Momentum

Momentum (ρ)

- Every moving object has momentum.
- Linear momentum is defined as the product of mass and velocity of an object.

momentum (kg m/s) = mass (kg) × velocity (m/s)

$\rho = mv$

- Momentum is a vector quantity and has the direction of velocity.

Newton's second law of motion states that:

The rate of change of momentum is directly proportional to the unbalanced force acting on that body and takes place in the same direction.

Hence in terms of momentum Newton's second law is:

$$F_{net} = \frac{\Delta p}{\Delta t}$$

If mass stays constant , then the above equation can be re-written as:

$$F_{net} = \frac{\Delta p}{\Delta t} = \frac{p_{final} - p_{initial}}{\Delta t} = \frac{mv_{final} - mv_{initial}}{\Delta t} = \frac{m(v_{final} - v_{initial})}{\Delta t} = \frac{m\Delta v}{\Delta t}$$

$$F_{net} = ma$$

Numerical:

A ball of mass 640g that is moving vertically downwards, hits the ground with a velocity of 12 m/s. Post impact, it bounces upwards with a velocity of 8m/s.

a. Calculate the momentum of the ball before and after impact.

b. Calculate the change in momentum during impact

Solution:

(a)Convert the mass from g to kg

Momentum of the ball before impact

= mass x velocity before impact

=0.64 x 12=7.68kgm/s= +7.78kgm/s

Momentum of the ball after impact

=mass x velocity after impact

=0.64 x 8 =5.12kgm/s =-5.12kgm/s

(b)Change in momentum

=Final momentum- Initial momentum

=(-5.12) - (7.78) =-12.9kgm/s

- Since momentum is a vector quantity, it has magnitude as well as direction.
- We can take any direction positive and any direction negative.
- In our sum , we have assumed that the upward direction is positive and the downward direction is negative.

Example:

A bullet with a mass of 0.03 kg leaves a gun at 1000 m/s. If the gun's mass is 1.5 kg, what is the velocity of the recoil on the gun?

momentum of bullet = mass × velocity

= 0.03 kg × 1,000 m/s

= 30 kg m/s

Rearrange the equation:

velocity = momentum ÷ mass

velocity of recoil on gun = 30 kg m/s ÷ 1.5 kg

= 20 m/s

Impulse

- If you get hit by a ball, the effect is greater if it bounces off you than if you catch it. This is because the change in momentum is greater if the ball bounces off you.
- Unit of impulse=kgm/s
- Impulse is a vector

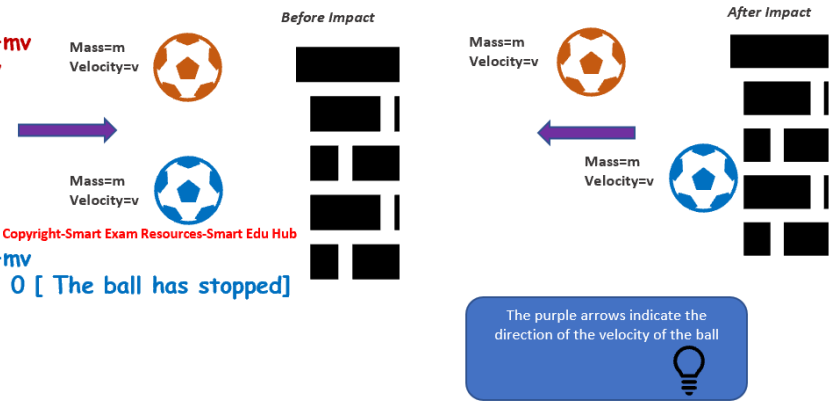
Example:

Comparing momentum of two objects

Solution:

For the orange ball:
Momentum before impact=Initial momentum=+mv
Momentum after impact=Final momentum=-mv
Change in momentum
=Final momentum-Initial momentum
=-mv – (+mv)
=-2mv

For the blue ball:
Momentum before impact=Initial momentum=+mv
Momentum after impact=Final momentum-mv= 0 [The ball has stopped]
Change in momentum
=Final momentum-Initial momentum
=-mv – (0)
=-mv



Conclusion: The red ball has a greater change in momentum as compared to the blue ball.

