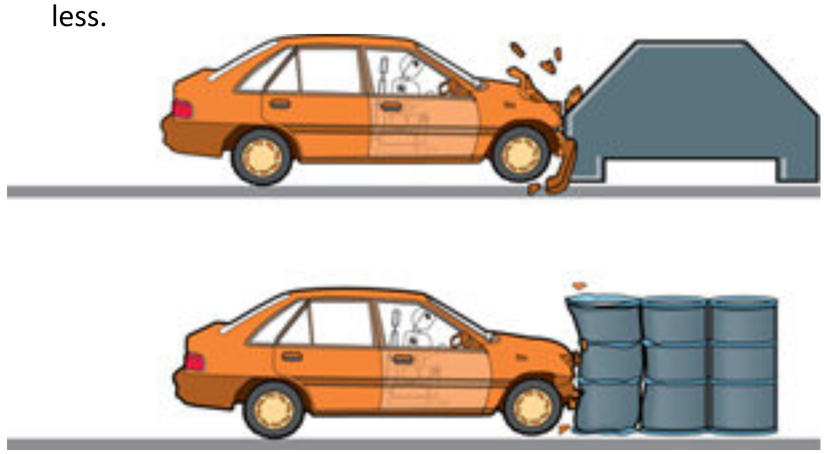
Physics 30
Conservation Laws Unit: Momentum

<u>Impulse and Change of Momentum</u>

- When we look at momentum, we are looking at a collection of objects and how they interact with each other.
- Newton's Three Laws of Motion are all based upon momentum (he called it the *quantity of motion*).
- The product of the mass and the velocity of an object is the object's momentum.
  - Momentum is a vector quantity – it has the same direction as the velocity used to calculate it.
  - Formula: $p = mv$ where: p = momentum, m = mass, v = velocity
  - The unit for momentum is kg*m/s
- If an object has constant motion (there are no forces acting upon it) then the momentum is constant (conserved).
  - This is how Newton's First Law applies to momentum.
- Therefore, if an object's velocity changes then the momentum must change as well. This works as follows:
  - When velocity changes, there must be acceleration – and therefore a force applied to the object.
  - The momentum change is equal to the amount of FORCE applied multiplied by the amount of TIME the force is applied to the object.
  - The net product of this force and time is called the IMPULSE – it is a vector quantity – it is also a change in momentum.
  - Impulse has the following formula:

    $\Delta p = m\Delta v$ OR $F\Delta t = m\Delta v$
  - Therefore $\Delta p = F\Delta t$
    - This equation is called the **impulse-momentum theorem** – this is another way of describing Newton's Second Law of Motion.
  - This theorem lets us make two conclusions:
    - If a change in velocity happens over a short period of time, the force will be great.
    - If a change in velocity happens over a long period of time, the force will be less.



How is the picture above a demonstration of impulse and momentum?

The Conservation of Momentum

- Newton's Third Law of Motion also plays a part in momentum. The third law states that for any action these is an equal and opposite reaction.
- If an impulse is imparted to an object to change its velocity, there must be an opposite impulse acting in the opposite direction – this occurs during a collision.
- When studying momentum changes, we must use a CLOSED-ISOLATED SYSTEM.
    - A system is closed if neither object leaves or enters the system and it is isolated if no net external force is exerted on it.
- In a closed and isolated system the LAW OF CONSERVATION OF MOMENTUM applies.
- It states: *The momentum of any closed, isolated system does not change.*
- This means that the momentum of all the objects in a system added together BEFORE a collision will equal the momentum of all the objects in a system added together AFTER a collision has occurred.
- During a collision, momentum can be transferred from one object to another – but the TOTAL momentum of the entire system is CONSERVED.
- Example: If two balls collide, the total momentum they have before the collision will equal the total momentum they have after the collision.
    - Q – Ball A has a mass of 0.5 kg and a velocity of 3.0 m/s [N] and it strikes ball B, which is at rest and has a mass of 0.4 kg. If ball A has a velocity of 1.5 m/s [N] after the collision, what is the velocity of ball B?
    - A – Momentum before must equal momentum after the collision:

$$p_{Ai} + p_{Bi} = p_{Af} + p_{Bf}$$

where p_{Ai} = initial momentum of ball A (mΔv)
p_{Bi} = initial momentum of ball B (mΔv)
p_{Af} = final momentum of ball A (mΔv)
p_{Bf} = final momentum of ball B (mΔv)

When we substitute in the known values, this becomes:

$$(0.5\text{ kg})(3.0\text{ m/s [N]}) + (0.4\text{ kg})(0.0\text{ m/s [N]}) = (0.5\text{ kg})(1.5\text{ m/s [N]}) + (0.4\text{ kg})(\Delta v)$$

$$1.5\text{ kg*m/s [N]} + \cancel{0.0\text{ kg*m/s [N]}} = 0.75\text{ kg*m/s [N]} + (0.4\text{ kg})(\Delta v)$$

$$0.75\text{ kg*m/s [N]} = (0.4\text{ kg})(\Delta v)$$

Answer: <u>Δv = 1.9 m/s [N]</u>

Conservation of Momentum in Two Dimensions

- The Law of Conservation of Momentum also works for collisions that occur in two dimensions (ex. North & East), so long as the system is isolated and closed.
- In order to calculate this – remember that momentum is a vector quantity. Also remember that any vector can be broken into components.
- The momentum in the initial system must be equal to the momentum in the final system
    - This means that if we used vector arrows to represent the momentum initially, the vector arrows used to represent momentum after the collision WILL ADD up to the initial momentum.
    - We can calculate this either graphically or analytically.