Week 5

A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

A-Level Physics Name: ____________ Score: ______

1. A 2.0 kg ball moves at 3.0 $\frac{m}{s}$. What is its momentum?

   ____________ $kg \cdot m/s$

2. Which best describes a drag (viscous) force?
   - ☐ a resistive force from a fluid on a moving object
   - ☐ a force that speeds an object up
   - ☐ a force only ever between two solids
   - ☐ another name for the weight

3. Total momentum stays constant when the resultant ______ force on the system is zero.

   ____

4. Momentum is a vector.

   ☐ True ☐ False

5. The drag force on a falling object grows as its speed grows.

   ☐ True ☐ False

6. In an inelastic collision, momentum is still conserved.

   ☐ True ☐ False

7. In its general form, Newton's second law says the resultant force equals the:
   - ☐ mass times the velocity
   - ☐ rate of change of momentum
   - ☐ mass times the distance
   - ☐ momentum times the time

8. At terminal velocity, the drag force is equal to the ______.

   ____

9. Compared with collisions in general, what is special about an **elastic** collision?
   - ☐ Kinetic energy is also conserved
   - ☐ Momentum is conserved
   - ☐ The objects always stick together
   - ☐ No forces act during it

10. Catching an egg with soft hands makes the contact time longer, which makes the average force ______.

____

A-Level Physics

1. **6 kg · m/s**

   $p = mv = 2.0 \times 3.0 = 6.0\ \frac{\mathrm{kg \cdot m}}{\mathrm{s}}$.

2. **a resistive force from a fluid on a moving object**

   Drag is the resistance a fluid (liquid or gas) exerts on something moving through it. Friction is the solid-on-solid case.

3. **external**

   With no resultant *external* force, the system's total momentum is conserved (internal forces come in third-law pairs and cancel).

4. **True**

   Yes — $p = mv$ points the same way as the velocity, so it has a direction.

5. **True**

   Yes — at rest the drag is zero, and it increases with speed. That is what eventually balances the weight.

6. **True**

   Momentum is conserved in **every** collision (no external force). In an inelastic one it is the *kinetic energy* that is not conserved.

7. **rate of change of momentum**

   $F = \frac{\Delta p}{\Delta t}$ — the rate of change of momentum. For constant mass this is $F = ma$.

8. **weight**

   Drag = weight, so the resultant force is zero and the speed stays constant.

9. **Kinetic energy is also conserved**

   All collisions conserve momentum; an elastic collision *also* conserves kinetic energy.

10. **smaller**

    Same change in momentum over a longer time means a smaller force: $F = \frac{\Delta p}{\Delta t}$.

A-LEVEL PHYSICS • EXERCISE SHEET

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.

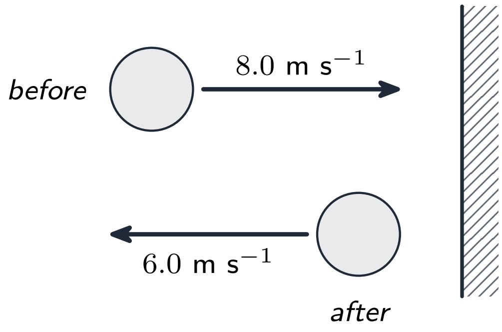
■ Newton's laws and F = ma

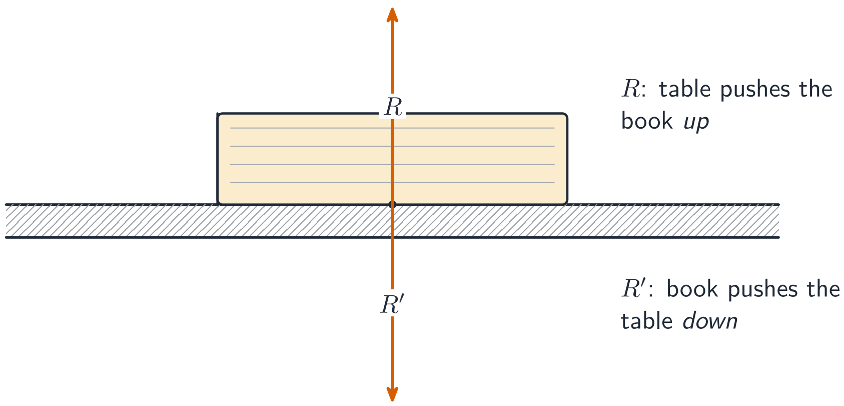
- **1st law:** with **zero resultant force**, an object stays at rest or moves at constant velocity.
- **2nd law:** resultant force = rate of change of momentum; for constant mass, $F = ma$.
- **3rd law:** if A pushes B, B pushes A with an **equal, opposite** force (a different object, same type).

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 kg m s^{-1} = N s). In a collision the average force is $F = \dfrac{\Delta p}{\Delta t}$ — 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 $F = \dfrac{\Delta p}{\Delta t}$, the **gradient of a momentum–time graph is the resultant force**. Read one off in four steps:

1. **A straight line means a constant resultant force.** A curve means the force is changing.
2. **The gradient is the force** — take it over the whole line, not from a single point.
3. **Divide by the mass to get the velocity** at any instant: $v = p/m$.
4. **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 ($g = 9.81$ 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

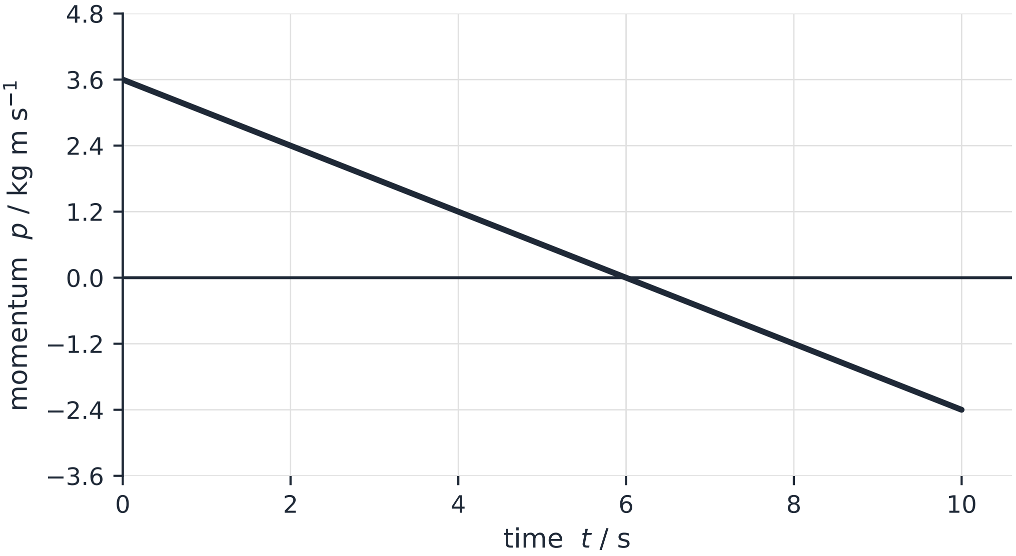
3.2 State **Newton's third law**, and give **one** example of a force pair. [2]

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

2.1 An object stays at **rest** or moves with **constant velocity** unless a **resultant (external) force** acts on it.

2.2 $p = mv = 1500 \times 20 = 3.0 \times 10^4$ kg m s^{-1}.

2.3 $a = F/m = 5.0/2.0 = 2.5$ m s^{-2}.

2.4 $W = mg = 60 \times 9.81 = 590$ N.

3.1 **B** — momentum.

