Forces and motion

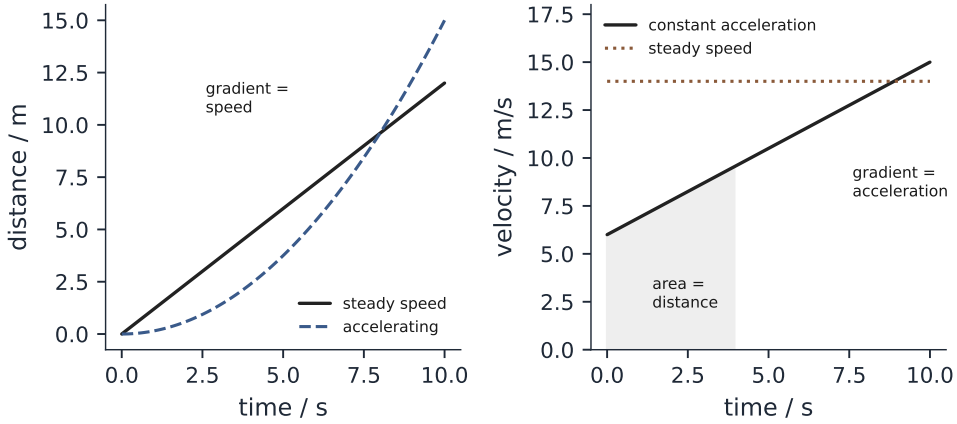
Pearson Edexcel · International GCSE · Physics

Describing and explaining motion

Physics begins with movement. This first section builds the toolkit: graphs that describe motion, the equations that link speed, acceleration and distance, the forces that cause every change, and (P) the momentum and moments that explain crumple zones and balanced beams.

Edexcel International GCSE Physics 4PH1, Section 1 (statements 1.1–1.33P). P-suffixed statements are the separate-science extension, assessed on Paper 2P; units to learn include the newton (N) and, (P), the newton metre and kg m/s.

Movement and position



Distance-time and velocity-time graphs: gradient means speed on one, acceleration on the other.

Average speed = distance moved ÷ time taken. On a distance–time graph the **gradient** is the speed: a straight sloping line is steady speed, a curve is acceleration, a flat line is at rest. **Acceleration** is the change of velocity per second:

$$a = \frac{v-u}{t} \qquad v^2 = u^2 + 2as$$

On a velocity–time graph the **gradient is acceleration** and the **area between the line and the time axis is the distance travelled**.

Worked check. A car accelerates from 4 m/s to 16 m/s in 6 s: $a = (16-4)/6 = 2$ m/s^2. Distance covered $= \frac{1}{2}(4+16) \times 6 = 60$ m.

> **Worked example ($v^2 = u^2 + 2as$).** A car travelling at 20 m/s brakes with a deceleration of 5.0 m/s^2. How far does it travel before it stops?

The car stops, so $v = 0$; it slows down, so $a = -5.0$ m/s^2.

$$0 = 20^2 + 2(-5.0)s \quad \Rightarrow \quad s = \frac{400}{10} = 40 \text{ m}$$

At 40 m/s (twice the speed) the same brakes need $\frac{1600}{10} = 160$ m: four times as far, because the speed is squared.

> **Worked example (reading a velocity–time graph).** A lift starts from rest, speeds up steadily to 3.0 m/s in 2.0 s, moves at 3.0 m/s for 6.0 s, then slows steadily to rest in 2.0 s. Distance = area under the graph $= \frac{1}{2}(2.0)(3.0) + (6.0)(3.0) + \frac{1}{2}(2.0)(3.0) = 3.0 + 18 + 3.0 = 24$ m. The acceleration at the start is $3.0 \div 2.0 = 1.5$ m/s^2.

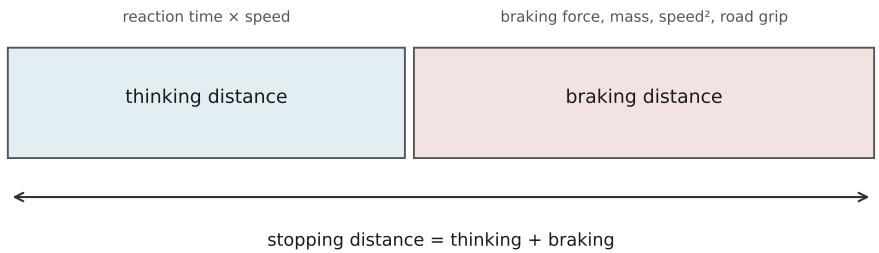
Forces and movement

Forces change a body's **speed, shape or direction**. Force is a **vector** (size + direction); scalars like speed have only size. Along a line, forces add: two 5 N pulls against one 8 N pull give a **resultant force** of 2 N. **Friction** opposes relative sliding, or its tendency, between contacting surfaces. The unbalanced force causes acceleration:

$$F = m \times a \qquad W = m \times g$$

Worked check. A 1200 kg car with a driving force of 3600 N against 1200 N of drag: $F = 2400$ N; $a = 2400/1200 = 2$ m/s^2. Weight at $g = 10$ N/kg: $W = 1200 \times 10 = 12\,000$ N.

