

Cambridge OCR GCSE Combined Science A — Physics

Topic P2

Forces

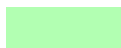
Specification J250 · Cambridge OCR

Free edition

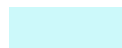
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Define Distance

- path length travelled (scalar). **Displacement** — the straight line from start to finish, with direction (vector).

Define Acceleration

- change in velocity per unit time; a vector.

Define Newton's laws

- first: constant velocity unless a resultant force acts; second: $F = ma$; third: interacting objects exert equal and opposite forces on each other.

HIGHER TIER

Define HT ONLY Momentum

- mass $\times$ velocity; a vector.

Define Weight

- the force on an object due to gravity, in newtons.
Gravitational field strength (g) — force of gravity per kilogram; 10 N/kg at the Earth's surface.

Define Elastic deformation

- a shape change fully recovered from. **Plastic deformation** — a permanent shape change.

Define Scalar

- size only. **Vector** — size *and* direction.

Define Speed

- distance per unit time (scalar). **Velocity** — speed in a stated direction (vector).

Define Resultant (net) force

- the single force with the same effect as all the forces acting.

HIGHER TIER

Define HT ONLY Inertia

- how difficult it is to change an object's velocity. **HT ONLY Inertial mass** — force $\div$ acceleration.

HIGHER TIER

Define HT ONLY Terminal velocity

- the constant velocity reached once drag balances the weight or driving force.

Define Work done

- energy transferred when a force moves an object along its line of action. **Power** — the rate of energy transfer.

Define Spring constant

- force per metre of extension; the gradient of a force–extension graph.

P2.1 Motion

Having looked at matter, we turn to forces. Some interactions involve contact, others do not, and direction matters — hence vector quantities.

Measuring distance and time (P2.1a, P2.1b)

Describe how to measure distance and time in a range of scenarios (P2.1a), and from graphs, and use these to calculate speed (P2.1b).

- **Pupil across the yard** — trundle wheel or tape measure; stopwatch, one person starting and stopping it to cut reaction-time error.
- **Trolley on a ramp, or free fall** — metre rule and a card of known length; **light gates** with a datalogger remove reaction time.
- **Car on a road** — marked posts a known distance apart; stopwatch or speed camera.
- **From a graph** — read values off the axes, or take the gradient.

WATCH OUT

Learners can find **action at a distance** challenging. They have a **tendency to believe that a velocity must have a positive value and difficulty in associating a reverse in direction with a change in sign** — which is why the **vector/scalar distinction** must be secure. A change from +8 m/s to -8 m/s is a change of **16 m/s**, not zero, and needs a force.

Motion graphs (P2.1e, HT ONLY P2.1f)

Relate changes and differences in motion to appropriate distance–time and velocity–time graphs; interpret lines and slopes (P2.1e).

Units, ratios and proportional reasoning (P2.1c)

Make calculations using ratios and proportional reasoning to convert units and to compute rates; J250 singles out **conversion from non-SI to SI units**. 1 km = 1000 m; 1 h = 3600 s; **km/h to m/s, divide by 3.6** (72 km/h = 20 m/s), the other way multiply by 3.6. Typical speeds: walking ≈ 1.5 m/s, running ≈ 3 m/s, cycling ≈ 6 m/s, a car in town ≈ 13 m/s, sound ≈ 330 m/s.

HIGHER TIER

The vector–scalar distinction (P2.1d)

Explain the vector–scalar distinction as it applies to **displacement and distance, and velocity and speed**. A vector can be negative just because it points the other way.

- **Distance** (scalar) against **displacement** (vector): once round a 400 m track, distance 400 m, displacement **zero**. **Speed** against **velocity**: 20 m/s north and 20 m/s south are the same speed but **opposite** velocities.
- Other scalars: mass, time, energy, temperature, work done, power. Other vectors: force, weight, acceleration, **HT ONLY** momentum.

Fix a **positive direction** and keep to it: with right positive, -5 m/s means 5 m/s to the left.

