

Impulse & Momentum

So far we have looked at collisions and the momentum before and after. During a collision there are forces acting for a given time which cause the changes in momentum of the different objects – the mechanics of the forces during a collision are considered here with the concept of **impulse**.



Introducing Impulse

When an **unbalanced force** acts on an object, it causes an **acceleration** (Newton's 2nd Law). We write this in terms of a familiar equation:

$$F = ma$$

Remember also that **acceleration** can be defined as:

$$a = \frac{v - u}{t}$$

Substituting this into Newton's 2nd Law and we get the following:

$$F = m \left(\frac{v - u}{t} \right)$$
$$F = \frac{mv - mu}{t}$$

From our studies of momentum, we know that $mv - mu$ is equal to the **change in momentum**, Δp so we can write:

$$F = \frac{\Delta p}{t}$$
$$Ft = \Delta p$$

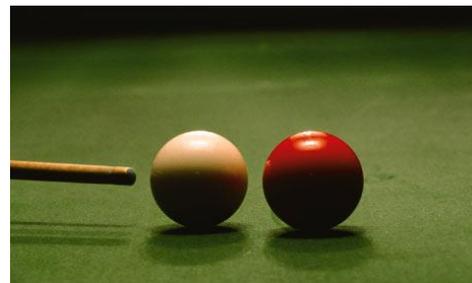
We define **impulse** as the **average force applied** multiplied by the **time for which the force is applied**. Therefore we can state:

$$\text{Impulse} = Ft = \Delta p = mv - mu$$

The units for impulse are **Newton seconds** (Ns) which is equivalent to the units for momentum, kgm/s.

Worked Example

In a game of snooker, the snooker cue applies an average force of 5 N to the cue ball which has a mass of 0.165 kg. The time of contact between the cue and the ball is 0.4 s. The cue ball was initially stationary. Calculate:



- The **impulse** between the cue and the cue ball.
- The speed with which the cue ball moves off.

a) To calculate the impulse, we need to use the **average force** and the **time**:

$$\text{Impulse} = Ft$$

$$\text{Impulse} = 5 \times 0.4$$

$$\text{Impulse} = 2Ns$$

b) The speed after comes from the **change in momentum** which is equal to the **impulse**:

$$\Delta p = Ft = mv - mu$$

$$2 = mv - mu$$

$$2 = (0.165 \times v) - 0$$

$$0.165v = 2$$

$$v = \frac{2}{0.165}$$

$$v = 12.12m/s$$

Questions

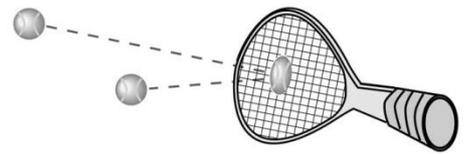
- A snooker cue exerts a force of 7N on a snooker ball of mass 200 g. The ball is initially stationary. Calculate the speed that the ball leaves the cue.
- A girl kicks a football with a mass of 500 g which was originally stationary. The average force applied by the girl was 40 N and the ball moved off with a velocity of 12 m/s. Calculate the time of contact between the girl's foot and the ball.



- A stationary golf ball is struck by a club. The club is in contact with the ball for 40 ms and the ball moves off with a speed of 20 m/s. The mass of the ball is 100 g. Calculate the average force applied to the ball.



4. A tennis ball of mass 200 g is originally travelling at 25 m/s towards a tennis racket. It is struck by the tennis racket with an average force of 75 N for a time of 350 ms. Calculate the speed that the tennis ball moves off with.

