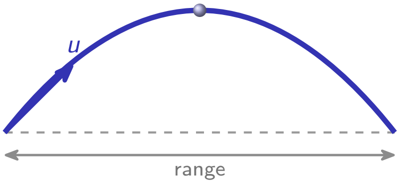
Kinematics

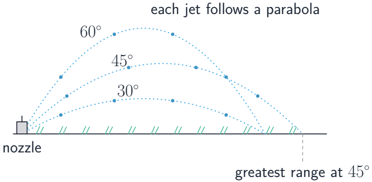
AS Physics ▪ Topic 2

A-Level Physics



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



From position to acceleration

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

displacement
位移
vector ▪ m

$\div t$ →

velocity
速度
vector ▪ $\mathrm{m\,s^{-1}}$

speedometer

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

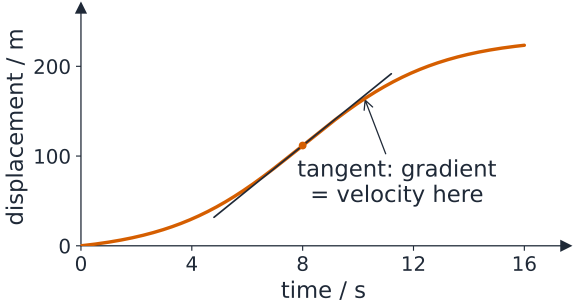
Distance vs displacement

- **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

Displacement–time graphs

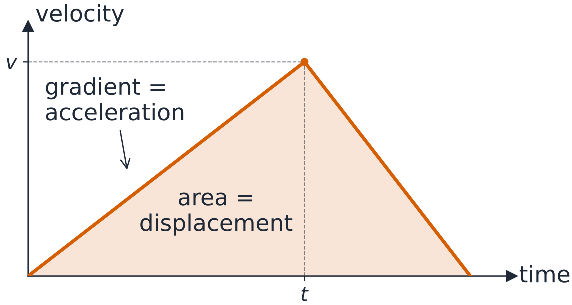


The gradient 斜率 of a displacement–time graph = **velocity**.

- 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

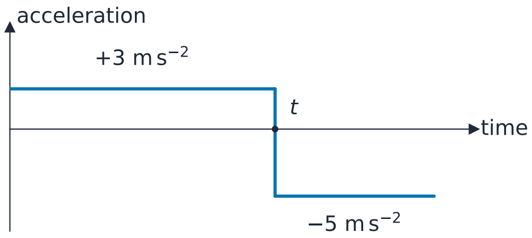


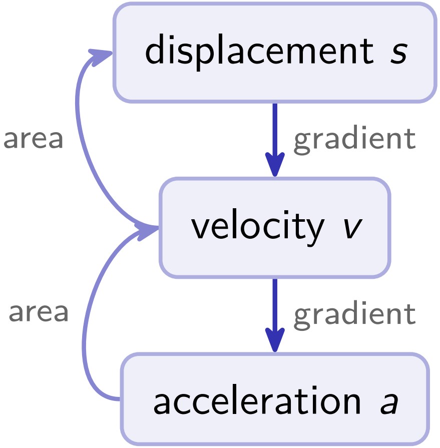
Two readings from one graph:

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

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

Gradient and area – at a glance





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.

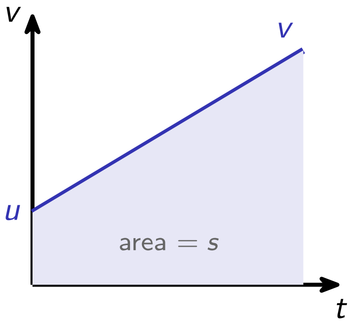
Worked example – find the acceleration

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

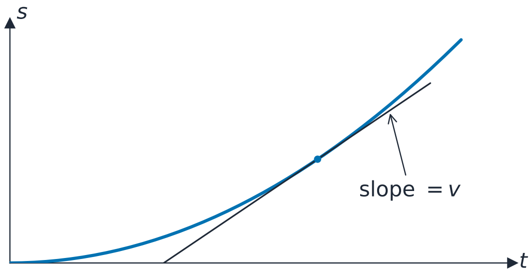
Knowns u, v, s; want a, so use $v^2 = u^2 + 2as$:

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

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



Where SUVAT comes from



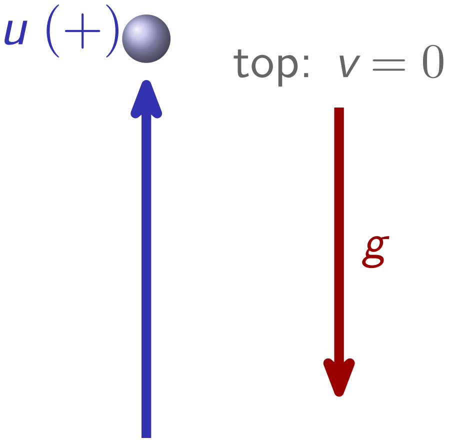
All four follow from the velocity–time graph:

- $v = u + at$ – 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

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 $s > 0$.

