Physics Notes – Ch. 6 Momentum and Collisions

I. Momentum - "inertia in motion" – equal to mass times velocity

Momentum describes a given object's motion

Q: So can a company truly have momentum…like "my investment company has momentum with it"?

A. Linear momentum

- defined as the product of mass times velocity; symbolized by a lower case "**p**"

$$\mathbf{p = mv}$$ and its units are kg · m/s or N.s

- Momentum is a **vector** quantity that has the same direction as the velocity

II. Momentum and its relationship to force

- A net Force is required to change momentum in magnitude **AND/OR** direction!

A change in momentum takes force and time. If one chooses to provide a really large **MAXIMUM change** in momentum, one should apply the **largest force** possible **AND** apply it for **as long a time as possible**.

For Example: If you wanted to move a stalled car…you wouldn't just push with all your might for a second and expect it to gain any momentum. This is the same reason why golfers, pitchers, batters, and parents pushing a child on a swing **ALL follow through** with the force they apply. A parent wouldn't just hit the swing hard and quickly to provide the child with the best swinging momentum…they push hard for a long time!

Newton and Momentum - Newton's second law states that an unbalanced (net) force acting on a mass will accelerate the mass in the direction of the force. Another way of saying this is that a net force acting on a mass will cause the mass to change its momentum. We can rearrange the equation for Newton's second law to emphasize the change in momentum:

Figure 6-2
When the ball is moving very fast, the player must exert a large force over a short time to change the ball's momentum and quickly bring the ball to a stop.

$$\mathbf{F}_{net} = m\mathbf{a}$$ and using the formula for acceleration we get

$$F_{net} = m\left(\frac{\Delta \mathbf{v}}{\Delta t}\right)$$

Rearranging this equation by multiplying both sides by Δt gives

$$\mathbf{F}\Delta t = m\Delta\mathbf{v} = m\mathbf{v}_f - m\mathbf{v}_i$$

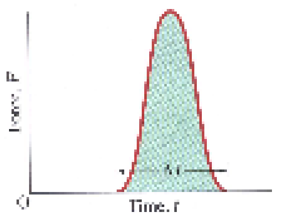
The left side of the equation **(F*Δt*) is called the *impulse***, and the right side is the ***change in momentum***. This equation reflects the *impulse-momentum theorem*, and in words can be stated *"a force acting on a mass during a time causes the mass to change its momentum"*. The force **F** in this equation is considered the *average force* acting over the time interval.

III. *Impulse-momentum theorem* - an applied impulse is equal to a change in momentum.

- **Impulse** = **F**Δt and **F**Δt=Δ**p**
- – the impulse of a force is the product of the **average force** and the **Δt** or **time interval** during which the force acts—which also is equal to the Δ**p**; impulse is a vector quantity and has the same direction as the average net force.

- Impulse is very useful when dealing with forces that act over a short time and/or time-varying forces—hitting a baseball with a bat, for instance.
- ***A change in momentum over a longer time requires less force.* The same impulse (same Δp) can be given to an object by a smaller force, F, if applied over a greater time interval, as long as FΔt remains the constant. *This is the reason why an egg dropped on a pillow does not break while an egg dropped from the same height on the hard surface does break.***

FIGURE 7–9 Force as a function of time during a typical collision.



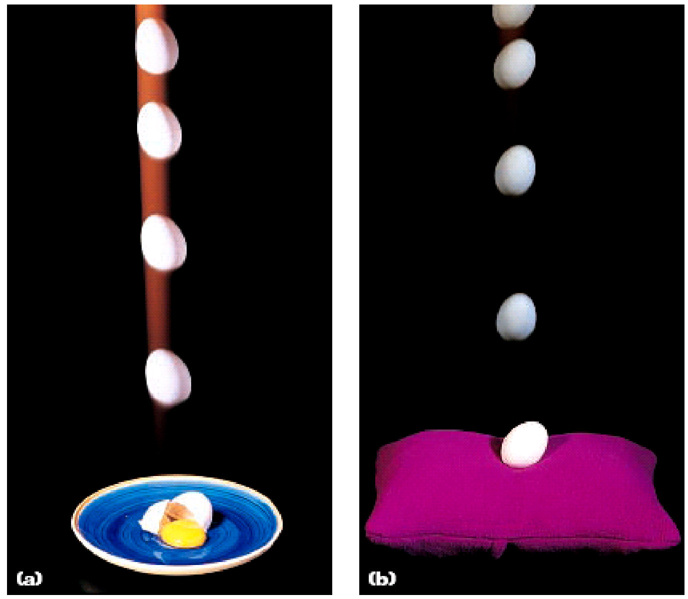
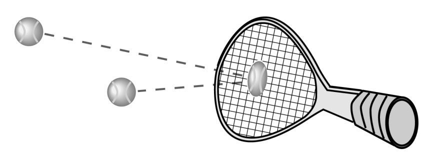


