Rosary School – Marj Elhamam

Chapter 4 Momentum

Name: ___________________ Date: ____ /____ / 2025

Grade: 9 (   ) Subject: **Physics**

Summary notes

Objectives:

1.25P know and use the relationship between momentum, mass and velocity:

momentum = mass × velocity (p = m × v)

1.26P use the idea of momentum to explain safety features

1.27P use the conservation of momentum to calculate the mass, velocity or momentum of objects

1.28P use the relationship between force, change in momentum and time taken:

$$\text{force} = \frac{\text{change in momentum}}{\text{time taken}} \qquad F = \frac{(mv - mu)}{t}$$

1.29P demonstrate an understanding of Newton's third law

Momentum:

- Momentum is a property that all moving objects have. It can be described as the effect of **masses in motion** or a measure of how difficult it is to stop something that is moving.
- An object with mass (m) moving at a velocity (v) will have a momentum (p)
- Momentum is calculated using the formula:

$$\boldsymbol{momentum = mass \times velocity}$$

In symbols:

$$\boldsymbol{p = m \times v}$$

p = momentum in kilogram metre per second (kg m/s)

m = mass in kilograms (kg)

v = velocity in metres per second (m/s)

Rearrange: $\boldsymbol{m = \frac{p}{v}}$, $\boldsymbol{v = \frac{p}{m}}$

- This means that an object **at rest** (i.e. v = 0) has **no momentum.**
- Momentum keeps an object moving in the same direction. It is difficult to change the direction of an object with a large momentum.
- Velocity is a **vector** quantity with both magnitude and direction.
- Momentum is a **vector** quantity since it depends on the object's velocity (direction of travel), this means momentum can be either **positive** or **negative**.

- If an object travelling to the right has positive momentum, then an object travelling in the opposite direction (to the left) will have negative momentum.

Example 1:

Calculate the momentum of a 2000 kg car travelling at 7 m/s?

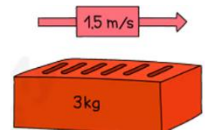
$$p = m \times v$$

= 2000 kg x 7 m/s
= 14000 kg.m/s

**Constant velocity → Constant momentum → Resultant force = Zero*

Example 2:

Determine which object has the most momentum, the tennis ball or the brick.



Question 1 page 47:

Work out, giving your answers in kg m/s, the momentum of the following moving objects:

a a bowling ball of mass 6 kg travelling at 8 m/s
b a ship of mass 50 000 kg travelling at 3 m/s
c a tennis ball of mass 60 g travelling at 180 km/h.

Change in momentum (Impulse):

- If the velocity of the object increases (acceleration) → momentum increases → change in momentum Δp **(impulse)** is positive.
- If the velocity of the object decreases (deceleration) → momentum decreases → change in momentum Δp **(impulse)** is negative.

Change in momentum (impulse) = final momentum - initial momentum

$$\Delta p = p_v - p_u$$

$$\Delta p = (mv) - (mu)$$

Example 3:

A car of a mass of 300 kg travelling at a velocity of 5 m/s accelerates to 13 m/s in 2 seconds. Calculate:

a. Initial momentum.

b. Final momentum.

c. Change in momentum:

- Newton's second law (F = ma) explains that the **rate of change in momentum** of an object is directly proportional to the force applied to that object.

Rate of change in momentum α Force applied

$$\frac{\Delta p}{t} \ \alpha \ \Sigma F$$

Rearrange:

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

$$\frac{mv - mu}{t} = F$$

$$\frac{m\,(v - u)}{t} = F$$

$$m \times a = F$$

➔ Rearrange the formula: $F \times t = \Delta p$ (impulse)

From example 3, calculate the resultant force acting on the car and its acceleration.

