

5.9 Momentum

Name: _____ Class: _____ Date: _____

Total: 26 marks

KEY WORDS force

Objective

Calculate momentum, apply conservation in collisions, and use $F = m\Delta v/\Delta t$ to explain safety features. Higher Tier; collision calculations and changes in momentum are physics only. Original questions for spec statements 4.5.7.1–4.5.7.3.

1 Key knowledge and worked examples

$$p = mv \quad F = \frac{m\Delta v}{\Delta t}$$

- Momentum p in kg m/s – a **vector** (direction matters).
- $F = m\Delta v/\Delta t$: force = **rate of change of momentum** (this is $F = ma$ written in changes).
- **Conservation**: in a **closed system**, total momentum before = total momentum after an event such as a collision.

Collision bookkeeping (physics only calculations):

1. write the momenta before, keeping signs for directions;
2. set total before = total after;
3. solve for the unknown mass or velocity.

Worked example. A 900 kg car at 12 m/s collides with a stationary 600 kg car; they lock together.

- Before: $900 \times 12 + 600 \times 0 = 10\,800$ kg m/s.
- After: combined mass 1500 kg at v : $1500v = 10\,800$ so $v = 7.2$ m/s.

Safety features all work the **same way** – they increase Δt :

Feature	How
air bag	inflates, squashes – slows you over more time
seat belt	stretches, extends the stopping time
crumple zone	folds, extending the collision time
crash mat / helmet / cushioned surface	deforms, lengthening the impact

So for the same momentum change $m\Delta v$, a bigger Δt gives a **smaller force**.

Worked example. A 1000 kg car at 20 m/s stops in 0.25 s: $F = 20\,000/0.25 = 80\,000$ N. With a crumple zone ($t = 0.50$ s): $F = 40\,000$ N – halved.

2 Practice

2.1 Calculate the momentum of a 60 kg runner at 8.0 m/s. [2]

2.2 State the conservation of momentum rule for a closed system. [1]

2.3 Explain how a cycle helmet protects the head, using $F = m\Delta v/\Delta t$. [3]

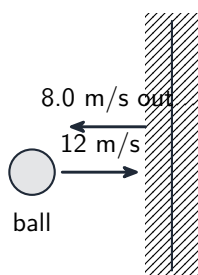
3 Exam-style questions

3.1 Two trolleys collide and stick. A: 2.0 kg at 3.0 m/s right; B: 1.0 kg at rest.

- (a) Calculate the total momentum before the collision. [2]
 - (b) Calculate their common velocity after. [2]
 - (c) State one assumption. [1]
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3.2 A 0.16 kg ball hits a wall at 12 m/s and rebounds at 8.0 m/s; contact lasts 0.020 s.

- (a) Calculate the change of momentum, taking right as positive (in at +12, out at -8). [3]
- (b) Calculate the mean force on the ball. [2]
- (c) State the size and direction of the mean force on the wall. [2]



3.3 In a crash test a 1200 kg car at 15 m/s is stopped in 0.12 s without a crumple zone and 0.30 s with one.

- (a) Calculate the magnitude of the momentum change. [2]
- (b) Calculate both mean force magnitudes. [3]
- (c) Explain, using the numbers, why the crumple zone reduces injury, and name the physics store that takes the energy. [3]

Solutions

2.1 $p = mv = 60 \times 8.0 = \mathbf{480}$ kg m/s (C1, A1).

2.2 In a closed system the total momentum before an event equals the total momentum after it.

2.3 The helmet's foam deforms, increasing the time over which the head's momentum changes; in $F = m\Delta v/\Delta t$ the same $m\Delta v$ over a longer Δt gives a smaller force on the head.

3.1 (a) $p = 2.0 \times 3.0 + 1.0 \times 0 = \mathbf{6.0}$ kg m/s (right) (C1, A1). (b) $3.0v = 6.0$ so $v = \mathbf{2.0}$ m/s right (C1, A1). (c) Closed system – no external horizontal forces (or friction negligible).

3.2 (a) Change $= m(v_{after} - v_{before}) = 0.16 \times (-8.0 - 12) = 0.16 \times (-20) = \mathbf{-3.2}$ kg m/s (sign convention C1, substitution C1, answer A1). (b) $F = \Delta p/\Delta t = -3.2/0.020 = \mathbf{-160}$ N – 160 N on the ball, to the left (C1, A1). (c) By the third law the wall feels an **equal and opposite** force: 160 N to the right.

3.3 (a) $\Delta p = m\Delta v = 1200 \times 15 = \mathbf{18\,000}$ kg m/s (C1, A1). (b) Without: $F = 18\,000/0.12 = \mathbf{150\,000}$ N (C1); with: $F = 18\,000/0.30 = \mathbf{60\,000}$ N. (c) The same momentum change spread over more than double the time cuts the force by 60 % (C1 for the comparison), a smaller mean force reduces the risk of injury, without guaranteeing that the impact is safe; the kinetic store of the car empties into internal energy of the deforming materials and surroundings; some energy is transferred by sound.