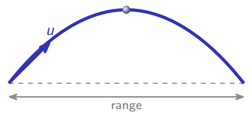
Kinematics

AS Physics ▪ Topic 2

A-Level Physics



What we will cover

1 Describing motion

From position to acceleration

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

displacement 位移 (vector ▪ m) $\xrightarrow{\div t}$ **velocity** 速度 (vector ▪ m s^{-1}) $\xrightarrow{\div t}$ **acceleration** 加 (vector

Speedometer

> Each is the rate of change *with time* of the one before it, and each has a scalar partner – **distance**, **speed**. Learn the exact words: the examiner gives marks for precise wording.

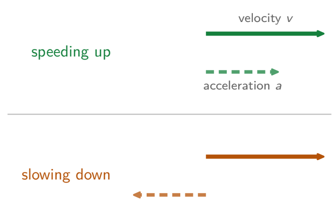
Distance vs displacement

- **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

Deceleration is not a separate quantity

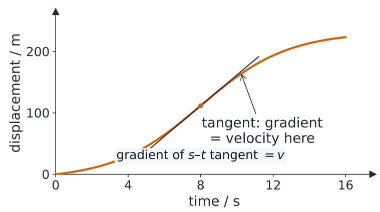


Deceleration 减速度 just means the acceleration points the opposite way to the velocity.

> It is not a separate quantity. In SUVAT, put it in as a negative a and let the signs do the work.

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

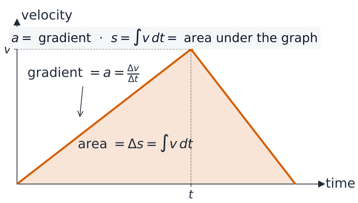
For a curve, draw a **tangent** 切线 and find *its* gradient.

Velocity–time graphs

Two readings from one graph:

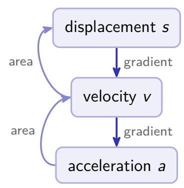
- gradient = acceleration
- area under the line = displacement

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

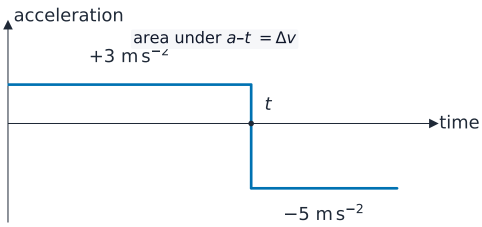


Gradient and area – at a glance

Two graphs carry most of the marks – displacement–time and velocity–time. Going down the chain you take a gradient; going up it you take an area.



Gradient and area – at a glance, in detail



Acceleration–time graph derived from the same motion

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.

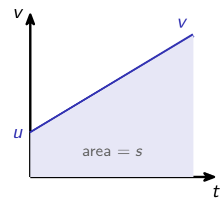
Worked example – find the acceleration

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

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

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

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

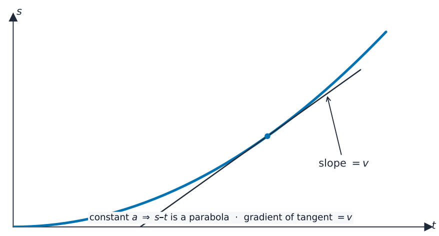


Where SUVAT comes from

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

Where SUVAT comes from, in detail

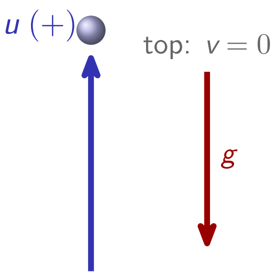


All four follow from the velocity–time graph.

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 $s > 0$.



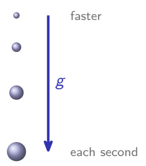
4 Free fall

Free fall under gravity

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

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

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



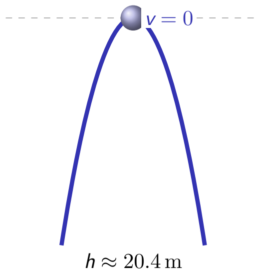
Worked example – greatest height

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

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

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

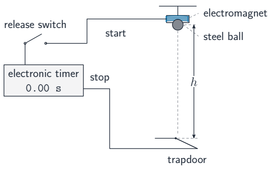
Up and back is **symmetric** 对称: total time $= 2u/g$.