<u>Conservation of momentum</u>:

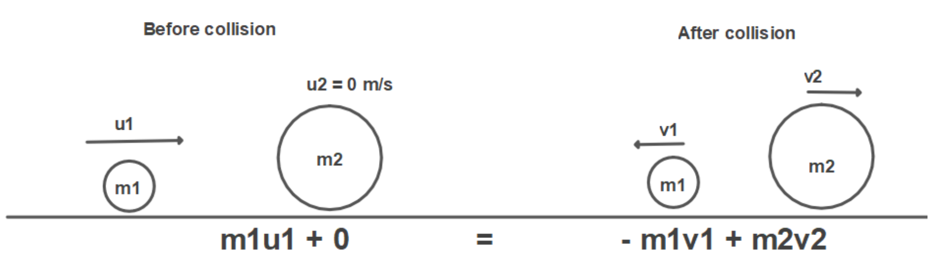
Explosions:

- The law of conservation of momentum can be applied to explosions where a stationary object explodes into two (or more) parts. The momentum before the explosion is equal to the momentum after the explosion.
- Rockets' motors push the rocket into space, where there is nothing to push against, by producing continuous controlled explosions that force large amounts of fast-moving gases out of the back of the rocket. The spacecraft as a result gains an equal and opposite momentum to that of the exhaust gases that pushes it forward.

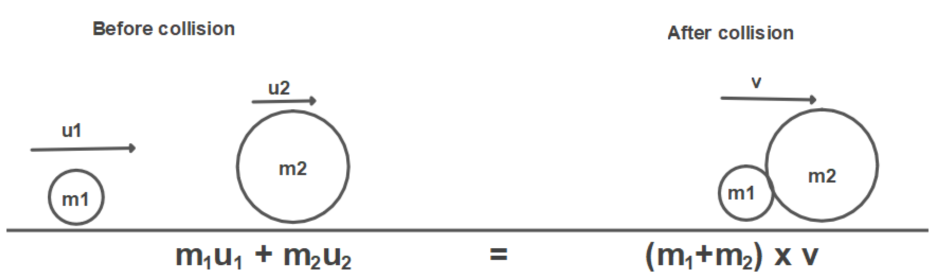
  (To understand this, imagine a deflating balloon. As the air rushes out, the balloon moves in the opposite direction. This phenomenon can be explained by **the principle of conservation of momentum.** As the air is expelled from the balloon, it gains momentum in one direction. To conserve momentum, the balloon must gain an equal amount of momentum in the opposite direction).

Collisions:

- For a collision between two objects:
  The total momentum before a collision = the total momentum after a collision
- In the example below:
  Before the collision: The momentum is only generated by mass $\mathbf{m_1}$ because it is the only moving object. If the right is taken as the positive direction, the total momentum of the system is $\mathbf{m_1 \times u_1}$
  After the collision: Mass $\mathbf{m_2}$ also now has momentum. The velocity of $\mathbf{m_1}$ is now $\mathbf{-v_1}$ (since it is now travelling to the left) and the velocity of $\mathbf{m_2}$ is $\mathbf{v_2}$
  The total momentum is now <u>the momentum of $\mathbf{m_2}$</u> + <u>the momentum of $\mathbf{m_1}$</u>.



- If the two masses join together after the collision their velocity after they collide will be the same (v) as they will be moving together:



> **Exam tip:**
> In the conservation of momentum questions, if a diagram is not given, drawing a simple diagram before and after collision can be helpful in tracking the masses and velocities (and direction).
> Choose the direction that is positive (right is usually given the positive sign and left the negative sign) and substitute the velocities according to their direction, positive and negative.

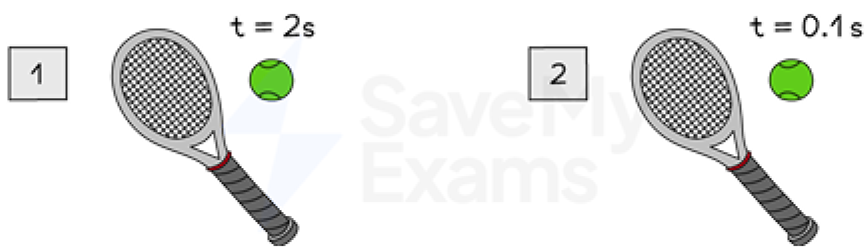
- Since momentum is a **vector** quantity, a system of objects with equal masses moving in opposite directions (e.g. towards each other) at the same speed will have an overall momentum of 0 since they will cancel out. Momentum is always conserved over time.

Example 4:

A tennis ball hits a racket twice, with a change in momentum of 0.5 kg m/s both times.