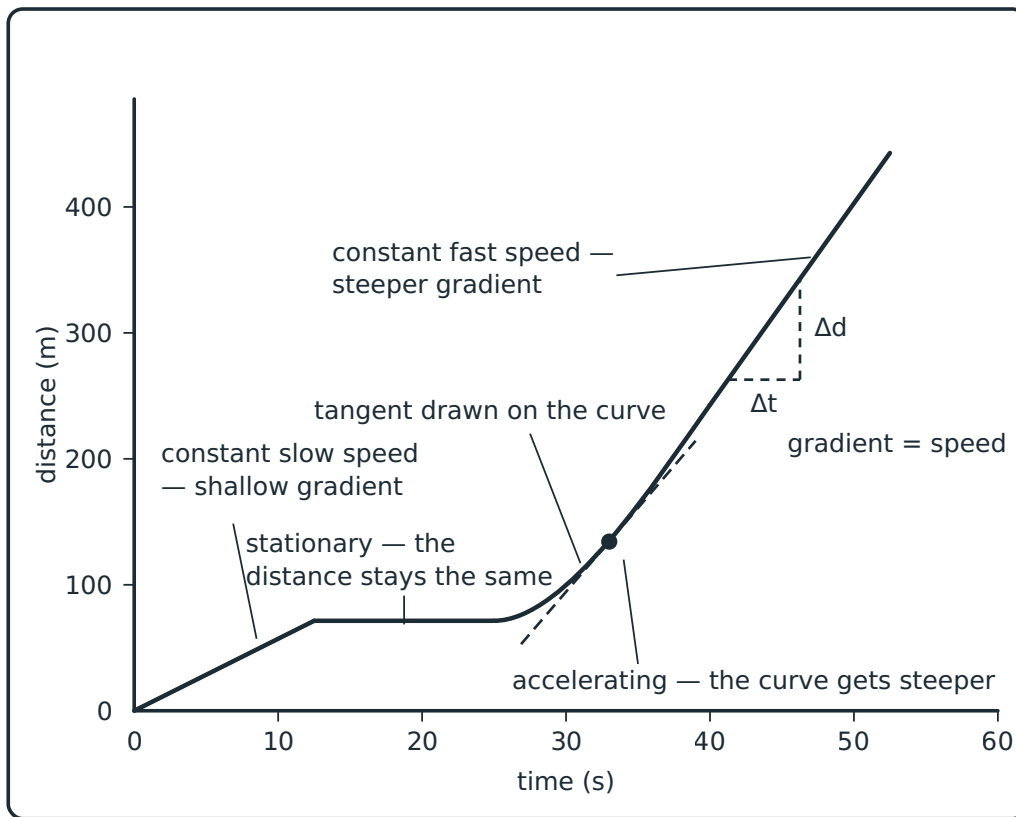
Feature	Distance–time	Velocity–time
Horizontal line	Stationary	Constant velocity
Straight slope up / down	Constant speed (steeper = faster) / returning to the start	Uniform acceleration / deceleration
Curve steepening / flattening	Accelerating / decelerating	Changing acceleration
Gradient / area under the line	Speed / nothing useful	Acceleration / HT ONLY distance travelled

HIGHER TIER

For the speed at an instant on a **curved** distance–time graph, draw a **tangent** and take its gradient.

HT ONLY Interpret enclosed areas in velocity–time graphs (P2.1f): the **area between the line and the time axis is the distance travelled** — split it into rectangles and triangles, or count squares for an irregular curve.

