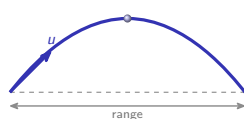


Kinematics

AS Physics ■ Topic 2

A-Level Physics



Kinematics

What we will cover

- 1 Describing motion
- 2 Motion graphs
- 3 The SUVAT equations
- 4 Free fall under gravity
- 5 Projectile motion
- 6 Problem-solving recap

1 Describing motion

Kinematics

Describing motion

From position to acceleration

Each quantity is the **rate of change** of the one before it:



Speedometer

Each has a **scalar** partner – **distance**, **speed** – with size but no direction.

Kinematics

Describing motion

Distance vs displacement

- **distance** – the whole path walked (a **scalar**)
- **displacement** 位移 – start to end in a straight line, **with direction** (a **vector**)

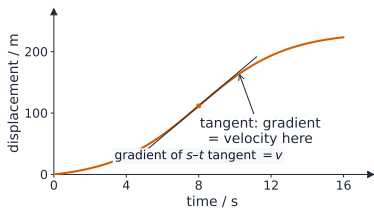
Walk a full loop: distance is large, displacement is **zero**.



Train motion

2 Motion graphs

Displacement–time graphs



The **gradient** 斜率 of a displacement–time graph = **velocity**.

- flat line → at rest
- straight slope → constant velocity
- curve → changing velocity

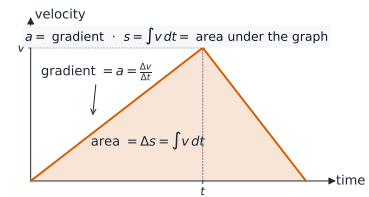
For a curve, draw a **tangent** 切线 and find its gradient.

Velocity–time graphs

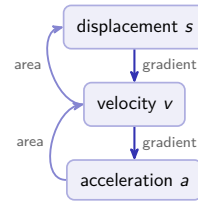
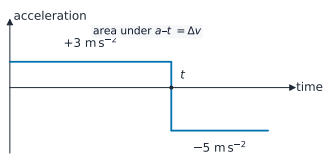
Two readings from one graph:

- **gradient** = acceleration
- **area** under the line = displacement

Area below the axis is *negative* – the object moved backwards.



Gradient and area – at a glance



Gradient of s - t is v ; gradient of v - t is a . Area under v - t is s ; area under a - t is Δv .

3 SUVAT equations

The four SUVAT equations

Straight line, **uniform acceleration** 匀加速: five symbols u, v, a, s, t – each equation drops one.

$$v = u + at$$

no s

$$s = ut + \frac{1}{2}at^2$$

no v

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

no a

$$v^2 = u^2 + 2as$$

no t

Pick the equation that holds your three knowns *and* your unknown.

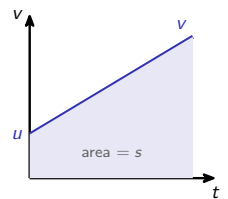
Worked example – find the acceleration

Car: $u = 8$, $v = 20 \text{ m s}^{-1}$ over $s = 56 \text{ m}$

Knowns u, v, s ; want a , so use $v^2 = u^2 + 2as$:

$$20^2 = 8^2 + 2a(56)$$

$$336 = 112a \Rightarrow a = 3.0 \text{ m s}^{-2}.$$



Kinematics

SUVAT equations

Where SUVAT comes from

All four follow from the velocity–time graph:

- $v = u + at$ – the **gradient** is a
- $s = \frac{1}{2}(u + v)t$ – area of a **trapezium** 梯形
- $s = ut + \frac{1}{2}at^2$ – sub $v = u + at$
- $v^2 = u^2 + 2as$ – eliminate t

Kinematics

SUVAT equations

Choose a positive direction

Pick one direction as + and keep it. Anything the other way gets a **minus sign**.

Ball thrown up, “up” positive: $u > 0$, $a = -g$, and at the top $v = 0$ but $s > 0$.

4

Free fall

Kinematics

Free fall

Free fall under gravity

Ignore **air resistance** 空气阻力: **free fall** 自由落体 has constant $g \approx 9.81 \text{ m s}^{-2}$ downward. Dropped from rest, fallen a height h :

$$h = \frac{1}{2}gt^2, \quad v = gt, \quad v^2 = 2gh.$$

Same for **every mass** – a feather and a hammer fall together in a vacuum.