Experiment – measuring g

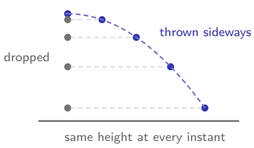
Drop from rest; measure height h and time t: $g = \dfrac{2h}{t^2}$.

- plot h against t^2 ⇒ gradient $= g/2$
- repeat ⇒ 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:

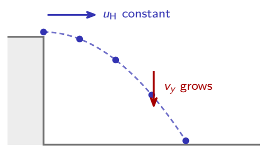
- **horizontal** 水平: constant velocity
- **vertical** 竖直: free fall at g

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

Horizontal throw

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

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



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

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

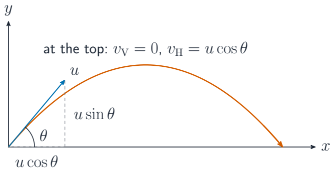
range $= u_H t \approx 30\,\mathrm{m}$

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: $t = \dfrac{u\sin\theta}{g}$.



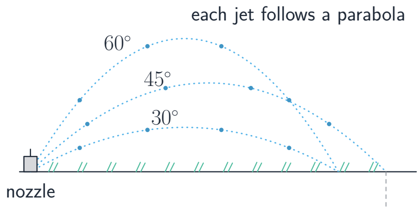
Bouncing ball

When a ball bounces, its velocity–time graph is a set of straight sloping lines (constant g) with a sudden jump at each bounce (the velocity flips direction and **energy** 能量 is lost.

> Add up the times and the distances across the bounces.

Every projectile traces a parabola

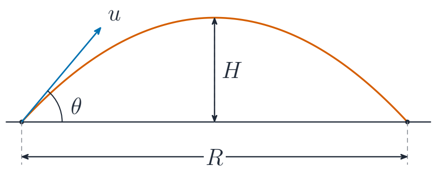
> Constant horizontal velocity with constant vertical acceleration gives a parabola – the same curve for a sprinkler, a ball or a shell.



Range and maximum height

From level ground, back to the same height:

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



6 Putting it together

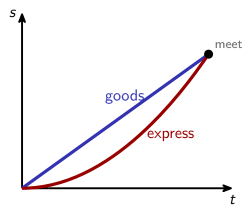
Two objects meeting

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

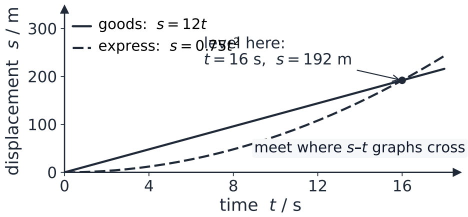
Goods train (constant u_G) and express (from rest, accel. a):

$$s_G = u_G t, \qquad s_E = \tfrac{1}{2}at^2.$$

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



Where the two graphs cross, the objects meet



> Same s at the same t – that crossing point is the meeting: read t off the time axis.

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

Exam tips

- Use the **SUVAT** equations only for **constant acceleration**; list s, u, v, a, t and pick the equation missing your unknown.
- Choose one direction as **positive** and keep signs consistent (usually $g = -9.81$ m s^{-2}).
- On a **velocity-time graph**, gradient = acceleration and area = displacement.
- For projectiles, treat **horizontal (constant velocity) and vertical ($a = g$) motion separately**, linked by the same time.

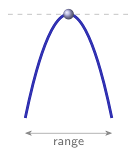
7 Recap

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 $3\,\mathrm{s}$ – how far?
3. Two balls, one dropped, one thrown sideways – which lands first?
4. Best launch angle for maximum range?



> **Answers** **1.** displacement **2.** $h = \frac{1}{2}gt^2 \approx 44\,\mathrm{m}$ **3.** same time (equal heights) **4.** $45°$