CIE International A Level Physics

Topic 2

Kinematics

Revision Booklet

This booklet covers:

- Distance, Displacement, Speed, Velocity and Acceleration
- Graphs of Motion
- Equations of Uniform Acceleration (SUVAT)
- Free Fall and Measuring g
- Projectile Motion

Core Definitions

Scalar and Vector Quantities

- **Distance** (scalar): the total length of path travelled, regardless of direction. Units: m.
- **Displacement** s (vector): the straight-line distance from start to finish *in a specified direction*. Units: m.
- **Speed** (scalar): distance travelled per unit time. Units: $\mathrm{m\,s^{-1}}$.
- **Velocity** v (vector): rate of change of displacement. Units: $\mathrm{m\,s^{-1}}$.
- **Acceleration** a (vector): rate of change of velocity. Units: $\mathrm{m\,s^{-2}}$.

Defining Equations

$$v = \frac{\Delta s}{\Delta t} \qquad\qquad a = \frac{\Delta v}{\Delta t}$$

Δs = change in displacement (m)
Δv = change in velocity ($\mathrm{m\,s^{-1}}$)
Δt = time interval (s)

Distance vs Displacement

A car that travels 400 m north then 400 m south has a total **distance** of 800 m but a **displacement** of zero. Always identify whether the question asks for a scalar or vector quantity before calculating.

Graphs of Motion

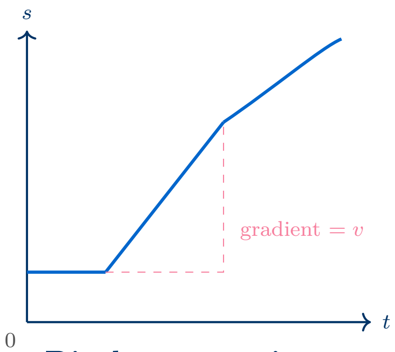
Reading Motion Graphs

Displacement–time (s–t) graph:

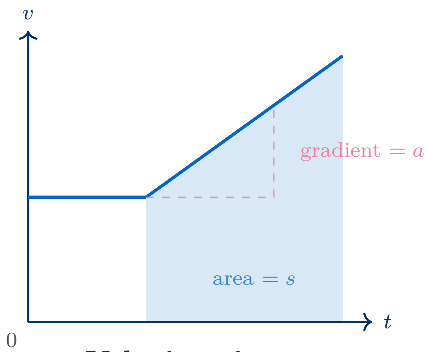
- Gradient = instantaneous velocity.
- Horizontal line $\Rightarrow$ stationary.
- Straight line $\Rightarrow$ constant (uniform) velocity.
- Curve $\Rightarrow$ changing velocity (acceleration present).

Velocity–time (v–t) graph:

- Gradient = instantaneous acceleration.
- Area under the graph = displacement.
- Horizontal line $\Rightarrow$ constant velocity (zero acceleration).
- Straight line $\Rightarrow$ uniform acceleration.



Displacement–time



Velocity–time

Equations of Uniform Acceleration (SUVAT)

Derivation

For **constant** acceleration, starting from the definitions of velocity and acceleration:

1. From $a = \Delta v/\Delta t$: $a = (v-u)/t \quad \Rightarrow \quad \boxed{v = u + at}$
2. Mean velocity $\times$ time: $s = \dfrac{u+v}{2} \times t \quad \Rightarrow \quad \boxed{s = \tfrac{1}{2}(u+v)t}$
3. Substitute equation (1) into (2): $s = \dfrac{u+u+at}{2}t \quad \Rightarrow \quad \boxed{s = ut + \tfrac{1}{2}at^2}$
4. Eliminate t: from (1), $t = (v-u)/a$; substitute into (2): $\Rightarrow \quad \boxed{v^2 = u^2 + 2as}$

The SUVAT Equations

Equation	Variable not present
$v = u + at$	s
$s = ut + \frac{1}{2}at^2$	v
$v^2 = u^2 + 2as$	t
$s = \frac{1}{2}(u+v)t$	a

s = displacement (m) u = initial velocity (m s^{-1})
v = final velocity (m s^{-1}) a = acceleration (m s^{-2}) t = time (s)

Valid only for ***uniform*** *(constant) acceleration in a straight line.*

SUVAT Problem Strategy

1. Write down the five variables: s, u, v, a, t.
2. Fill in the known values; identify what you are finding.
3. Choose the equation that contains those four variables (three known + one unknown).
4. Solve; check units and sign conventions.