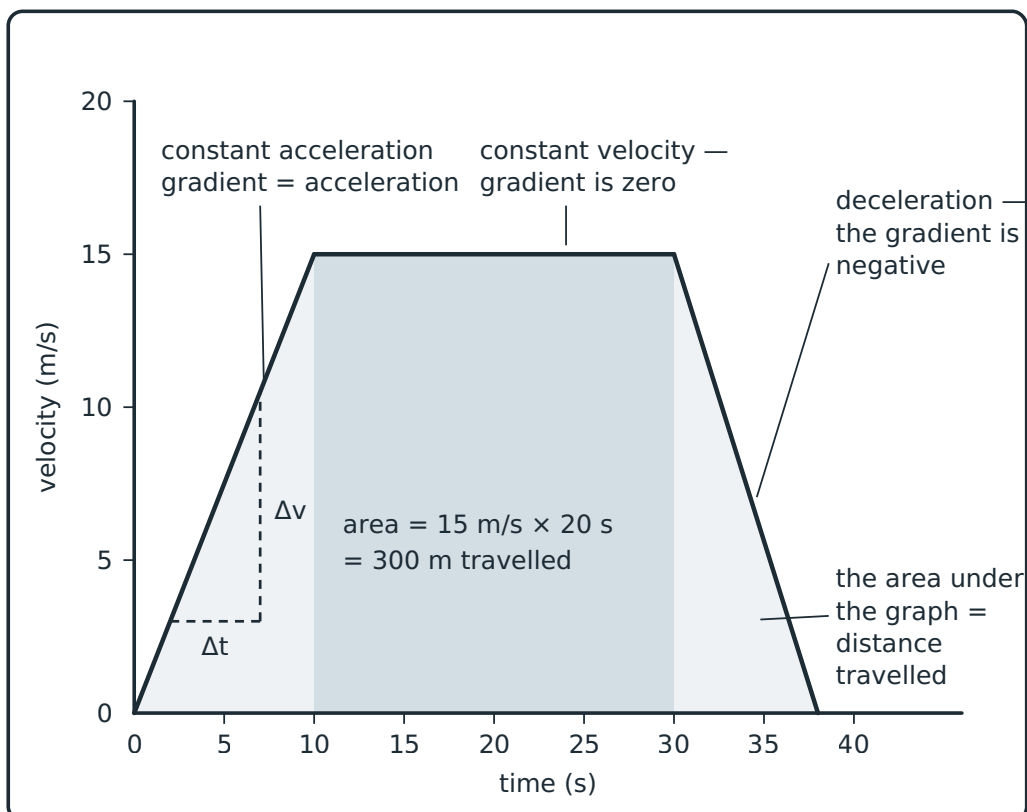
Reading speed from the gradient of a distance–time graph.



How to read it

- flat line = stationary
- steeper line = faster
- gradient = speed
- speed = distance $\div$ time
- a curved line means the speed is changing
- to find the speed at an instant on a curve, draw a tangent and find its gradient

Reading acceleration from the gradient and distance from the area of a velocity–time graph.



How to read it

- gradient = acceleration
 - flat line = constant velocity
 - downward slope = deceleration
 - area under the graph = distance travelled
- Higher tier only
- split the area into triangles and rectangles, or count squares

Speed, distance, time and acceleration (P2.1g, P2.1h)

Calculate average speed for non-uniform motion (P2.1g), and apply formulae relating distance, time and speed, for uniform motion and for motion with uniform acceleration (P2.1h).

P2.2 Newton's laws

Newton's laws define how motion changes, relating those changes to force and mass.

HIGHER TIER

Representing forces as vectors (P2.2c, HT ONLY P2.2e, HT ONLY P2.2g, HT ONLY P2.2h)

Represent forces as vectors (P2.2c) with **free body force diagrams**: the object as a box or dot, one arrow per force acting on it, its **length** showing size, labelled with the force's name and value.

HT ONLY Use vector diagrams to illustrate resolution of forces, a **net force (resultant force)**, and **equilibrium situations (P2.2e)** — scale drawings limited to **parallel and perpendicular vectors only**. For two perpendicular forces, draw them head-to-tail to scale and complete the rectangle; the diagonal is the resultant.

