

3.1 Momentum and Newton's laws of motion

Name: _____ Class: _____ Date: _____

Total: 32 marks

KEY WORDS force 力 • mass 质量 • acceleration 加速度 • resultant force 合力 • weight 重力

Objective

Build the skills to answer exam questions on **momentum and Newton's laws** — $F = ma$, momentum, impulse, and the three laws.

You must be able to:

- recall and use $F = ma$ and **weight** $= mg$
- use **linear momentum** $p = mv$ and force as **rate of change of momentum**, $F = \Delta p / \Delta t$
- state and apply **Newton's three laws**
- read a **momentum–time graph**: the change, the gradient, and what the motion is doing

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

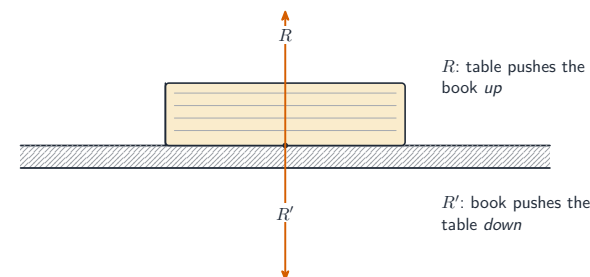
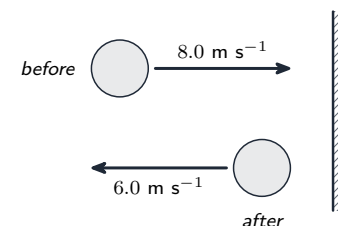
■ Newton's laws and $F = ma$

- 1st law:** with **zero resultant force**, an object stays at rest or moves at constant velocity.
- 2nd law:** resultant force = rate of change of momentum; for constant mass, $F = ma$.
- 3rd law:** if A pushes B, B pushes A with an **equal, opposite force** (a different object, same type).

Weight is the effect of a **gravitational field** 引力场 on a mass: $W = mg$, where g is both the **gravitational field strength** (N kg^{-1}) and the **acceleration of free fall** (m s^{-2}) — the same number, 9.81 near the Earth's surface, because a mass in free fall has only its weight acting on it, so $mg = ma$ gives $a = g$. **Mass** is the property that resists a change in motion (in kg) and is the **same everywhere**; **weight** is a force and **changes** with the field — an object weighs less on the Moon (smaller g) even though its mass is unchanged.

■ Momentum and impulse

Linear momentum $p = mv$ (a vector, unit $\text{kg m s}^{-1} = \text{N s}$). In a collision the average force is $F = \frac{\Delta p}{\Delta t}$ — assign each direction a sign.



Newton third-law force pairs

Worked example. A 0.20 kg ball hits a wall at 8.0 m s^{-1} and rebounds at 6.0 m s^{-1} in 0.050 s. Take the rebound direction as positive ($u = -8.0$, $v = +6.0$):

$$\Delta p = m(v - u) = 0.20(6.0 - (-8.0)) = 2.8 \text{ kg m s}^{-1}, \quad F = \frac{2.8}{0.050} = 56 \text{ N}.$$

■ Reading a momentum–time graph

Because $F = \frac{\Delta p}{\Delta t}$, the **gradient of a momentum–time graph is the resultant force**. Read one off in four steps:

- A straight line means a constant resultant force.** A curve means the force is changing.
- The gradient is the force** — take it over the whole line, not from a single point.
- Divide by the mass to get the velocity** at any instant: $v = p/m$.
- Where the line crosses $p = 0$ the object is momentarily at rest**, and after that it is moving the other way.

A resistive force such as air resistance **cannot** give a straight line: it gets smaller as the object slows, and it is **zero** when the object is at rest — so a graph whose gradient is unchanged at the crossing point rules it out.

2 Practice

Now apply the methods above.

2.1 State **Newton's first law** of motion. [1]

2.2 Calculate the **momentum** of a 1500 kg car travelling at 20 m s^{-1} . [2]

2.3 A resultant force of 5.0 N acts on a 2.0 kg mass. Find its **acceleration**. [2]

2.4 Calculate the **weight** of a 60 kg person ($g = 9.81 \text{ m s}^{-2}$). [1]

3 Exam-style questions

3.1 The unit kg m s^{-1} is the unit of which quantity? [1]

- A force
- B momentum
- C energy
- D power

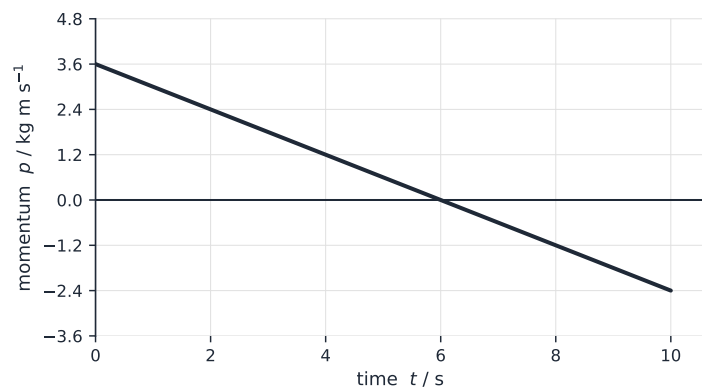
3.2 State **Newton's third law**, and give **one** example of a force pair. [2]

3.3 A 0.20 kg ball hits a wall at 8.0 m s^{-1} and rebounds straight back at 6.0 m s^{-1} . The contact lasts 0.050 s. **Show that** the magnitude of the average force on the ball is about 56 N. [4]

3.4 Using Newton's second law, explain why a **longer** contact time gives a **smaller** average force for the same change in momentum. [2]

3.5 An object is taken from the Earth to the Moon, where g is smaller. State what happens to its **mass** and to its **weight**. [2]

3.6 A trolley of mass 1.2 kg moves in a straight line along a horizontal track. The graph shows how the momentum p of the trolley varies with time t .