Positive direction must be defined clearly at the start — be consistent throughout.

Free Fall and Measuring g

Free Fall

Free fall is the motion of an object under gravity alone, with no air resistance. The object accelerates uniformly downwards at the **acceleration of free fall**:

$$g = 9.81\ \text{m s}^{-2} \quad \text{(near Earth's surface)}$$

Free fall is uniform acceleration, so all four SUVAT equations apply with $a = g$.

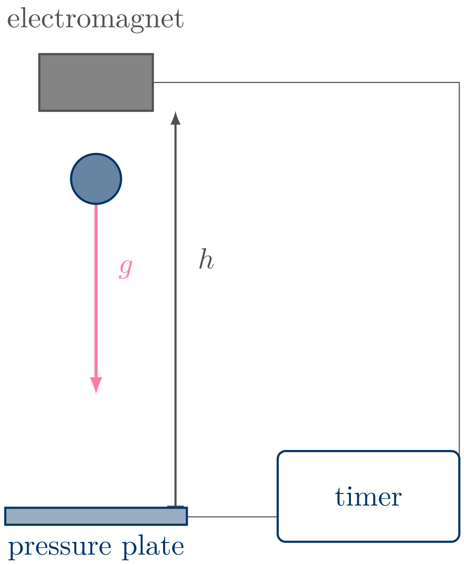
Experiment: Determining g Using a Falling Object

Method — Electromagnetic Release and Trapdoor Timer

1. A steel ball is held by an electromagnet at a measured height h above a trapdoor switch.
2. The circuit is broken simultaneously: the ball is released and a millisecond timer starts.
3. When the ball hits the pressure plate the timer stops, giving the time of fall t.
4. Use $h = \frac{1}{2}gt^2$ (with $u = 0$) to find g:

$$g = \frac{2h}{t^2}$$

5. Repeat for several values of h; plot h against t^2 — the gradient equals $g/2$.



Sources of Uncertainty and Improvements

- **Reaction time**: eliminated by electronic (not manual) timing.
- **Residual magnetism**: the ball may not release instantly — add a thin bit of tape between the ball and the magnet.
- **Air resistance**: use a dense, compact sphere to minimise drag.
- **Height measurement**: measure from the *bottom* of the ball to the pressure plate; use a ruler held vertically alongside.
- **Graph method**: plotting h vs t^2 and finding the gradient $= g/2$ averages over many measurements, reducing random error.

Projectile Motion

Projectile Motion

A **projectile** moves under gravity alone after launch. Its motion resolves into two **independent** components:

- **Horizontal**: uniform velocity (no force, so no acceleration).
- **Vertical**: uniform acceleration downwards at $g = 9.81\ \mathrm{m\,s^{-2}}$.