Figure 6-5
A large force exerted over a short time **(a)** causes the same change in the egg's momentum as a small force exerted over a longer time **(b)**.

Question: Which impulse provides the most change in momentum –

a. One that stops the object?
b. One that stops the object and then makes it go again in the opposite direction?

For Maximum Δp, you should apply maximum force for a maximum time…so follow through!!



A. Depending on the situation and desired effects…a person might want to produce the same change in momentum with:

1. the least amount of force - *a change in momentum over a longer time requires less force*; the same impulse and therefore, the same change in momentum (Δp) can be given to an object by a smaller force, F, if applied over a greater time interval, as long as FΔt remains the constant. **Ex. *this is one reason why cars are designed to crumple upon impact and why nets are used to stop the fall of trapeze artists and tightrope walkers.***

2. the maximum force - *If you hit for a shorter time interval, you can make the force greater for the same change in momentum. This is evident in Karate chops.*

Question: Why is it that falling onto a smooth tile floor hurts you more than the same distance and type of fall onto a carpeted floor? ____ ***[No - "because it is softer" is not the answer]…SO - Why is it that falling onto softer surfaces hurts less than falling onto harder surfaces?***

- ***Example 1:*** A 1400 kg car moving westward with a velocity of 15 m/s collides with a utility pole and is brought to rest in 0.30 s. Find the magnitude of the force exerted on the car during the collision.

IV. Law of conservation of momentum

- A net force is required to change an object's momentum (Newton's 2nd law). You probably remember from Newton's 3rd law that forces always occur in pairs (action-reaction), so when two objects interact the forces they apply on each other must be equal in magnitude and opposite in direction.
- **Since the forces involved are of equal magnitude and they act over the same amount of time, the impulse on each object must also be of equal magnitude. Since each object experiences the same magnitude of impulse, the magnitude of the change in momentum of each object must also be the same. This is the basis for the law of conservation of momentum.**
- The ***law of conservation of momentum*** *states "**The total momentum of all objects interacting with one another remains <u>constant</u>…regardless of the nature of the forces between the objects".***
- The Law of Conservation of Momentum is particularly useful when dealing with situations where the forces are not constant such as collisions, explosions, rocket propulsions, etc.—a form of a controlled explosion.
- For example, look at figure 7-6 below. Before the rocket is fired, $p_{total} = 0$. As fuel burns, p_{total} remains unchanged ($p_{total} = 0$). The backward p of the expelled gas is just balanced by the forward p gained by the rocket. Thus, rockets can accelerate in empty space.

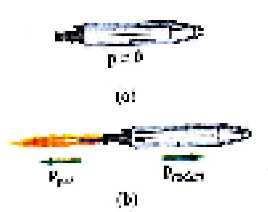


FIGURE 7–6 (a) A rocket, containing fuel, at rest in some reference frame. (b) In the same reference frame, the rocket fires and gases are expelled at high speed out the rear. The total vector momentum, $p_{gas} + p_{rocket}$, remains zero.