Solved examples from past papers:

7 An object of mass 50 kg accelerates from a velocity of 2.0 m/s to a velocity of 10 m/s in the same direction.

0625/21/M/J/16

What is the impulse provided to cause this acceleration?

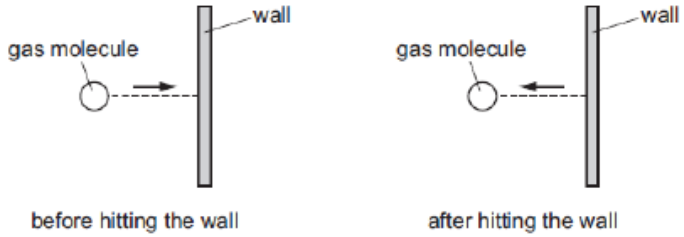
A 250 Ns **B** 400 Ns **C** 850 Ns **D** 2500 Ns

Explanation:

Change on velocity= (10-2)=8 m/s
mass =50kg
Hence the impulse that caused this acceleration
=F= m x (Change in velocity)= 50 x 8 =400Ns

---

8 A gas molecule strikes the wall of a container. The molecule rebounds with the same speed.



before hitting the wall after hitting the wall

What happens to the kinetic energy and what happens to the momentum of the molecule?

0625/23/M/J/16

	kinetic energy	momentum
A	changes	changes
B	changes	stays the same
C	stays the same	changes
D	stays the same	stays the same

Answer =C

Explanation:

Since there is no change in the speed, so the kinetic energy stays the same. The momentum changes because the direction of motion and hence the velocity changes. So the momentum which is a product of mass and velocity changes too.

Principle of momentum

Statement:

The total linear momentum of any system is constant, provided that no external forces are acting on it.

The following points should be kept in mind while using the principle of momentum:

- Momentum is a vector quantity so its direction must always be included in calculations.
- The system must be isolated- only the interacting objects must be considered and there can be no forces acting on that system from outside.
- Immediately after an interaction, external forces like friction will usually affect the motion of objects.

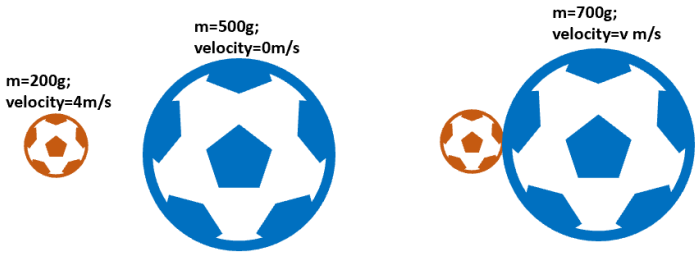
In real lives:

- Loss of momentum will happen because the system is not isolated as the system will be acted upon by external forces.
- Some or all momentum may appear to be lost when something collides with an object that has a much greater mass. The motion after impact may be too small to observe or measure .Example: a person jumping on the earth's surface. The predicted motion of the " person-earth system" is insignificant after impact.
- The force of gravity generally increases the momentum of falling objects. But the objects are not in isolated systems, there are external forces acting on them. For example: a 3kg rock experiences a gravitational force towards the earth of approximately 30N and therefore gains momentum as it accelerates downwards. The law of conservation of momentum clearly predicts that the earth must gain an equal momentum upwards towards the rock. Because the mass of the earth is so large, its gain of momentum is insignificant.