3.2 When object 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, etc.).

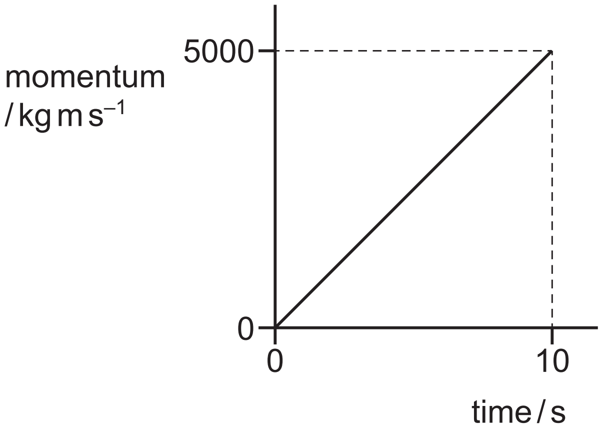
3.3 Take rebound as positive: $u = -8.0$, $v = +6.0$; $\Delta p = 0.20\,(6.0 - (-8.0)) = 2.8$ kg m s^{-1}; $F = \Delta p/\Delta t = 2.8/0.050 = 56$ N.

3.4 $F = \Delta p/\Delta t$; for the same Δp, a larger Δt gives a smaller F (the force is inversely proportional to the contact time).

3.5 The **mass stays the same**; the **weight decreases**, because g is smaller on the Moon.

3.6 (a) Momentum is the **product of mass and velocity**.
(b) $v = \dfrac{p}{m} = \dfrac{3.6}{1.2} = 3.0$ m s^{-1}.
(c) $\Delta p = (-2.4) - (+3.6) = -6.0$ kg m s^{-1}, i.e. a change of magnitude 6.0 kg m s^{-1}.
(d) $F = \dfrac{\Delta p}{\Delta t} =$ the gradient $= \dfrac{6.0}{10} = 0.60$ N.
(e) The trolley slows down **uniformly** — the line is straight, so the force and therefore the deceleration are constant — coming momentarily to rest at $t = 6.0$ s.
(f) The line is **straight**, so the resultant force is constant, whereas air resistance would get **smaller** as the trolley slows; and at $t = 6.0$ s the trolley is momentarily at rest, where air resistance would be **zero**, yet the gradient there is unchanged.
(g) Axes labelled *displacement* and *time / s*; from the origin the line rises with a **decreasing** positive gradient, reaching a maximum at $t = 6.0$ s; after 6.0 s the displacement **falls**, with a gradient of increasing magnitude, but is still positive at $t = 10$ s.
(h) At $t = 2.0$ s, $p = +2.4$ kg m s^{-1}; at $t = 8.0$ s, $p = -1.2$ kg m s^{-1}. The magnitude has halved and the **direction has reversed** — momentum is a vector, so the two are not simply "smaller" and "bigger".

11 The graph shows how the momentum of a motorcycle changes with time.



What is the resultant force on the motorcycle?

A 500 N **B** 5000 N **C** 25 000 N **D** 50 000 N

12 A rocket has a weight of W and an initial acceleration of a as the rocket leaves the ground vertically. The acceleration of free fall is g.

Which expression gives the initial upward force exerted on the rocket due to the engine?

A $\frac{Wa}{g} + W$ **B** $\frac{Wa}{g}$ **C** $\frac{Wa}{g} - W$ **D** $Wa + W$

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8 Which statement describes the weight of an object?

A It is equal to the mass of the object multiplied by its acceleration.

B It is equal to the resultant force when the object falls at terminal (constant) velocity.

C It is the force acting on the object due to a gravitational field.

D It is the property of the object that resists change in motion.

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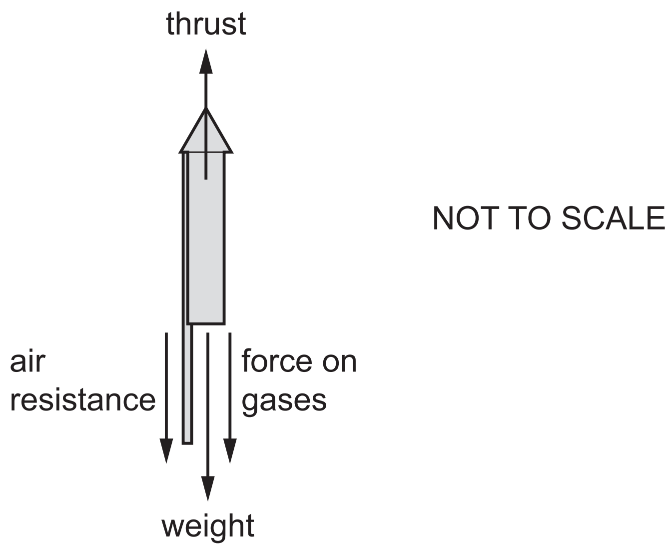
8 The acceleration of free fall on the Earth is different to the acceleration of free fall on the Moon.

How do the mass and weight of an object on the Earth compare to its mass and weight on the Moon?

	mass	weight
A	different	different
B	different	same
C	same	different
D	same	same

10 A firework travels vertically upwards in air. Gases are pushed vertically downwards from the firework.

Several forces that act on the firework and gases are shown.



Which forces are a Newton's third law pair?

A air resistance and force on gases

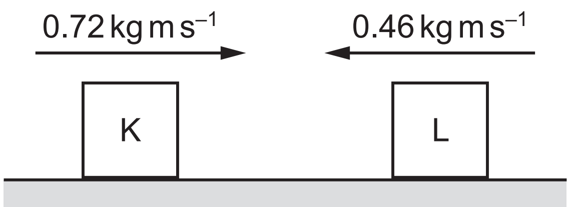
B air resistance and thrust

C force on gases and thrust

D thrust and weight

11 Two blocks K and L slide towards each other along a horizontal frictionless surface.

The diagram shows the momentum of the two blocks just before they collide.



During the collision, the blocks are in contact with each other for a time of 0.084 s.

After the collision, the blocks separate and block L moves back along its original path with a momentum of $0.12\,\text{kg m s}^{-1}$.

What is the magnitude of the average force exerted on block L by block K during the collision?

A 3.1 N **B** 4.0 N **C** 6.9 N **D** 7.1 N

9 A rocket engine ejects 90 kg of exhaust gas per second at a velocity of $190\,\mathrm{m\,s^{-1}}$ relative to the rocket.

What is the force acting on the rocket due to the ejected gas?

A 2.1 kN **B** 17 kN **C** 18 kN **D** 162 kN

11 A cyclist is riding at a constant speed on a level road.

According to Newton's third law of motion, what is equal and opposite to the backward push of the back wheel on the road?

A the force exerted by the cyclist on the pedals

B the forward push of the road on the back wheel

C the tension in the cycle chain

D the total air resistance and friction force

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9 Which statement **defines** force?

A When a force acts on a body that is free to move, the force is the product of the mass of the body and its acceleration.

B When a force acts on a body that is free to move, the force is the rate of change of momentum of the body.

C When a force acts on a body that is free to move, the force is the work done by the force divided by the distance moved by the body.

D When a force acts on a lever and causes a moment, the force is the moment divided by the perpendicular distance of the force from the pivot.

2 An object of constant mass moves in a straight line. The variation with time t of the momentum p of the object is shown in Fig. 2.1.

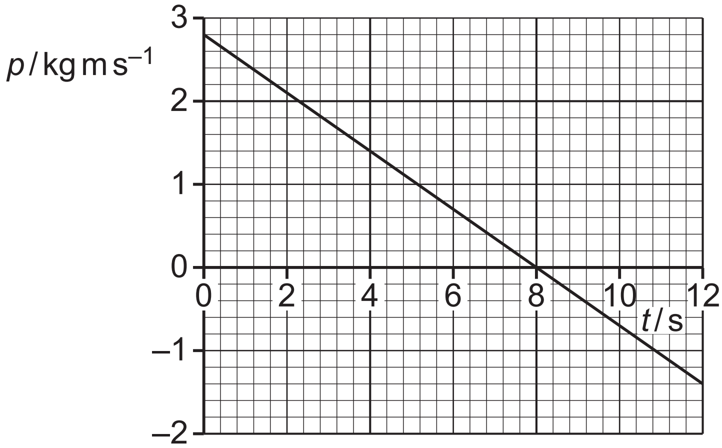


Fig. 2.1

(a) Define momentum.

