Momentum

By the end of this unit you will be able to:

Define and calculate momentum

Define and calculate impulse

Use the Law of Conservation of Momentum to solve problems

Explain the Law of Conservation of Momentum, including what systems it applies to

Solve Conservation of Momentum problems in 2D

Momentum

- Inertia
  - Inertia is the tendency of an object to resist change in velocity
    - Mass is a measure of the amount of inertia an object has
  - Let's consider two examples
    - Which of these is harder to stop?
      - A Mini Cooper moving at 10 m/s
      - A tractor trailer moving at 10 m/s

- The two objects are moving at the same speed
  - The more massive vehicle is harder to stop
  - This can be explained through inertia
    - » It has more mass therefore more inertia making it harder to stop
- Which of these is harder to stop?
  - A baseball thrown from a major league pitcher
  - A baseball rolling along the ground
- The baseball has the same amount of inertia in each case
  - But the faster moving baseball is harder to stop
- This leads us to the concept of momentum

- Momentum (p)
  - Also called “inertia of motion”
    - Momentum describes how difficult it is to change the state of motion of a moving object
      - The faster an object is moving, the harder it is to change its motion
      - The larger the mass of the object, the harder it is to change its motion
      - This means that momentum must depend on mass and speed
    - As a definition, momentum is the product of mass and velocity

- Momentum is a vector quantity that points in the same direction as the velocity
- The units on momentum are (kg·m/s)

$$p = mv$$

- Impulse (Ft)
  - Consider the following example:
    - I am playing baseball and I want to hit the baseball such that it goes as fast as possible once it leaves the bat
    - What are the two components of the hit that will cause the baseball to go as fast as possible?
      - First is a large force
      - Second would be following through on the hit
        - » Following through on a hit increases the time the baseball is in contact with the bat
        - » Increasing the time the baseball is in contact with the bat (the contact time) will increase the time that the force can act
      - I cannot hit the baseball well if you lack one of the above components

- This idea of the force and the time the force will act (the contact time) is called the impulse
- Units: N·s
- By definition, the impulse is the product of the force and the contact time

$$Impulse = Ft$$

- So the force and the time the force can act (the contact time) together determine the impulse
  - But what is the point?
  - Go back to the baseball hit example
    - » If I apply a large force to the baseball over a very short time the baseball won’t go very fast upon leaving the bat
    - » Ditto if I apply a small force over a long time
      - » This is a bunt
  - So, both force and the contact time determine how fast the baseball will be moving after being hit with the bat
    - » This leads us to the conclusion that impulse must have something to do with velocity and therefore momentum

Impulse-Momentum Theorem

- Impulse-Momentum Theorem
  - How are impulse and momentum related?

Start with Newton's Second Law

$$F = ma$$

Solve this kinematic equation for a

$$v = v_o + at$$

Substitute into Newton's Second Law

$$F = m\left(\frac{v - v_o}{t}\right)$$

Substitute the new version of Newton's Second Law into the Impulse definition

$$Impulse = m\left(\frac{v - v_o}{t}\right)\Delta t$$

Now simplify

$$Impulse = mv - mv_o$$

Since p = mv, the impulse can be written as

$$Impulse = p - p_o$$

Which really means that the impulse is equal to the change in momentum of the object

$$Impulse = \Delta p$$

- So, the impulse of an object is equal to the change in momentum of the object
- This is called the Impulse – Momentum Theorem
  - When a net force acts on an object, the impulse of the net force is equal to the change in momentum of the object