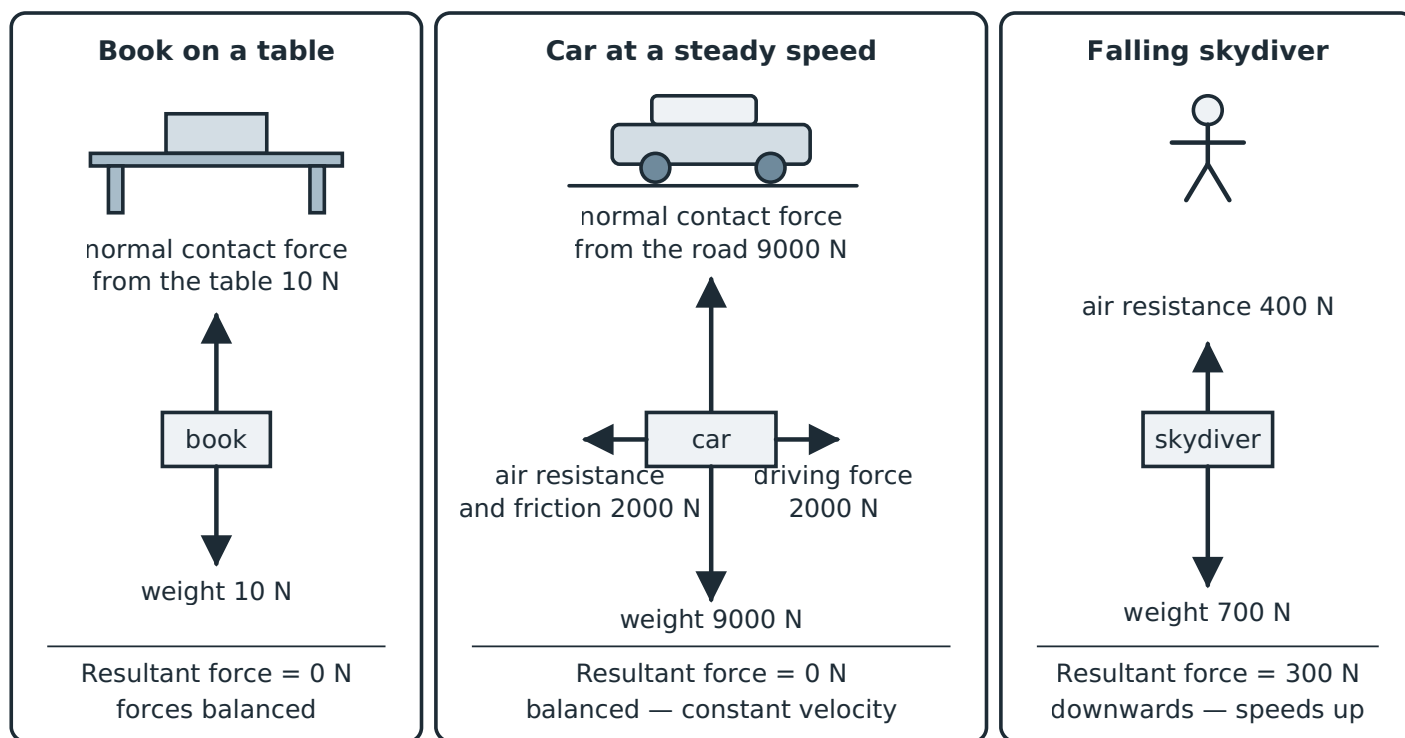
HT ONLY Describe, using free body diagrams, examples where **two or more forces lead to a resultant force on an object (P2.2g)** — a car whose driving force exceeds drag. **HT ONLY** Describe, using free body force diagrams, the special case of **balanced forces when the resultant force is zero (P2.2h)** — qualitative only: **equilibrium**, as for a book on a table.

Interactions between objects (P2.2a, P2.2b)

Recall examples of ways in which objects interact (P2.2a) — J250 lists **electrostatics, gravity, magnetism and contact (including normal contact force and friction)** — and **describe how such examples involve interactions between pairs of objects which produce a force on each object (P2.2b)**:

- **Non-contact**: **gravity, electrostatic and magnetic** (charges or poles attracting or repelling). **Contact**: the **normal contact force** (a surface pushing at right angles to itself), **friction, air resistance (drag) and tension**.
- This sets up the third law: **forces come in pairs, one on each interacting object**.

Free body force diagrams for balanced and unbalanced forces.



The length of each arrow shows the size of the force. A longer arrow means a bigger force.

Newton's first law (P2.2d)

Apply Newton's first law to explain the motion of an object moving with uniform velocity, and also an object where the speed and/or direction change — an object remains at rest, or at constant velocity, unless acted on by a resultant force.

- Resultant **zero** — a stationary object stays stationary; a moving one keeps the same speed in a straight line.
- Resultant **not zero** — the **speed and/or direction changes**; the object accelerates.
- J250 restricts this to **forces on one body, and resultant forces and their effects, qualitative only**. A car at a steady 25 m/s has driving force balanced by drag, and weight by the normal contact force — exactly why its velocity does not change.

HIGHER TIER

Newton's second law (P2.2i, HT ONLY P2.2j)

Apply Newton's Second Law in calculations relating forces, masses and accelerations (P2.2i).

HT ONLY Explain that inertia is a measure of how difficult it is to change the velocity of an object, and that the inertial mass is defined as the ratio of force over acceleration (P2.2j) — $m = F \div a$, the second law read backwards. A large inertial mass needs a large force for a given acceleration.

WATCH OUT

Learners commonly have misconceptions about **objects needing a net force for them to continue to move steadily**, and **struggle to understand that stationary objects also have forces acting on them**. The first law fixes both: steady motion needs **zero** resultant force, and a book on a table has a weight and a normal contact force.

