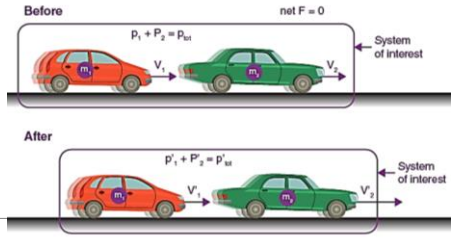
Newton's laws of motion II



Mechanics - Linear momentum

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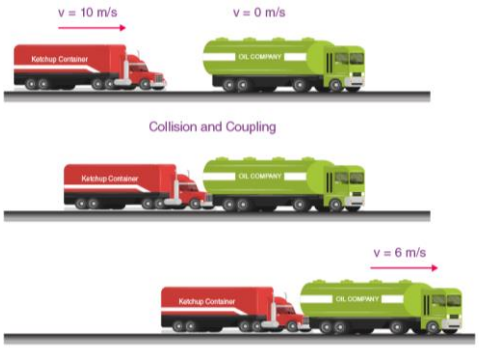
Introduction

In this topic we are going to discuss the following:

- Impulse
- Conservation of momentum
- Collisions



Impulse

- **Impulse** is the product of a **force** applied to an object and the **time** over which the force acts.
- Impulse represents the effect of a force on a given object over a specific period of time.
- It is responsible for changing the overall momentum of a given object.
- Impulse is calculated by the formula:

Impulse = F * t

Where:

F = Force acting on an object in **N**

t = Time duration the force acts on the object in **s**

- The SI unit of impulse is **Newton-second** (**Ns**).
- The SI unit can also be written as **Kg.m/s** since impulse is equivalent to change in momentum of a given body.

Impulse

Example:

A tennis ball of mass 0.3 kg is hit by the racket, applying a force of 50N for 0.1 seconds. Work out the impulse on the ball.

Solution

Impulse = F * t

F = 50N, t = 0.1s

Impulse = 50N * 0.1s

= **5Ns**

Relationship between impulse and Change in momentum.

- The impulse applied to an object results in a change in the object's momentum.
- This shows that impulse is just another way to describe how momentum changes when a force acts on an object for a certain amount of time.
- As such we can say that impulse is directly related to the change on momentum of a given body.

Impulse

Mathematically:

Impulse = Δp =m(v−u)

Where:

Δp = change in momentum

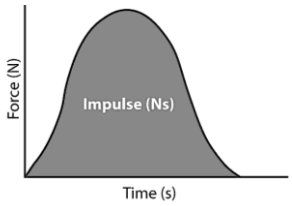
m = mass of the object

v = final velocity

u = initial velocity

Note:

•Both impulse and change in momentum have the **same quantity** but are framed differently: **impulse** in terms of **force** and **time**, and **momentum** in terms of **mass** and **velocity**.



Impulse

Exercise

A soccer ball of mass 500g is kicked, causing it to accelerate from rest to a velocity of 15m/s in 3 seconds. Calculate the following:

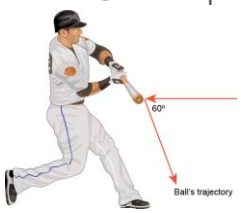
a. Change in momentum of the ball.

b. Acceleration of the ball.

c. The Force that caused the acceleration.

d. The Impulse on the ball.

e. What can you say about the answer found in question **a** and in question **d**.



A 155g baseball is incoming at a velocity of 25 m/s. The batter hits the ball as shown in the image. The outgoing baseball has a velocity of 20 m/s. What is the magnitude of the impulse acting on the ball during the hit?

Conservation of linear momentum

- Conservation of momentum looks at the total momentum of bodies before and after collision or interaction.
- The law of conservation of momentum states that "***when two or more bodies collide, their total momentum remains constant unless an external force is applied***."

OR

- It states that " ***in a closed system, the total momentum before a collision is equal to the total momentum after the collision".***
- The word **closed system** means a system with **no external forces**.
- The law of conservation of momentum is a direct consequence of Newton's laws of motion.
- Common examples of the law of conservation of momentum include:
  a. An air filled balloon.
  b. System of a gun and a bullet.
  c. Motion of rockets.

Conservation of linear momentum

The Formula

- Consider two sports balls **1** and **2** of masses M_1 and M_2 and initial velocities as U_1 and U_2 respectively moving in the same direction with different velocities as shown below:

- On collision, ball **1** pushes ball **2** with a force F_1 and ball 2 reacts by pushing ball **1** with an equal but opposite force F_2 ,thus: $F_1 = -F_2$
- Since the collision time is the same for both balls, ball **2** will receive an impulse of $F_1 t$ from ball **1**, and ball **1** will also receive an impulse of $-F_2 t$ from ball **2**.