Change in momentum, where the colliding bodies stick to each other and then move together

In an isolated system, one ball with a mass of 200g and velocity 4m/s, collides with a stationary ball of mass 500g that is at rest. After collision, the two balls stick to each other and move with a velocity "v".

a. Calculate the velocity of the ball after collision



Before collision

After collision

Solution:

(a)Momentum of the red ball before impact
= mass x velocity before impact
=(0.2x 4)kgm/s
Momentum of the blue ball before impact
= mass x velocity before impact
=(0.5x 0)kgm/s

Momentum of the red and the blue ball after impact
=(their combined mass) x(velocity after impact)
=[(0.7) x v]kgm/s

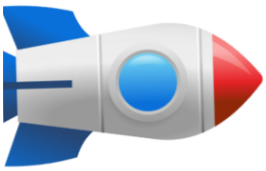
According to the conservation of momentum, the momentum before impact=Momentum after impact
Hence; [(0.2x 4) +(0)] = [(0.7) x v]
⇒ v= 0.8/0.7= 1.14m/s =1m/s
⇒ Hence their velocity after impact= 1 m/s

- Direction of velocity is the same as the balls are not travelling in the opposite direction
- It is important to change the mass of the balls into kilograms to get the value of momentum in kgm/s

Rocket engine:

- What is the momentum of a rocket and its fuel, when it in simply floating space? Well it is zero
- It is only when the rocket engines are fired and the gases are expelled at high speed, they develop a momentum. The reason being the gases that are expelled have a backward momentum and in order to conserve the momentum, the rocket and its fuel then develops a forward momentum.

Zero momentum



Backward momentum of the expelled gases

Forward momentum of the rocket

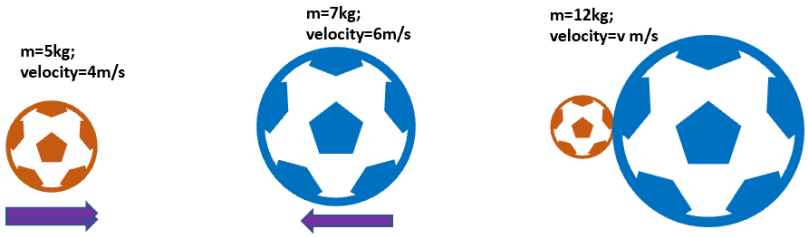
Numerical

Change in momentum, where the two bodies travelling in the opposite direction collide with each other and then stick together and move.

In an isolated system, one red ball with a mass of 5kg and velocity 4m/s moving to the right ,collides with a blue ball of mass 7kg and a velocity of65m/s to the left.. After collision, the two balls stick to each other and move with a velocity "v".
a. Calculate the velocity of the ball after collision

Solution:

(a)Momentum of the red ball before impact
= mass x velocity before impact
=(5 x 4)kgm/s
Momentum of the blue ball before impact
= mass x velocity before impact
=-(7x 6)kgm/s



Before collision

After collision

Momentum of the red and the blue ball after impact
=(their combined mass) x(velocity after impact)
=[(12) x v]kgm/s

According to the conservation of momentum: Momentum before impact=Momentum after impact
Hence; [(5 x (+4)) +(7 x (-6))] = [(12) x v]
⇒ v= (20-42)/12= -1.8m/s
⇒ Hence their velocity after impact is in the left direction and has a magnitude of 1.8m/s

- Direction of velocity to the right is taken as positive and to the left is taken as negative

APPLICATION BASED QUESTIONS:

MCQ

0625/22/O/N/16

8 A girl of mass 50 kg runs at 6.0 m/s.

What is her momentum?

A 300 J **B** 300 kg m/s **C** 900 J **D** 900 kg m/s

---

8 A moving body undergoes a change of momentum. F/M/17-P22

What is a unit for change of momentum?

A Nm **B** N/m **C** Ns **D** N/s

---

9 A ball of mass 2.0 kg is travelling at a speed of 12 m/s. It moves towards an object of mass 3.0 kg which is at rest.

M/J/17-P22

The ball hits the object and sticks to it.

