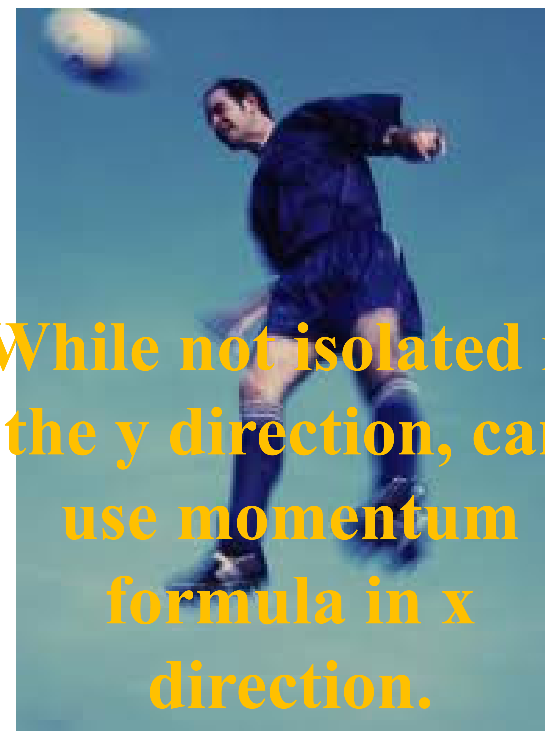
$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

This is a vector formula. What does that mean?