....

.... [1]

(b) Calculate the change in momentum of the object from time t = 0 to t = 12 s.

change in momentum = ... kg m s^{-1} [1]

(c) Calculate the magnitude of the resultant force acting on the object.

force = ... N [2]

(d) Describe the variation of the speed of the object from time $t = 0$ to $t = 8.0\,s$.

....

.... [1]

(e) By reference to Fig. 2.1, explain why the resultant force acting on the object during the first 8.0 s of its motion cannot be due to air resistance.

....

....

....

.... [2]

(f) At time $t = 0$ the displacement d of the object is zero.

On Fig. 2.2, sketch the variation of d with time t from $t = 0$ to $t = 12\,s$.

Numerical values of d are not required.

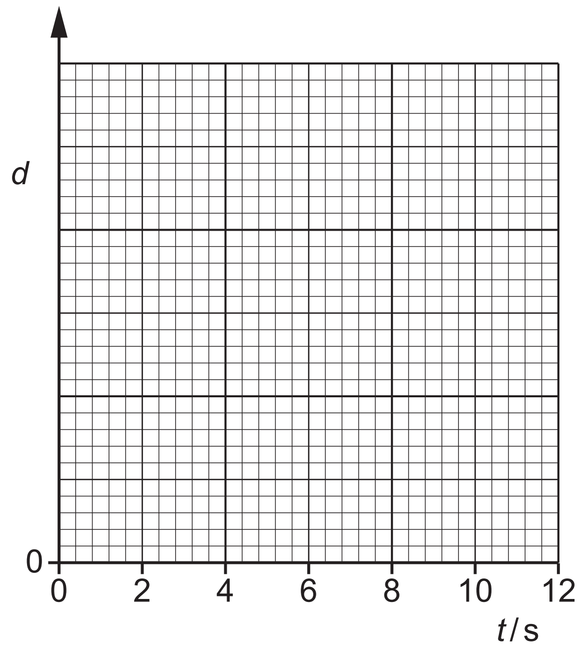


Fig. 2.2

[3]

[Total: 10]

8 An astronaut of mass m in a spacecraft experiences a gravitational force $F = mg$ when stationary on the launchpad.

What is the gravitational force on the astronaut when the spacecraft is launched vertically upwards with an acceleration of $0.2g$?

A $1.2mg$ **B** mg **C** $0.8mg$ **D** 0

3.2 Non-uniform motion

Name: ______________ Class: __________ Date: ____________ **Total: 31 marks**

KEY WORDS drag 阻力 • terminal velocity 收尾速度 • viscous 黏性 • gravitational potential energy 重力势能 • velocity 速度

Objective

Build the skills to answer exam questions on **non-uniform motion** — friction and drag, falling through air, and terminal velocity.

You must be able to:

- describe **friction** 摩擦力 and **drag** 阻力 (drag grows with speed)
- explain the motion of an object falling through air
- explain **terminal velocity** 收尾速度 and the energy transfer
- balance the **three** forces on an object falling through a **liquid** (weight, upthrust, drag)
- **draw** labelled force arrows, and get a terminal speed out of a given drag equation

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.

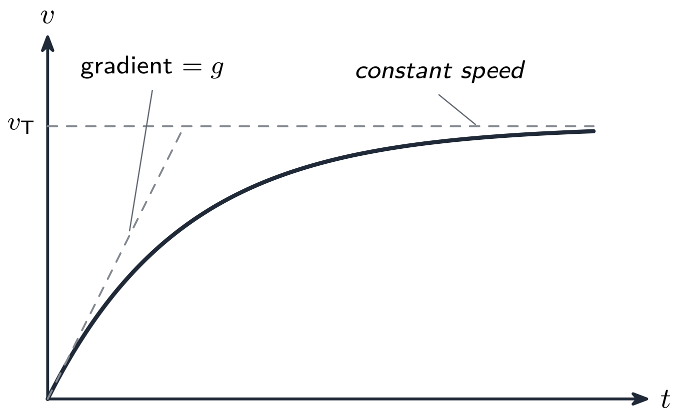
■ Drag increases with speed

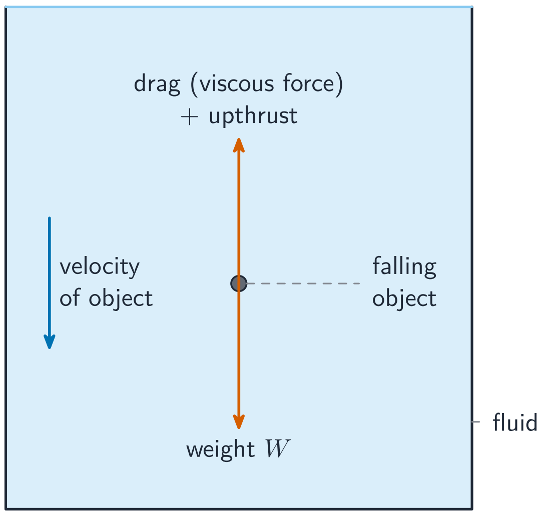
A **drag** (viscous) force from a fluid opposes motion. A simple model: **drag is zero at zero speed and grows as the speed grows**.

■ Falling through air → terminal velocity

An object dropped from rest:

1. at first only **weight** acts → it accelerates at g;
2. as it speeds up, **drag grows**, so the resultant force and the acceleration **shrink**;
3. when **drag** = **weight**, the resultant force is zero → constant speed, the **terminal velocity**.





Forces on a falling object reaching terminal velocity

■ Energy at terminal velocity

At terminal velocity the kinetic energy is **constant**, so the lost **gravitational potential energy** is transferred to **thermal energy of the air** — **not** to extra KE of the faller.

■ Falling through a LIQUID: three forces, not two

In air the upthrust is tiny and we ignore it. In a **liquid** it is not, so **three** forces act on a sinking object:

- **weight** $W = mg$, down (or $\rho_{\text{object}}Vg$);
- **upthrust** U, up — the weight of the liquid pushed aside, $U = \rho_{\text{liquid}}Vg$;
- **viscous drag** D, up, growing with speed.

Upthrust exists because the **pressure in a liquid increases with depth**: the pressure on the bottom of the object is larger than on the top, so the upward force on the bottom beats the downward force on the top, and the difference is the upthrust.

At **terminal velocity** the object is not accelerating, so

$$W = U + D$$

Worked example. A sphere of volume 2.0×10^{-7} m^3 and mass 1.6×10^{-3} kg falls through oil of density 900 kg m^{-3}. The drag is $D = kv$ with $k = 1.4 \times 10^{-2}$ kg s^{-1}.

$$W = mg = 1.6 \times 10^{-3} \times 9.81 = 1.57 \times 10^{-2}\ \text{N}$$

$$U = \rho V g = 900 \times 2.0 \times 10^{-7} \times 9.81 = 1.77 \times 10^{-3}\ \text{N}$$

$$D = W - U = 1.39 \times 10^{-2}\ \text{N} \quad \Rightarrow \quad v = \frac{D}{k} = \frac{1.39 \times 10^{-2}}{1.4 \times 10^{-2}} = 0.99\ \text{m s}^{-1}$$

Write $W = U + D$ **first** — that line is the method mark, whatever happens to the arithmetic afterwards.

A **heavier** (or denser) object reaches a **higher** terminal velocity — it needs more speed (more drag) to balance its larger weight. Opening a **parachute** suddenly increases the drag, so drag exceeds weight and the diver **decelerates** to a new, much **lower** terminal velocity.

2 Practice

Now apply the methods above.

