

Momentum

Mark Scheme



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1. Someone once said that energy is the message and momentum is the messenger. Let that sink in.

a) Which of the following is the correct definition of momentum?

A – is the only correct answer.	1 mark
	Total: 1 mark

b) A rugby player with a mass of 90 kg is running forwards at a velocity of 8 m/s.

B – is the only correct answer.	1 mark
	Total: 1 mark

c) The Law of Conservation of Momentum states that in a closed system, the total momentum before an event is equal to the total momentum after the event.

C – is the only correct answer.	1 mark
	Total: 1 mark

d) A bowling ball is rolling down an alley at a steady velocity of 6.0 m/s.

D – is the only correct answer.	1 mark
	Total: 1 mark

e) An object with a mass of 3.0 kg moves downwards at 4.0 m/s, as shown in the figure below.

Which other object has a momentum that is identical to the momentum of this object?

B – is the only correct answer.	1 mark
	Total: 1 mark

f) Two objects, A and B, move directly towards each other. The objects have the exact same mass.

A – is the only correct answer.	1 mark
	Total: 1 mark

(Total for Question 1 is 6 marks)

2. Momentum is calculated by multiplying an object's mass by its velocity.
Use the equation $p = m \times v$ to solve the following problems.

- a) A football of mass 0.4 kg is kicked with a velocity of 25 m/s.
Calculate the momentum of the football.

$p = m \times v$ $p = 0.4 \times 25$	1 mark
$p = 10 \text{ kg m/s}$	1 mark
	Total: 2 marks

- b) A sprinter of mass 65 kg runs down a track at a constant velocity of 8 m/s.
Calculate the momentum of the sprinter.

$p = m \times v$ $p = 65 \times 8$	1 mark
$p = 520 \text{ kg m/s}$	1 mark
	Total: 2 marks

- c) A family car of mass 1200 kg is travelling along a motorway at 15 m/s.
Calculate the momentum of the car.

$p = m \times v$ $p = 1200 \times 15$	1 mark
$p = 18\,000 \text{ kg m/s}$	1 mark
	Total: 2 marks

- d) A tennis ball of mass 60 g is hit with a velocity of 40 m/s.
Calculate the momentum of the tennis ball.

Award 1 mark for the conversion for grams to kilograms. $60 \text{ g} \div 1000 = 0.06 \text{ kg}$	1 mark
$p = m \times v$ $p = 0.06 \times 40$	1 mark
$p = 2.4 \text{ kg m/s}$	1 mark
	Total: 3 marks

- e) A toy car of mass 250 g has a momentum of 1.5 kg m/s.

Calculate the velocity of the toy car.

Award 1 mark for the conversion for grams to kilograms. $250 \text{ g} \div 1000 = 0.25 \text{ kg}$	1 mark
$v = p \div m$ $v = 1.5 \div 0.25$	1 mark
$v = 6 \text{ m/s}$	1 mark
	Total: 3 marks

- f) A bullet of mass 15 g is fired from a rifle at a velocity of 300 m/s.

Calculate the momentum of the bullet.

Award 1 mark for the conversion for grams to kilograms. $15 \text{ g} \div 1000 = 0.015 \text{ kg}$	1 mark
$p = m \times v$ $p = 0.015 \times 300$	1 mark
$p = 4.5 \text{ kg m/s}$	1 mark
	Total: 3 marks

- g) A bird of mass 350 g is flying with a momentum of 4.2 kg m/s.

Calculate the velocity of the bird.

Award 1 mark for the conversion for grams to kilograms. $350 \text{ g} \div 1000 = 0.35 \text{ kg}$	1 mark
$v = p \div m$ $v = 4.2 \div 0.35$	1 mark
$v = 12 \text{ m/s}$	1 mark
	Total: 3 marks

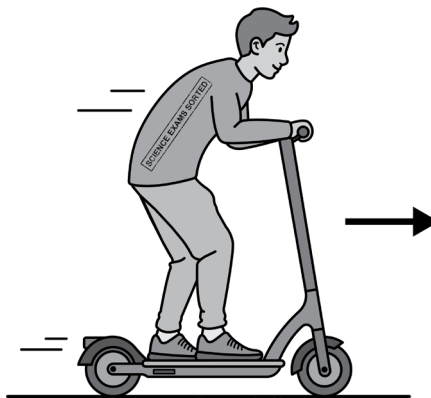
- h) A remote-controlled boat is moving at a velocity of 4 m/s. It has a momentum of 3.6 kg m/s.

Calculate the mass of the boat.