Ex: collision of two billiard balls on a frictionless surface

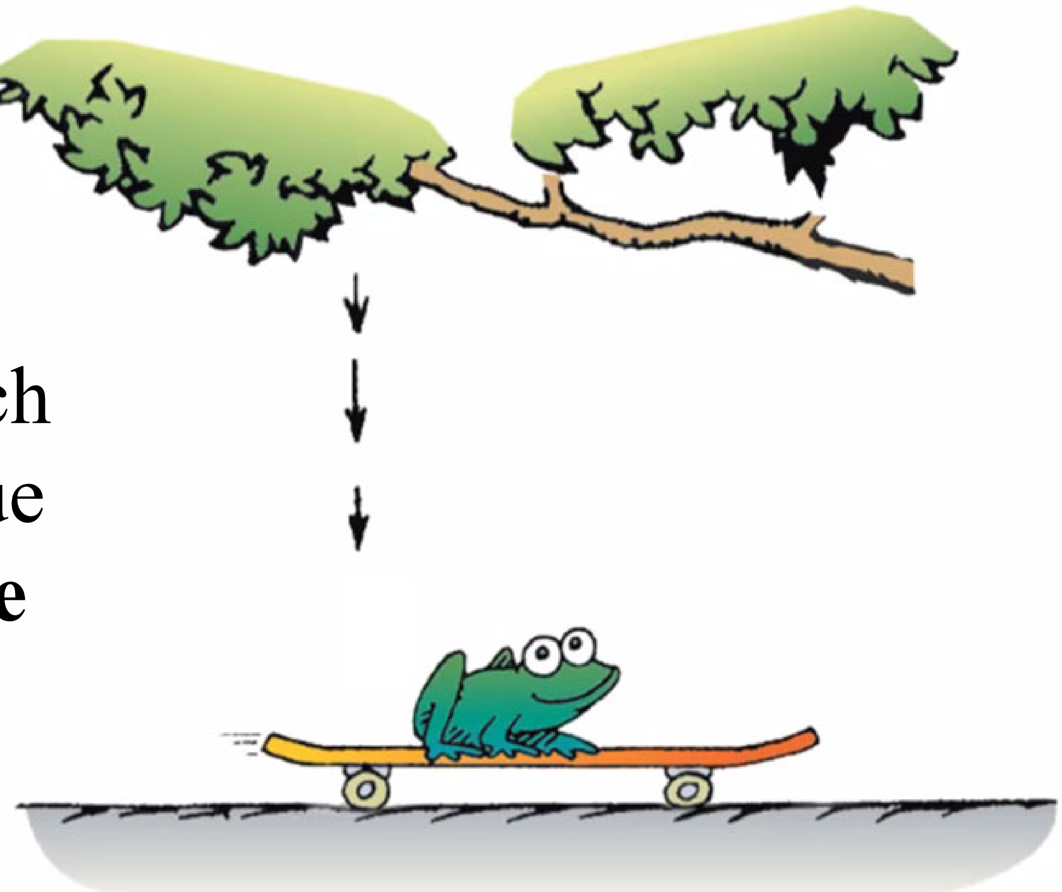


Conservation of momentum

The head of a 0.2 kg golf club is traveling at 55 m/s just before it strikes a 0.046 kg golf ball at rest on a tee. After the collision, the club head travels (in the same direction) at 40 m/s. Find the speed of the golf ball just after impact.

Treat the system as isolated during the instant of collision.

A frog dropped down onto a skateboard that is rolling to the right at a constant speed on a horizontal surface. Which quantities have the same value ***just before* and just *after*** **the package lands in the cart**?



A. The horizontal component of total momentum

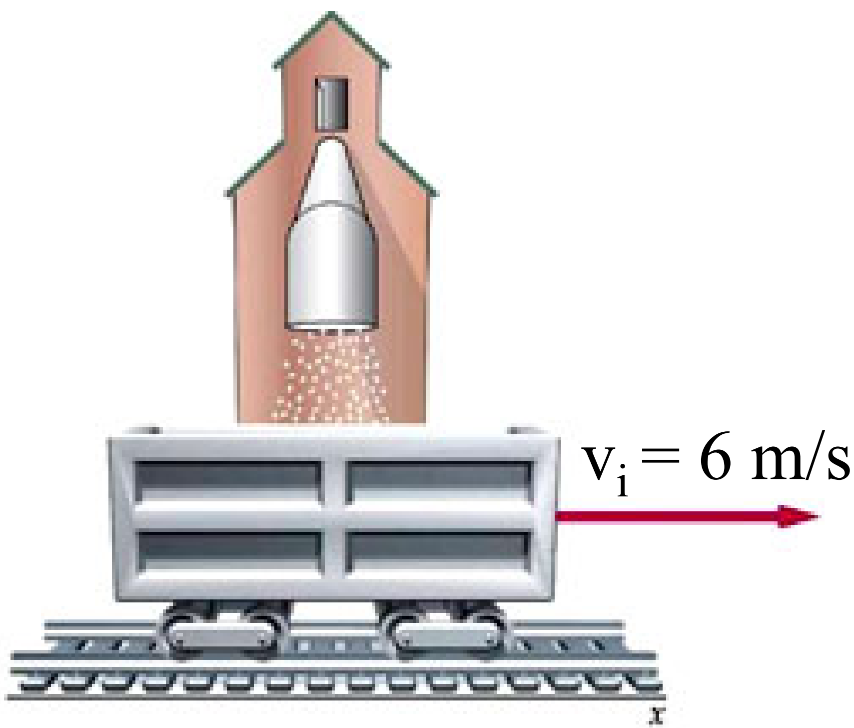
B. The vertical component of total momentum

C. Both of the above

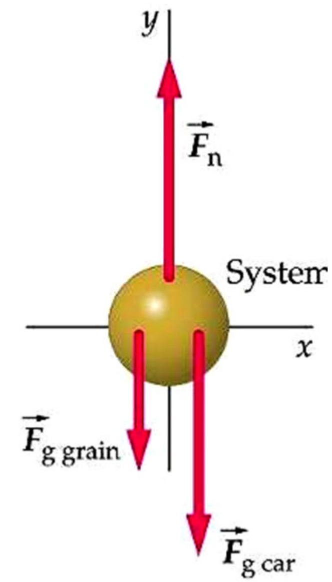
D. None of the above

Q78

A 500-kg freight package is dropped vertically onto a 1000-kg rail cart moving at 6 m/s. The package is moving at 3 m/s just before landing on the cart. After the drop, the speed of the cart and package is closest to:



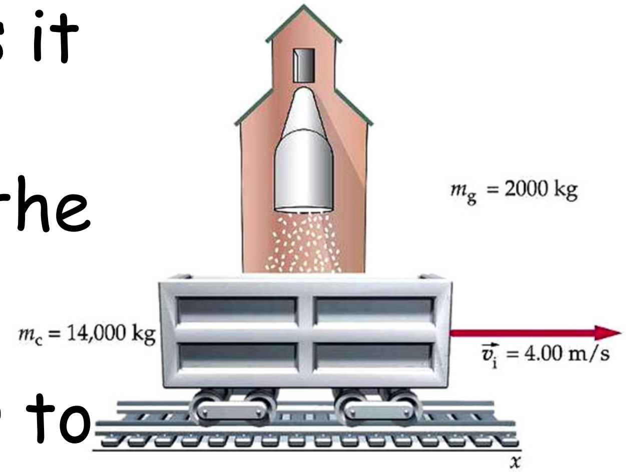
A. 9 m/s
B. 7 m/s
C. 6 m/s
D. 4 m/s
E. 3 m/s



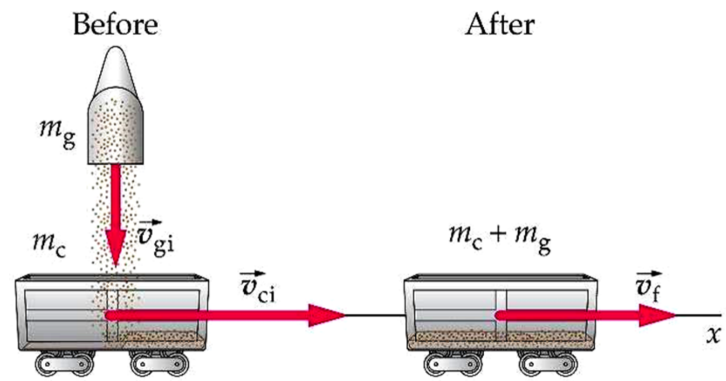
Q79

Example: A Runaway Railroad Car

A 14,000 kg railroad car is rolling at 4.00 m/s toward an intersection. As it passes a grain elevator, 2,000 kg of grain suddenly drops vertically into the car. Ignore friction and air drag.



How long does it take for the car to travel the 500 m distance from the grain elevator to the intersection?



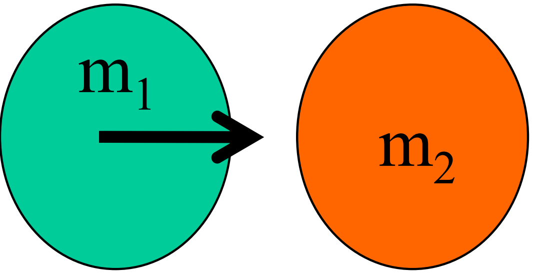
Conserved in x direction

$$\therefore P_{\text{sys fx}} = P_{\text{sys ix}}$$

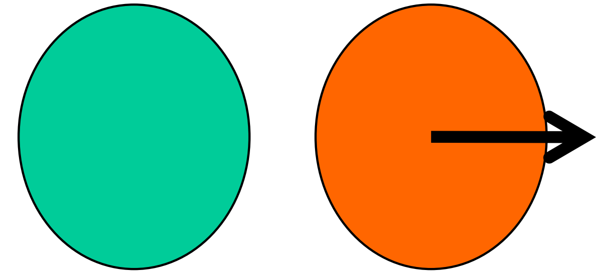
$$(m_c + m_g)v_{fx} = m_c v_{ix} + m_g(0)$$