2.1 State what happens to the **drag force** on an object as its speed increases. [1]

2.2 State the condition (in terms of forces) for an object to move at **terminal velocity**. [1]

2.3 State the acceleration of an object **just after** it is released and begins to fall through air. [1]

2.4 State the main energy transfer for a parachutist falling at **terminal velocity**. [1]

3 Exam-style questions

3.1 A parachutist falls at constant (terminal) velocity. Which statement is **not** correct? [1]

- **A** Gravitational PE is converted to kinetic energy of the air.
- **B** Gravitational PE is converted to kinetic energy of the parachutist.
- **C** Gravitational PE is converted to thermal energy of the air.
- **D** The resultant force on the parachutist is zero.

3.2 Describe and explain the motion of an object dropped from rest and falling through air, until it reaches terminal velocity. [4]

3.3 A skydiver is falling at terminal velocity. State the **resultant force** on her and explain why her velocity stays **constant**. [2]

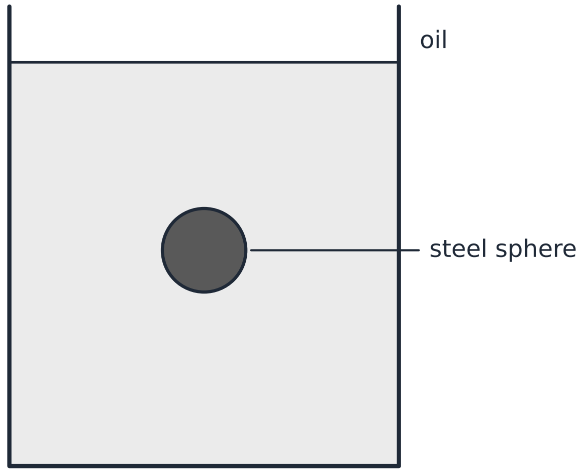
3.4 Sketch a **velocity–time graph** for an object falling from rest through air, labelling the terminal velocity. [2]

3.5 A skydiver falling at terminal velocity opens her parachute.

(a) State what happens to her velocity **just after** the parachute opens. [1]

(b) Explain, in terms of **forces**, why she settles to a new **lower** terminal velocity. [2]

3.6 A small steel sphere of radius 3.0 mm is released from rest just below the surface of a tall jar of oil. The density of steel is 7800 kg m^{-3} and the density of the oil is 900 kg m^{-3}.



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

(b) **Explain** how the pressure in the oil gives rise to an **upthrust** on the sphere. [2]

(c) On the diagram above, **draw** labelled arrows from the sphere to show the **three** forces acting on it as it falls. [3]

(d) The volume of a sphere of radius r is $\frac{4}{3}\pi r^3$. **Show that** the upthrust on the sphere is about 1.0×10^{-3} N. [2]

(e) The viscous drag on the sphere is given by $D = 6\pi\eta r v$, where v is its speed. **Deter-**

mine the SI base units of η. [2]

(f) The oil has $\eta = 0.20$ kg m^{-1} s^{-1}. **Determine** the terminal speed of the sphere. [3]

(g) **Calculate** the resultant force on the sphere at the instant it is released from rest, and state its direction. [2]

Solutions

2.1 It **increases** as the speed increases (zero at zero speed).

2.2 The **drag (resistive) force equals the weight**, so the **resultant force is zero**.

2.3 g (about 9.81 m s^{-2}) — the maximum acceleration, since drag is still zero.

2.4 Gravitational potential energy → **thermal energy of the air**.

3.1 B — at terminal velocity the KE of the parachutist is constant, so PE is **not** converted to her KE.

3.2 Just after release only weight acts, so acceleration = g; as speed rises, drag increases, so the resultant force and acceleration **decrease**; when drag = weight the resultant force is zero and the speed is constant — terminal velocity.

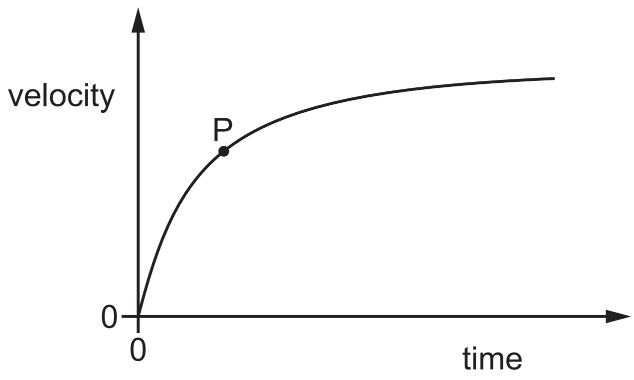
3.3 The resultant force is **zero**; with no resultant force there is no acceleration, so the velocity stays constant (Newton's first law).

3.4 Curve from the origin rising with an initial gradient (steepest at the start), bending and **flattening** to a horizontal line at the terminal velocity (labelled).

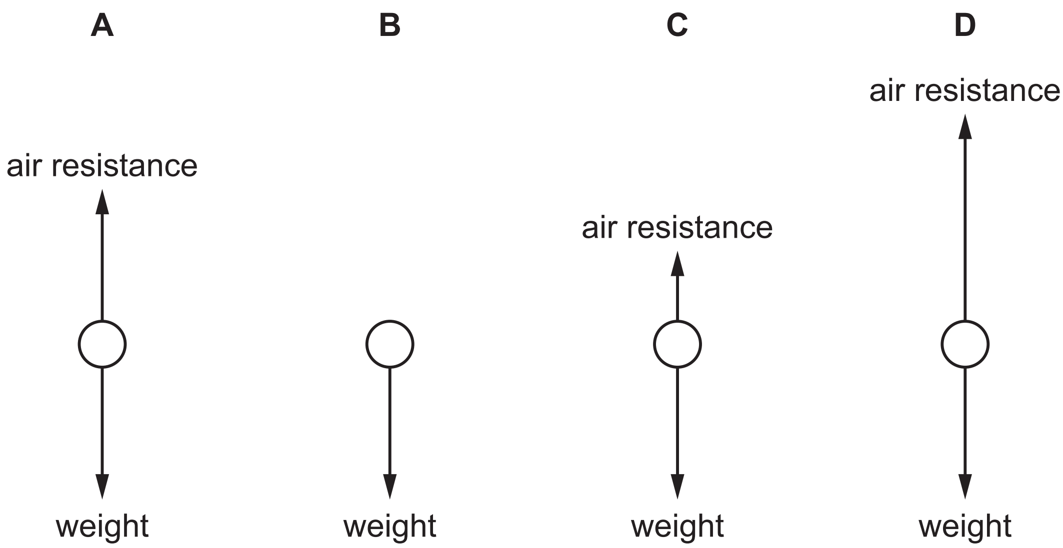
3.5 (a) Her velocity **decreases** (she decelerates). (b) The parachute greatly increases the **drag**, so drag now exceeds weight and the resultant force is **upward**; as she slows, the drag falls until **drag = weight** again, giving a new, lower terminal velocity.