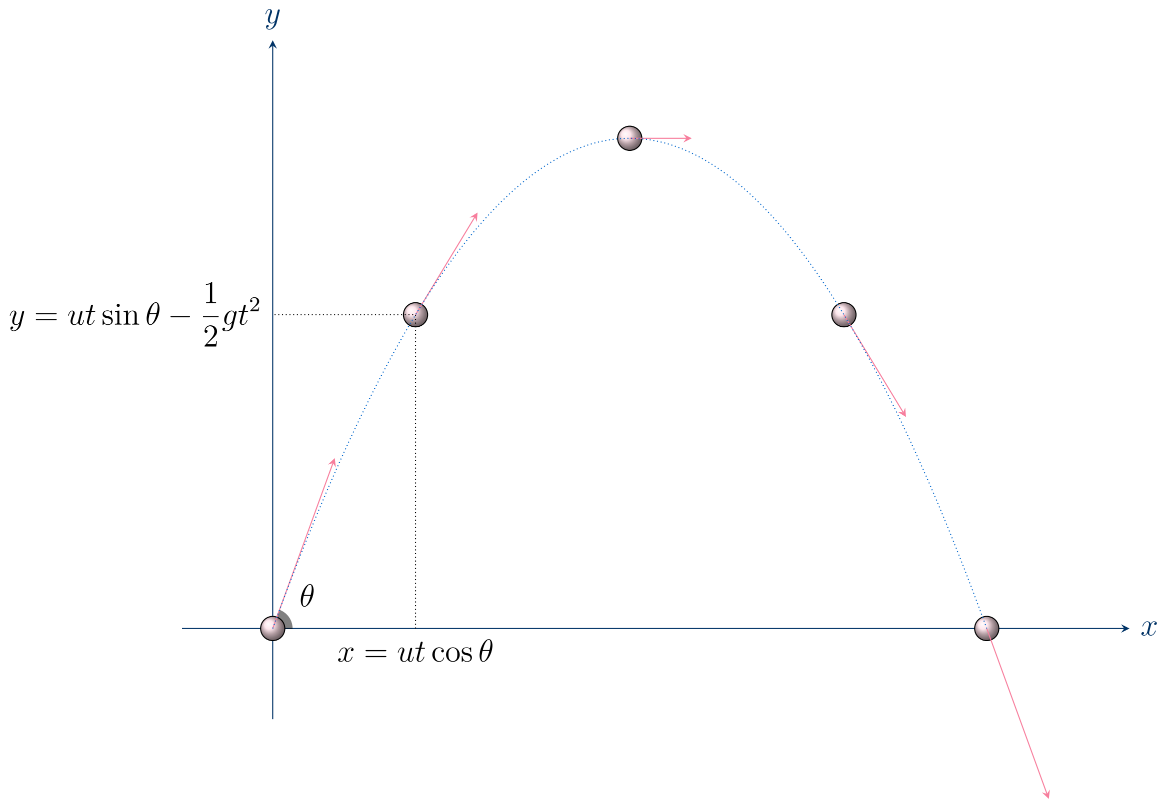
The two components share the same time t but are otherwise treated separately.

Projectile Equations

For a projectile launched with speed u at an angle θ to the horizontal :

	Horizontal	**Vertical**
Initial velocity	$u_x = ucos\theta$	$u_y = usin\theta$
Acceleration	0	g (downwards)
Velocity at time t	$v_x = ucos\theta$	$v_y = usin\theta - gt$
Displacement at time t	$x = utcos\theta$	$y = utsin\theta - \frac{1}{2}gt^2$

Resultant speed: $v = \sqrt{v_x^2 + v_y^2}$ Angle from horizontal: $\theta = \arctan\left(\frac{v_y}{v_x}\right)$



Common Mistakes in Projectile Problems

- Never mix horizontal and vertical quantities in the same SUVAT equation.
- The horizontal velocity **does not change** (no air resistance assumed).
- Time is the same for both components — find t from the vertical motion first.
- For a horizontal launch: $u_x = u$, $u_y = 0$.

Worked Examples

Example 1 — SUVAT: Braking Car

Question: A car travelling at 30 $\mathrm{m\,s^{-1}}$ brakes uniformly and stops in 4.5 s. Calculate (a) the deceleration and (b) the stopping distance.

Solution

Known: $u = 30\ \mathrm{m\,s^{-1}}$, $v = 0$, $t = 4.5$ s
(a) Use $v = u + at$:

$$0 = 30 + a \times 4.5 \quad \Rightarrow \quad a = \frac{-30}{4.5} = \mathbf{-6.7}\ \mathrm{m\,s^{-2}}$$

(b) Use $s = \frac{1}{2}(u+v)t$:

$$s = \tfrac{1}{2}(30+0)(4.5) = \mathbf{67.5}\ \mathrm{m}$$

Example 2 — Free Fall

Question: A stone is dropped from rest off a cliff and hits the water 3.2 s later. Calculate (a) the height of the cliff and (b) the speed on impact.

Solution

Known: $u = 0$, $a = 9.81\ \mathrm{m\,s^{-2}}$, $t = 3.2$ s
(a) Use $s = ut + \frac{1}{2}at^2$:

$$s = 0 + \tfrac{1}{2}(9.81)(3.2)^2 = \tfrac{1}{2} \times 9.81 \times 10.24 = \mathbf{50.2}\ \mathrm{m}$$

(b) Use $v = u + at$:

$$v = 0 + 9.81 \times 3.2 = \mathbf{31.4}\ \mathrm{m\,s^{-1}}$$

Example 3 — Projectile Motion

Question: A ball is launched horizontally at 15 $\mathrm{m\,s^{-1}}$ from a platform 20 m above the ground. Calculate (a) the time of flight and (b) the horizontal range.

