1.2 Motion

Name: _____ Class: _____ Date: _____ **Total: 28 marks**

KEY WORDS speed–time graph - • acceleration • terminal velocity • deceleration • uniform

Objective

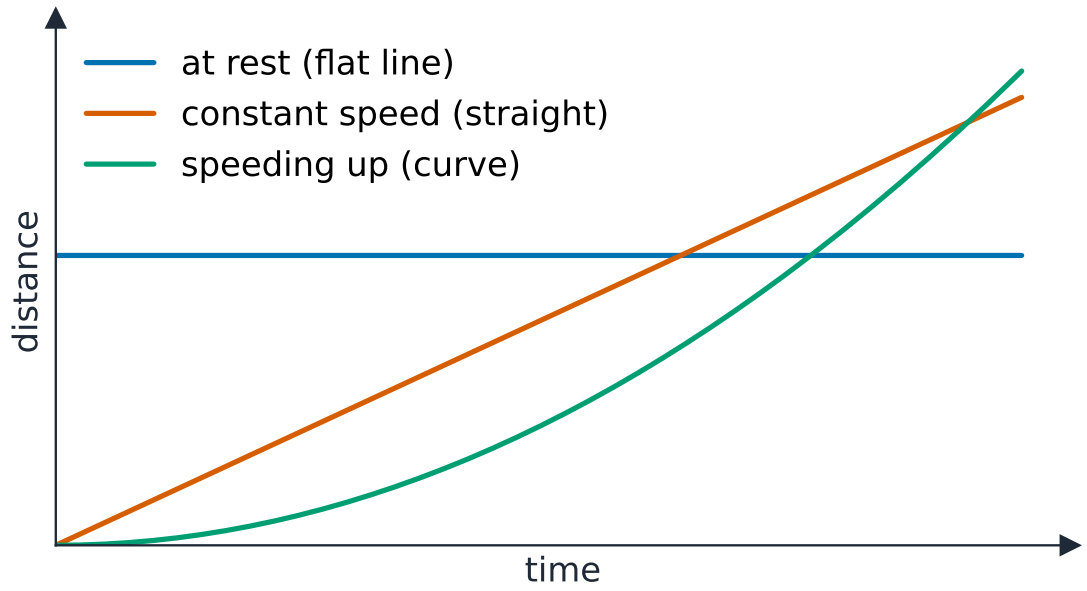
Build the skills to answer exam questions on **motion** – speed, velocity, **acceleration**, motion graphs, and **terminal velocity**.

You must be able to:

- use $v = \frac{s}{t}$ and $a = \frac{\Delta v}{\Delta t}$
- read distance–time and speed–time graphs (gradient and area)
- describe falling objects and terminal velocity

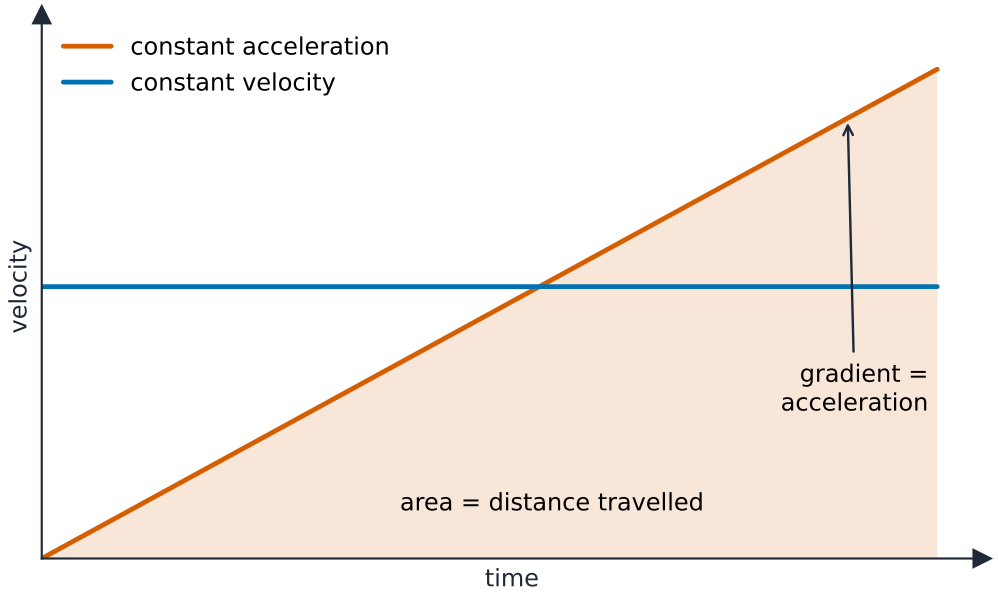
1 Key knowledge and worked examples

Graphs and acceleration



Distance–time: flat = at rest, straight slope = constant speed, rising curve = speeding up

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Velocity–time: gradient = acceleration, area under the line = distance

Car $8 \to 20\ \frac{\text{m}}{\text{s}}$ **in** 4.0 **s:** $a = \dfrac{20-8}{4.0} = 3.0\ \frac{\text{m}}{\text{s}^2}$.

■ Reading a speed-time graph, and deceleration

Describe each straight section of a speed–time graph by name: a horizontal line is **constant speed**; a line sloping up is **constant (uniform) acceleration**; a line sloping down is **constant deceleration**. A **deceleration** is a negative acceleration, so put a minus sign in the arithmetic: slowing from $12\ \frac{\text{m}}{\text{s}}$ to $4\ \frac{\text{m}}{\text{s}}$ in 4.0 s gives $a = \dfrac{4-12}{4.0} = -2.0\ \frac{\text{m}}{\text{s}^2}$, a deceleration of $2.0\ \frac{\text{m}}{\text{s}^2}$.