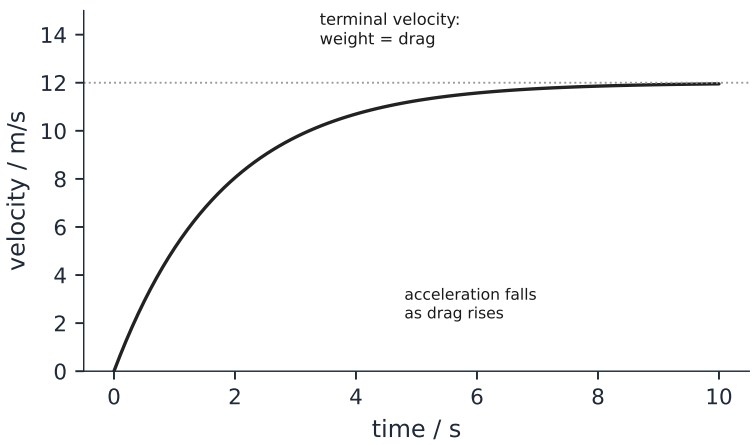
Stopping distance = thinking distance + braking distance. Thinking grows with speed and reaction time (tiredness, alcohol, phones); braking grows with speed squared, mass, weak brakes, poor grip (wet or icy roads, worn tyres).



Stopping distance splits into thinking distance and braking distance.

> **Worked example (thinking distance).** A driver's reaction time is 0.70 s and the car moves at 25 m/s. Thinking distance = speed × reaction time = $25 \times 0.70 = 17.5$ m. If the braking distance at this speed is 48 m, the stopping distance is $17.5 + 48 = 65.5$ m, about 66 m. A tired driver with a reaction time of 1.4 s adds another 17.5 m.

Ignoring upthrust in this falling-in-air model, **falling objects** accelerate while weight exceeds drag; as speed rises, drag rises, the resultant falls, until **weight = drag – terminal velocity** .

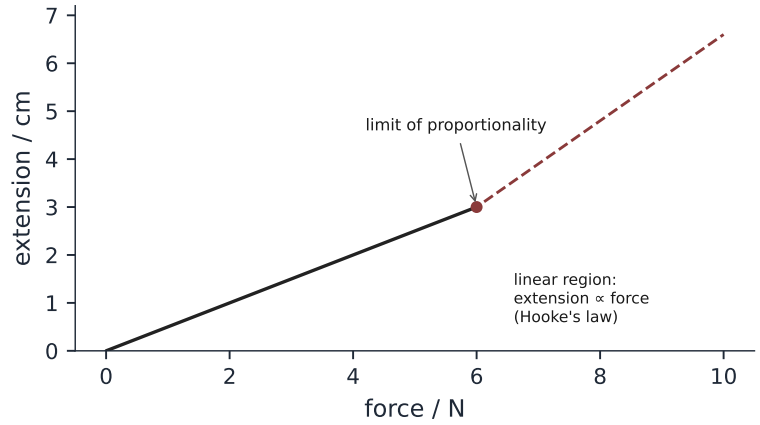


Velocity against time for a falling object levelling at terminal velocity.

Forces and shape

A spring stretches with load. In the **initial linear region, extension is proportional to force – Hooke's law** ; beyond the **limit of proportionality** it bends away. **Elastic behaviour** recovers the original shape when the force is removed. Practical: hang masses on a spring (or rubber band), plot force against extension.

> **Worked example.** A spring is 8.0 cm long with no load. With a 2.0 N load it is 10.5 cm long. Extension = $10.5 - 8.0 = 2.5$ cm. If it obeys Hooke's law, a 4.0 N load gives twice the extension, 5.0 cm, so the spring is $8.0 + 5.0 = 13.0$ cm long, not $2 \times 10.5 = 21$ cm.



A force-extension graph with a linear region to the limit of proportionality.