$$v_{fx} = v_{ix}\frac{m_c}{m_c + m_g}$$

$$d = v_{fx}\Delta t$$



Colliding objects

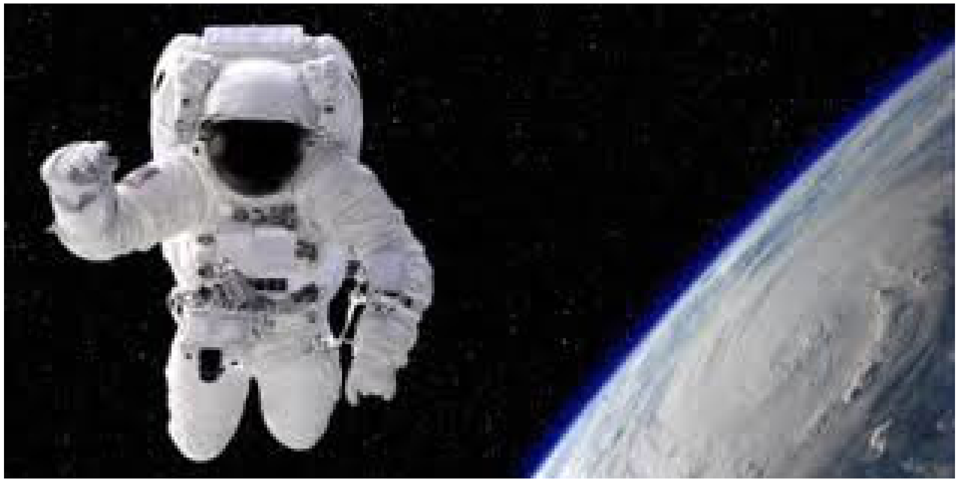


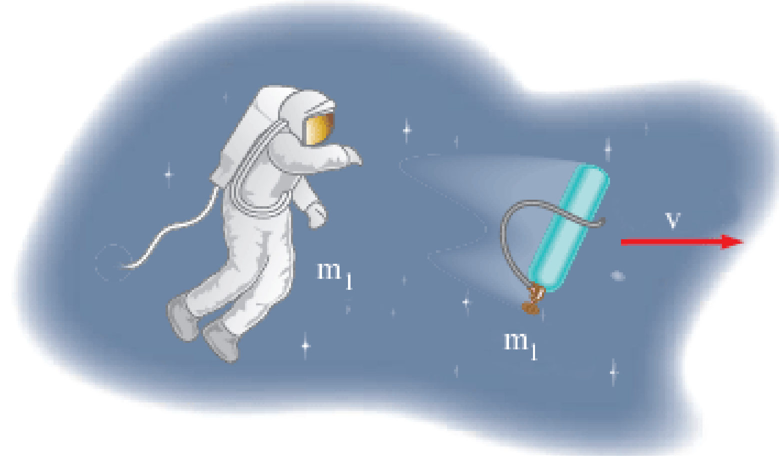
initial $m_2=2m_1$ final

- Let $m_2=2m_1$, so m_2 is twice as massive.
- Let's say you hit ball 1 with $v_{1i}=10$m/s into stationary ball 2, $v_{2i}= 0$ m/s.
- Let's say that after the collision, ball 1 is stationary. (not always the case)
- What is the final velocity of ball 2?