$m = p \div v$ $m = 3.6 \div 4$	1 mark
$m = 0.9 \text{ kg}$	1 mark
Convert the kg into g: $0.9 \times 1000 = 900 \text{ g}$	1 mark
	Total: 3 marks

(Total for Question 2 is 21 marks)

3. A teenager is scooting along a path on an illegal e-scooter.

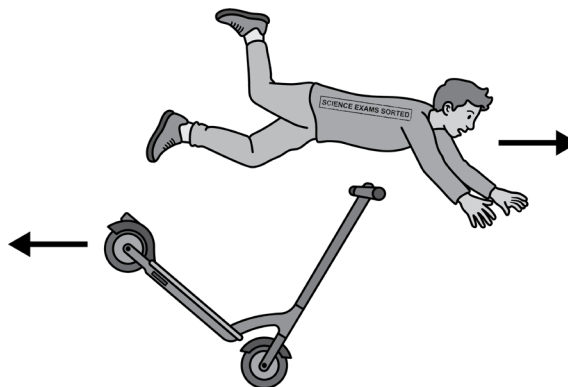


- a) The teenager has a mass of 60 kg and the scooter has a mass of 15 kg. They are travelling together at a constant velocity of 4.0 m/s.

Calculate the total momentum of the teenager and the scooter.

Mass = 60 + 15 = 75 kg	1 mark
$p = m \times v$	
$p = 75 \times 4.0$	
$p = 300 \text{ kg m/s}$	1 mark
	Total: 2 marks

As the teenager scoots along he decides to jump forward off the e-scooter.

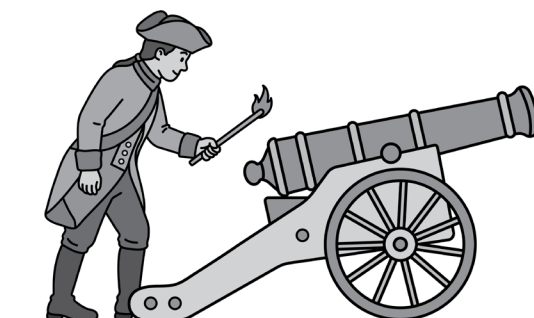


- b) Using your knowledge of momentum, explain why the teenager moves forwards and the scooter moves backwards as he jumps.

An explanation to include the following:	
To jump forwards, the teenager applies a force backwards against the scooter.	1 mark
A description of Newton's third law . Or that the scooter exerts an equal and opposite (forward) force on the teenager.	1 mark
For momentum to be conserved, if the student gained forwards momentum then the scooter must gain backwards momentum so that momentum remains constant.	1 mark
Award 1 mark for for stating that total momentum must be conserved.	
	Total: 3 marks

(Total for Question 3 is 5 marks)

4. A historical reenactment group is preparing to fire a cannon. The figure below shows a reenactor with the cannon.

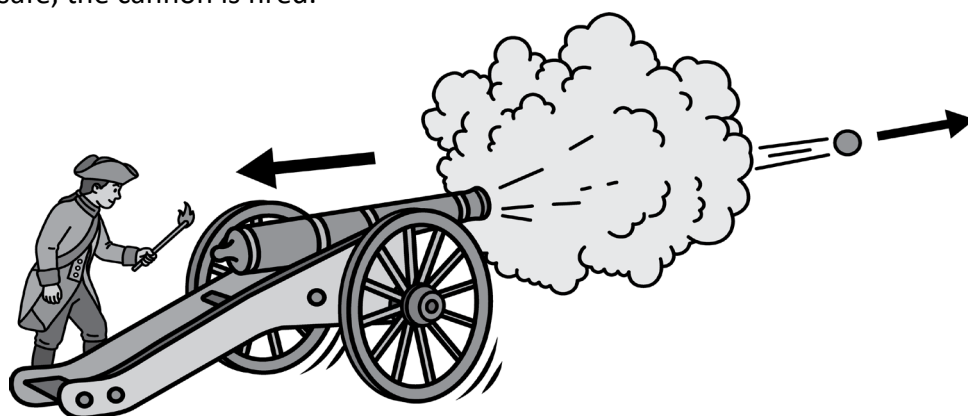


- a) Before it is fired, the cannon and the cannonball are both stationary.

The mass of the cannon is 800 kg and the mass of the cannonball is 5 kg.
State the total momentum of the cannon and cannonball **before** firing.

0 kg m/s	1 mark
	Total: 1 mark

When it is safe, the cannon is fired.



