

Straight-line motion with graphs and equations

AP Physics 1 (algebra-based) · Lesson

Quick answer: One-dimensional kinematics describes straight-line motion using position, velocity and acceleration, without asking what causes it. Velocity is the rate of change of position and acceleration is the rate of change of velocity. When acceleration is constant, four equations link displacement, velocities, acceleration and time.

Level: AP Physics 1 (algebra-based) · **Curriculum:** AP P1 Unit 1

What do position, velocity and acceleration measure?

Kinematics describes how an object moves along a line without asking what pushes it. Every quantity needs a sign: pick one direction as positive and keep it for the whole problem. A negative number then simply means the opposite direction.

Definition

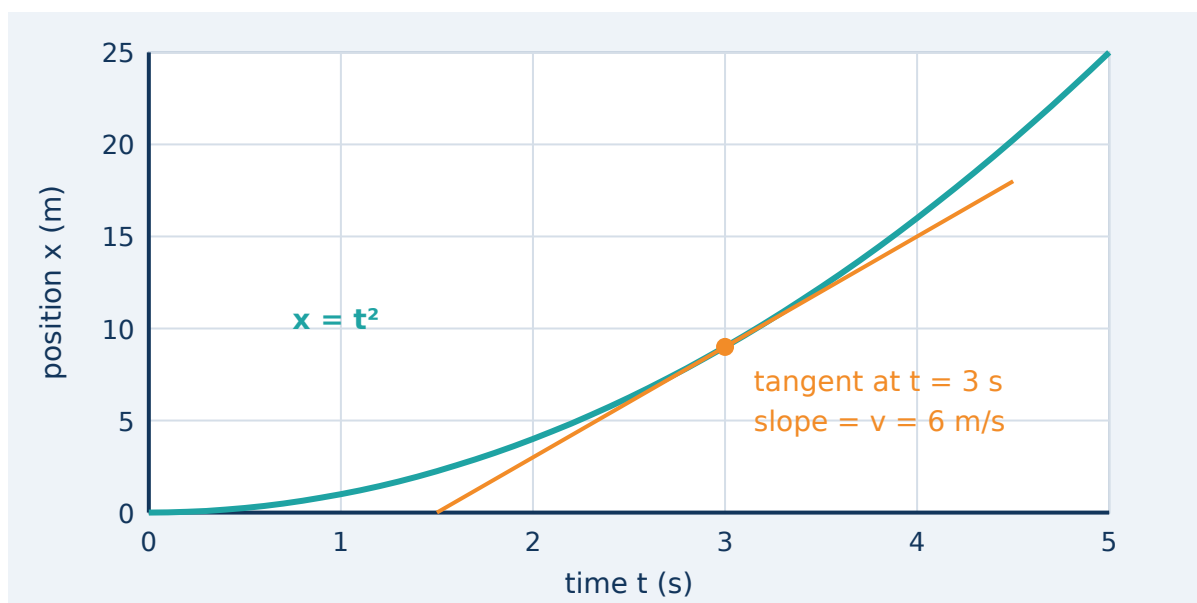
Displacement $\Delta x = x - x_0$ is the change in position, a vector. Distance is the total path length, a scalar. Average velocity is $v = \Delta x / \Delta t$, and average acceleration is $a = \Delta v / \Delta t$.

Speed is the size of the velocity. A runner who finishes a lap and stands where she started has covered a large distance but has zero displacement, so her average velocity is zero.