$$F_{net}t = \Delta p$$


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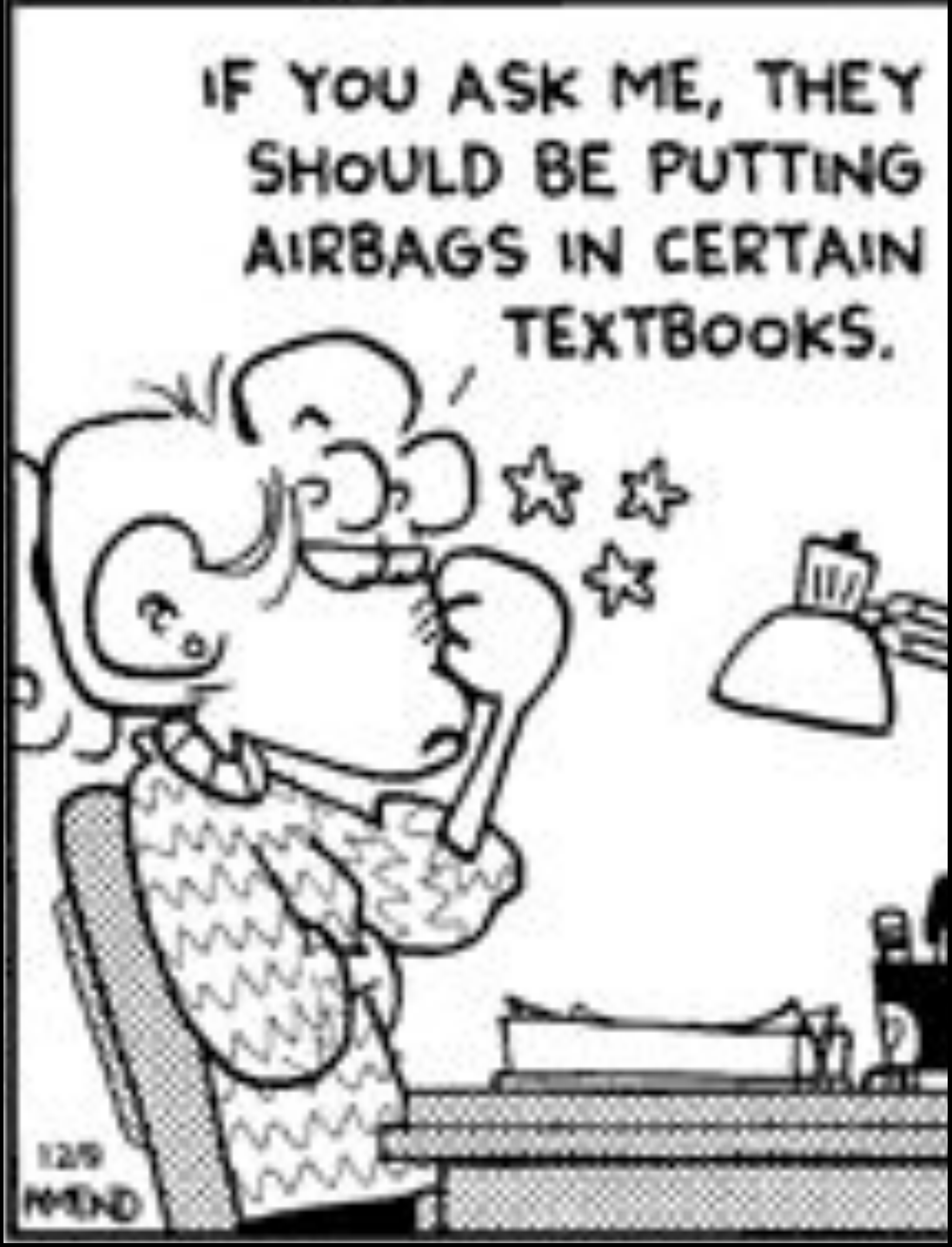
ZzZz...


WHAM!

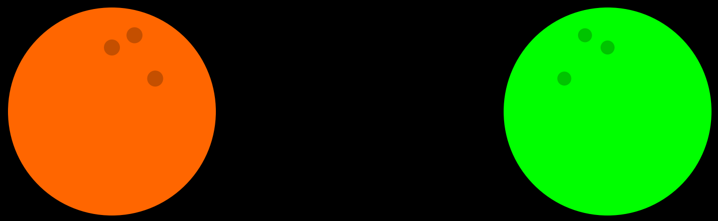


In terms of Impulse and Momentum, what is the purpose of an air bag?

For that matter, what is the purpose of seat belts, crumple zones, or any other safety feature in a car?

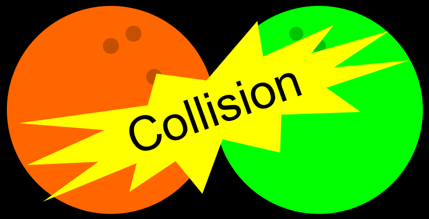
Conservation of Momentum

- System
  - A system is collection of objects
  - Systems are useful in determining what object(s) we are looking at in a problem
    - Consider a system of two bowling balls



- When looking at a system, there are two types of forces
  - Internal forces
  - External forces

- Internal Forces are forces that are exerted from one part of the system to another part of the same system
  - Example
    - If the two bowling balls collide this is an internal force because one part of the system (the orange bowling ball) strikes another part of the system (the green bowling ball)



- External Forces are forces that are exerted on the system by objects that are outside of the system
  - Example:
    - The friction acting on the bowling balls is an external force
    - So is gravity and so is the normal force

- Isolated System
  - A system where the net force of all the external forces is zero
    - So, friction is assumed to be zero
    - The weight and the normal force on the system are equal
    - All other external forces are assumed to be zero
  - Typically, I am looking at what happens to a system by something from the outside
    - Meaning that the internal forces don’t really matter to me
      - They especially don’t matter when looking at conservation of momentum

- Conservation of Momentum
  - One of the three pillars of physics that prohibit certain events from taking place
    - The other two are Conservation of Energy and the 2nd Law of Thermodynamics
  - The total momentum of an isolated system is conserved
    - Conserved, if you don’t remember, means constant
    - Conservation of Momentum applies to any system with any number of objects, as long as the total external force is zero
    - We will be using conservation of linear momentum to analyze collisions