They also find it hard to **differentiate between scalar and vector quantities**, especially **objects with a changing direction not having a constant vector value** — an object moving in a circle. **This issue also arises with momentum and changes in momentum of colliding objects**: a ball rebounding from a wall undergoes a large momentum change even though its speed is unaltered.

ANALOGY

Inertia — the shopping trolley. An empty trolley starts, stops and swerves at a touch; one loaded with sand fights every change. That is the **mass**, not the speed — the reluctance to have your velocity changed. It is why seatbelts are needed: in a crash the car stops but you keep going.

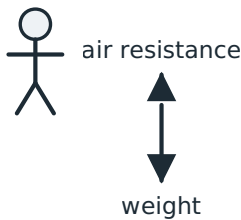
HT ONLY Terminal velocity (P2.2f)

HT ONLY Describe examples of the forces acting on an isolated solid object or system (P2.2f), to include objects that reach terminal velocity, for example skydivers, and applying similar ideas to vehicles.

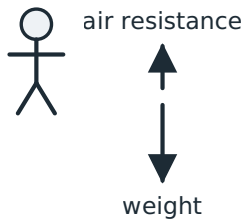
- A falling object accelerates at first because its **weight** far exceeds the **air resistance**. As it speeds up, air resistance grows; when **air resistance equals weight** the resultant is **zero** and it falls at constant **terminal velocity**.
- Opening a parachute raises air resistance sharply: the resultant now acts upwards, the skydiver **decelerates**, air resistance falls again, and a new, lower terminal velocity is reached.
- Vehicles** are the same: top speed is set by drag growing until it balances the driving force.

How a falling skydiver reaches terminal velocity.

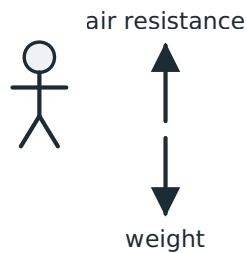
Higher tier only

**1 just jumped**

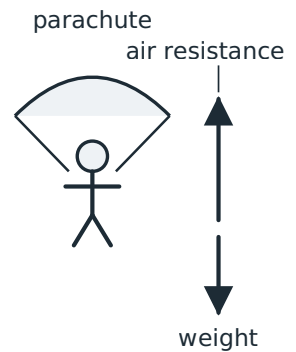
air resistance is very small at first, so there is a large resultant force downwards

**2 speeding up**

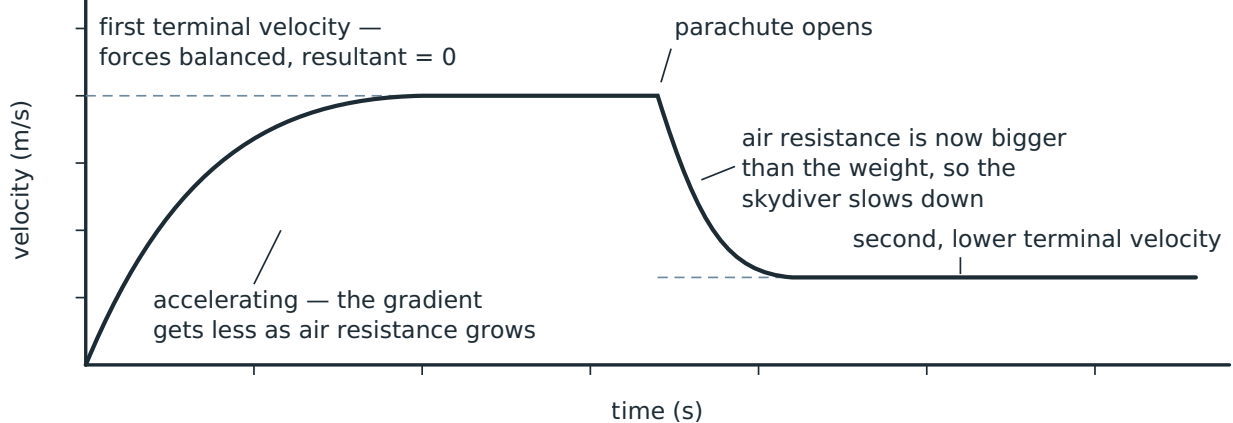
air resistance grows as the speed increases, so the resultant force and the acceleration fall

**3 terminal velocity**

air resistance = weight, so the resultant force is zero — the skydiver falls at terminal velocity

**4 parachute opens**

air resistance is now bigger than the weight, so the skydiver slows down to a new, lower terminal velocity



HT ONLY Momentum and its conservation (P2.2k)

HT ONLY Define momentum and describe examples of momentum in collisions (P2.2k), to include an idea of the law of conservation of momentum in collisions. Velocity is a vector, so **momentum is a vector**: direction and sign matter.