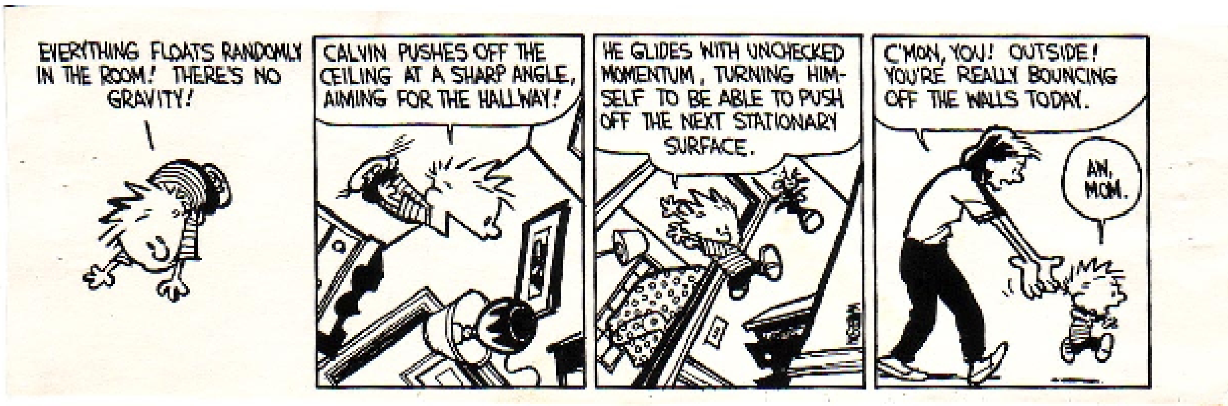
- **Note** *that when applying the law of conservation of momentum the objects must be* ***isolated.*** In an isolated system the only forces present are those between the objects of the system ***(internal forces—*** *action-reaction pairs)****.*** The net external force must be zero **($\Sigma F_{external} = 0$).** For example, you may think that momentum is not conserved for a falling rock since its speed and momentum are increasing as it falls; however, you must take into account that the earth is accelerating up towards the rock. Momentum is conserved for the earth-rock system.

A. **Momentum Conservation in Collisions**

2 classifications of collisions

1. **Elastic collision** – both p and KE are conserved
2. **Inelastic collision** – p is conserved but KE is not – remember the **<u>total</u> energy is always conserved**, just not the specific type.

   In a perfectly (totally) inelastic collision-- the 2 objects completely stick together and move as one new combined mass



Question:
An astronaut is on a spacewalk tethered to the shuttle's robot arm. Suddenly the tether is broken and the astronaut needs to get back to the shuttle. How could the astronaut use the bag of lucky marbles that she always carries with her on missions (collected during a physics project in high school) … to help her get back to the shuttle?

Steps for solving problems using conservation of linear momentum

1. Decide which objects are included in the system.
2. Verify that the system is isolated (**Σ F$_{external}$ = 0**); if it is not, you will have to include the other objects causing the forces
3. Set the total final momentum equal to the total initial momentum; *remember that momentum is a vector quantity, thus analyze x and y independently if necessary*

$$\boldsymbol{p}_{1i} + \boldsymbol{p}_{2i} = \boldsymbol{p}_{1f} + \boldsymbol{p}_{2f}$$

- ***Example 2.*** A 76.0 kg boater, initially at rest in a stationary 45.0 kg boat, steps out of the boat and onto the dock. If the boater moves out of the boat with a velocity of 2.5 m/s to the right, what is the final velocity of the boat?

- ***Example 3.*** A 1850 kg luxury sedan stopped at a traffic light is struck from the rear by a compact car with a mass of 975 kg. The two cars become entangled as a result of the collision. If the compact car was moving at a velocity of 22.0 m/s to the north before the collision, what is the velocity of the entangled mass after the collision?

- ***Example 4.*** Two clay balls collide head-on in a perfectly inelastic collision. The first ball has a mass of 0.500 kg and an initial velocity of 4.00 m/s to the right. The mass of the second ball is 0.250 kg, and it has an initial velocity of 3.00 m/s to the left. What is the final velocity of the composite ball of clay after the collision? What is the decrease in kinetic energy during the collision?

- ***Example 5.*** A 0.15 kg toy car moving to the right at 20.0 cm/s collides with a 0.20 kg car moving to the left at 30.0 cm/s. After the collision, the 0.15 kg car moves with a velocity of 37.1 cm/s to the left. Find the velocity of the 0.20 kg car after the collision.

Physics - Ch. 6 homework practice problems:
Pg's. 232-234 #'s 3, 5, 8, 10, 12, 15, 16, 17, 22, 26, 30, 32, and 35.