3.6 (a) Pressure is the **normal force per unit area**.
(b) The pressure in a liquid **increases with depth**, so the upward force on the bottom of the sphere is greater than the downward force on its top, and the difference is the upthrust.
(c) An arrow vertically **downwards** labelled *weight*; an arrow vertically **upwards** labelled *upthrust*; an arrow vertically **upwards** labelled *(viscous) drag*.
(d) $V = \frac{4}{3}\pi(3.0 \times 10^{-3})^3 = 1.13 \times 10^{-7}$ m^3; $U = \rho_{\text{oil}} V g = 900 \times 1.13 \times 10^{-7} \times 9.81 = 1.0 \times 10^{-3}$ N.
(e) $\eta = \dfrac{D}{6\pi r v} = \dfrac{\text{kg m s}^{-2}}{\text{m} \times \text{m s}^{-1}} = \text{kg m}^{-1}\,\text{s}^{-1}$. ($6\pi$ has no units.)
(f) Weight $= \rho_{\text{steel}} V g = 7800 \times 1.13 \times 10^{-7} \times 9.81 = 8.7 \times 10^{-3}$ N; at terminal velocity $W = U + D$, so $D = 8.7 \times 10^{-3} - 1.0 \times 10^{-3} = 7.7 \times 10^{-3}$ N; $v = \dfrac{D}{6\pi\eta r} = \dfrac{7.7 \times 10^{-3}}{6\pi(0.20)(3.0 \times 10^{-3})} = 0.68$ m s^{-1}.
(g) At rest the speed is zero, so the **drag is zero** and only weight and upthrust act: resultant $= 8.7 \times 10^{-3} - 1.0 \times 10^{-3} = 7.7 \times 10^{-3}$ N, directed **downwards**. (This is the same size as the drag at terminal velocity, which is why the sphere ends up moving at 0.68 m s^{-1}.)

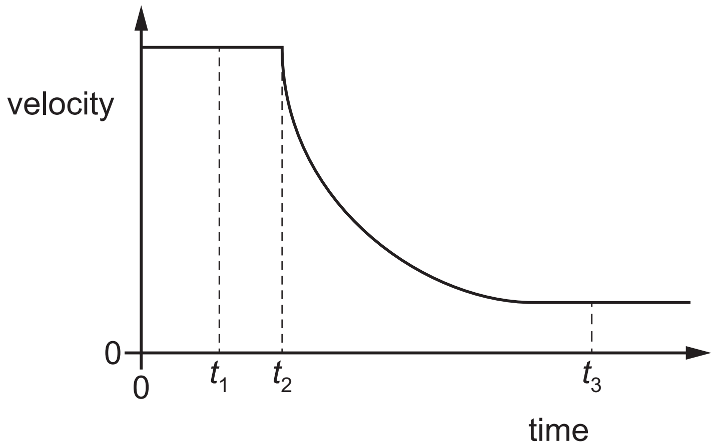
8 A sphere falls from rest through the air. The graph shows the variation with time of the sphere's velocity.



Which diagram shows the forces acting on the sphere when it is at the velocity corresponding to point P on the graph?



11 A skydiver is falling at constant velocity. She then opens her parachute. The graph shows the variation with time of her velocity.



Which statements about the motion of the skydiver are correct?

1 The magnitude of the acceleration is maximum at time t_2.

2 The magnitude of the drag force at time t_1 equals the magnitude of the drag force at time t_3.

3 The magnitude of the drag force is maximum at time t_1.

A 1 and 2 **B** 1 and 3 **C** 2 only **D** 3 only

2 **(a)** **(i)** Define pressure.

....

.... [1]

(ii) Explain how hydrostatic pressure results in an upthrust force acting on a solid object immersed in a liquid.

....

....

....

.... [2]

(b) A small steel ball of radius *r* and mass *m* falls vertically at terminal speed *v* through oil.

The viscous drag force *D* that acts on the ball is given by

$$D = 6\pi\eta r v$$

where η is a property of the oil called its viscosity.

(i) On Fig. 2.1, draw labelled arrows from the ball to show the directions of the **three** forces that act on the ball as it falls.

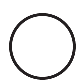


Fig. 2.1

[3]

(ii) Determine the SI base units of η.

base units .... [2]

(c) The oil in **(b)** has a density of $920\,kg\,m^{-3}$ and a viscosity of 4.7 in SI units.

The steel ball has a mass of $2.4 \times 10^{-3}\,kg$ and a radius of $4.2 \times 10^{-3}\,m$.

(i) Show that the upthrust force acting on the ball is $2.8 \times 10^{-3}\,N$.

[1]

(ii) Determine the terminal speed v of the ball.

v = ... $m\,s^{-1}$ [3]

[Total: 12]

20 A parachutist is falling at constant (terminal) velocity.

Which statement is **not** correct?

A Gravitational potential energy is converted into kinetic energy of the air.

B Gravitational potential energy is converted into kinetic energy of the parachutist.

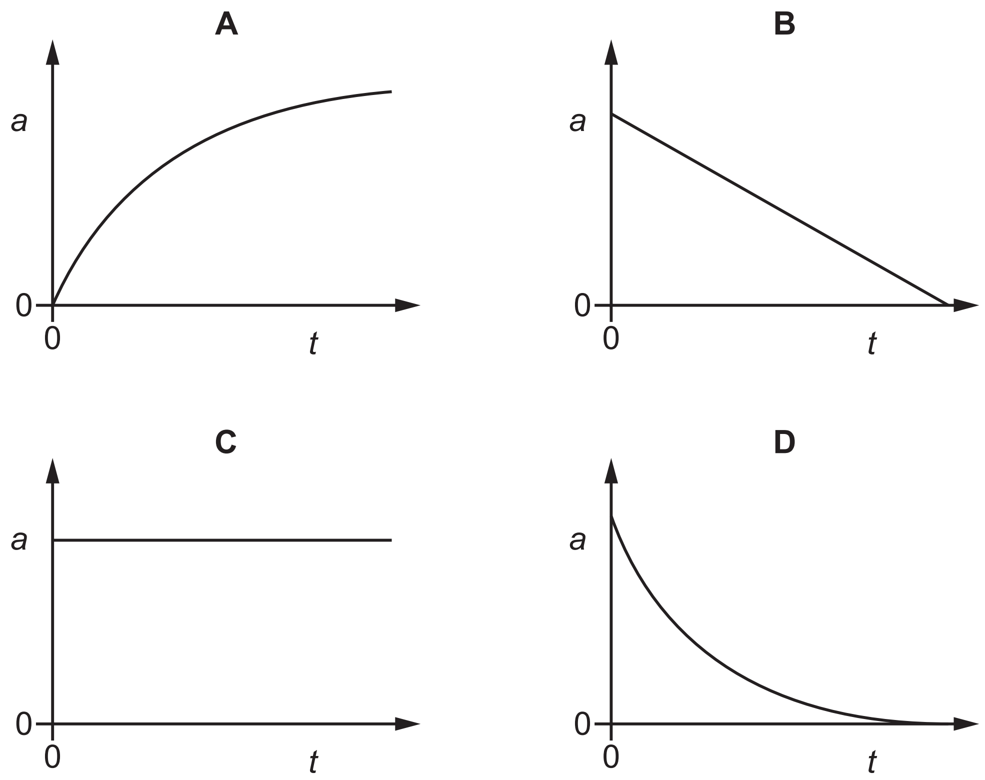
C Gravitational potential energy is converted into thermal energy of the air.

D Gravitational potential energy is converted into thermal energy of the parachutist.

A-Level Physics: **s25 12**

12 A stone is released from rest and falls a long distance in air.

Which graph could show the variation with time *t* of the acceleration *a* of the stone?



8 Two spheres are released from rest at equal heights above the ground.

Both spheres reach terminal velocity.

One sphere has a larger density than the other sphere.

Both spheres have equal volumes.

Which statement is correct while both spheres are at terminal velocity?

A The drag forces on the spheres are equal.

B The resultant forces on the spheres are equal.

C The velocities of the spheres are equal.

D The weights of the spheres are equal.

A-Level Physics: **s25 14**

8 A skydiver is falling vertically with terminal velocity when their parachute opens fully.

Which statement describes the motion of the skydiver for the first few seconds after the parachute opens fully?

A falling with non-uniform acceleration and increasing speed

B falling with non-uniform acceleration and decreasing speed

C falling with uniform acceleration and increasing speed

D falling with uniform acceleration and decreasing speed

3 A car of mass 1500 kg is travelling along a straight horizontal road at constant velocity v. The car is subject to a total resistive force F, as shown in Fig. 3.1.

