

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

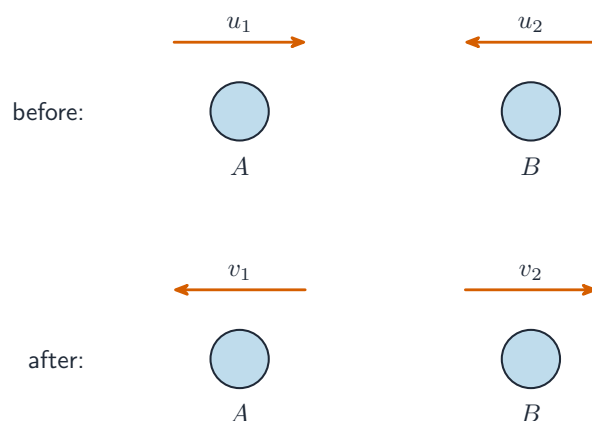
Momentum $p = mv$: mass times velocity, unit kg m s^{-1} . Because velocity has a direction, momentum has a direction. In one dimension, choose a positive direction and give every velocity a sign before you add.

■ 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]
