Lecture Notes

(Impulse & Momentum)

Intro:

- earlier in the year, we introduced Galileo's Principle of Inertia and we talked how Newton used this idea to formulate his first law of motion

- Newton discussed inertia in terms of objects both at rest and in motion; today we will discuss the concept of inertia in motion only

- when you are dealing with both momentum and motion you are talking about momentum

- momentum is inertia in motion; specifically, it is the product of mass and velocity

$$\text{Momentum} = \text{mass} \times \text{velocity}$$
$$\boldsymbol{p} = m\boldsymbol{v}$$

- the unit of momentum is kg·m/s

- it is intuitive to say that an aircraft carrier is harder to stop than a plastic toy boat moving at the same speed; the carrier has more momentum than the toy boat

- by looking at the definition of momentum you can see that a moving object can have a large momentum either by having a large mass or a large velocity or both

- the aircraft carrier has more momentum traveling at the same speed as the toy boat by virtue of its larger mass

- the toy boat could have as much or even more momentum as the aircraft carrier, but its velocity would have to be extremely fast

Impulse:

- a change in momentum can occur if there is a change in mass, a change in velocity, or both

- if the momentum of an object changes while the mass remains unchanged, which is usually the case, then it is due to a change in velocity

- changes in velocity are due to accelerations; accelerations are due to net forces acting on objects

- the greater the net force on an object, the greater the acceleration, the greater the velocity change, the greater the change in momentum

- there is another important factor in changing momentum; time

- apply a force to a crate on the ground for a brief amount of time and you get a small change in momentum; if you apply that same force for a longer amount of time, then you get a larger change in momentum

- a long sustained force will produce a greater change in momentum than the same force applied briefly

- in terms of momentum, both the amount of force and the amount of time during which the force act are important; the product of these two terms is called the impulse

$$\text{Impulse} = \text{force} \times \text{time interval}$$
$$\text{Impulse} = \boldsymbol{F}\Delta t$$

- whenever you exert a force on an object you also exert an impulse

- the resulting acceleration depends on the force; the resulting change in momentum depends on the force and the time in which the force acts

<u>Impulse-Momentum Equation</u>:

- the relationship of impulse and momentum is derived from Newton's 2nd law of motion; $\boldsymbol{F} = m\boldsymbol{a}$; then time interval of impulse is hidden in the acceleration variable ($\Delta\boldsymbol{v}/\Delta t$)

- if you rearrange Newton's 2nd law you get:

Force × time interval = change in mass × velocity (momentum)

$$\boldsymbol{F}\Delta t = m\Delta\boldsymbol{v}$$

<u>Increasing Momentum</u>:

- if you want to increase the momentum of something as much as possible, you not only apply the greatest force possible, you also apply that force for as long as possible

- for example, long range cannons have long barrels; the longer the barrel the greater the velocity of the shell

- this occurs because the longer barrel allows more time for the force of the exploding gunpowder to act on the shell (increasing Δt)

- the force that is exerted on most objects varies over time; for example, in the cannon the gunpowder applies a greater force initially and the begins to lessen as the shell goes down the barrel

- so, in order to simplify things, we will use the average force acting on an object

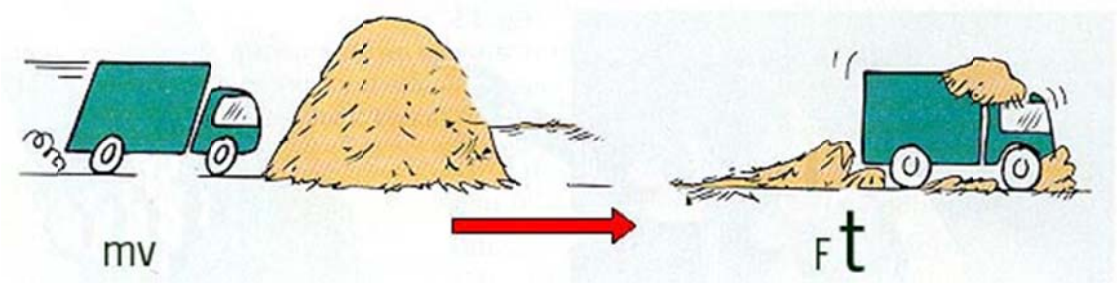
Decreasing Momentum (Over a Long Time):

- one intuitive way to discuss decreasing momentum is to imagine you are in a car out of control and you can either slam into a concrete wall or a haystack

- it's obvious which solution is the better choice; the more important reason in physics is why this is the better choice