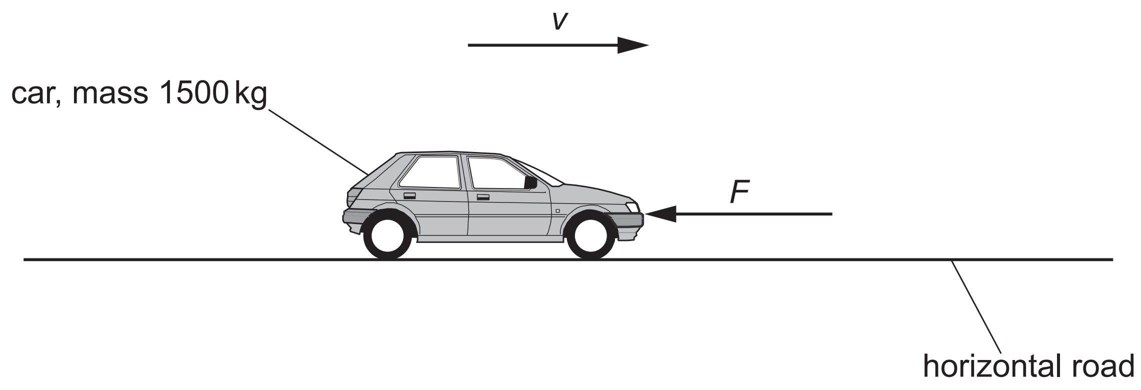


Fig. 3.1

(a) Show that the power P developed by the engine in overcoming the total resistive force is given by the equation

$$P = Fv\ .$$

[2]

(b) The car now moves up a slope at a constant speed of $30\,\mathrm{m\,s^{-1}}$.
The slope is at an angle to the horizontal of 6.0°, as shown in Fig. 3.2.

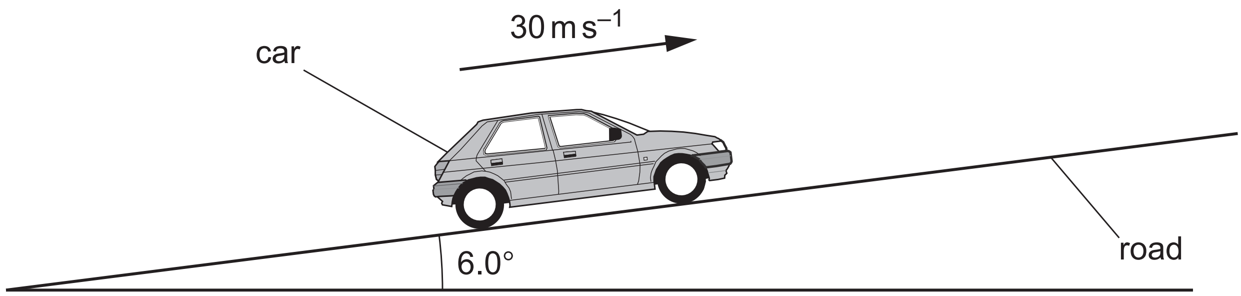


Fig. 3.2

The total resistive force acting on the car is 1600 N.

(i) Show that the increase in gravitational potential energy of the car in a time of 1.0 s is 46 000 J.

[2]

(ii) Use the information in **(b)(i)** to determine the power developed by the engine to move the car up the slope.

power = ... W [2]

(c) The car picks up a passenger and then continues up the slope at the same speed as in **(b)**.

State and explain the effect, if any, that the passenger has on:

(i) the air resistance acting on the car

....

.... [1]

(ii) the power developed by the engine.

....

.... [1]

[Total: 8]

A-LEVEL PHYSICS • EXERCISE SHEET

3.3 Linear momentum and its conservation

Name: ____________ Class: ________ Date: __________ **Total: 34 marks**

KEY WORDS conservation of momentum 动量守恒 • elastic collision 弹性碰撞 • relative speed 相对速率 • inelastic collision 非弹性碰撞 • collision 碰撞

Objective

Build the skills to answer exam questions on **conservation of momentum** 动量守恒 — collisions, explosions, and elastic vs inelastic interactions.

You must be able to:

- state and apply **conservation of momentum** (using signed velocities)
- distinguish **elastic** and **inelastic** collisions
- use the elastic test: relative speed of **approach** = relative speed of **separation**
- **calculate** the percentage of kinetic energy transferred away in a collision
- apply momentum conservation to a **nuclear decay**, and say what else is conserved

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.

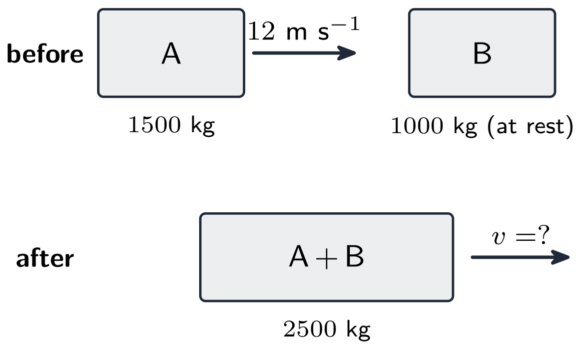
■ The principle

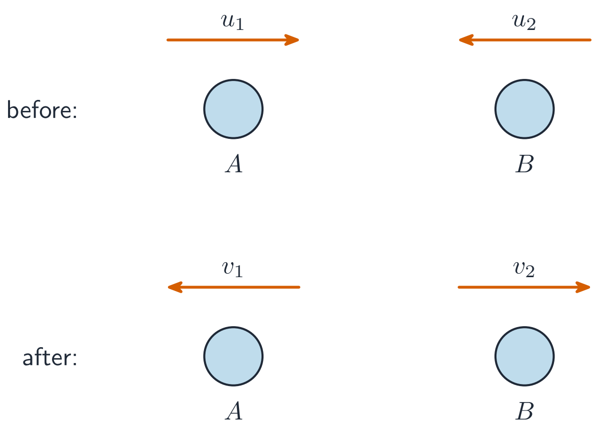
With **no resultant external force**, total momentum is **constant**. Always write momenta with **signs** (positive in one direction).

Explosion/recoil. A 2.0 kg and a 3.0 kg trolley spring apart from rest. Total momentum stays zero:

$$0 = (2.0)(6.0) + (3.0)(-v) \Rightarrow v = 4.0 \text{ m s}^{-1} \text{ (opposite way).}$$

■ Inelastic collision (objects stick)





Momentum is conserved in a head-on collision

Momentum conserved, $v_1 = v_2 = v$:

$$1500(12) + 1000(0) = (2500)\,v \Rightarrow v = \frac{18\,000}{2500} = 7.2 \text{ m s}^{-1}.$$

■ Elastic vs inelastic

- **Every** collision conserves **momentum**.
- An **elastic** collision **also** conserves **kinetic energy**; test: $u_1 - u_2 = -(v_1 - v_2)$ (relative speed of approach = of separation).
- An **inelastic** collision loses KE (to heat/sound/deformation); if they stick, it is perfectly inelastic.

■ How much kinetic energy was lost?

"Elastic or not" is usually asked as a **number**. Work out the kinetic energy on each side and compare:

$$\%\text{ transferred away} = \frac{E_{\text{K,before}} - E_{\text{K,after}}}{E_{\text{K,before}}} \times 100$$

Worked example (the two cars above). Before: $\frac{1}{2}(1500)(12)^2 = 1.08 \times 10^5$ J. After: $\frac{1}{2}(2500)(7.2)^2 = 6.48 \times 10^4$ J. So $\dfrac{1.08 \times 10^5 - 6.48 \times 10^4}{1.08 \times 10^5} \times 100 = 40\%$ is transferred to other forms. **Momentum is unchanged** all the same — that is the point of the question.

- **A decay is an explosion**

A stationary nucleus that decays is a two-body explosion, so the total momentum stays **zero**:

$$m_1 v_1 = m_2 v_2$$

The masses can be left in **atomic mass units** — they appear on both sides, so they cancel out of the ratio. Momentum, **charge (proton number)**, **nucleon number** and **total energy** are all conserved; kinetic energy is **not**, because energy is released from the nucleus.