- Thus: $-F_2 t = F_1 t$
- But remember impulse = change in momentum = **mv – mu**

Conservation of linear momentum

- Just after the collision, the ball will have final velocities as V_1 and V_2 respectively.

- As such:

impulse on ball 1: $-F_2 t = M_1 V_1 - M_1 U_1$ ..i

impulse on ball 2: $F_1 t = M_2 V_2 - M_2 U_2$ ..ii

- Equating **i** and **ii** we get:

$$-(M_1 V_1 - M_1 U_1) = M_2 V_2 - M_2 U_2$$

$$-M_1 V_1 + M_1 U_1 = M_2 V_2 - M_2 U_2$$

- Grouping like terms together we get:

$$M_1 U_1 + M_2 U_2 = M_1 V_1 + M_2 V_2$$

- But $M_1 U_1 + M_2 U_2$ = total momentum before the collision and $M_1 V_1 + M_2 V_2$ = total momentum after the collision.
- Therefore ***total momentum before collision = total momentum after collision***.

Conservation of linear momentum

Example

Two ice skaters push off from each other. Skater 1 has a mass of 60 kg and moves with a velocity of 3 m/s. Skater 2 has a mass of 50 kg. If skater 2 moves in the opposite direction, what is skater 2's velocity?

Solution

$$M_1 U_1 + M_2 U_2 = M_1 V_1 + M_2 V_2$$

$M_1 = 60kg$, $M_2 = 50kg$, $U_1 = 0m/s$, $U_2 = 0m/s$,

$V_1 = 3m/s$, $V_2 = ?$

$$(60 * 0) + (50 * 0) = (60 * 3) + (50 * V_2)$$

$$0 = 180 + 50V_2$$

$$-180 = 50 V_2$$

$$-180/50 = V_2$$

$$\mathbf{-3.6\ m/s = V_2}$$

- Skater 2 moves with a velocity of 3.6 m/s in the opposite direction.

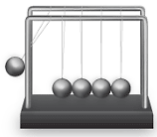
Collisions

Collison

- This an event where two or more objects come **into contact** with a significant force, resulting in an exchange of momentum and energy.
- During a collision, the objects involved apply forces on each other, which can change their speeds, direction, and state of motion.
- We have **two** types of collisions, namely:
  a. Elastic collision
  b. Inelastic collision

Elastic collision

- A type of collision in which both the **kinetic energy** and **momentum** are **conserved**.
- In this type of collision, the objects involved **bounce off** each other without causing permanent deformation on each other or generating heat.



Collision of smooth balls

Collisions

- Examples of elastic collisions include:
  a. Collision of smooth billiard balls on a pool table.
  b. Collision of molecules in gases.
  c. Collision of rubber balls on a hard surface.

Inelastic collision

- This is a type of collision in which the total momentum is conserved but, some of the kinetic energy is lost as sound, heat, or even deformation.
- The objects involved in this type of collision may stick together or deform after the collision.

Collision of cars as an example of inelastic collision

Completely or Perfectly inelastic collision

- This is a type of inelastic collision in which the objects involved **stick** to each other and move as a combined mass.
- In this types of inelastic collision we have **maximum loss** of the **kinetic energy**.

Collisions

•Examples of inelastic collisions include:

a. Car crush.
b. Meteor impact on earth.
c. A clay ball hitting a wall.

Assignment: In groups of 5's, answer all questions.

a. Describe an experiment that can be carried out to demonstrate elastic collisions. – *Refer to E&S book 4 pg: 33 to 34*

b. Describe an experiment that can be carried out to demonstrate inelastic collisions. – *Refer to E&S book 4 pg: 35 to 36*

c. State the law of conservation of linear momentum.

d. State any **three** effects of force on a given object.

e. A 6.8kg ball moving at 0.50m/s collides with a 4.7kg ball at rest. If the ball moves at 0.25m/s after the collision. How fast does the lighter ball move?

f. A 2,000 kg truck moving at 10 m/s hits a car stopped at a traffic light. After the collision, the two vehicles move together at 8m/s. What was the mass of the car?

Collisions

Figure 1 shows two vehicles, use it to answer question **g** and **h**.

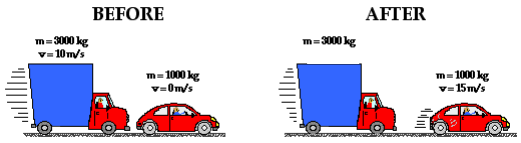


Figure 1

g. State the type of collision demonstrated in **Figure 1**.

h. Assuming that momentum is conserved during the collision, determine the velocity of the truck immediately after the collision.

Next: Frictional Force