- Conservation of Linear Momentum and Collisions
  - Conservation of linear momentum states that, for an isolated system, the momentum along the x-axis and along the y-axis are constant
  - Because momentum is constant, I can look at what happens before and after the collision and not have to worry about what is happening during the collision
    - During the collision there are internal forces, but remember these don't matter when talking about conservation of momentum
  - We can look at what happens in each direction before and after the collision
    - Because the momentum in each direction is constant

– So the following must be true

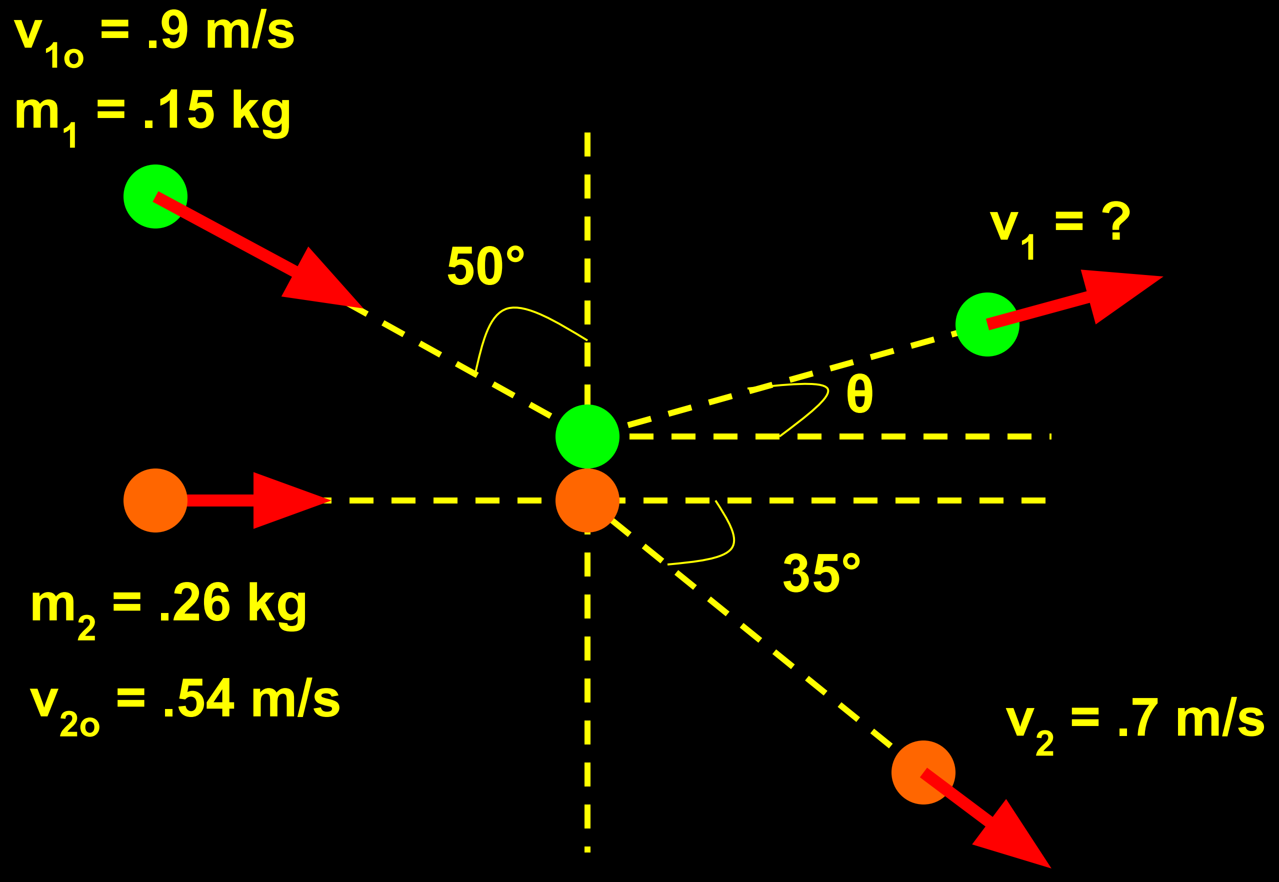
$$p_x = p_{ox} \qquad p_y = p_{oy}$$

– Example 1 (To be worked in class)
  - A train is being assembled at a switching yard. Car 1 has a mass of 65×10^3 kg and is moving with a velocity of .8 m/s. Car 2 has a mass of 92×10^3 kg and is moving with a velocity of 1.2 m/s. Find the final velocity of the two cars after they hook together

- **Example 2 (To be worked in class)**
  - **Starting from rest, two skaters push off of each other on smooth, level ice. The mass of the woman is 54 kg and the mass of the man is 88 kg. After the push off, the woman is traveling with a velocity of 2.5 m/s. Neglecting friction, find the velocity of the man.**

– **Example 3** **(To be worked in class)**

- **Given the following picture, find v_1 and θ.**



– Example 3 (To be worked in class)

- Given the following picture, find v_1 and θ.