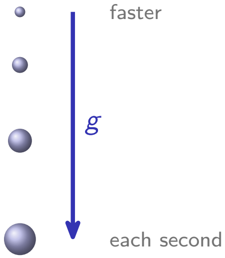


Free fall under gravity

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.



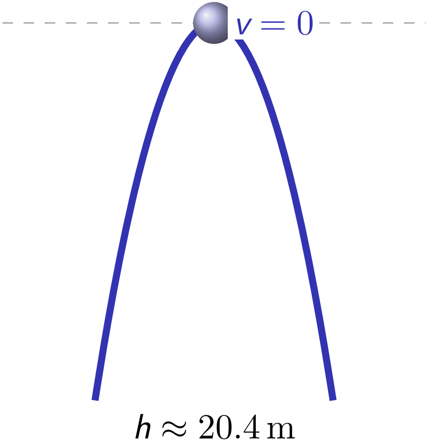
Worked example – greatest height

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

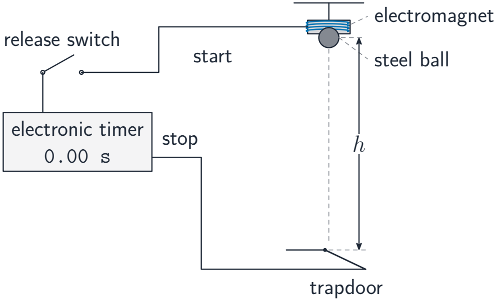
At the top $v = 0$, so $h = \dfrac{u^2}{2g}$:

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

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



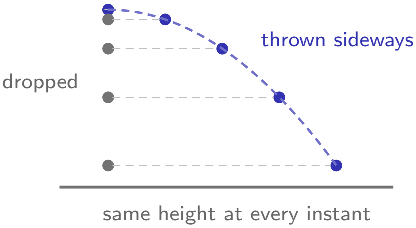
Experiment – measuring g



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

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

Two independent motions



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

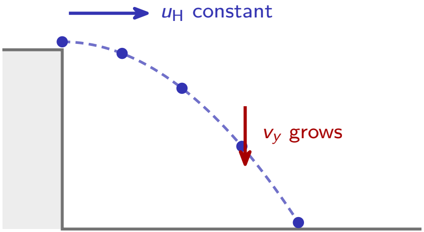
- **horizontal** 水平: constant velocity
- **vertical** 竖直: free fall at g

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

Horizontal throw

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

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

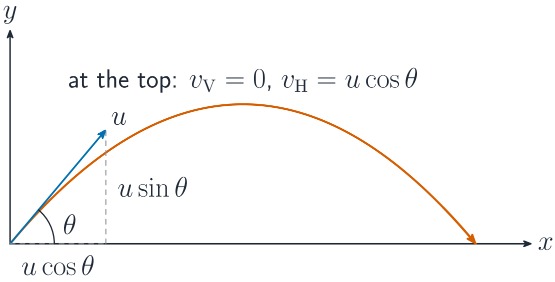


Cliff $h = 20\,\mathrm{m}$, $u_\mathrm{H} = 15\,\mathrm{m\,s^{-1}}$

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

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

Launched at an angle

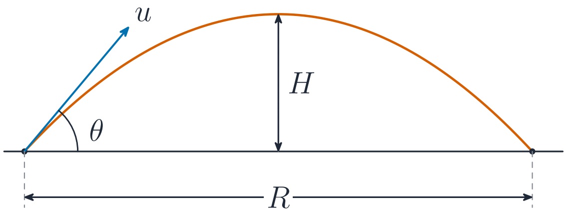


Resolve the launch speed u into **components** 分量:

- $u_{\mathrm{H}} = u\cos\theta$ – stays constant
- $u_{\mathrm{V}} = u\sin\theta$ – falls to 0 at the top

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

Range and maximum height



From level ground, back to the same height:

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

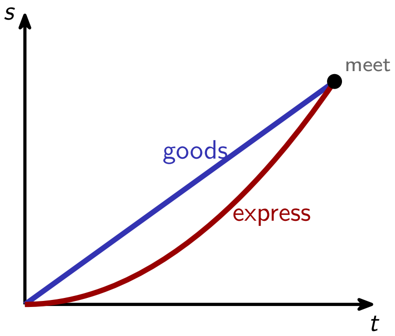
Two objects meeting

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

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

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

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



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

Topic 2 – key takeaways

1 Vectors

displacement, velocity, acceleration have direction

2 Graphs

gradient & area read off velocity and displacement

3 SUVAT

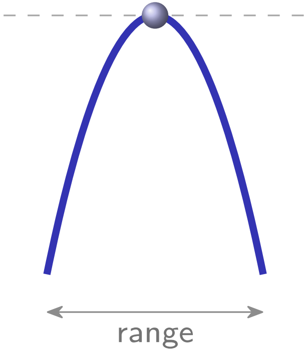
four equations for uniform acceleration

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.** $45°$