Momentum and moments (P)

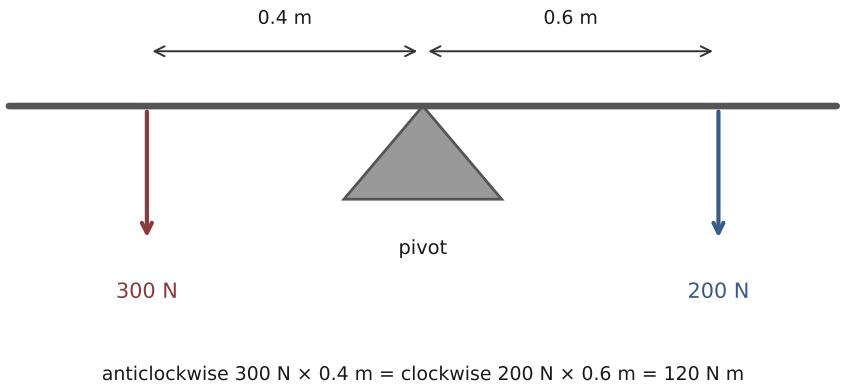
$$p = m \times v \qquad F = \frac{mv - mu}{t}$$

Momentum (kg m/s) is conserved when the resultant external force on the chosen system is zero; over a short collision, negligible external impulse gives total before ≈ total after.

> **Worked example (P).** A 1200 kg car moving at 15 m/s hits a stationary 800 kg car and they move off together. Total momentum before = $1200 \times 15 + 800 \times 0 = 18\,000$ kg m/s. After, the combined mass is 2000 kg, so $v = 18\,000 \div 2000 = 9.0$ m/s.

If the collision lasted 0.15 s, the force on the 800 kg car was $F = \dfrac{mv - mu}{t} = \dfrac{800 \times 9.0 - 0}{0.15} = 48\,000$ N. A crumple zone that stretched the time to 0.30 s would halve this force. **Safety features** work by stretching the time of a collision, so for the same momentum change the force is smaller – crumple zones, seat belts, airbags. **Newton's third law**: to every action there is an equal and opposite reaction.

Moment = force × perpendicular distance from the pivot. A beam balances when **clockwise moments = anticlockwise moments**; the weight of a body acts through its **centre of gravity** .



A loaded beam with two weights on supports: clockwise moments equal anticlockwise moments.

Worked check. Two children (300 N at 0.4 m, 200 N at 0.6 m from the pivot) on a see-saw: clockwise $200 \times 0.6 = 120$ N m; anticlockwise $300 \times 0.4 = 120$ N m – balanced.

Common mistakes

- Using $v^2 = u^2 + 2as$ with a positive when the object is slowing down. A deceleration goes in as a negative acceleration.
- Doubling the length of a spring instead of its extension when the load doubles. Only the extension is proportional to the force.
- Saying no forces act on a skydiver at terminal velocity. Weight and drag both act; they are equal, so the *resultant* force is zero.
- Forgetting that velocity has direction in momentum questions. If two objects move towards each other, give one velocity a minus sign.
- Measuring a moment's distance along the beam to a force that is not perpendicular. Use the perpendicular distance from the pivot to the line of the force.
- Thinking that alcohol or tiredness increase the braking distance. They increase the reaction time, so the *thinking* distance.

Check yourself

1. What does the gradient of a distance-time graph give, and of a velocity-time graph?
2. A cyclist covers 900 m in 3 minutes. Calculate the average speed in m/s.
3. Calculate the acceleration from 30 m/s to rest in 5 s.
4. State the equation linking unbalanced force, mass and acceleration, and its unit.
5. Name two factors that lengthen the thinking distance and two that lengthen the braking distance.
6. Explain, in terms of forces, why a skydiver reaches terminal velocity.
7. State Hooke's law.
8. (P) A 60 kg runner at 8 m/s: calculate momentum.
9. (P) Explain how a crumple zone protects passengers.
10. (P) What is the moment of a 50 N force at 0.3 m from the pivot?

Answers: 1 speed; acceleration (and the area under the velocity-time line is distance); 2 $900/180 = 5$ m/s; 3 $a = (0 - 30)/5 = -6$ m/s^2 (deceleration of 6 m/s^2); 4 F = ma, with F in newtons; 5 thinking – higher speed, longer reaction time; braking – higher speed (speed^2), mass, poor brakes/tyres, wet or icy roads; 6 drag rises with speed until it equals the weight – resultant and acceleration reach zero, so velocity is constant; 7 extension is proportional to force, up to the limit of proportionality; 8 (P) $p = 60 \times 8 = 480$ kg m/s; 9 (P) it crumples, lengthening the collision time; force = momentum change ÷ time, so a longer time means a smaller force on the passengers; 10 (P) $50 \times 0.3 = 15$ N m.