(a) **Define** momentum. [1]

(b) **Determine** the speed of the trolley at time $t = 0$. [2]

(c) Calculate the change in momentum of the trolley between $t = 0$ and $t = 10$ s. [1]

(d) **Determine** the magnitude of the resultant force acting on the trolley. [2]

(e) **Describe** the motion of the trolley between $t = 0$ and $t = 6.0$ s. [2]

(f) By reference to the graph, **explain** why the resultant force acting on the trolley cannot be air resistance. [2]

(g) At time $t = 0$ the displacement of the trolley is zero. In the space below, **sketch** the variation with time of its displacement from $t = 0$ to $t = 10$ s. Numerical values are not required, but **label** both axes. [3]

(h) **Compare** the momentum of the trolley at $t = 2.0$ s with its momentum at $t = 8.0$ s. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- Newton's first law: an object stays at **rest** or moves at **constant velocity** unless a **resultant (external) force** acts on it

2.2

- $p = mv$

$$p = (1500 \text{ kg})(20 \text{ m s}^{-1}) = \mathbf{3.0 \times 10^4 \text{ kg m s}^{-1}}$$

2.3

- $F = ma \Rightarrow a = F/m$

$$a = \frac{5.0 \text{ N}}{2.0 \text{ kg}} = \mathbf{2.5 \text{ m s}^{-2}}$$

2.4

- weight $W = mg$

$$W = (60 \text{ kg})(9.81 \text{ m s}^{-2}) = \mathbf{590 \text{ N}}$$

3.1 B

- kg m s^{-1} is mass $\times$ velocity, which is **momentum** $p = mv$
- A** force is kg m s^{-2} (rate of change of momentum)
- C** energy is $\text{kg m}^2 \text{s}^{-2}$; **D** power is one more s^{-1}

3.2

- Newton's third law: when A exerts a force on B, B exerts an **equal and opposite** force on A (same type, different bodies)
- example: a rocket pushes gas down, the gas pushes the rocket up (or foot / ground)

3.3

- take rebound as positive: $u = -8.0 \text{ m s}^{-1}$, $v = +6.0 \text{ m s}^{-1}$

$$\Delta p = m(v - u) = (0.20 \text{ kg})(6.0 \text{ m s}^{-1} - (-8.0 \text{ m s}^{-1})) = 2.8 \text{ kg m s}^{-1}$$

$$F = \frac{\Delta p}{\Delta t} = \frac{2.8 \text{ kg m s}^{-1}}{0.050 \text{ s}} = \mathbf{56 \text{ N}}$$

3.4

- $F = \Delta p / \Delta t$
- for the same Δp , a larger contact time Δt gives a **smaller** F

3.5

- mass stays the same**
- weight decreases**, because g is smaller on the Moon

3.6

- (a) momentum is the **product of mass and velocity**

- (b) $v = p/m$

$$v = \frac{3.6 \text{ kg m s}^{-1}}{1.2 \text{ kg}} = \mathbf{3.0 \text{ m s}^{-1}}$$

- (c) $\Delta p = (-2.4 \text{ kg m s}^{-1}) - (+3.6 \text{ kg m s}^{-1}) = -6.0 \text{ kg m s}^{-1}$

- change of magnitude **6.0** kg m s^{-1}

- (d) $F = \Delta p / \Delta t$ = gradient of the p - t graph

$$F = \frac{6.0 \text{ kg m s}^{-1}}{10 \text{ s}} = \mathbf{0.60 \text{ N}}$$

- (e) the trolley slows **uniformly** (straight line $\Rightarrow$ constant force)

- it is momentarily at rest at $t = 6.0 \text{ s}$

- (f) the line is **straight**, so the resultant force is constant; air resistance would get **smaller** as it slows

- at $t = 6.0 \text{ s}$ the trolley is at rest, so air resistance would be **zero**, yet the gradient is unchanged

- (g)

- axes labelled displacement and time / s
- from the origin the line rises with a **decreasing** positive gradient, maximum at $t = 6.0 \text{ s}$
- after 6.0 s displacement **falls** (gradient of increasing magnitude) but is still positive at $t = 10 \text{ s}$

- (h) at $t = 2.0 \text{ s}$, $p = +2.4 \text{ kg m s}^{-1}$; at $t = 8.0 \text{ s}$, $p = -1.2 \text{ kg m s}^{-1}$

- the magnitude has halved **and** the **direction has reversed** — momentum is a vector