- b) Immediately after firing, the 5 kg cannonball is moving forwards with a velocity of 120 m/s.
Calculate the recoil velocity of the 800 kg cannon.

Total momentum after = total momentum before = 0	1 mark
Momentum of the cannon ball: $p = m \times v$ $p = 5 \times 120$ $p = 600 \text{ kg m/s}$	1 mark
Momentum of the cannon = - 600 kg m/s Making note: it's a minus as it's going in the opposite direction and momentum is a vector quantity so size and direction both come into this 😊	1 mark
Velocity of the cannon: $v = p \div m$ $v = - 600 \div 800$ $v = - 0.75 \text{ m/s}$	1 mark
	Total: 4 marks

- c) The reenactor standing behind the cannon is hit by the recoiling cannon and severely injured.

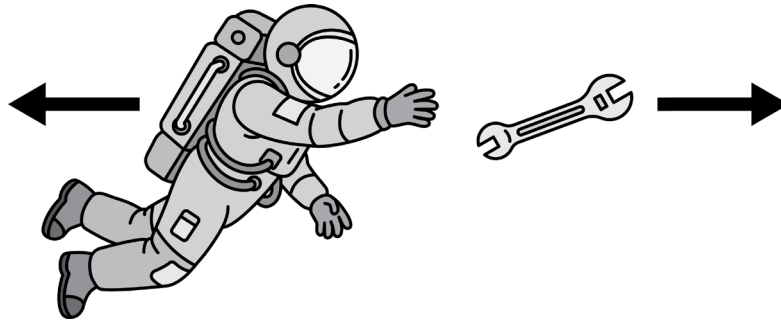
A student suggests that if they had used a much **heavier** cannon, it would have been safer for the reenactor.

Explain, using physics principles, why a heavier cannon would recoil at a lower velocity.

An explanation to include the following:	
The total backward momentum of the cannon ($- 600 \text{ kg m/s}$) is fixed by the cannonball.	1 mark
Because $v = p \div m$, if the mass (m) of the cannon is much larger, its resulting velocity (v) must be much smaller (to produce the same overall momentum).	1 mark
Allow 1 mark for linking a larger mass to a smaller velocity (must reference $p = m \times v$ or state they are inversely proportional).	
	Total: 2 marks

(Total for Question 4 is 7 marks)

5. An astronaut is floating completely stationary outside a space station.



The astronaut has become disconnected from the space station and needs to move back towards the airlock quickly. To do this, the astronaut throws a heavy wrench directly **away** from the airlock.

The astronaut has a mass of 120 kg and the metal wrench has a mass of 4.0 kg.

- a) The astronaut throws the wrench forwards with a velocity of 15 m/s.
Calculate the recoil velocity of the astronaut immediately after the wrench is thrown.
You **must** show your working.

Total momentum after = total momentum before = 0	1 mark
Calculate the momentum of the wrench: $p = m \times v$ $p = 4 \times 15$ $p = 60 \text{ kg m/s}$	1 mark
Momentum of the astronaut = -60 kg m/s	1 mark
Velocity of the cannon: $v = p \div m$ $v = -60 \div 120$ $v = -0.50 \text{ m/s}$	1 mark
	Total: 4 marks

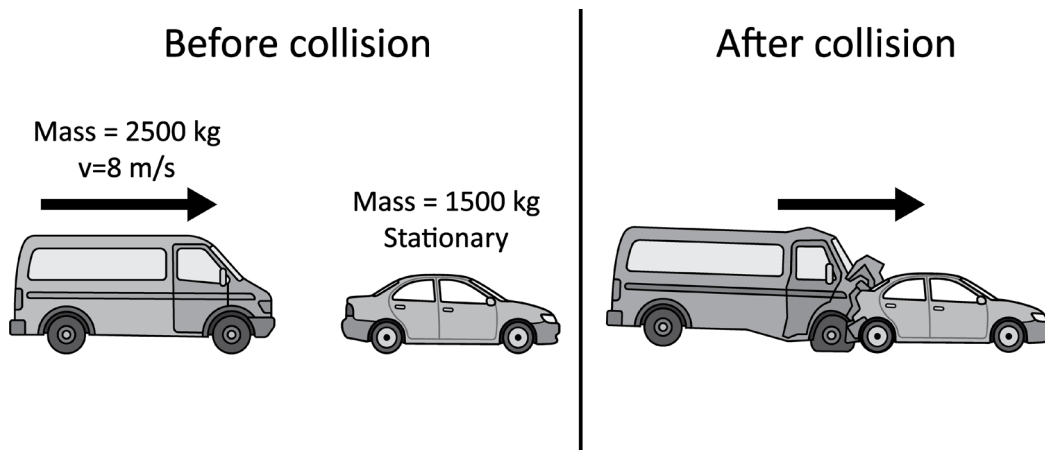
- b) Explain, using the principle of conservation of momentum, why throwing the wrench forwards causes the astronaut to move backwards.

