Conservation of momentum

4.5.7.2 · Forces · revision notes

In a closed system, the total momentum before an event equals the total momentum after it. This is Higher tier content. You need to use conservation of momentum to calculate velocities after collisions and explosions, and to explain events such as recoil.

Key facts

- Closed system: total momentum before = total momentum after
- Objects stick together: $m_1u_1 + m_2u_2 = (m_1 + m_2)v$
- Recoil: parts move in opposite directions with equal-sized momentum
- $p = m v$ for each object; add them, using signs for direction
- Explosion from rest: total momentum = 0 before and after
- The heavier part moves more slowly

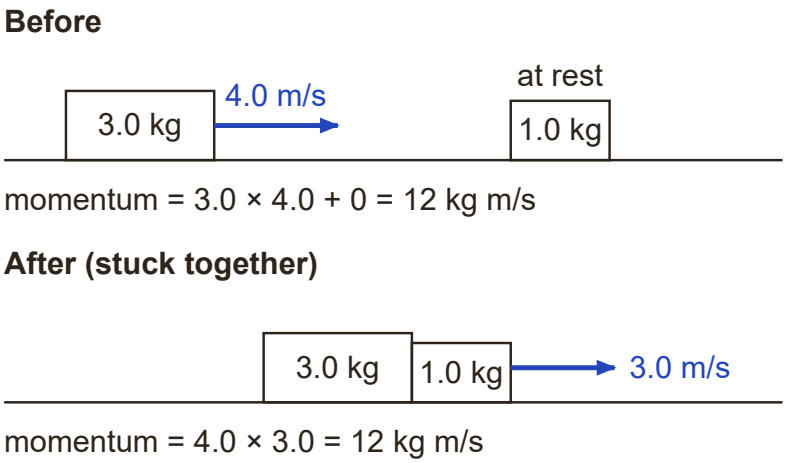
Notes

The law

- In a **closed system**, the total momentum before an event is equal to the total momentum after the event. This is called **conservation of momentum**.
- A closed system is one on which no external forces act.
- Events include collisions (objects hit each other and bounce apart or stick together) and explosions (objects that start together push apart).

Collisions

- Total momentum before = total momentum after: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$.
- In a collision, the momentum one object gains equals the momentum the other loses. So when a moving object hits a stationary one, the moving object slows down and the other speeds up.
- If the objects stick together, they move off with the same velocity: $m_1u_1 + m_2u_2 = (m_1 + m_2)\,v$.
- Example: a 3.0 kg trolley moving at 4.0 m/s hits a stationary 1.0 kg trolley and they stick together. 3.0 × 4.0 = (3.0 + 1.0) × v, so v = 3.0 m/s.

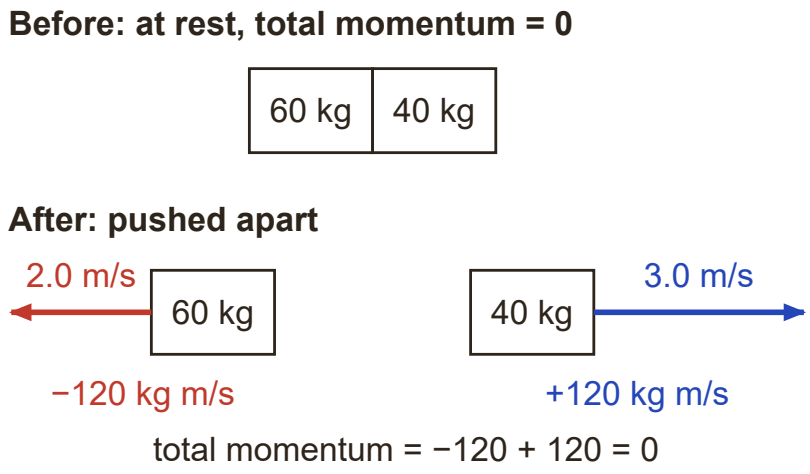


Total momentum before = total momentum after = 12 kg m/s.

- For objects moving towards each other, give one direction + and the other −.
- In the lab, measure trolley velocities before and after a collision with light gates, a data logger or a ticker timer, then compare the total momentum before and after.

Explosions and recoil

- If everything is at rest before an explosion, the total momentum is zero.
- Afterwards the total momentum must still be zero, so the parts move in opposite directions with momentum of equal size.
- Example: when a gun fires a bullet forwards, the gun recoils backwards. The gun moves much more slowly because its mass is much larger.
- Example: a 60 kg skater and a 40 kg skater push apart from rest. If the 40 kg skater moves at 3.0 m/s, the 60 kg skater moves at 40 × 3.0 ÷ 60 = 2.0 m/s in the opposite direction.



