

1.4 Momentum and its conservation

Name: _____ Class: _____ Date: _____

Total: 20 marks

KEY WORDS momentum • conservation • external force
• isolated system

Objective

Build the skills to answer WPH11 questions on **momentum** : calculate $p = mv$ with signs, apply conservation of linear momentum in one dimension, and link the principle to Newton's laws. This sheet covers Unit 1 statements 13–14.

You must be able to:

- calculate momentum as $p = mv$, with a unit of kg m s^{-1} and a direction
- state the principle of conservation of linear momentum and its condition (no external force)
- solve one-dimensional collisions and explosions, with a sign convention
- explain how conservation of momentum follows from Newton's second and third laws
- evaluate a prediction by computing the total momentum

1 Key knowledge and worked examples

■ Momentum is a vector

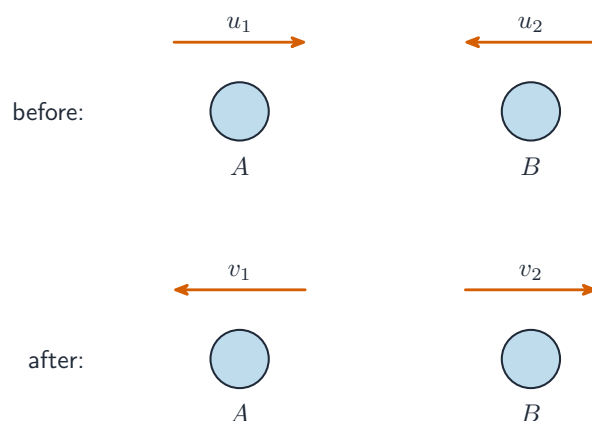
Momentum $p = mv$: mass times velocity, unit kg m s^{-1} . Because velocity has a direction, momentum has a direction. In one dimension, choose a positive direction and give every velocity a sign before you add.

■ The principle of conservation of linear momentum

When no **external** force acts on a system, the total momentum before an event equals the total momentum after it:

$$p_{\text{before}} = p_{\text{after}}$$

- The forces **between** the bodies are internal; they redistribute momentum but cannot change the total.
- Momentum is conserved in **every** collision and explosion in an isolated system – even when kinetic energy is not.



■ Why it holds: Newton's laws

During the collision, A exerts a force on B and B exerts an equal and opposite force on A (third law), for the **same** contact time. Equal and opposite forces for equal times give equal and opposite changes of momentum – so the total is unchanged. Conservation of momentum is Newton's laws wearing a shorter name.

■ Worked example 1: a head-on sticking collision

A trolley of mass 1.5 kg moving at 0.40 m s^{-1} to the right meets a stationary trolley of mass 0.50 kg; they stick together. Find their common velocity.

- Known: masses, velocities, stuck together after. Why: no external horizontal force, so conserve momentum along the track (right positive).

$$p_{\text{before}} = p_{\text{after}}$$

$$1.5 \text{ kg} \times 0.40 \text{ m s}^{-1} + 0.50 \text{ kg} \times 0 = (1.5 \text{ kg} + 0.50 \text{ kg}) V$$

$$V = \frac{0.60 \text{ kg m s}^{-1}}{2.0 \text{ kg}} = 0.30 \text{ m s}^{-1}$$

- Check: between 0 and 0.40 m s^{-1} , in the original direction – sensible for sticking.

■ Worked example 2: evaluate a prediction

Glider A (0.15 kg) moves right at 0.32 m s^{-1} ; glider B (0.20 kg) moves left at 0.11 m s^{-1} . They collide and stick. A student predicts they move left. Is the prediction correct?

- Known: masses and velocities in opposite directions. Why: the direction of the stuck pair is the sign of the total momentum. Right positive.

$$p_{\text{before}} = 0.15 \text{ kg} \times 0.32 \text{ m s}^{-1} - 0.20 \text{ kg} \times 0.11 \text{ m s}^{-1}$$

$$p_{\text{before}} = 0.048 \text{ kg m s}^{-1} - 0.022 \text{ kg m s}^{-1} = +0.026 \text{ kg m s}^{-1}$$

- The total momentum is positive (to the right), so the pair moves **right** – the prediction is **not** correct. The conclusion must follow from the computed momentum, not from a guess.