During the first hit, the contact time is 2 s and during the second hit, the contact time is 0.1 s

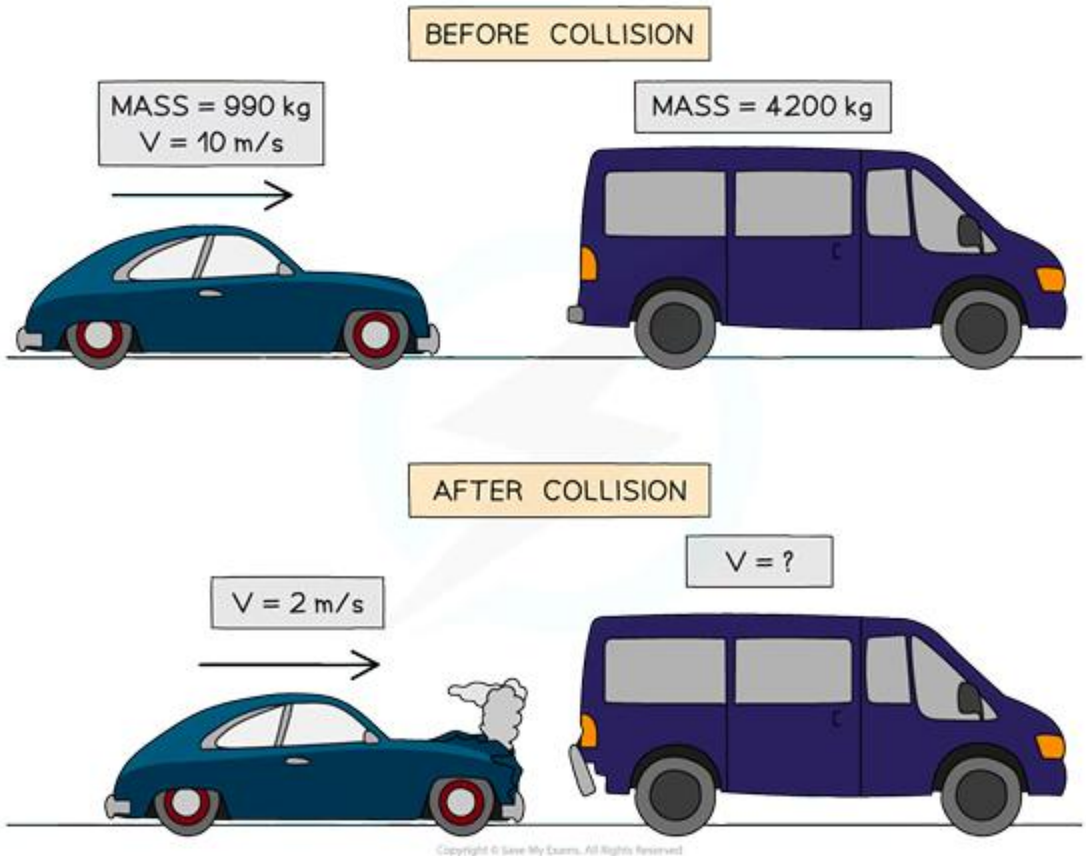
Determine which strike of the tennis racket experiences the greatest force from the tennis ball.



Example 5:

The diagram shows a car and a van, just before and after the car collides with the van, which is initially at rest.

The car initially moves at a speed of 10 m/s, but this reduces to 2 m/s after the collision.



The mass of the car is 990 kg and the mass of the van is 4200 kg.

Calculate the velocity of the van when it is pushed forward by the collision.

Example 6:

A car of mass 1500 kg hits a wall at an initial velocity of 15 m/s and rebounds with a velocity of 5 m/s. The car is in contact with the wall for 3 seconds.

Calculate the average force experienced by the car and state the direction of the force.

<u>Newton's third law:</u>

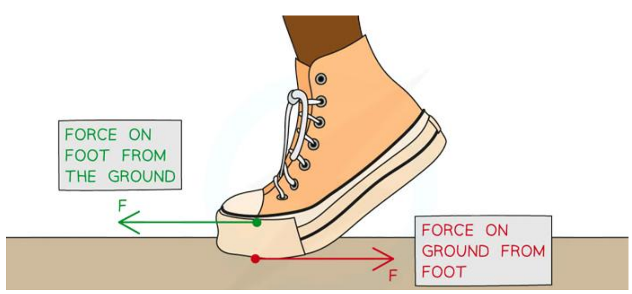
Newton's third law of motion can be defined as follows:

Whenever two objects interact, the forces they exert on each other are equal in magnitude and opposite in direction.