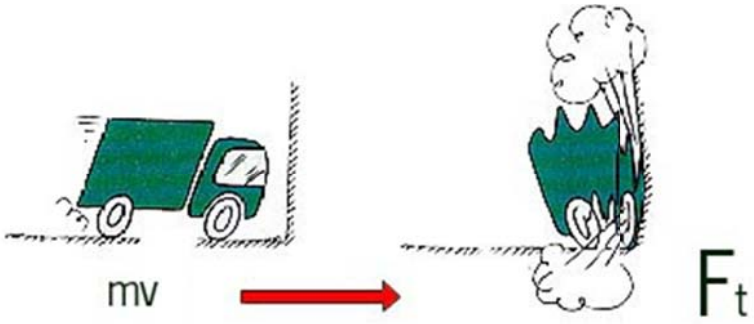
- in either case, hitting the wall or the haystack, your momentum will be decreased by the same impulse ($\boldsymbol{F}\Delta t$); remember impulse is the product of force and time, but does not mean the same force or same time

- you have a choice; if you hit the haystack your time will be extended (the time during which your momentum is brought to zero)



- this longer time corresponds to a lesser force; for example, if you extend the time by 100 times, then the force will decrease by 100

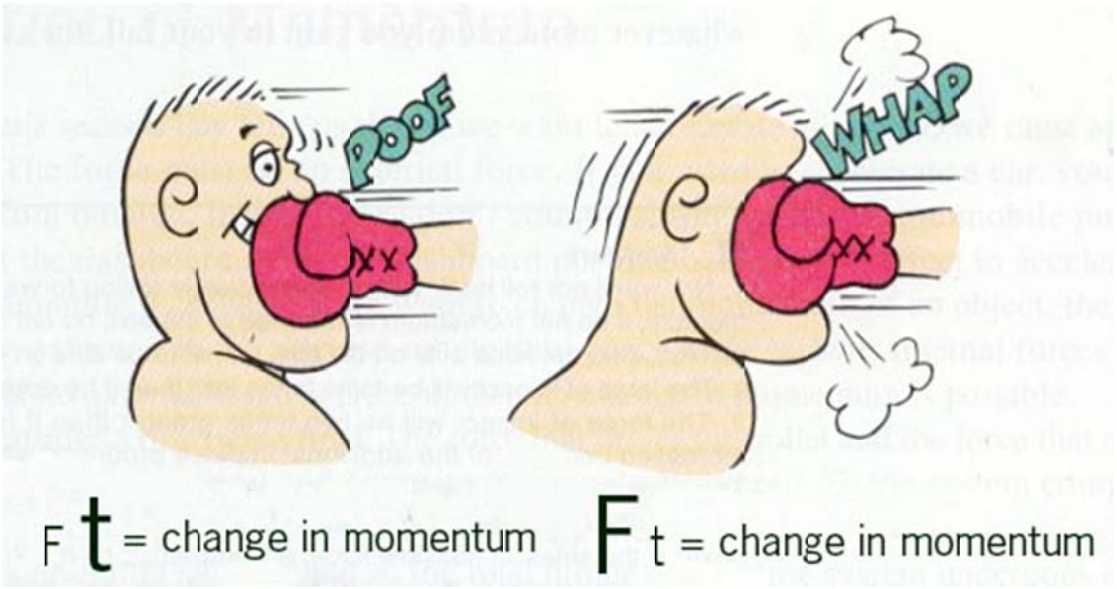
- if you hit the wall, the time will be reduced, so the force will increase



- people often use the knowledge of impulse to their advantage; for example, a wrestler thrown to the floor will relax their muscles in order to extend the crash into a series of smaller impacts

- the wrestler will have his/her foot, knee, hip, ribs, and shoulder hit the mat in turn; this will increase the time of impact which reduces the amount of force on the body

- a boxer will move his face backwards in order to increase the time of impact of an opponent's blow



- ballet dancers prefer to dance on a wooden floor rather than a concrete floor, because the wooden floor has "give"

<u>Decreasing Momentum (Over a Short Time)</u>:

- in certain situations it is advantageous to decrease your momentum quickly

- when you decrease the time interval, the size of the force will increase; for example, a karate master will endeavor to hit a stack of bricks with a quick blow; this will maximize the force of the blow

Bouncing:

- impulses become even greater if bouncing occurs

- bouncing will amplify the impulse because it takes an additional impulse to throw an object back after collision

- for example, take the case of a flower pot hitting you head; if the pot breaks upon colliding with your head it does some damage; if the pot bounces off your head without breaking, it would do even more damage to your body

- your head has to provide an additional impulse to send the pot back off your head

- the effect was known and used for mining in California during the gold rush; a man named Pelton created a water wheel with curved blades to maximize the impulse of the water on the wheel