Kinematics

A.1 · SL and HL

600 m flown, zero displacement

Physics needs a **scalar** (**distance**) and a **vector** (displacement) for the two answers.

- A drone flies 300 m east, then 300 m back west.
- Its trip meter reads 600 m; it ends where it started.
- This unit: describing motion $\rightarrow$ graphs $\rightarrow$ equations $\rightarrow$ projectiles $\rightarrow$ drag.

Scalars and vectors of motion

Distance, speed

Total path length.

Average speed = total **distance** ÷ elapsed time.

Displacement, velocity

Change in position, with direction.

Velocity = rate of change of **displacement**.

Acceleration

- Speeding up, slowing down or changing direction are all accelerations.
- A car on a bend at steady speed is accelerating.

Acceleration rate of change of velocity; **average** $\bar{a} = \Delta v/\Delta t$ over a finite interval ($\mathrm{m\,s^{-2}}$).

Average or instantaneous?

Average

Uses a whole interval.

Total **displacement** $\div$ total time.

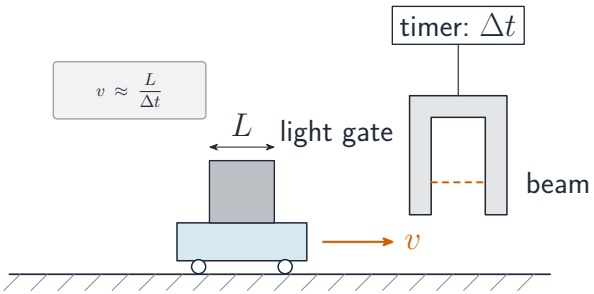
Instantaneous

The value at one moment.

A speedometer reading.

A light gate trades a shorter averaging interval against timing and length uncertainty.

Measuring speed with a light gate

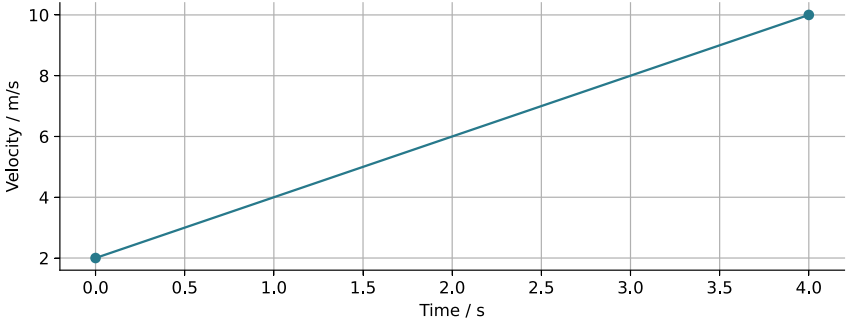


A short card gives a speed close to the **instantaneous** value

Gradients and areas

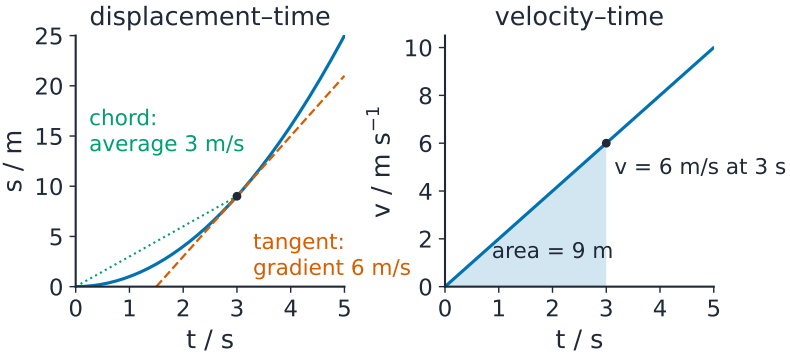
Graph	**Gradient**	**Area under**
s–t	velocity	—
v–t	acceleration	**displacement**
a–t	—	change in velocity

A straight velocity–time line



- Gradient $= (10 - 2)/4 = 2.0$ m s^{-2}.
- Trapezium area $= \frac{1}{2}(2 + 10) \times 4 = 24$ m.

Tangent or chord?



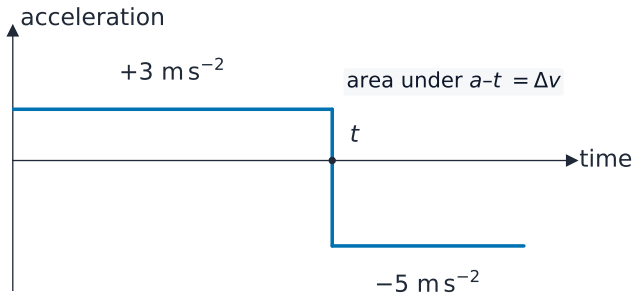
- **Tangent** at 3 s: gradient 6.0 m s^{-1}, the **instantaneous** velocity.
- Chord from 0 to 3 s: gradient 3.0 m s^{-1}, the **average** velocity.