2 Practice

Now apply the methods above.

2.1 State the **principle of conservation of momentum**. [1]

2.2 State what is conserved in (a) an **elastic** and (b) an **inelastic** collision. [2]

2.3 Two trolleys, 2.0 kg and 3.0 kg, are pushed apart from rest by a spring. The 2.0 kg trolley moves off at 6.0 m s^{-1}. Find the speed of the 3.0 kg trolley. [2]

2.4 State the test (using relative speeds) for an **elastic** collision. [1]

3 Exam-style questions

3.1 In an **inelastic** collision, which quantity is conserved? [1]

- **A** kinetic energy only
- **B** momentum only
- **C** both momentum and kinetic energy
- **D** neither

3.2 A 1500 kg car moving at 12 m s^{-1} hits a stationary 1000 kg car and they lock together. Calculate their **common velocity** just after the collision. [3]

3.3 A 0.50 kg ball moving at 4.0 m s^{-1} collides **elastically** and head-on with a stationary 0.50 kg ball. State the velocity of **each** ball after the collision. [2]

3.4 Explain why the **kinetic energy** can decrease in a collision while the **momentum** does not. [2]

3.5 On a horizontal frictionless track, trolley A of mass 1.6 kg moves to the right at 4.5 m s^{-1}. Ahead of it, trolley B of mass 0.90 kg moves to the right at 1.5 m s^{-1}. A catches B, and the two move off together.

(a) **State** the principle of conservation of momentum. [2]

(b) **Determine** the common velocity of the trolleys after the collision. [3]

(c) **Calculate** the percentage of the total kinetic energy that is transferred to other forms during the collision. [3]

(d) **State and justify** whether this collision is elastic. [2]

3.6 A radon-220 nucleus, at rest and far from anything else, breaks apart into a polonium nucleus and an α-particle. Measurements show the polonium nucleus moves off at 2.2×10^5 m s^{-1}.

(a) **Complete** the equation for the decay. [1]

$$^{220}_{86}\text{Rn} \rightarrow \,^{\_\_}_{\_\_}\text{Po} + \,^{4}_{2}\alpha$$

(b) By considering momentum, **calculate** the speed of the α-particle. [3]

(c) **State** three quantities that are conserved as the nucleus breaks apart. [3]

(d) **Determine** the ratio $\dfrac{\text{kinetic energy of the } \alpha\text{-particle}}{\text{kinetic energy of the polonium nucleus}}$, and comment on which fragment carries away most of the released energy. [3]

Solutions

2.1 With **no resultant external force**, the **total momentum** of a system stays **constant**.

2.2 (a) Elastic — **momentum and kinetic energy**; (b) inelastic — **momentum only** (KE decreases).

2.3 $0 = (2.0)(6.0) + (3.0)(-v) \Rightarrow v = 12/3.0 = 4.0 \text{ m s}^{-1}$.

2.4 The **relative speed of approach** equals the **relative speed of separation**.

3.1 **B** — momentum only.

3.2 $1500(12) + 1000(0) = (1500 + 1000)v$; $18\,000 = 2500v$; $v = 7.2 \text{ m s}^{-1}$.

3.3 Equal masses, elastic, target at rest: the first ball **stops** (0 m s^{-1}) and the second moves off at 4.0 m s^{-1}.

3.4 In a collision the equal-and-opposite forces conserve total momentum; but kinetic energy can be transferred to **thermal/sound/deformation** energy, so total KE can decrease.

3.5 (a) For a system with **no resultant external force** (an isolated system), the **total momentum stays constant** — total momentum before = total momentum after.
(b) $p_{\text{before}} = (1.6)(4.5) + (0.90)(1.5) = 7.2 + 1.35 = 8.55 \text{ kg m s}^{-1}$; after the collision the mass is $1.6 + 0.90 = 2.5$ kg; $v = \dfrac{8.55}{2.5} = 3.4 \text{ m s}^{-1}$ to the right.
(c) $E_{\text{K,before}} = \frac{1}{2}(1.6)(4.5)^2 + \frac{1}{2}(0.90)(1.5)^2 = 16.2 + 1.01 = 17.2$ J; $E_{\text{K,after}} = \frac{1}{2}(2.5)(3.42)^2 = 14.6$ J; $\dfrac{17.2 - 14.6}{17.2} \times 100 = 15\%$.
(d) **Not elastic** — kinetic energy is not conserved: about 15% of it is transferred to thermal and sound energy and to deforming the trolleys.

3.6 (a) ${}^{220}_{86}\text{Rn} \rightarrow {}^{216}_{84}\text{Po} + {}^{4}_{2}\alpha$ — nucleon number $220 = 216 + 4$ and proton number $86 = 84 + 2$.
(b) The nucleus is stationary, so the total momentum stays **zero** and the two fragments carry equal and opposite momentum: $4u \times v_\alpha = 216u \times 2.2 \times 10^5$, so $v_\alpha = \dfrac{216 \times 2.2 \times 10^5}{4} = 1.2 \times 10^7 \text{ m s}^{-1}$, in the opposite direction. (The mass unit u cancels.)
(c) Any three of: **momentum**, **total energy**, **charge (proton number)**, **nucleon number**. Kinetic energy is **not** conserved — it is created from the nucleus's store of energy.
(d) The momenta are equal in magnitude, and $E_K = \dfrac{p^2}{2m}$, so for the same p the kinetic energy is **inversely proportional to the mass**: $\dfrac{E_\alpha}{E_{\text{Po}}} = \dfrac{m_{\text{Po}}}{m_\alpha} = \dfrac{216}{4} = 54$. The light α-particle carries away about 98% of the released energy — which is why it, not the recoiling nucleus, is what a detector sees.

9 In which situation is total linear momentum **always** conserved?

A in all collisions between two objects

B in collisions between two objects moving at equal and opposite velocity

C in collisions between two objects that form an isolated system

D in collisions between two objects with the same mass

10 An object of mass m moving with velocity $9.0\,m\,s^{-1}$ has a head-on elastic collision with a stationary object of mass $2m$.

After the collision, both objects are moving. No external forces act on the system.

What is the velocity of the object of mass $2m$ after the collision?

A $-6.0\,m\,s^{-1}$ **B** $-3.0\,m\,s^{-1}$ **C** $4.5\,m\,s^{-1}$ **D** $6.0\,m\,s^{-1}$

A-Level Physics: **w25 12**

9 What is a statement of the principle of conservation of momentum?

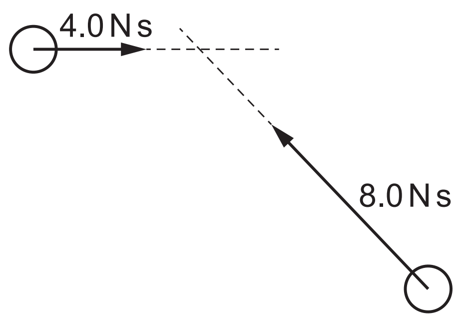
A In an elastic collision, momentum is constant.

B Momentum is the product of mass and velocity.

C The force acting on a body is proportional to its rate of change of momentum.

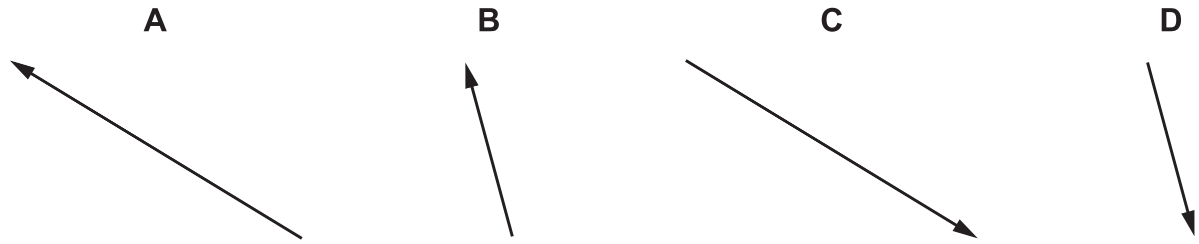
D The momentum of an isolated system is constant.