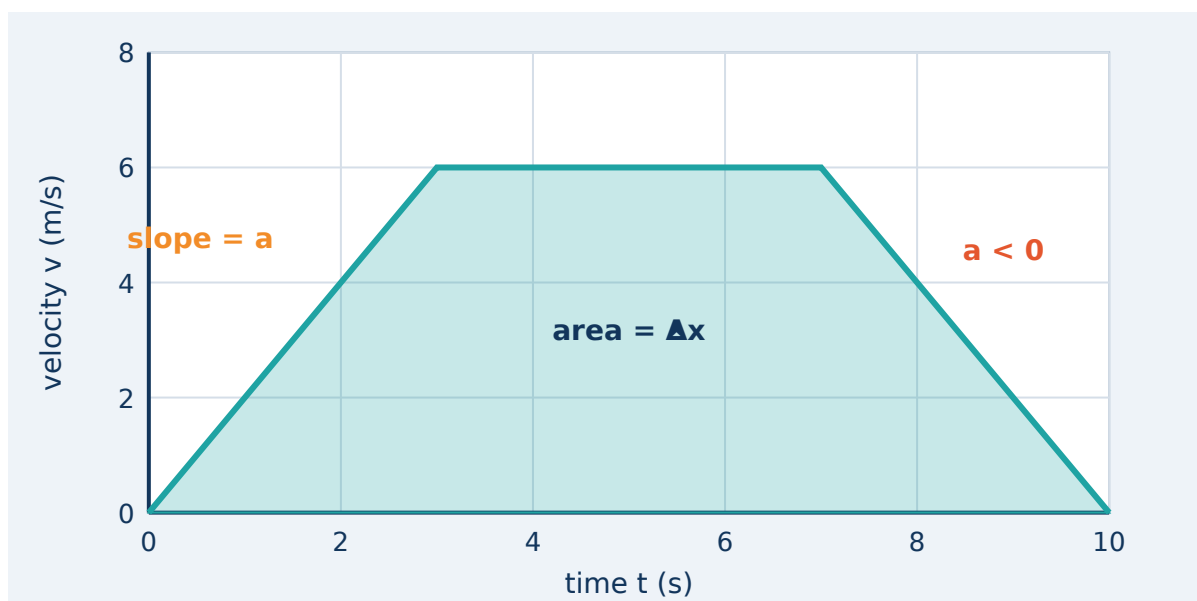
How do you read motion graphs?

A graph is a compact description of the motion. Look at what the slope means and what the area means, and many problems are solved without any equation.

Graph	Slope gives	Area under curve gives
position x against t	velocity	not used
velocity v against t	acceleration	displacement
acceleration a against t	not used	change in velocity



A steeper position-time curve means a larger velocity; the tangent at one instant gives the instantaneous velocity.



On a velocity-time graph the slope is the acceleration and the shaded area is the displacement; below the axis the area counts as negative.

When the velocity-time graph is a straight line the acceleration is constant. When it is a curve, the acceleration changes and the kinematic equations no longer apply.

Which equations work for constant acceleration?

Formula

$$v = v_0 + at$$

$$\Delta x = v_0 t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a\Delta x$$

$$\Delta x = \frac{1}{2}(v_0 + v)t$$

Here v_0 and v are the initial and final velocities (m/s), a is the constant acceleration (m/s²), t is the time (s) and Δx is the displacement (m).

Each equation leaves out one of the five variables. List what you know and what you want, then choose the equation that contains exactly those four.

Worked example

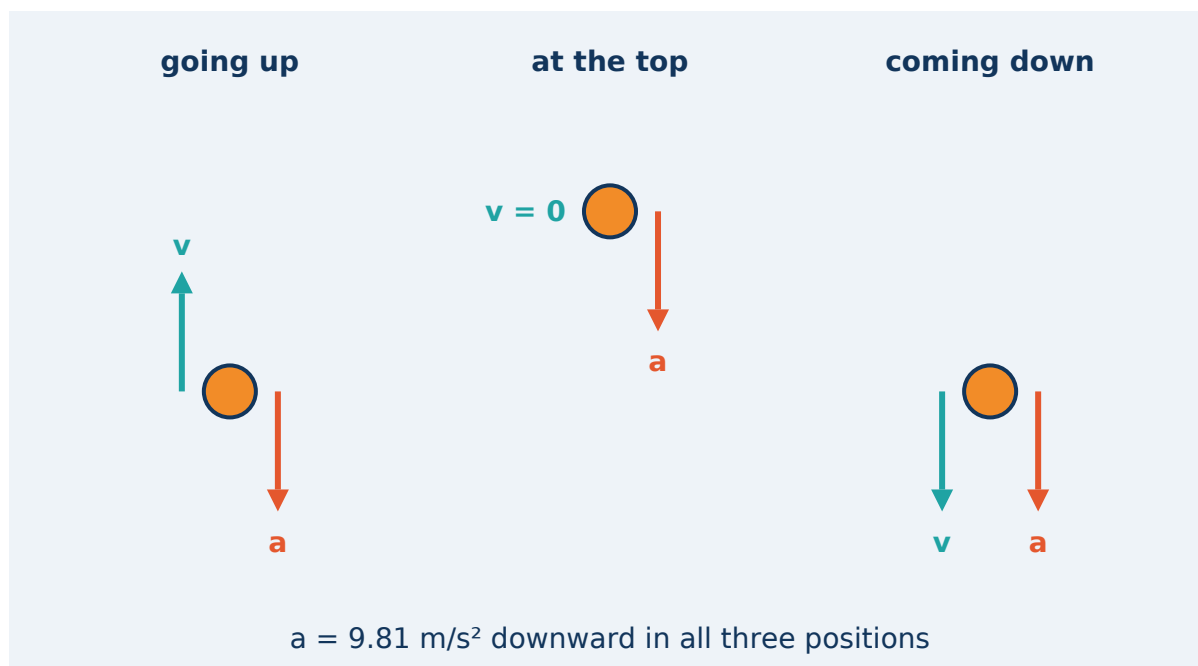
A skier moving at 4.0 m/s speeds up down a slope at 1.5 m/s² for 6.0 s. Find the final speed and the displacement.