Area below the axis

> A v–t line crossing the time axis means the object reverses.

- Area below the time axis is **displacement** in the negative direction.
- Add signed areas for displacement, sizes for **distance**.

Reading an acceleration–time graph



The area under a–t is the change in velocity

Four equations, five quantities

Leaves out	Equation
s	$v = u + at$
a	$s = \frac{1}{2}(u + v)t$
v	$s = ut + \frac{1}{2}at^2$
t	$v^2 = u^2 + 2as$

Worked example: braking

1. **List.** $u = 25$, $v = 0$, $s = 50$; t not needed.
2. **Choose.** $v^2 = u^2 + 2as$ gives $0 = 625 + 100a$.
3. **Time.** $50 = 12.5t$, so $t = 4.0$ s.

Decision

$a = -6.25$ m s^{-2}, against the motion

Free fall

For a vertical throw, at the top $v = 0$ but $a = 9.8$ m s^{-2} downwards.

- Thrown up at 12 m s^{-1}: top at 7.3 m after 1.2 s.
- Falling back, velocity and acceleration are both negative, so it speeds up.

Check: a ball thrown upwards

Your turn

A ball is thrown up at 15 m s^{-1}. What is its maximum height?

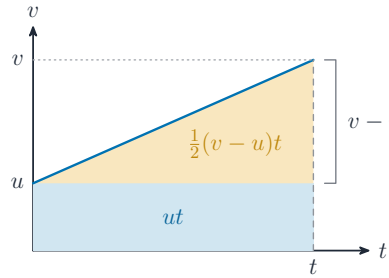
A. 0.77 m

B. 1.5 m

C. 11.5 m

D. 23 m

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



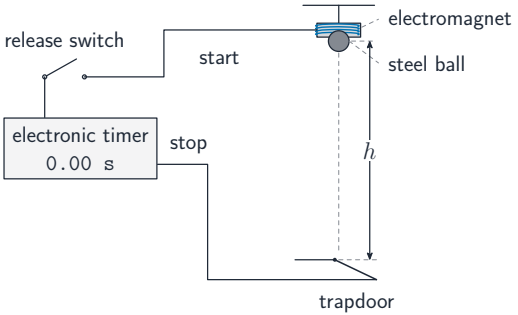
gradient $= a \Rightarrow v = u + at$

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

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

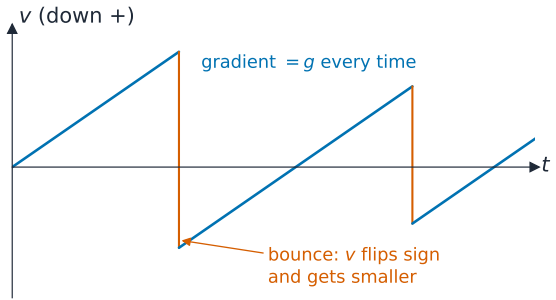
The area under the line is the **displacement**

Measuring g with a falling ball



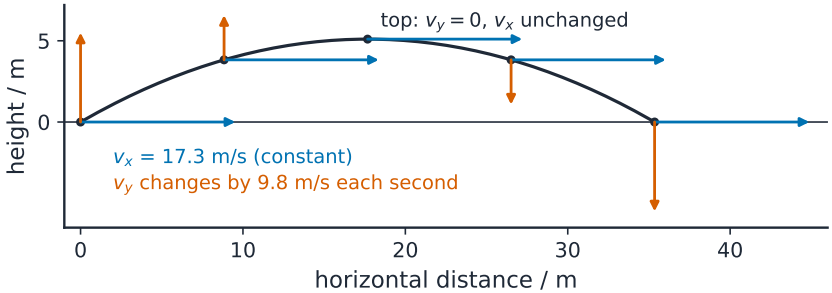
Plot h against t^2: the gradient is $\frac{1}{2}g$

A bouncing ball on a velocity–time graph



Each rebound is slower, so each flight is shorter

Two independent motions



- Horizontal: no force, so u_x stays constant.
- Vertical: acceleration g downwards; time links the two.

Launched horizontally

1. **Given** A ball leaves a 1.25 m table horizontally at 3.0 m/s; take g = 9.8 m/s^2. Find flight time, **range** and landing velocity.
2. **Vertical.** $1.25 = \frac{1}{2}(9.8)t^2$, so $t = 0.505$ s.
3. **Horizontal.** $x = 3.0 \times 0.505 = 1.5$ m.
4. **Landing.** $v_y = 4.9$ m s^{-1}, speed 5.8 m s^{-1} at 59° below horizontal.

Decision

Never put u_x into a vertical equation.