An explanation to include the following:	
The total momentum of the system must be conserved (must remain zero).	1 mark
By throwing the wrench, the wrench gains positive/forward momentum.	1 mark
Therefore, the astronaut must gain an equal amount of backward momentum so that the total combined momentum remains zero.	1 mark
	Total: 3 marks

(Total for Question 5 is 7 marks)

6. A van is moving along a road towards a stationary car.

The figure below shows the van and the car just before and just after they collide.



- a) Calculate the momentum of the van just before the collision.

Show clearly how you work out your answer.

$p = m \times v$	1 mark
$p = 2500 \times 8$	
$p = 20\,000 \text{ kg m/s}$	1 mark
	Total: 2 marks

- b) State the momentum of the car just **before** the collision.

0 kg m/s	1 mark
	Total: 1 mark

- c) During the collision, the van and the car join **together**.

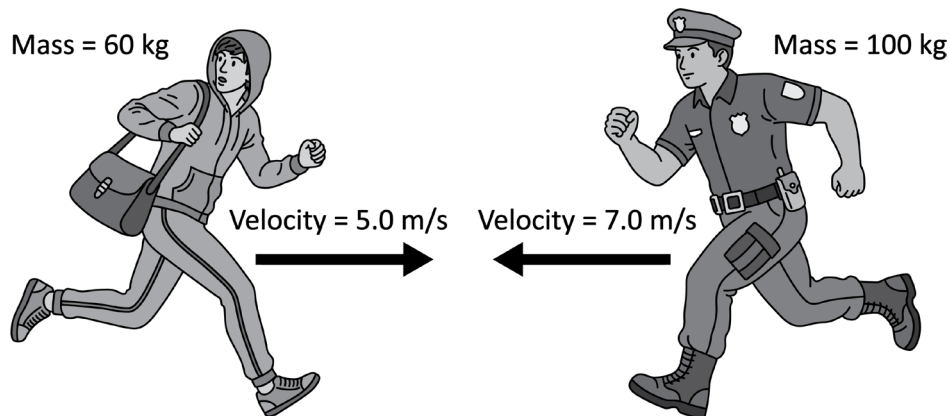
Using the principle of conservation of momentum, calculate the new velocity of the van and car as they move away together. Show clearly how you work out your answer.

Total momentum after = total momentum before = 20 000 kg m/s	1 mark
Calculate the total mass: Combined mass = 2500 + 1500 Combined mass = 4000 (kg)	1 mark
Velocity after the collision: $v = p \div m$ $v = 20\,000 \div 4000$	1 mark
$v = 5 \text{ m/s}$	1 mark
	Total: 4 marks

(Total for Question 6 is 7 marks)

7. A thief is running away from a crime scene.

A heavily built police officer runs directly towards the thief to tackle them.



The thief does not see the police officer approaching.

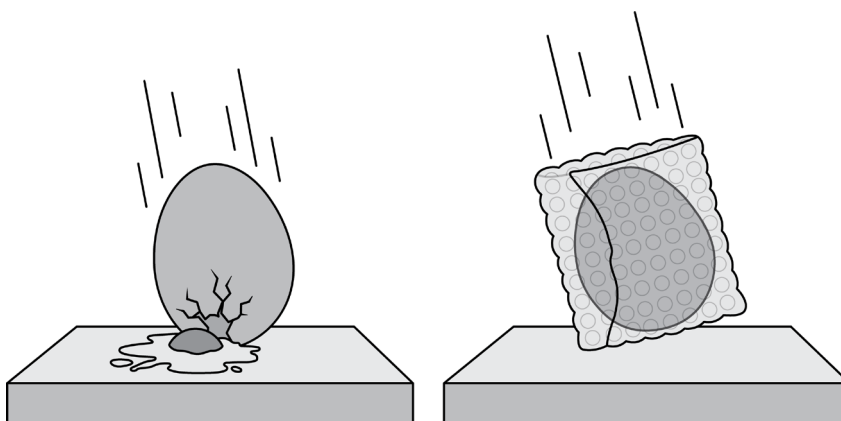
When they collide, the police officer grabs the thief and holds on tightly, meaning they move **together** as one combined mass.

Calculate the new velocity of the police officer and the thief immediately after the collision.

