Cambridge IGCSE · Physics 0625 · Notes

Forces

Read online at **pastopic.com/cambridge/physics-0625/notes/forces**

Last checked 29 September 2026

Read first: **Motion**, **Mass and weight**, **Physical quantities and measurement techniques**

What you need to know

By the end of this topic you should be able to:

Effects of forces

1. **Know that forces can change the size and shape of an object**: they stretch, squash, bend and twist things.
2. **Sketch, plot and interpret load–extension graphs** for an elastic solid such as a spring, and describe the experiment that gives the results.
3. **Find the resultant of two or more forces acting along the same straight line.**
4. **Know that an object stays at rest, or keeps moving in a straight line at constant speed, unless a resultant force acts on it.**
5. **State that a resultant force can change an object's velocity** by changing its speed, its direction of motion, or both.
6. **Describe solid friction** as the force between two surfaces that can oppose (impede) motion and that produces heating.
7. **Know that friction (drag) acts on an object moving through a liquid**, such as a boat or a ball falling through oil.
8. **Know that friction (drag) acts on an object moving through a gas**: air resistance is drag in air.
9. **Extended only:** define the **spring constant** as force per unit extension, and recall and use $k = \dfrac{F}{x}$.
10. **Extended only:** define and use the **limit of proportionality** for a load–extension graph and identify that point on the graph. (You do not need the elastic limit.)
11. **Extended only:** recall and use $F = ma$, and know that the resultant force and the acceleration are **in the same direction**.
12. **Extended only:** describe, without calculating, motion in a circle caused by a force at right angles to the motion: with mass and radius fixed, a bigger force means a bigger speed; with mass and speed fixed, a bigger force means a smaller radius; a bigger mass needs a bigger force to keep the same speed and radius. (The equation $F = \frac{mv^2}{r}$ is not needed.)

Turning effect of forces

13. **Describe the moment of a force** as a measure of its turning effect, and give everyday examples.

14. **Define the moment of a force** as moment = force × perpendicular distance from the pivot, and recall and use this equation.
15. **Apply the principle of moments** with one force on each side of the pivot, including balancing a beam.
16. **State that an object is in equilibrium** when there is no resultant force **and** no resultant moment on it.
17. **Extended only:** apply the principle of moments when there is more than one force on a side of the pivot.
18. **Extended only:** describe an experiment to show that there is no resultant moment on an object in equilibrium.

Centre of gravity

19. **State what the centre of gravity is.**
20. **Describe an experiment to find the centre of gravity** of an irregularly shaped flat sheet (a plane lamina).
21. **Describe, in words, how the position of the centre of gravity affects the stability** of simple objects.

Understand it

What a force can do

A force is a push or a pull, measured in **newtons (N)**. It has a size and a direction, so it is drawn as an arrow. Forces can:

- **change the size and shape** of an object: stretching a spring, squashing a sponge, bending a ruler;
- **change the motion** of an object: make it speed up, slow down or change direction.

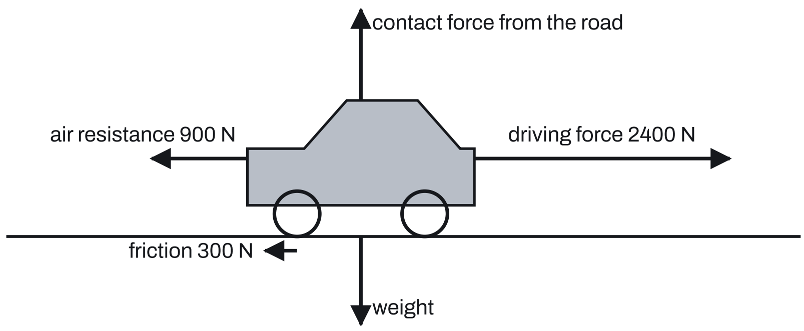
A force can never change an object's **mass**: that stays the same however hard you push. Its speed, direction, shape, size and volume can all change.

The resultant force

Usually several forces act on an object at once. The **resultant force** is the single force that would have the same effect as all of them together. When the forces act along the same straight line:

- forces in the **same direction add**;
- forces in **opposite directions subtract**, and the resultant points the way of the bigger side.

Always give the **size and the direction** of a resultant.



resultant = 2400 – 900 – 300 = 1200 N forwards
vertical forces are equal, so they cancel

In the diagram the vertical forces cancel, so only the horizontal ones matter: $2400 - 900 - 300 = 1200$ N **forwards**. The car speeds up.

Balanced forces: no change in motion

If the forces **balance**, the resultant is **zero**, and the motion does not change:

- an object at rest **stays at rest**;
- a moving object **keeps moving in a straight line at constant speed**.