10 The diagram shows the view from above of two balls moving along a horizontal frictionless surface before they collide. The momentum of each ball is also shown.



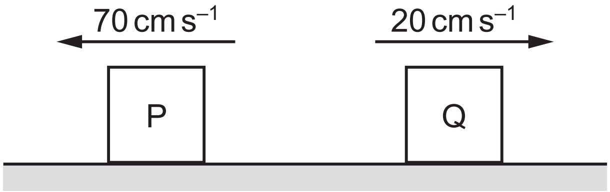
The balls stick together during the collision.

Which vector diagram represents the combined momentum of the balls after the collision?



12 Two different blocks, P and Q, slide towards each other on a horizontal frictionless surface. The blocks have an elastic collision.

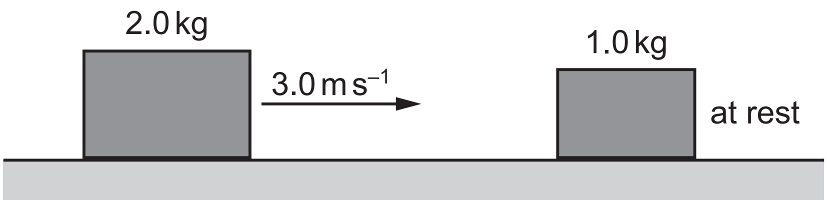
The diagram shows the velocities of the two blocks immediately after the collision.



Which row gives possible velocities of the two blocks immediately before the collision?

	velocity of P	velocity of Q
A	10 $cm\,s^{-1}$ to the right	60 $cm\,s^{-1}$ to the left
B	50 $cm\,s^{-1}$ to the right	zero
C	20 $cm\,s^{-1}$ to the left	70 $cm\,s^{-1}$ to the right
D	60 $cm\,s^{-1}$ to the right	30 $cm\,s^{-1}$ to the left

10 An object of mass 2.0 kg is travelling at a speed of 3.0 $m\,s^{-1}$ on a horizontal frictionless surface. This object collides head-on with a stationary object of mass 1.0 kg. The two objects stick together on impact.



How much kinetic energy is lost on impact?

A zero **B** 2.0 J **C** 2.4 J **D** 3.0 J

11 A moving object X collides with a stationary object Y.

The objects separate after the collision.

The collision is perfectly elastic and there are no external forces acting.

Which word equation is **not** correct?

A during the collision, (force acting on object X) + (force acting on object Y) = zero

B (relative speed of approach of X and Y) + (relative speed of separation of X and Y) = zero

C (total kinetic energy before collision) = (total kinetic energy after collision)

D (total momentum before collision) = (total momentum after collision)

9 What is always conserved in elastic collisions?

	total kinetic energy	total velocity
A	yes	yes
B	yes	no
C	no	yes
D	no	no

10 Which statement does **not** describe an elastic collision between two objects?

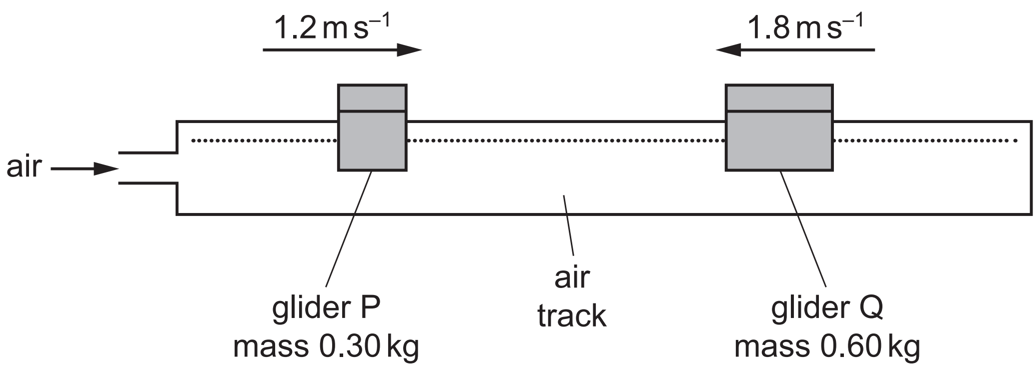
A The relative speed of approach of the two objects equals the relative speed of separation.

B The total kinetic energy of the objects is conserved.

C The total kinetic energy of the objects is reduced.

D The total linear momentum of the objects is conserved.

9 Two gliders are travelling towards each other on a horizontal air track. Glider P has mass 0.30 kg and is moving with a constant speed of $1.2\,m\,s^{-1}$. Glider Q has mass 0.60 kg and is moving with a constant speed of $1.8\,m\,s^{-1}$.



The gliders have a perfectly elastic collision.

What are the speeds of the two gliders after the collision?

	speed of P $/\,m\,s^{-1}$	speed of Q $/\,m\,s^{-1}$
A	1.2	0.6
B	2.0	1.4
C	2.8	0.2
D	3.6	0.6

4 **(a)** State the principle of conservation of momentum.

....

....

.... [2]

(b) An object A of mass 4.0 kg travels at a velocity of $6.0\,m\,s^{-1}$ to the right on a horizontal frictionless surface. It moves towards a second object B of mass 2.0 kg that is moving at a velocity of $3.0\,m\,s^{-1}$ in the same direction as A, as shown in Fig. 4.1.

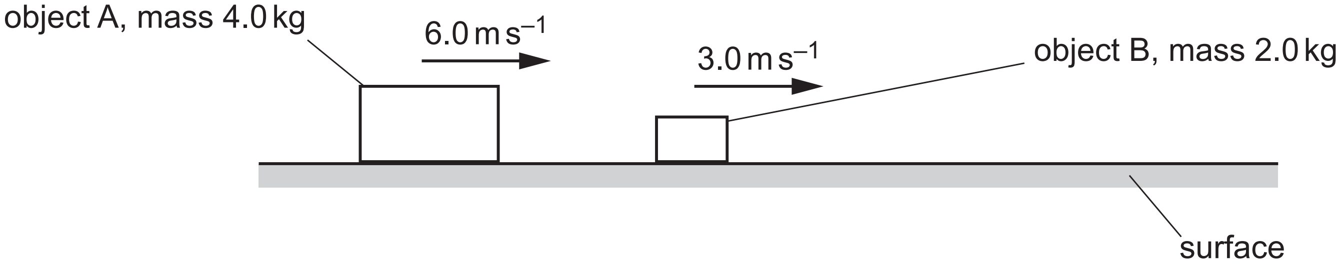


Fig. 4.1

Object A collides with object B. The two objects join and move off together with velocity *v*.

Calculate:

(i) velocity *v*

v = ... $m\,s^{-1}$ [2]

(ii) the percentage of the total initial kinetic energy of the two objects that is transferred to other forms of energy during the collision.

percentage = ...% [2]

[Total: 6]

7 An isolated stationary nucleus Q decays into nucleus R and an α-particle. The α-particle has speed $1.5 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

(a) Complete the equation for this decay.

$$^{\dots\dots}_{88}\mathrm{Q} \longrightarrow {}^{222}_{\dots\dots}\mathrm{R} + {}^{4}_{2}\alpha$$

[1]

(b) By considering momentum, calculate the speed of nucleus R after the decay.

speed = ... $\mathrm{m\,s^{-1}}$ [3]

(c) State **three** quantities that are conserved during the decay.

1 ....

2 ....

3 ....

[3]

[Total: 7]