Calculate the momentum of the thief: $p = m \times v$ $p = 60 \times 5$ $p = 300 \text{ kg m/s}$	1 mark
Calculate the momentum of the police officer: $p = m \times v$ $p = 100 \times 7$ $p = 700 \text{ kg m/s}$	1 mark
Total momentum: $P = 300 + (-700) = -400 \text{ kg m/s}$	1 mark
Calculate combined mass: $\text{Mass} = 100 + 60 = 160 \text{ kg}$	1 mark
Calculate final velocity: $v = p \div m$ $v = -400 \div 160$ $\text{velocity} = -2.5 \text{ (m/s)}$	1 mark
State the direction: The answer is negative, therefore they move in the direction the officer was running (left).	1 mark
	Total: 6 marks

(Total for Question 7 is 6 marks)

8. A student is doing an experiment where they drop some fragile objects onto a concrete floor.



The student drops a plain egg, which shatters when it hits the floor.

They then wrap an identical egg in a thick layer of bubble wrap and drop it from the exact same height. This egg bounces and survives.

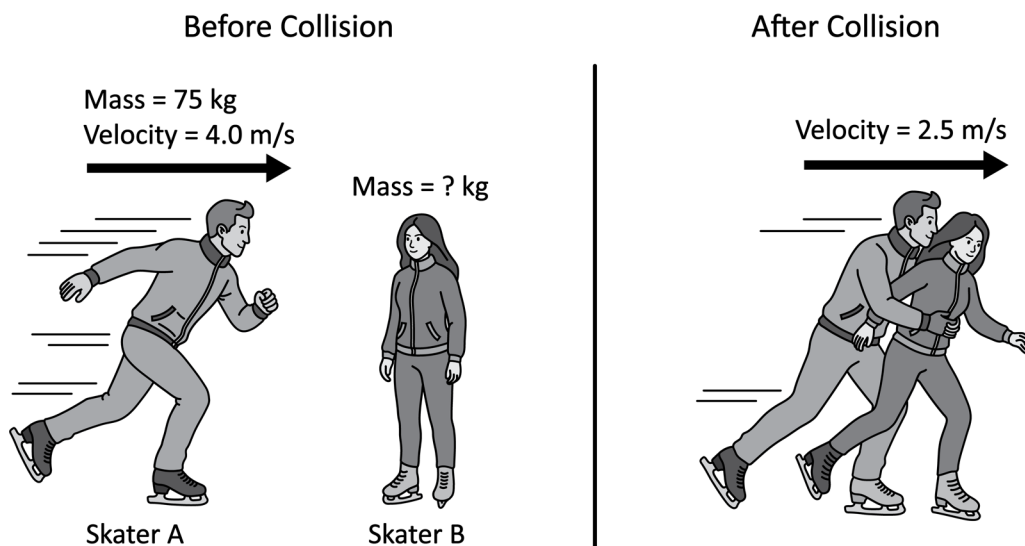
Both eggs have the exact same mass and hit the floor at the exact same velocity.

Explain how the bubble wrap reduces the impact force experienced by the egg.

An explanation to include the following:	
The feature (in this case bubble wrap) increases the time taken to stop (during the collision).	1 mark
So, the rate of change of momentum decreases.	1 mark
Because $\text{Force} = \text{change in momentum} \div \text{time}$ ($F = \Delta p \div t$)	1 mark
Reducing the force that is experienced by the object.	1 mark
	Total: 4 marks

(Total for Question 8 is 4 marks)

9. Two ice skaters are on a frozen lake.



Skater A has a mass of 75 kg and is gliding forwards at a velocity of 4.0 m/s. Skater B is stationary.

Skater A collides with skater B and grabs hold of them. The two skaters slide forwards **together** at a new velocity of 2.5 m/s.

Using the principle of conservation of momentum, calculate the **mass** of skater B.
You **must** show all of your working.

Calculate the momentum of skater A: $p = m \times v$ $p = 75 \times 4$ $p = 300 \text{ kg m/s}$	1 mark
State the momentum of skater B: 0 kg m/s	1 mark
Total before = total after	
Total after = combined mass $\times$ final velocity	1 mark
Let's use some algebra 😊 $300 = (75 + m) \times 2.5$ $300 = 187.5 + 2.5m$ $2.5m = 300 - 187.5$ $2.5m = 112.5$ $m = 112.5 \div 2.5$ $m = 45 \text{ kg}$	1 mark 1 mark 1 mark
	Total: 6 marks

(Total for Question 9 is 6 marks)