Solution

(a) Vertical motion ($u_y = 0$, $a = 9.81\ \mathrm{m\,s^{-2}}$, $s = 20$ m):

$$20 = \tfrac{1}{2}(9.81)t^2 \quad \Rightarrow \quad t^2 = \frac{20}{4.905} \quad \Rightarrow \quad t = \mathbf{2.02}\ \mathrm{s}$$

(b) Horizontal motion ($u_x = 15\ \mathrm{m\,s^{-1}}$, constant):

$$x = u_x \times t = 15 \times 2.02 = \mathbf{30.3}\ \mathrm{m}$$

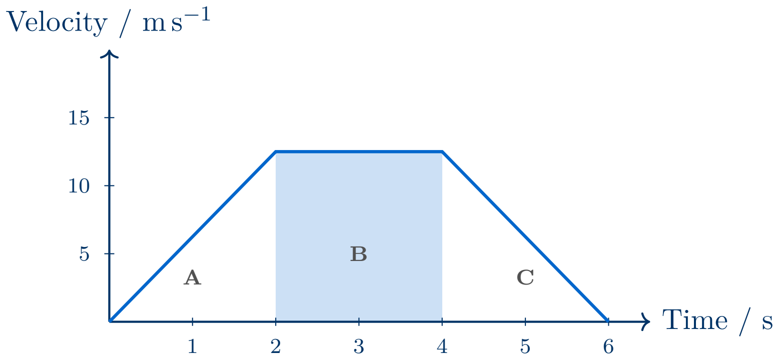
Practice Exam Questions

Section A — Short Answer Questions

Q1. Distinguish between *distance* and *displacement*, and between *speed* and *velocity*.

[4 marks]

Q2. The velocity–time graph below shows the motion of an object. Describe the motion in each labelled region and state what the shaded area represents.



[4 marks]

Q3. Define acceleration and state its SI unit.

[2 marks]

Q4. State the two conditions under which the SUVAT equations are valid.

[2 marks]

Section B — Longer Structured Questions

Q5. A student drops a ball bearing from rest and measures the time t it takes to fall a height h. The results are shown in the table below.

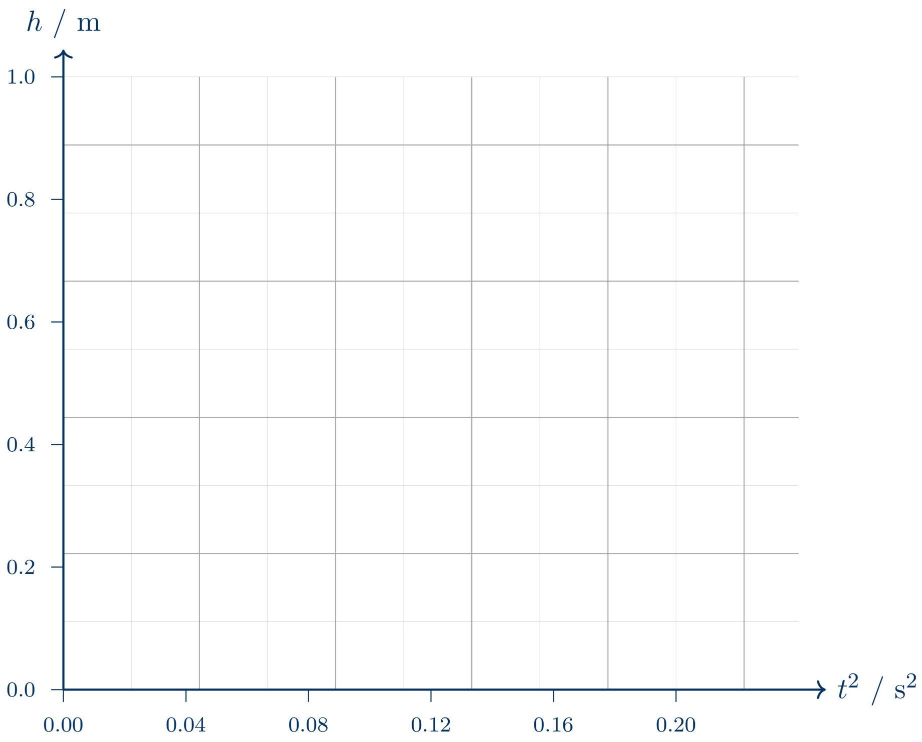
Height h **/ m**	**Time** t **/ s**	t^2 / s^2
0.20	0.202	
0.40	0.285	
0.60	0.350	
0.80	0.404	
1.00	0.451	

(a) Complete the t^2 column in the table above.