$$v = v_0 + at = 4.0 + 1.5 \times 6.0 = 13 \text{ m/s. } \Delta x = v_0 t + \frac{1}{2}at^2 = 4.0 \times 6.0 + \frac{1}{2} \times 1.5 \times 6.0^2 = 24 + 27 = 51 \text{ m.}$$

Answer: **13 m/s and 51 m.**

How does free fall fit in?

Near Earth's surface, an object moving only under gravity has an acceleration of 9.81 m/s² downward, whatever its mass, when air resistance is ignored. The acceleration is the same while rising, at the top and while falling. Only the velocity changes sign.



The acceleration arrow never changes: it points downward all the way up, at the top and all the way down.

Worked example

A delivery drone hovers 45 m above a field and releases a parcel from rest. Take down as positive and ignore air resistance. Find the fall time and the landing speed.

$$\Delta y = \frac{1}{2}gt^2, \text{ so } t = \sqrt{(2 \times 45 / 9.81)} = \sqrt{9.174} = 3.03 \text{ s. Then } v = gt = 9.81 \times 3.03 = 29.7 \text{ m/s.}$$

Answer: **3.03 s and 29.7 m/s** downward.

Common mistake

Many students think a negative acceleration always means slowing down. An object slows down only when velocity and acceleration have opposite signs. A cart moving in the

negative direction with a negative acceleration speeds up.

Lina's tip

Before using any equation, write a list of the five variables with signs: Δx , v_0 , v , a , t . Cross out the one you neither know nor need. The equation that omits it is your tool.

How do AP questions test this topic?

AP Physics 1 often asks you to translate between representations: describe a graph in words, sketch the matching graph, or explain with an equation why a quantity changes. Always say what the slope or area represents, and justify claims with the sign of velocity and acceleration.

Key points to remember

- Average velocity = $\Delta x / \Delta t$ in m/s; average acceleration = $\Delta v / \Delta t$ in m/s^2 .
- Slope of an x-t graph is velocity; slope of a v-t graph is acceleration; area under a v-t graph is displacement.
- Constant acceleration: $v = v_0 + at$, $\Delta x = v_0 t + \frac{1}{2}at^2$, $v^2 = v_0^2 + 2a\Delta x$.
- Free fall with no air resistance: $a = 9.81 \text{ m/s}^2$ downward at every point of the flight.
- An object speeds up when velocity and acceleration have the same sign.

Straight-line motion with graphs and equations: frequently asked questions

What is the difference between distance and displacement?

Distance is the total length of the path and is never negative. Displacement is the straight-line change in position with a direction, so it can be zero or negative.

When can I use the kinematic equations?

Only when the acceleration is constant during the whole interval. If the acceleration changes, split the motion into stages where it is constant, or use graphs.

Why is the acceleration at the top of a thrown ball not zero?

The velocity is momentarily zero but is still changing at 9.81 m/s^2 downward. Acceleration measures how fast the velocity changes, not the velocity itself.

How do you find displacement from a velocity-time graph?

Find the area between the curve and the time axis. Area above the axis counts as positive displacement and area below it as negative.

Does a heavier object fall faster?

Not when air resistance is negligible. All objects in free fall share the acceleration 9.81 m/s^2 , so a heavy and a light ball dropped together land together.