A) 5 m/s
B) 10 m/s
C) 20 m/s
D) -5 m/s
E) -20 m/s

Q77

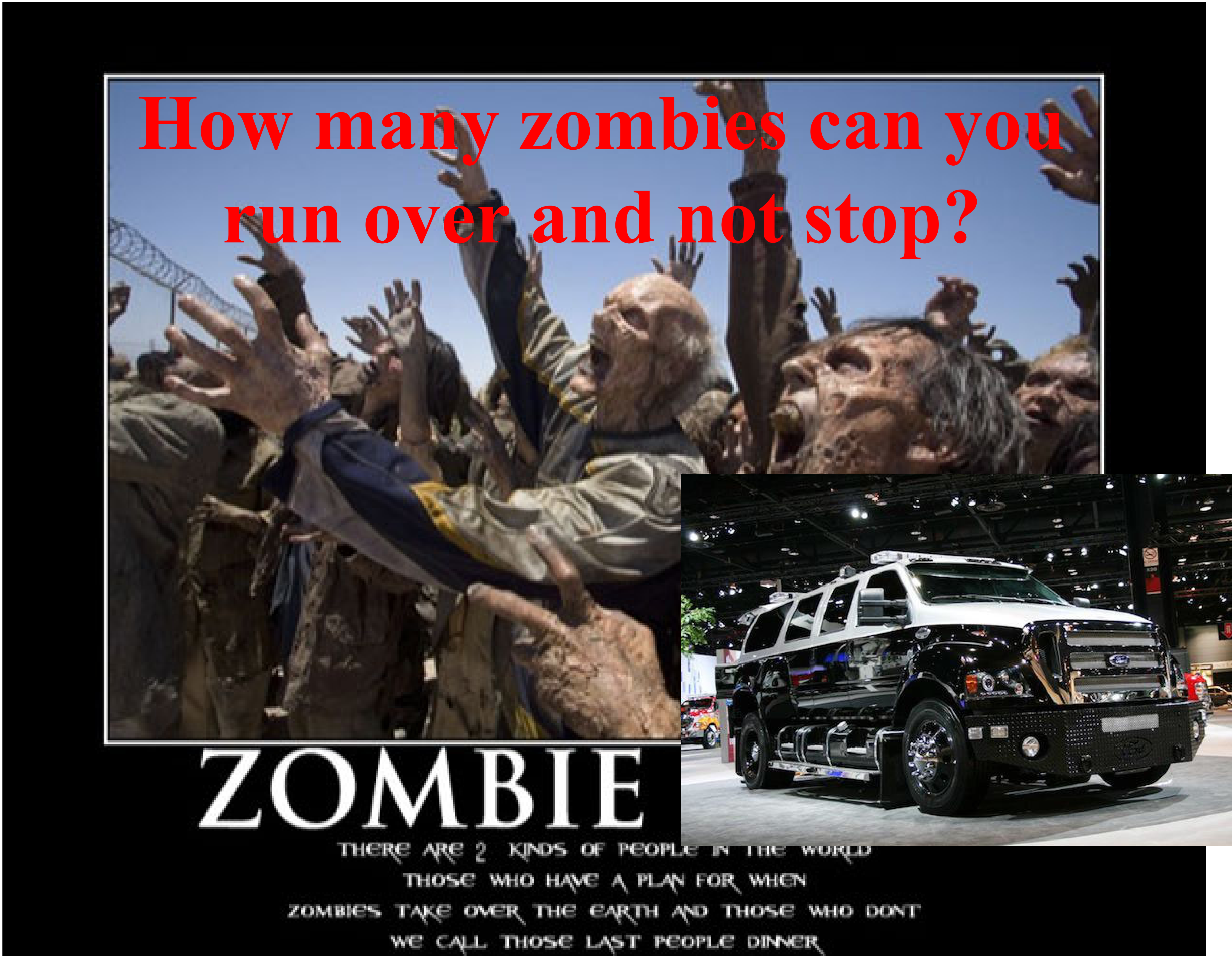




An astronaut in her space suit has a total mass of $m_1 = 87$ kg, including her oxygen tank. Her tether line loses its attachment to her spacecraft and she is too far to grab on! Initially at rest with respect to her spacecraft, she throws her oxygen tank of mass $m_2 = 12.0$-kg away from her spacecraft with a speed $v = 8.00$ m/s to propel herself back toward the spacecraft.

Determine the maximum distance she can be from the craft and still return within 2.00 min (the amount of time the air in her helmet remains breathable).

How many zombies can you run over and not stop?



Let's consider this situation again Could find recoil of soccer player.