An explosion or push-apart: the momenta are equal and opposite, so the total stays zero.

How to answer each type of question

State the law of conservation of momentum 2 marks **Grade 6**

1. Say 'in a closed system'.
2. Say 'total momentum before = total momentum after' (the event).

Example. State the law of conservation of momentum.

Model answer.

In a closed system (1)

the total momentum before an event is equal to the total momentum after the event (1).

Collision in which the objects join

4 marks | Grade 7

1. Calculate the total momentum before.
2. State that the momentum after is the same.
3. Divide by the combined mass to find the velocity.

Example. A railway wagon of mass 8000 kg moves at 3.0 m/s and collides with a stationary wagon of mass 4000 kg. The wagons couple together.
Calculate their velocity just after the collision.

Model answer.

momentum before = 8000 × 3.0 = 24 000 kg m/s	(1)
momentum after = 24 000 kg m/s (momentum is conserved)	(1)
24 000 = (8000 + 4000) × v	(1)
v = 2.0 m/s	(1)

Explosion or recoil calculation

4 marks | Grade 7

1. State that the total momentum before is zero.
2. Calculate the momentum of the part you know.
3. The other part has equal momentum in the opposite direction: divide by its mass.

Example. A cannon of mass 900 kg fires a cannonball of mass 6.0 kg forwards at 150 m/s. Both are at rest before firing.
Calculate the recoil velocity of the cannon.

Model answer.

total momentum before = 0	(1)
momentum of cannonball = 6.0 × 150 = 900 kg m/s forwards	(1)
cannon's momentum = 900 kg m/s backwards, so v = 900 ÷ 900	(1)
v = 1.0 m/s backwards	(1)

Explain an event using momentum

3 marks | Grade 7

1. Give the total momentum before the event.
2. Say that momentum is conserved.
3. Explain what this means for the objects afterwards.

Example. An astronaut is floating at rest in space. She throws a tool away from her. Explain why she moves in the opposite direction.

Model answer.

The total momentum before the throw is zero (1).

Momentum is conserved, so the total momentum after the throw is also zero (1).

The tool has momentum in one direction, so the astronaut must have momentum of equal size in the opposite direction (1).

Collision with objects moving in opposite directions

4 marks | Grade 8

1. Choose a positive direction and give each velocity a sign.
2. Add the momenta to find the total.
3. Divide by the combined mass; the sign of the answer gives the direction.

Example. Trolley A (mass 2.0 kg) moves to the right at 3.0 m/s. Trolley B (mass 1.0 kg) moves to the left at 4.0 m/s. They collide and stick together. Calculate their velocity after the collision.

Model answer.

taking right as positive: p of A = +6.0 kg m/s; p of B = 1.0 × (−4.0) = −4.0 kg m/s (1)

total momentum = +2.0 kg m/s (1)

2.0 = (2.0 + 1.0) × v (1)

v = +0.67 m/s, i.e. 0.67 m/s to the right (1)

Don’t lose marks

- Forgetting to add the masses when the objects stick together.
- Ignoring direction for objects moving towards each other (not using a negative sign).
- Using kinetic energy instead of momentum to find the velocities after a collision.
- Leaving the direction out of the final answer.

More tips

Memory tricks

- Before = After. Writing 'total momentum before = total momentum after' first often earns a mark on its own.
- Stuck together? Add the masses on the 'after' side.
- Started at rest? The total momentum is zero, so afterwards the momenta are equal and opposite.
- Sense check: if a moving object hits and sticks to a stationary one, the pair must move more slowly than the moving object did.

Exam technique

- Draw a quick before-and-after sketch with the masses, the velocities and your positive direction.
- Give the final velocity with a direction, or say what the sign means.
- In 'explain' questions, mention the closed system, 'total momentum before = total momentum after', and equal and opposite momentum where relevant.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 6 — **State the law of conservation of momentum**
In a closed system, the total momentum before an event equals the total momentum after it.

Grade 6 — **Calculate the total momentum of a system**
Add the momentum of each object, taking direction into account.

Grade 7 — **Calculate the velocity after objects join**
Total momentum before = $(m_1 + m_2) \times v$ after.

Grade 7 — **Explain explosions and recoil using momentum**
The total momentum is zero before, so the parts move apart with equal and opposite momentum.

Grade 7 — **Explain what a closed system is**
No external forces act on the system, so its total momentum cannot change.

Grade 8 — **Solve collisions with objects moving in opposite directions**
Use + and − for direction; the sign of the answer gives the direction of motion.

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