Which row gives the total momentum, and the speed of both objects immediately after the collision?

	total momentum kg m/s	speed m/s
A	0	4.8
B	0	8.0
C	24	4.8
D	24	8.0

EXPENDED THEORY

2 Fig. 2.1 shows a hammer being used to drive a nail into a piece of wood.

F/M/2016-P42

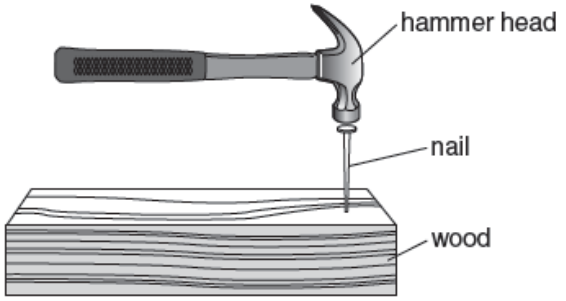


Fig. 2.1

The mass of the hammer head is 0.15 kg.
The speed of the hammer head when it hits the nail is 8.0 m/s.
The time for which the hammer head is in contact with the nail is 0.0015 s.

The hammer head stops after hitting the nail.

(a) Calculate the change in momentum of the hammer head.

change in momentum = ...[2]

(b) State the impulse given to the nail.

impulse = ...[1]

(c) Calculate the average force between the hammer and the nail.

average force = ...[2]

[Total: 5]

2 **(a)** Explain why momentum is a vector quantity. F/M/2017-P42

.....[1]

(b) The crumple zone at the front of a car is designed to collapse during a collision.

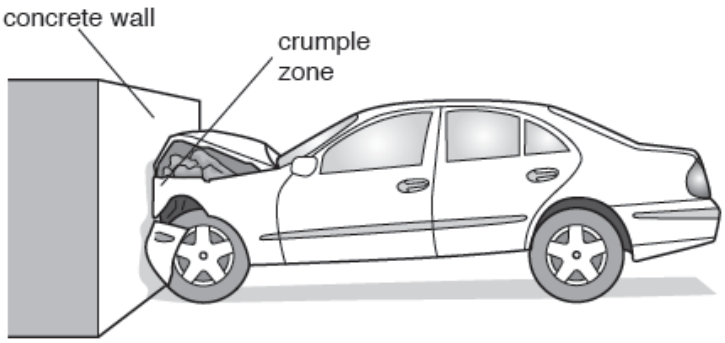


Fig. 2.1

In a laboratory test, a car of mass 1200 kg is driven into a concrete wall, as shown in Fig. 2.1.

A video recording of the test shows that the car is brought to rest in 0.36 s when it collides with the wall. The speed of the car before the collision is 7.5 m/s.

Calculate

(i) the change of momentum of the car,

change of momentum = ...[2]

(ii) the average force acting on the car.

average force = ...[2]

(c) A different car has a mass of 1500 kg. It collides with the same wall and all of the energy transferred during the collision is absorbed by the crumple zone.

(i) The energy absorbed by the crumple zone is 4.3×10^5 J. Show that the speed of the car before the collision is 24 m/s.

[2]

(ii) Suggest what would happen to the car if it is travelling faster than 24 m/s when it hits the wall.

.....

.....[1]

[Total: 8]

3 **(a)** Underline the pair of quantities which must be multiplied together to calculate *impulse*.

force and mass | force and velocity | mass and time

time and velocity | weight and velocity | force and time [1]

(b) Fig. 3.1 shows a collision between two blocks A and B on a smooth, horizontal surface.

M/J/17-P42

Fig. 3.1

Before the collision, block A, of mass 2.4 kg, is moving at 3.0 m/s. Block B, of mass 1.2 kg, is at rest.

After the collision, blocks A and B stick together and move with velocity *v*.

(i) Calculate

1. the momentum of block A before the collision,

momentum = ...[2]

2. the velocity *v*,

velocity = ...[2]

3. the impulse experienced by block B during the collision.

impulse = ...[2]

(ii) Suggest why the total kinetic energy of blocks A and B after the collision is less than the kinetic energy of block A before the collision.

.....

.....[1]

[Total: 8]

4 A balloon contains a fixed mass of gas.

(a) Explain, in terms of the momentum of molecules, how the gas in the balloon exerts a pressure.

.....

.....

.....

.....[2]