The **area under a speed-time line** is the distance travelled. Split the area into rectangles and triangles: a rectangle is speed × time; a triangle is $\frac{1}{2}$ × base × height.

Worked example (show that). A bus is at $10\ \frac{\text{m}}{\text{s}}$ for 120 s, then decelerates uniformly to rest in 40 s. Show that it travels about 1400 m. Rectangle: $10 \times 120 = 1200$ m. Triangle: $\frac{1}{2} \times 40 \times 10 = 200$ m. Total 1400 m. In a "show that" question, always finish with the number the question quotes.

Near the Earth all objects fall with the same **acceleration of free fall** $g \approx 9.8\ \frac{\text{m}}{\text{s}^2}$ while air resistance is small. As speed rises, air resistance grows until it equals the weight; the resultant force is then zero and the object falls at a steady **terminal velocity** .

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2 Practice

2.1 A runner covers 100 m in 12.5 s. Find the average speed. [2]

2.2 State what the area under a speed–time graph represents. [1]

2.3 A car slows from 18 $\frac{\text{m}}{\text{s}}$ to 6.0 $\frac{\text{m}}{\text{s}}$ in 4.0 s. Calculate its acceleration and state what the sign means. [3]

2.4 State how you find the distance travelled from a speed-time graph. [1]

3 Exam-style questions

3.1 On a distance–time graph, a horizontal (flat) line means the object is: [1]

- ☐ **A** accelerating
- **B** at rest
- **C** at constant speed
- **D** decelerating

3.2 A car accelerates uniformly from rest to 24 $\frac{\text{m}}{\text{s}}$ in 8.0 s.

(a) Find the acceleration. [2]

(b) Find the distance travelled (area under the speed–time graph). [2]

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3.3 A skydiver falls and reaches terminal velocity. Explain, in terms of forces, why the speed becomes steady. [3]

3.4 Fig. 3.1 describes the first five minutes of a bus journey. The bus is at rest until $t = 0.90$ min, speeds up uniformly to 7.5 $\frac{\text{m}}{\text{s}}$ at $t = 2.9$ min, holds that speed until $t = 3.5$ min, then slows uniformly to rest at $t = 4.5$ min.

(a) Describe the motion of the bus between $t = 2.9$ min and $t = 3.5$ min, and between $t = 3.5$ min and $t = 4.5$ min. [2]

(b) Calculate the acceleration of the bus between $t = 0.90$ min and $t = 2.9$ min. [3]

(c) Show that the bus travels about 270 m while it is speeding up. [2]

(d) Calculate the deceleration of the bus in the last minute, and state what the sign of your answer means. [3]

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(e) A stone is dropped from a tall building. Describe how its acceleration changes from the moment it is released until it reaches terminal velocity, and explain why. [3]

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Solutions

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

2.1

- $v = s/t$

$$v = \frac{s}{t} = \frac{100\ \text{m}}{12.5\ \text{s}} = \mathbf{8.0}\ \frac{\text{m}}{\text{s}}$$

2.2

- the distance travelled

2.3

- $a = \Delta v/\Delta t$

$$a = \frac{v - u}{t} = \frac{6.0\ \frac{\text{m}}{\text{s}} - 18\ \frac{\text{m}}{\text{s}}}{4.0\ \text{s}} = -\mathbf{3.0}\ \frac{\text{m}}{\text{s}^{\mathbf{2}}}$$

- the minus sign means the car is decelerating, so the acceleration is opposite to the motion

2.4

- find the area under the line (between the line and the time axis)

3.1 B

- a flat line on a distance–time graph means the distance is not changing – at rest

3.2

(a) $a = \Delta v/\Delta t$

$$a = \frac{v - u}{t} = \frac{24\ \frac{\text{m}}{\text{s}} - 0}{8.0\ \text{s}} = \mathbf{3.0}\ \frac{\text{m}}{\text{s}^{\mathbf{2}}}$$

(b) distance = area of the triangle

$$s = \tfrac{1}{2}\, t\, v = \tfrac{1}{2}(8.0\ \text{s})(24\ \frac{\text{m}}{\text{s}}) = \mathbf{96}\ \text{m}$$

3.3

- as the diver speeds up, air resistance increases
- when air resistance equals the weight, the resultant force is zero
- so there is no acceleration and the speed stays constant (terminal velocity)

3.4

(a) between 2.9 and 3.5 min: constant speed

- between 3.5 and 4.5 min: constant (uniform) deceleration to rest

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(b) time $= (2.9 - 0.90) \times 60$ s $= 120$ s

- $a = \Delta v / \Delta t$

$$a = \frac{v - u}{t} = \frac{7.5 \ \dfrac{\text{m}}{\text{s}} - 0}{120 \text{ s}} = \mathbf{0.063} \ \frac{\text{m}}{\text{s}^\mathbf{2}}$$

(c) distance = area of the speeding-up triangle

$$s = \tfrac{1}{2} \, t \, v = \tfrac{1}{2}(120 \text{ s})(7.5 \ \frac{\text{m}}{\text{s}}) = \mathbf{450} \text{ m}$$

- for the first 72 s of it the area is 270 m

(d) time = 60 s; $a = \Delta v / \Delta t$

$$a = \frac{v - u}{t} = \frac{0 - 7.5 \ \dfrac{\text{m}}{\text{s}}}{60 \text{ s}} = -\mathbf{0.13} \ \frac{\text{m}}{\text{s}^\mathbf{2}}$$

- the minus sign means the bus is slowing down, so the resultant force is opposite to the motion

(e) at first the acceleration is g, because only the weight acts

- as the stone speeds up, air resistance grows and the resultant force falls, so the acceleration decreases
- when air resistance equals the weight the resultant force and the acceleration are zero and the speed is constant

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