A zero resultant does **not** mean "no forces" or "not moving". A car cruising at a steady 25 m/s on a straight road has a big driving force, but it is exactly balanced by air resistance and friction. A parachutist falling at terminal velocity has air resistance equal to her weight. A lift moving down at a steady speed pushes up on your feet with a force equal to your weight.

If there **is** a resultant force, the velocity **must** change: the object speeds up, slows down, or changes direction. So you can read forces from motion, and motion from forces:

Forces	Motion
Resultant is zero (balanced)	at rest, or constant speed in a straight line
Resultant forwards (same way as the motion)	speeds up
Resultant backwards (against the motion)	slows down
Resultant at right angles to the motion	changes direction (for example moves round a circle)

On a speed–time graph, a flat (horizontal) section means constant speed, so the resultant force there is zero.

Friction and drag

Friction is the force between two surfaces in contact. It acts **against** the motion (or against the way the object would slide), so it can slow things down or stop them sliding. Friction also **heats** the surfaces: rub your hands together, or feel hot brakes after a car stops.

Drag is friction on an object moving through a **fluid**:

- through a **gas**, it is called **air resistance**: on a car, a cyclist, a falling skydiver or a flying bird it points **backwards**, opposite to the motion;
- through a **liquid**, it is **water resistance** or drag: on a boat, a swimmer, or a ball sinking in oil.

Drag gets **bigger as the speed increases**. That is why a car with a constant driving force reaches a top speed: as it speeds up, the drag grows until it equals the driving force, the resultant becomes zero, and the speed stops increasing. Smooth, pointed (streamlined) shapes reduce air resistance.

Weight, tension in a spring and magnetic forces are **not** friction.

Resultant force and acceleration: F = ma

Extended only: the resultant force F, the mass m and the acceleration a are linked by

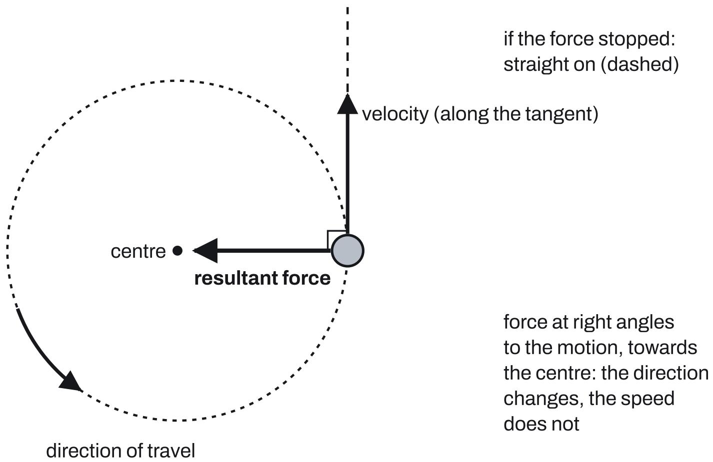
$$F = ma \qquad (F \text{ in N},\ m \text{ in kg},\ a \text{ in m/s}^2).$$

The acceleration is always **in the same direction as the resultant force**. A resultant of 1900 N on a 950 kg car gives $a = \dfrac{1900}{950} = 2.0$ m/s². The same force on a smaller mass gives a bigger acceleration, and a bigger force on the same mass gives a bigger acceleration.

Extended only: F must be the **resultant** force. If a question gives you a driving force and friction, subtract first; if it gives you the acceleration and asks for a driving force, find the resultant with $F = ma$ and then add the resistive forces back on.

Moving in a circle

Extended only: an object moving round a circle at constant speed is **always changing direction**, so its velocity is changing and there **must** be a resultant force on it. That force acts **at right angles to the motion, towards the centre of the circle**. It changes the direction but not the speed.



The force can come from many things: the tension in a string whirling a ball, friction between the tyres and the road for a car going round a bend, gravity for a satellite or the Moon. If the force stops (the string breaks), the object carries on in a **straight line** along the tangent; it does **not** fly outwards along the radius.

Extended only: how big the force must be:

- **faster** (same mass and radius) → a **bigger** force is needed;
- **tighter bend**, smaller radius (same mass and speed) → a **bigger** force is needed;
- **bigger mass** (same speed and radius) → a **bigger** force is needed.

So a car slides off a bend when the friction it needs is more than the road can give: when it goes too fast, the bend is too tight, the road is icy or wet (less friction), or it is heavily loaded.