In other words:

For every <u>action</u> there is an equal and opposite <u>reaction.</u>

Newton's third law explains the forces that enable someone to walk. The foot exerts a **push** force on the ground. The ground exerts a **push** force on the foot. The forces are equal in magnitude and opposite in direction.



The foot pushes the ground backwards, and the ground pushes the foot forwards. Newton's third law explains the forces that enable people to walk.

Recognizing Newton's third law:

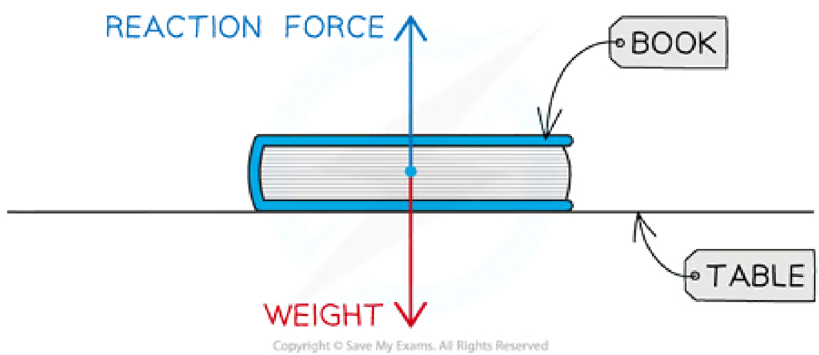
Force diagrams can be used to represent Newton's third law.

Use the following three rules to help you identify a third law pair:

1. The two forces in a third law pair act on different objects.
2. The two forces in a third law pair always are equal in size but act in opposite directions.
3. The two forces are always the same type: weight, reaction force, etc.

Example 7:

A physics textbook is at rest on a table. Student A draws a free body force diagram for the book and labels the forces acting on it as weight and rection force.

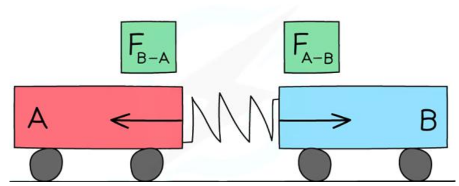


Student A says the diagram is an example of Newton's third law of motion. Student B disagrees with Student A.

By referring to the vector diagram, state and explain who is correct.

<u>Newton's third law in collisions</u>

According to Newton's Third Law: When two objects collide, both objects will react, generally causing one object to speed up (gain momentum) and the other object to slow down (lose momentum).



Momentum & safety features

- Since **force** is equal to **the rate of change in momentum**, the **force of an impact** in a vehicle collision can be **decreased** by **increasing the contact time** over which the collision occurs.
- The contact time is the time in which the person is in contact with what they have collided with. Therefore, safety features are created **to reduce the impact of a force**, such as in: vehicles, playgrounds, bicycle helmets and gymnasium crashmats.

Safety features in vehicles

- Vehicle safety features are designed to absorb energy upon an impact by **changing shape**.
- The main vehicle safety features are **crumple zones**, **seat belts** and **airbags**.
- For a given force upon impact, these absorb the energy from the impact and ***increase the time*** over which the ***force*** takes place. This, in turn, ***increases the time taken for the change in momentum*** of the passenger and the vehicle to come to rest.
- The **increased time** reduces the **force** and risk of injury on a passenger.
- The usefulness of safety features depends on two main factors: mass and velocity. If the impact is from a large mass, for example, a truck travelling very fast and colliding with a wall, the momentum will be very large. The change in momentum (ie. from a high speed to rest) will also be very large. This means that a very long contact time is needed to reduce the force of impact.

Safety features on a car:

Seat belts

- These are designed to stop a passenger from colliding with the interior of a vehicle by keeping them fixed to their seat in an abrupt stop.
- They are designed to *stretch* slightly to **increase the time** for the passenger's momentum to reach zero and **reduce the force** on them in a collision.