2 Practice

2.1 Calculate the momentum of a 1200 kg car moving at 18 m s^{-1} . [1]

2.2 A 60 kg skater at rest pushes a 3.0 kg ball away at 4.0 m s^{-1} . Calculate the skater's recoil velocity. [2]

2.3 State the condition needed for the total momentum of a system to be conserved in a collision. [1]

2.4 A 2.0 kg trolley at 1.5 m s^{-1} catches up with a 1.0 kg trolley at 0.50 m s^{-1} moving the same way. They couple. Calculate their common velocity. [3]

3 Exam-style questions

3.1 A truck of mass $2m$ moving at speed v meets a car of mass m moving at speed v in the opposite direction. They collide and move off together. Which expression gives their common speed? [1]

- ☐ **A** $\frac{v}{3}$
B $\frac{v}{2}$
C v
D $\frac{2v}{3}$

3.2 In which situation is the total momentum of the two trolleys conserved? [1]

☐

- A** a trolley rolling to a stop on a rough track
- B** two trolleys colliding on a frictionless air track
- C** a trolley accelerating down a sloped track
- D** a trolley pulled by a falling mass

3.3 On an air track, glider P (mass 0.25 kg) moves at 0.20 m s^{-1} towards glider Q (mass 0.15 kg), which moves towards P at 0.40 m s^{-1} . The gliders collide and move apart after the collision.

(a) Explain how Newton's third law applies to the gliders during the collision. [1]

(b) The collision separates the gliders. State what is conserved in the collision and the condition for it. [2]

(c) After the collision, P moves back at 0.10 m s^{-1} . Calculate the velocity of Q after the collision. [3]

3.4 In a Newton's cradle, sphere A is pulled aside and released. A strikes the resting row and stops; sphere E leaves the other end.

(a) State what happens to the total momentum of the five spheres during the collision, with a reason. [2]

(b) Explain, using conservation of momentum and of energy, why the collision sends out **one** sphere rather than two spheres at lower speed. [*Assume the collision conserves kinetic energy.*] [3]

Solutions

2.1 $p = mv = 1200 \text{ kg} \times 18 \text{ m s}^{-1} = 2.2 \times 10^4 \text{ kg m s}^{-1}$.

2.2 The system starts at rest, so $0 = m_{\text{skater}}v_{\text{skater}} + m_{\text{ball}}v_{\text{ball}}$: $v_{\text{skater}} = -\frac{3.0 \text{ kg} \times 4.0 \text{ m s}^{-1}}{60 \text{ kg}} = -0.20 \text{ m s}^{-1} = 0.20 \text{ m s}^{-1}$ backwards.

2.3 No external force acts on the system (the system is isolated).

2.4 $p_{\text{before}} = p_{\text{after}}$: $2.0 \times 1.5 + 1.0 \times 0.50 = 3.0 V$, so $V = \frac{3.5 \text{ kg m s}^{-1}}{3.0 \text{ kg}} = 1.2 \text{ m s}^{-1}$ forwards.

3.1 A. Take the truck's direction as positive: $2mv - mv = 3mV$, so $V = \frac{v}{3}$. B forgets the mass ratio; C keeps the speed unchanged; D adds the momenta wrongly.

3.2 B. Only on the frictionless track is there no external horizontal force on the pair. A, C and D each have an external force (friction, a component of weight, the falling mass's pull).

3.3 (a) P exerts a force on Q and Q exerts an equal and opposite force on P. (b) Total momentum, because no external force acts on the two gliders. (c) Right positive, P's initial direction: $0.25 \times 0.20 + 0.15 \times (-0.40) = 0.25 \times (-0.10) + 0.15 v_Q$: $0.050 - 0.060 = -0.025 + 0.15 v_Q$, so $v_Q = \frac{0.015}{0.15} = 0.10 \text{ m s}^{-1}$ to the right.

3.4 (a) It is conserved: the forces between the spheres are internal to the system, and no external horizontal force acts. (b) Momentum conservation requires the outgoing momentum to equal A's incoming momentum. Kinetic energy conservation then requires $\frac{1}{2}mv^2$ to match as well; two equal spheres at half the speed would conserve momentum but carry only half the kinetic energy, so the only solution satisfying both is one sphere leaving at (almost) the same speed.