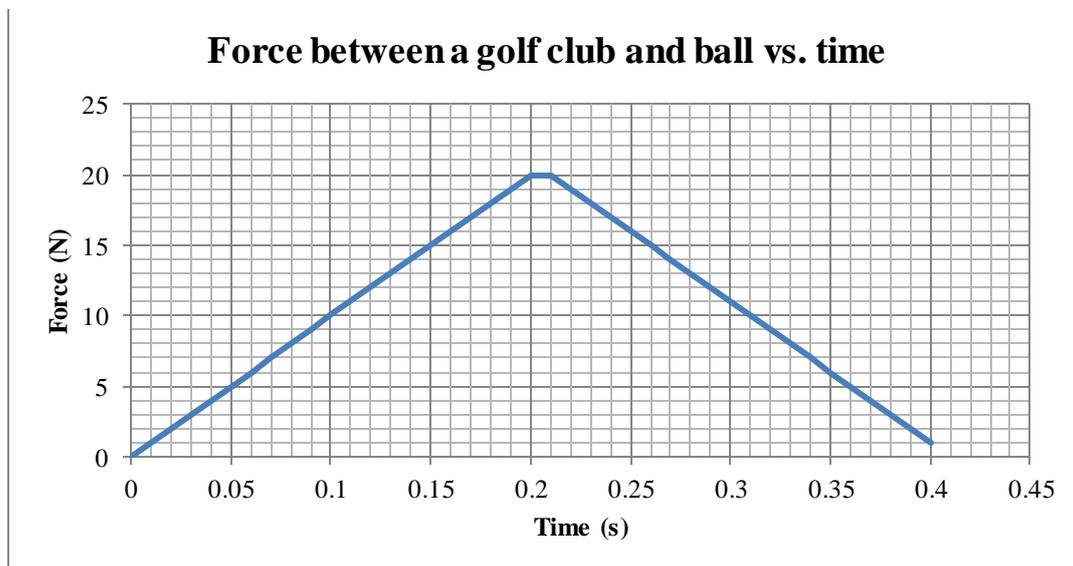


5. A car collides head on with a wall. The car was originally travelling at 25 m/s and is brought to rest in a time of 500 ms. The car has a mass of 1200 kg. Calculate the average force acting on the car during the collision.

Force-Time Graphs

The concept of impulse is very useful in situations where the force applied is not constant. Examples of this conclude most collisions, as the force will vary as the objects deform and then reform. In this case, the **force applied** can be plotted as a graph against **time**. The **impulse** is then the **area under** a force-time graph.

Consider the example of a golf club striking a golf ball. The club exerts a force which is small at first as it comes into contact with the ball, increasing as the club is pushed through the ball and then decreasing as the ball leaves the club. This can be plotted on a graph as shown below:



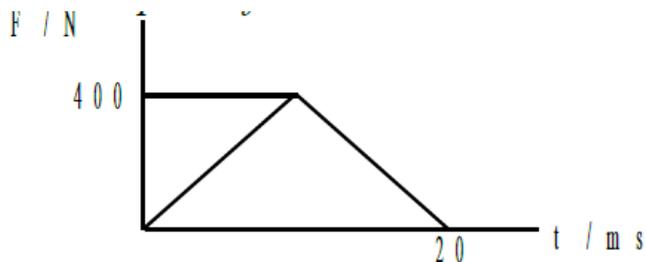
Calculating the area under the graph will give the **impulse** which is then equal to the **change in momentum** of the golf ball.

A curved graph would be approximated at Higher Physics by a triangle as shown above and the area calculated from the area of a triangle:

$$A = \frac{1}{2}bh$$

Worked Example

A tennis ball of mass 100 g is initially at rest. It is hit by the racket which is in contact with the ball for 20 ms. The force of contact varies over this time period as shown in the graph below. Determine the speed of the ball as it leaves the racket.



The impulse is given by the area under the graph:

$$A = \frac{1}{2}bh$$

$$A = \frac{1}{2} \times (20 \times 10^{-3}) \times 400$$

$$A = 4Ns$$

This impulse is equal to the change in momentum:

$$\Delta p = mv - mu = 4$$

$$(0.1 \times v) - (0.1 \times 0) = 4$$

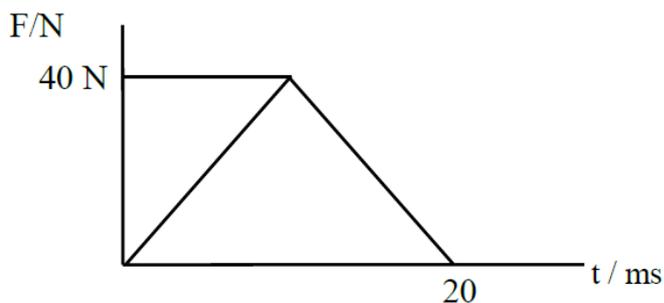
$$0.1v = 4$$

$$v = \frac{4}{0.1}$$

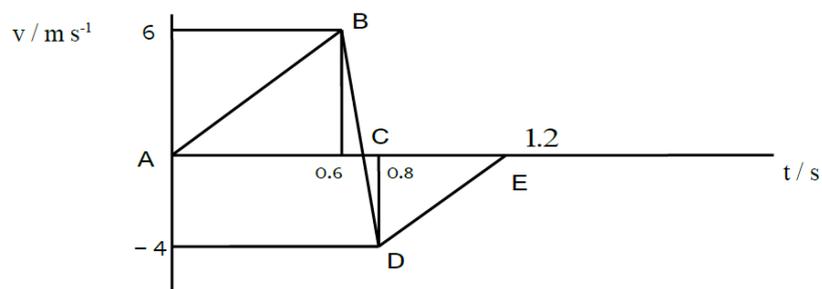
$$v = 40m/s$$

Questions

1. The graph below shows how the force exerted on a hockey ball by a hockey stick varies with time. If the ball has a mass of 150 g and is initially stationary, determine the speed the ball leaves the stick with.