Airbags

- These are deployed at the front on the dashboard and steering wheel when a collision occurs.
- They act as a soft cushion that deflates slowly to prevent injury on the passenger when they are thrown forward upon impact.

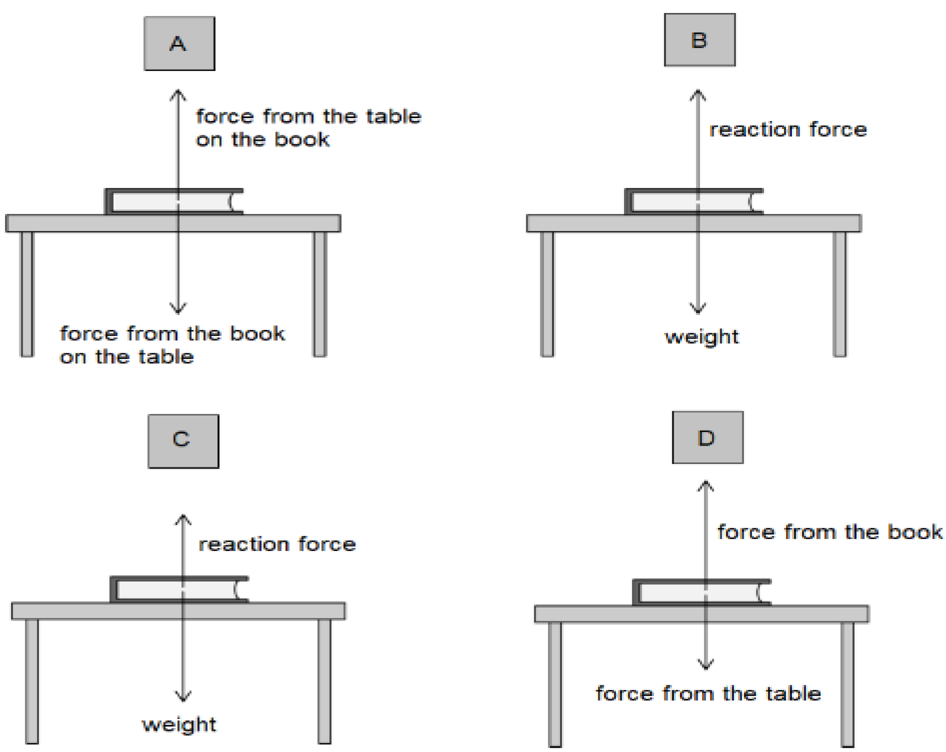
Crumple zones

- These are designed into the exterior of vehicles.
- They are at the front and back and are designed to crush or crumple in a controlled way in a collision.
- This is why vehicles after a collision look more heavily damaged than expected, even for relatively small collisions.
- The crumple zones **increase the time** over which the vehicle comes to rest, **lowering the impact force** on the passengers.

Past papers questions:

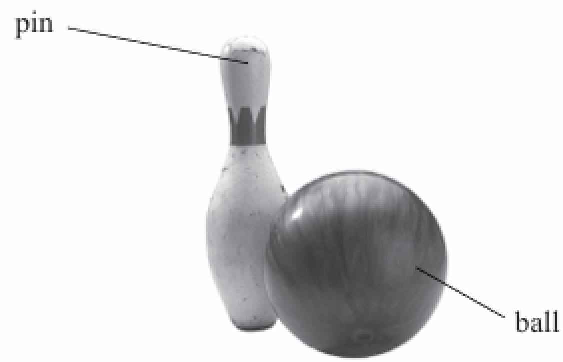
1. Four students draw a Newton's Third Law force pair for a book on a table.

Which student's Newton's Third Law force pair is correct?