Similar idea: Cardiology (Challenging setup)

In research of cardiology and exercise physiology, it is often important to know the mass of blood pumped by a person's heart in one stroke. This information can be obtained by means of a *ballistocardiograph*. The instrument works as follows: The subject lies on a horizontal pallet floating on a film of air. Friction on the pallet is negligible. Initially, the momentum of the system is zero. When the heart beats, it expels a mass m of blood into the aorta with speed v, and the body and platform move in the opposite direction with speed V. The speed of the blood can be determined independently. Assume that the blood's speed is 50.0 cm/s in one typical trial. The mass of the subject plus the pallet is 54.0 kg. The pallet moves 6.00 10^{-5} m in 0.160 s after one heartbeat. Calculate the mass of blood that leaves the heart. Assume that the mass of blood is negligible compared with the total mass of the person.

Forces of Motion

- Cars move due to the force of friction between the tires and road.
- Planes take advantage of air resistance.
- Boats use the resistance of the water.
  - But what about rockets in space? There is no air in space to provide a resistance

Rockets not tested

Just in case you are interested.

It's slightly more complicated, but just conservation of momentum.

The New York Times Response To Rockets in Space

*("New York Times," 13 January, **1920**, p. 12, col. 5)*

"That Professor Goddard…does not know the relation of action to reaction, and … the need to have something better than a vacuum against which to react--to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools."

What do you think about this critique?

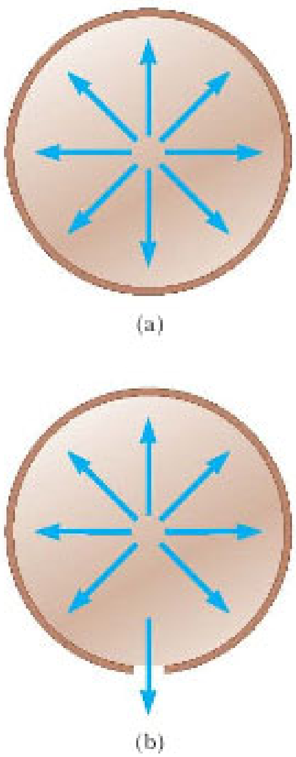
2 Lessons: Even brilliant scientists make mistakes.
And frequently, even experts don't agree.

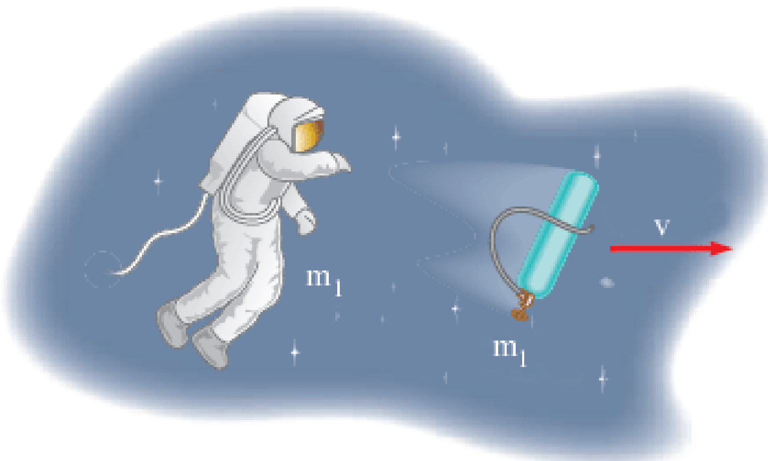
Rocket Propulsion

- While it's true that there is no friction to propel rockets forward in space, there is conservation of momentum.

$$\vec{p}_{i,system} = \vec{p}_{f,system}$$

$$m_1\vec{v}_{i1} + m_2\vec{v}_{i2} = m_1\vec{v}_1' + m_2\vec{v}_2'$$





Instead of throwing the tank, imagine just letting the gas in the tank spray out (safer, but slower)

Note: Changing mass

Rocket video

http://www.youtube.com/watch?v=vPQvTgD2quQ