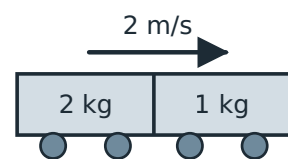
HT ONLY Conservation of momentum: in a closed system, **total momentum before = total momentum after**. An **explosion** from rest has zero total momentum, so the pieces fly apart with **equal and opposite** momenta — a water rocket rises with exactly the momentum the expelled water carries down. A longer collision time means a **smaller force** for the same momentum change: crumple zones, airbags, crash mats.

Conservation of momentum in a collision, and why a longer collision time means a smaller force.

Higher tier only

Two trolleys collide and stick together

before: 
 momentum before = $(2 \text{ kg} \times 3 \text{ m/s}) + (1 \text{ kg} \times 0 \text{ m/s})$
 $= 6 \text{ kg m/s}$

after: 
 momentum after = $(2 \text{ kg} + 1 \text{ kg}) \times 2 \text{ m/s} = 6 \text{ kg m/s}$

total momentum before = total momentum after
 momentum is conserved in a closed system

a closed system: no external forces act on the trolleys

Longer collision time, smaller force

The same change in momentum spread over a longer time gives a smaller force on the people.

No calculation is required — the explanation is qualitative.

Safety features

- crumple zones • air bags
- seat belts • crash mats
- cycle helmets
- cushioned playground surfaces

**Work done, energy transfer and power (P2.2l, P2.2m, P2.2n)**

Use the relationship between work done, force and distance moved along the line of action of the force, and describe the energy transfer involved (P2.2l); calculate relevant values of stored energy and energy transfers, converting between newton-metres and joules (P2.2m); explain the definition of power as the rate at which energy is transferred (P2.2n).

Newton's third law (P2.2o) and HT ONLY circular motion (P2.2p)

Recall and apply Newton's Third Law (P2.2o), in situations of equilibrium and non-equilibrium: when two objects interact, the forces they exert on each other are equal in size and opposite in direction. The pair acts on two different objects and is the **same type** of force, so it can never cancel and does **not** explain equilibrium. A book on a table is in equilibrium because its **weight** and the **normal contact force** balance — both on the same object; the partner of the book's weight is its pull **on the Earth**.

HT ONLY Explain why an object moving in a circle with a constant speed has a changing velocity (P2.2p) — **qualitative only**. Velocity is a **vector**, and an object going round a circle continually changes **direction**, so its **velocity changes** even though its speed does not. That is an acceleration, needing a resultant force towards the centre — from the string, from friction on the tyres, or from gravity.

P2.3 Forces in action

Forces can change an object's shape as well as its motion, and fields let interactions happen without contact.

Force and extension (P2.3c, P2.3d, P2.3e, P2.3f)

Extension is the increase in length on the original, unstretched length — never the total length. **Describe the relationship between force and extension for a spring and other simple systems (P2.3c)** from the **graphical representation of the extension of a spring**, force (y) against extension (x):

- A **straight line through the origin** while force and extension are directly proportional: a **linear** relationship.
- Beyond the **limit of proportionality** it **curves** — **describe the difference between linear and non-linear relationships between force and extension (P2.3d)**: equal force increases then give bigger and bigger extensions. A rubber band is non-linear from the start.
- The **elastic limit** is the point beyond which the object no longer returns to its original length.