Kinematics

Free fall

Worked example – greatest height

Thrown straight up at $u = 20 \text{ m s}^{-1}$

At the top $v = 0$, so $h = \frac{u^2}{2g}$:

$$h = \frac{20^2}{2 \times 9.81} = \frac{400}{19.62} \approx 20.4 \text{ m}.$$

Up and back is **symmetric** 对称: total time = $2u/g$.

Kinematics

Free fall

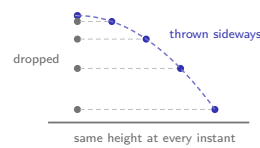
Experiment – measuring g

Drop from rest; measure height h and time t : $g = \frac{2h}{t^2}$.

- plot h against $t^2 \Rightarrow \text{gradient} = g/2$
- repeat $\Rightarrow$ less **random error** 随机误差
- light gates** 光电门 remove reaction-time error

5 Projectiles

Two independent motions



A **projectile** 抛体 has two motions that do not affect each other:

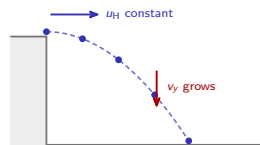
- **horizontal** 水平: constant velocity
- **vertical** 竖直: free fall at g

Solve each as its own SUVAT problem – linked only by the time t .

Horizontal throw

- horizontal: $x = u_H t$ (constant)
- vertical: $y = \frac{1}{2} g t^2$ (from rest)

Time to land depends **only on the height** – not on u_H .



Cliff $h = 20 \text{ m}$, $u_H = 15 \text{ m s}^{-1}$

$$t = \sqrt{2h/g} \approx 2.0 \text{ s}$$

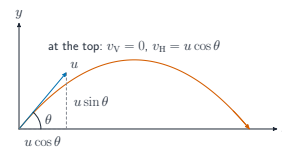
$$\text{range} = u_H t \approx 30 \text{ m}$$

Launched at an angle

Resolve the launch speed u into **components** 分量:

- $u_H = u \cos \theta$ – stays constant
- $u_V = u \sin \theta$ – falls to 0 at the top

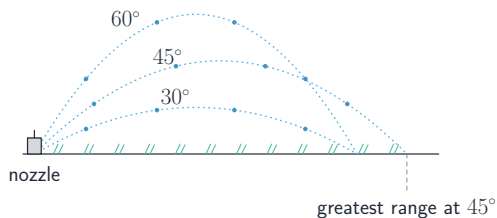
Time to the top: $t = \frac{u \sin \theta}{g}$.



Every projectile traces a parabola

Constant horizontal velocity with constant vertical acceleration gives a **parabola** — the same curve for a sprinkler, a ball or a shell.

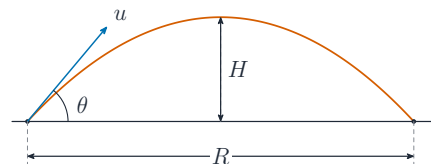
each jet follows a parabola



Range and maximum height

From level ground, back to the same height:

- total flight time $= 2 t_{\text{up}}$
- **range** 射程 $R = u_H \times \text{flight time}$
- greatest range at $\theta = 45^\circ$



6 Putting it together

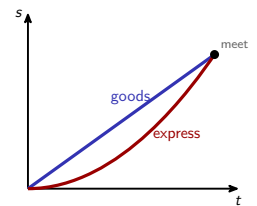
Two objects meeting

Same start time, same positive direction; set the displacements equal.

Goods train (constant u_G) and express (from rest, accel. a):

$$s_G = u_G t, \quad s_E = \frac{1}{2} a t^2.$$

Level again when $s_G = s_E$: $t = \frac{2u_G}{a}$.



Solving any kinematics problem

- 1 Draw a diagram; mark + direction
- 2 List the SUVAT symbols & signs
- 3 Pick the equation with your 4 symbols
- 4 Projectiles: split H & V, linked by t

5. check the units and the size of your answer

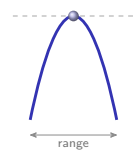
7 Recap

Topic 2 – key takeaways

- 1 **Vectors**
displacement, velocity, acceleration have direction
- 2 **Graphs**
gradient & area read off velocity and displacement
- 3 **SUVAT**
four equations for uniform acceleration
- 4 **Projectiles**
split into independent H and V motions

Check yourself

- 1 What does the **area** under a $v-t$ graph give?
- 2 A stone dropped from rest falls for 3 s – how far?
- 3 Two balls, one dropped, one thrown sideways – which lands first?
- 4 Best launch angle for maximum range?



Answers 1. displacement 2. $h = \frac{1}{2} g t^2 \approx 44 \text{ m}$ 3. same time (equal heights) 4. 45°