Launched at 30° above the horizontal

1. **Given** Launch at 20 m/s, 30° above horizontal; land at the launch level. Take g $= 9.8$ m/s^2.
2. **Resolve.** $u_x = 17.3$, $u_y = 10.0$ m s^{-1}.
3. **Flight time.** $0 = 10.0t - 4.9t^2$, so $t = 2.04$ s.
4. **Height.** $0 = 100 - 19.6h$, so $h = 5.1$ m.

Decision

Range $= 17.3 \times 2.04 = 35$ m

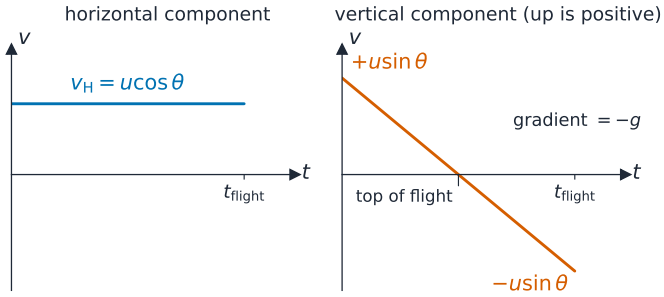
Launched below the horizontal

1. **Given** Launch at 15 m/s, 20° below horizontal, from a 30 m cliff; take g = 9.8 m/s^2.
2. **Resolve.** $u_x = 14.1$, $u_y = 5.13$ m s^{-1} down.
3. **Quadratic.** $30 = 5.13t + 4.9t^2$, so $t = 2.01$ s.
4. **Shortcut.** Landing speed $\sqrt{15^2 + 2(9.8)(30)} = 29$ m s^{-1} by energy.

Decision

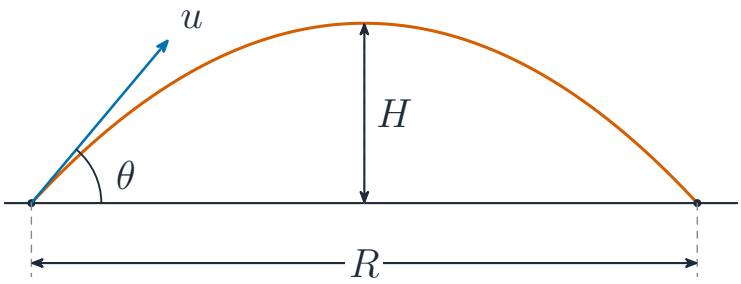
Lands $14.1 \times 2.01 = 28$ m out

The two velocity components of a projectile



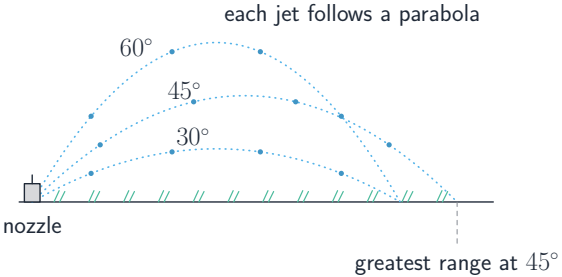
Vertical velocity is zero at the top, not the speed

Range and maximum height



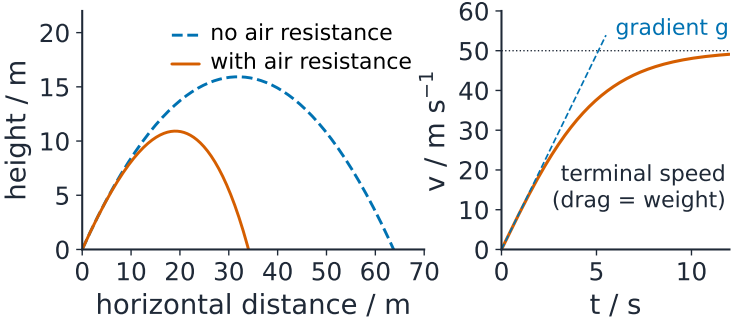
On level ground, the path is symmetric

The same speed at three angles



$30°$ and $60°$ land at the same **range**

What air does to a projectile



- **Drag** opposes the velocity and grows with speed.
- **Range** and height are smaller; the descent is steeper than the ascent.

Terminal speed

- At first acceleration is close to g; **drag** grows with speed.
- Opening a parachute makes drag exceed weight, so it decelerates to a lower **terminal speed**.

> **Terminal speed** the constant speed reached when drag equals weight, so the resultant force is zero

Exam tips

> Use the equations of motion only for constant acceleration.

- State the positive direction before you substitute.
- **Tangent** gradient is **instantaneous**; chord gradient is **average**.
- Time is the only quantity the two projectile directions share.

Check yourself

Try these

Find the total stopping distance at 30 m s^{-1} with 0.70 s reaction time and 6.0 m s^{-2} braking.

Find the range of a football kicked at 25 m s^{-1}, 40° above horizontal.

Sketch the v–t graph of a skydiver who opens a parachute.