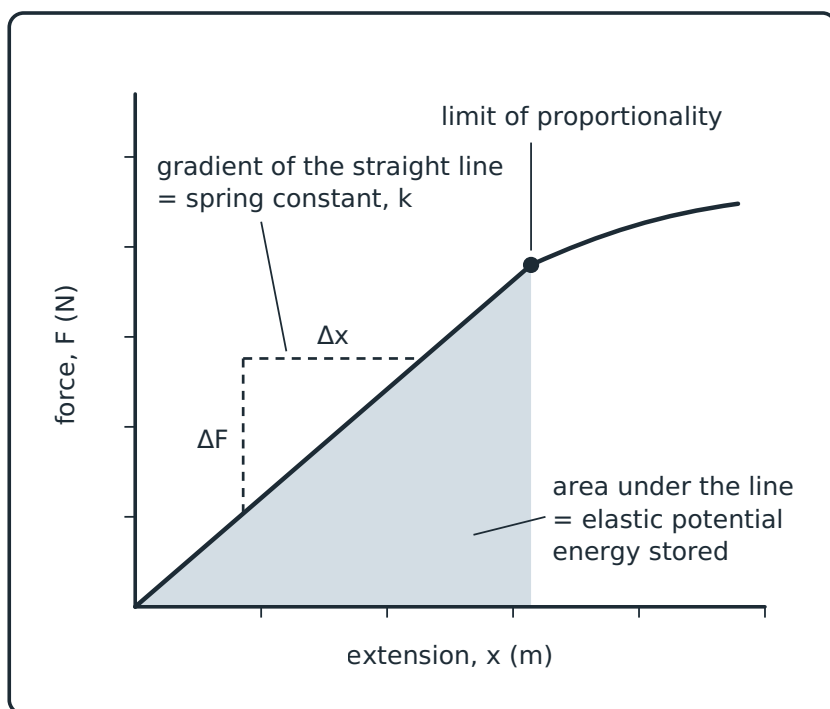
Deforming objects: elastic and plastic (P2.3a, P2.3b)

Explain that to stretch, bend or compress an object, **more than one force has to be applied (P2.3a)** — one force on a free object simply accelerates it; changing its *shape* needs at least two, as in pulling both ends of a spring.

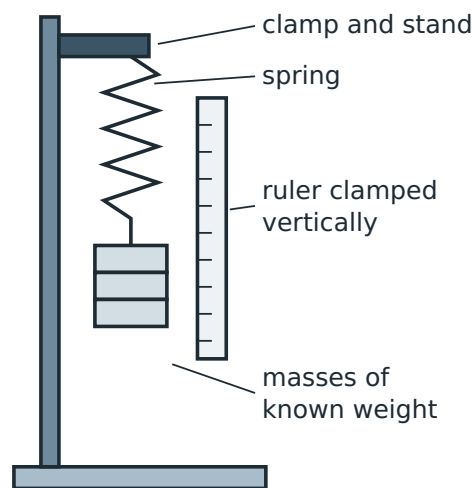
Describe the difference between elastic and plastic deformation (distortions) caused by stretching forces (P2.3b):

- **Elastic** — the object **returns completely** to its original shape and length when the forces are removed, as a spring below its elastic limit does.
- **Plastic** — the object is **permanently changed**: a spring past its **elastic limit**, or a bent paper clip.

The force–extension graph for a spring, and the apparatus used to obtain it.



PAG P2 (Forces)



- extension = stretched length – original (unstretched) length
- force is directly proportional to extension up to the limit of proportionality: $F = kx$
- gradient of the straight line = spring constant, k (in N/m)
- area under the line = elastic potential energy stored: $E = \frac{1}{2} kx^2$ (given on the equation sheet)

Gravity, weight and free fall (P2.3g, P2.3h, P2.3i)

Describe that all matter has a gravitational field that causes attraction, and that the field strength is much greater for massive objects (P2.3g) — noticeable only when one mass is very large.

Define weight, describe how it is measured, and describe the relationship between the weight of an object and the gravitational field strength, g (P2.3h). Weight is the force acting on an object due to gravity, in newtons, measured with a calibrated spring balance (newtonmeter). Mass, in kilograms on a balance, does not change when you move; the weight does, because g does. J250 requires knowledge that the gravitational field strength is known as g and has a value of 10 N/kg at the Earth's surface. Recall the acceleration in free fall (P2.3i) — also 10 m/s^2 , because $F = ma$ and $W = mg$ are the same equation when gravity is the only force acting.

WATCH OUT

Because of the everyday use of "weighing", learners commonly have difficulty understanding that the weight of an object is not the same as the mass — a supermarket scale labelled in kilograms measures mass. Keep them apart: **mass in kilograms on a balance, weight in newtons on a newtonmeter**, linked by $W = mg$.

OCR also notes that the concept of force multipliers can be challenging, though covered at Key Stage 3. The principle is $W = Fs$: a device giving out a larger force moves a correspondingly smaller distance, so no energy is created.