[1 mark]

(b) Plot a graph of h (y-axis) against t^2 (x-axis) on the grid below and draw a best-fit straight line.

[3 marks]



(c) Determine the gradient of your line and use it to calculate g.

[3 marks]

(d) Suggest one source of systematic error in this experiment and explain how it would affect the value of g obtained.

[2 marks]

Q6. A ball is kicked horizontally from the top of a vertical cliff at a speed of 12 $\mathrm{m\,s^{-1}}$. The ball lands 35 m from the base of the cliff.

(a) Show that the time of flight is approximately 2.9 s.

[2 marks]

(b) Calculate the height of the cliff.

[2 marks]

(c) Calculate the speed and direction of the ball just before it hits the ground.

[3 marks]

Mark Scheme and Answers

Q1. Distance is a scalar — the total length of path travelled [1]; displacement is a vector — the straight-line distance in a specified direction from start to finish [1]. Speed is the scalar rate of change of distance [1]; velocity is the vector rate of change of displacement [1].

Q2. Region A: uniform acceleration (straight line, positive gradient) [1]; Region B: constant velocity (horizontal line, zero acceleration) [1]; Region C: uniform deceleration to rest (straight line, negative gradient) [1]; shaded area = displacement during region B [1].

Q3. Acceleration is the rate of change of velocity [1]; SI unit: $\mathrm{m\,s^{-2}}$ [1].

Q4. Acceleration must be **uniform** (constant) [1]; motion must be in a **straight line** [1].

Q5(a). t^2 values (3 s.f.): 0.0408, 0.0812, 0.1225, 0.1632, 0.2034 $\mathrm{s^2}$ [1].

Q5(b). Points plotted correctly to within half a small square [1]; sensible scale used [1]; best-fit straight line through or close to the origin [1].

Q5(c). Gradient = $\Delta h/\Delta t^2$ read from the line using a large triangle [1]; since $h = \frac{1}{2}g\,t^2$, gradient = $g/2$ [1]; $g = 2 \times$ gradient $\approx$ **9.8** $\mathbf{m\,s^{-2}}$ [1].

Q5(d). Any valid systematic error, e.g. residual magnetism delays the ball's release, so the ball already has a small downward velocity when the timer starts [1]; this makes the measured t smaller than the true fall time, so t^2 is underestimated, the gradient is too large, and the calculated value of g is **too high** [1].

Q6(a). Horizontal: $x = u_x t$, so $t = 35/12 = 2.92$ s ≈ 2.9 s [2].

Q6(b). $h = \frac{1}{2}g\,t^2 = \frac{1}{2} \times 9.81 \times (2.92)^2 =$ **41.8** m [2].

Q6(c). $v_y = g\,t = 9.81 \times 2.92 = 28.6\ \mathrm{m\,s^{-1}}$ [1]; resultant speed $= \sqrt{12^2 + 28.6^2} =$ **31.0** $\mathbf{m\,s^{-1}}$ [1]; angle below horizontal = arctan(28.6/12) = **67.2**ř [1].

Revision Checklist

Use this checklist to track your understanding. Tick each box when you are confident:

	Learning Objective	Confidence (1–3)
☐	Define and distinguish distance, displacement, speed, velocity and acceleration	
☐	Determine velocity from the gradient of a displacement–time graph	
☐	Determine acceleration from the gradient of a velocity–time graph	
☐	Determine displacement from the area under a velocity–time graph	
☐	Derive the four SUVAT equations from the definitions of v and a	
☐	Select and apply the correct SUVAT equation to solve problems	
☐	Describe the free-fall experiment and identify sources of uncertainty	
☐	Use $h = \frac{1}{2}gt^2$ and a graph of h vs t^2 to determine g	
☐	Resolve projectile motion into independent horizontal and vertical components	
☐	Calculate range, time of flight, and velocity components for a projectile	

Key: 1 = Need more work   2 = Getting there   3 = Confident

Good luck with your revision!

Remember: always define a positive direction before starting a SUVAT problem, and keep horizontal and vertical components completely separate in projectile questions.