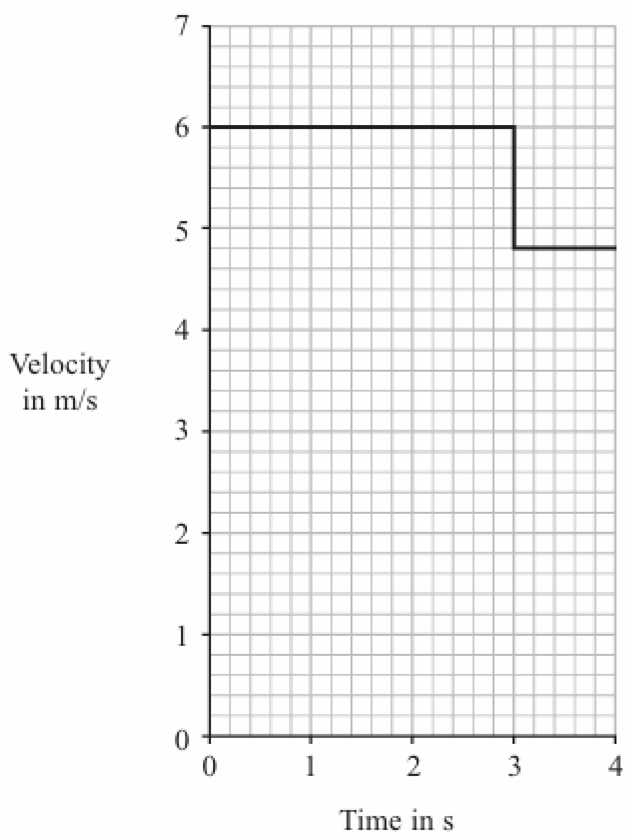


2. 4PH0 JAN 2013 2P

8 A bowling ball rolls for 3 s and hits a pin.



The graph shows how the velocity of the ball changes with time.



(a) How can the graph be used to find the distance that the ball rolls before it hits the pin?

(1)

....

....

....

(b) The mass of the ball is 6.4 kg.

(i) State the equation linking momentum, mass and velocity.

(1)

(ii) Calculate the momentum of the ball before it hits the pin.
Give the unit.

(3)

Momentum = ... Unit ....

(c) (i) What is the velocity of the ball after it hits the pin?

(1)

Velocity = ... m/s

(ii) After the collision, the ball and the pin have the same velocity.

Calculate the mass of the pin.

(3)

Mass = ... kg

(Total for Question 8 = 9 marks)

3.

Some questions must be answered with a cross in a box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 (a) Which of these is a device used to measure force?

(1)

☐ **A** newton meter

☐ **B** ruler

☐ **C** thermometer

☐ **D** voltmeter

(b) Airbags are safety devices used in cars to protect the driver if there is a crash.

(i) State the formula linking momentum, mass and velocity.

(1)

(ii) A person inside a car has a mass of 72 kg and a velocity of 13 m/s.

Show that the momentum of the person is about 900 kg m/s.

(1)

(iii) The person experiences a crash and comes to rest in 0.29 s.

Calculate the force on the person.

(2)

force = ... N

(iv) Which statement explains how airbags protect the driver?

(1)

☐ **A** increase the force acting on the driver

☐ **B** increase the time taken for the driver to stop

☐ **C** increase the kinetic energy store of the driver

☐ **D** increase the momentum of the driver

(Total for Question 1 = 6 marks)

4. 4PH1Jun 2022 1PR

2 This question is about momentum.

(a) Which of these is the correct unit for momentum?

(1)