2. A ball of mass 100 g falls from a height of 20 cm onto a surface and rebounds to a height of 18 cm. The duration of the impact is 25 ms. Calculate:
- The change in momentum caused by the bounce.
 - The average force exerted by the ball on the surface.
3. A rubber ball of mass 40 g is dropped from a height of 0.8 m onto the pavement. It rebounds to a maximum height of 0.45 m. The average force of contact between the pavement and the ball is 2.8 N.
- Calculate the velocity of the ball just before it hits the ground and the velocity of the ball just after leaving the ground.
 - Calculate the time of contact between the ball and the pavement.
4. A ball of mass 400 g travels horizontally along the ground and collides with a wall. The velocity-time graph below represents the motion of the ball for the first 1.2 seconds.



- Describe the motion of the ball between positions AB, BC, CD and DE.
 - What is the time of contact with the wall?
 - Calculate the average force between the ball and the wall.
 - How much energy is lost due to contact with the wall?
5. Water is ejected from a fire hose at a rate of 25 kg per second and a speed of 50 m/s. If the water hits a wall, calculate the average force exerted on the wall. Assume the water does not rebound from the wall.



6. A rocket burns fuel at a rate of 50 kg per second, ejecting it with a speed of 1800 m/s. Calculate the force exerted on the rocket.

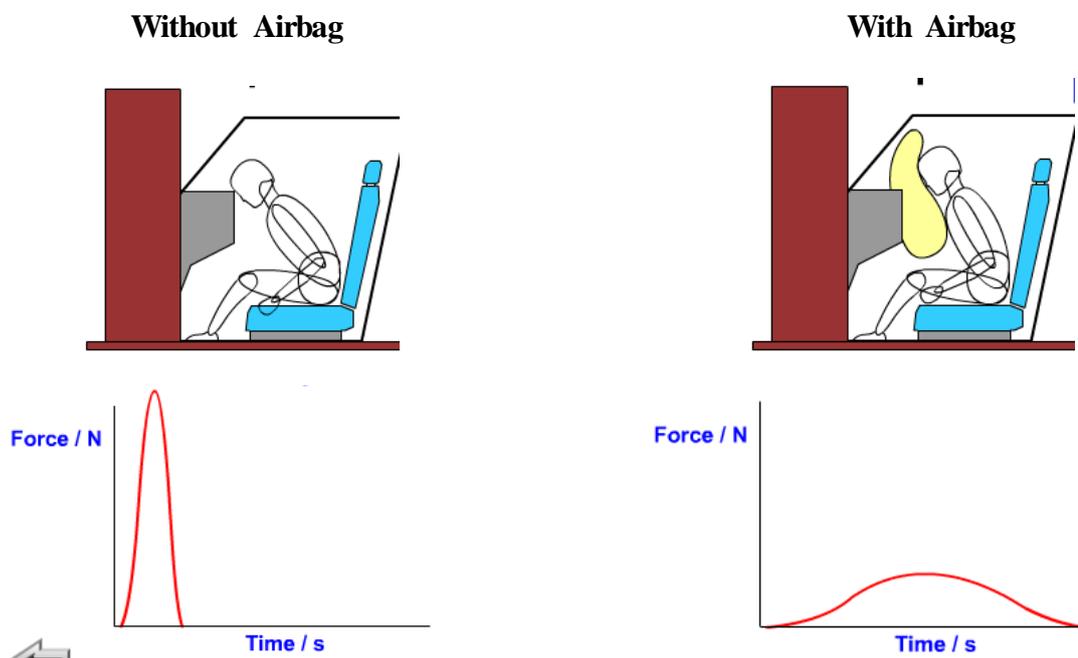
7. A 2 kg trolley travelling at 6 m/s collides with a stationary trolley of mass 1 kg. They lock together during the collision and move off.
- Calculate the combined velocity of the trolleys after the collision.
 - Calculate the momentum gained by the 1 kg trolley.
 - Calculate the momentum lost by the 2 kg trolley.
 - If the time of collision is 0.5 s, find the force acting on each trolley.

Impulse, Collisions & Road Safety

We have seen that the average force acting during a collision is linked to the length of time of the collision and the change of momentum. Common sense dictates that the greater the change in momentum (the greater the speed before the crash), the greater the forces acting during the collision. Our studies of impulse reveal that as you **increase** the time of the impact, the average force is **reduced**. This can be applied to car safety to make accidents survivable.

The Air Bag

An airbag (also known as a *Supplementary Restraint System* or *SRS*) is used to **increase** the time of contact between the occupant of the car and solid objects of the interior. The force-time graphs below show the forces acting during a collision with and without an airbag:



Research different advancements in car safety – for example, the crumple zone. Use your knowledge of momentum, impulse and collisions to explain why the safety advancements improve the safety of cars in the event of an accident.