☐ **A** kg / m / s

☐ **B** kg^2 m / s

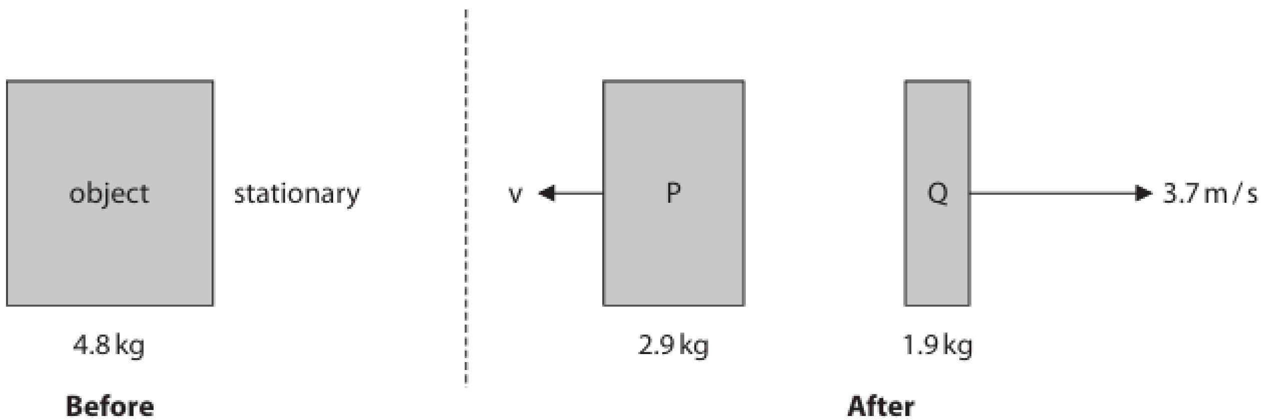
☐ **C** kg m / s^2

☐ **D** kg m / s

(b) The diagram shows an object before and after an explosion.

The object breaks into two parts, P and Q.

The parts move away from each other in opposite directions.



(i) State what is meant by the **principle of conservation of momentum**.

(1)

....

....

(ii) Calculate the magnitude of the velocity of part P after the explosion.

(3)

velocity = ... m / s

(c) A child drops an egg from a height of 10 cm and the egg lands on the floor.

Explain why the egg is less likely to break if the floor is covered with a thick carpet than if the floor were covered in hard tiles.

(3)

....

....

....

....

....

....

....

....

....

(Total for Question 2 = 8 marks)

5. 4PH0- JAN -2P-2019 q9

A student investigates the motion of a toy train.

The toy train is released from rest and rolls down the slope.

(a) The toy train has a mass of 0.039 kg.

The toy train moves with a velocity of 0.56 m/s when it reaches the bottom of the slope.

(i) State the equation linking momentum, mass and velocity.

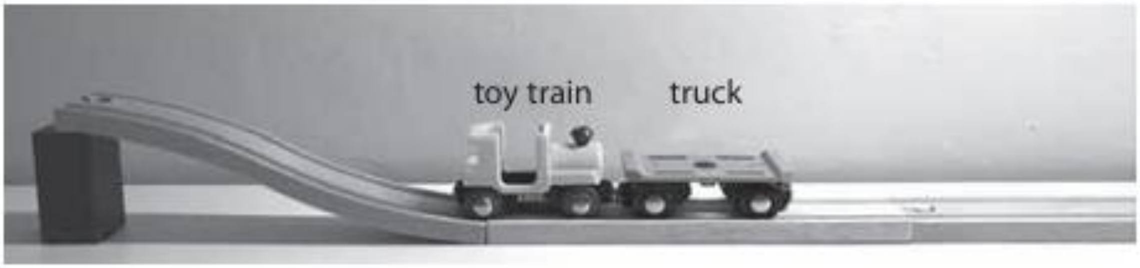
(1)

(ii) Calculate the momentum of the toy train when it reaches the bottom of the slope.

(1)

momentum = ... kg m/s

(iii) The toy train hits the truck and they stick together.



The train and truck move away together with a velocity of 0.26 m/s.

Calculate the mass of the truck.

(3)

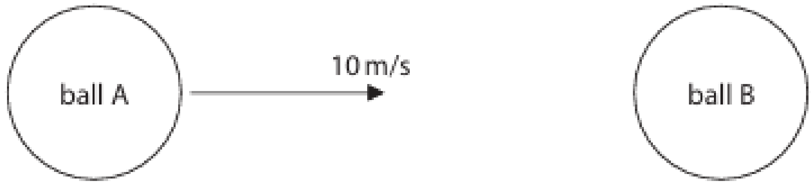
mass = ... kg

6. 4PH0 JAN 2018 2P

4 This question is about collisions.

The diagram shows ball A moving in the direction shown by the arrow.

Ball A collides with ball B, a stationary ball of the same mass and size as ball A.



(a) State the principle of conservation of momentum.

(1)

....

....

(b) Ball A collides with ball B.

- before the collision, ball A moves with a velocity of 10 m/s
- after the collision, ball B moves in the same direction as ball A with a velocity of 8 m/s
- ball A continues to move in the same direction, but at a lower velocity

Calculate the velocity of ball A after the collision.
[mass of each ball = 0.16 kg]

(3)

velocity of ball A = ... m/s

Teacher: Zeina Abu Manneh