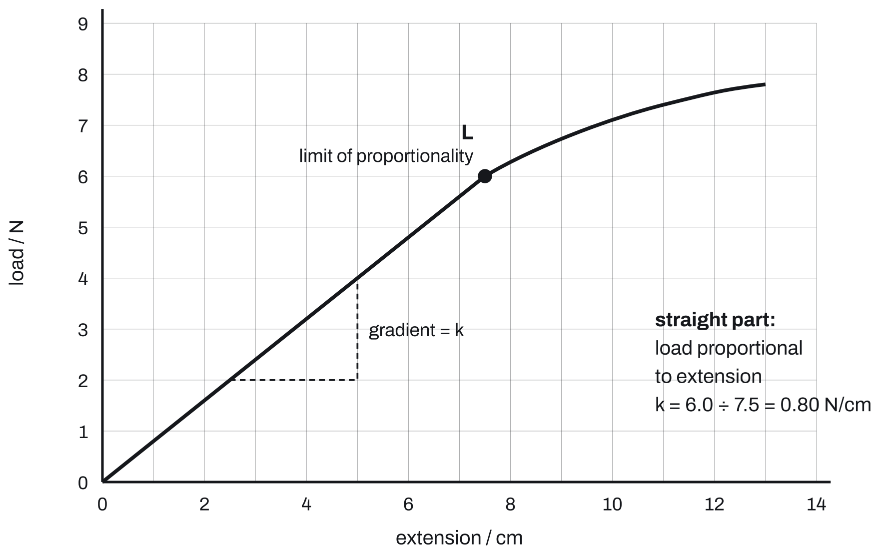
Stretching a spring

Hang a spring from a clamp and add loads (weights) to the bottom. The spring gets longer. The **extension** is how much longer it is than its **unstretched (original) length**:

$$\text{extension} = \text{stretched length} - \text{unstretched length}.$$

The experiment.

1. Clamp the spring to a stand with a metre rule held vertically beside it. Fix a pointer to the bottom of the spring to read against the rule.
2. Measure the **unstretched length** (or the pointer reading) with no load. Read the rule with your eye level with the pointer to avoid parallax.
3. Hang a load of known weight (for example a 1.0 N mass hanger), and record the new length. Keep adding equal loads, recording the load and the length each time.
4. Work out each extension (length minus unstretched length) and plot a graph of load against extension. Repeat readings while taking the loads off to check them.



For a spring, the first part of the graph is a **straight line through the origin**: the extension is **proportional** to the load. Double the load, double the extension. Some questions call this Hooke's law.

Extended only: the straight line only lasts up to the **limit of proportionality** (point L). Beyond it, extension is no longer proportional to load and the graph **curves**. On a load–extension graph (load up the side) it becomes **less steep**; on an extension–load graph (extension up the side) it becomes **steeper**. Either way, beyond L each extra newton gives more extension than before.

If the graph shows **length** instead of extension, it is still a straight line, but it cuts the length axis at the **unstretched length**, not at zero. To find the unstretched length, carry the straight line back to zero load.

The spring constant

Extended only: the **spring constant** k is the **force per unit extension**:

$$k = \frac{F}{x} \qquad (F \text{ in N},\ x \text{ is the extension}).$$

Its unit is **N/m** or **N/cm** (newtons per metre, or per centimetre). A stiff spring has a large k: it needs a large force for each centimetre of stretch. On the straight part of a load–extension graph, k is the **gradient**; on an extension–load graph, k is $\frac{1}{\text{gradient}}$, so it is safest to read one point off the line and divide load by extension. The spring above has $k = \frac{6.0}{7.5} = 0.80$ N/cm, so a load of 2.0 N stretches it by $2.0 \div 0.80 = 2.5$ cm.

A spring pushed shorter (compressed) works the same way: the "extension" is negative, and the force pushes back.

Moments: the turning effect of a force

A force can make something **turn** about a fixed point called the **pivot** (or fulcrum): opening a door about its hinges, a spanner turning a nut, a see-saw, a wheelbarrow, scissors, a crowbar. The turning effect is called the **moment** of the force:

$$\text{moment} = \text{force} \times \text{perpendicular distance from the pivot}.$$

The unit is the **newton metre (N m)**, or N cm if the distance is in cm. A 25 N force at right angles to a spanner, 0.32 m from the nut, has a moment of $25 \times 0.32 = 8.0$ N m.

The distance must be the **perpendicular** distance: measured from the pivot to the **line of the force**, at right angles to it. A force that pulls along the spanner, or whose line passes through the pivot, has no moment at all.

To get a bigger moment:

- use a **bigger force**, or
- apply it **further from the pivot** (a longer spanner, pushing a door at the handle side, not near the hinges), and
- push **at right angles** to the handle.

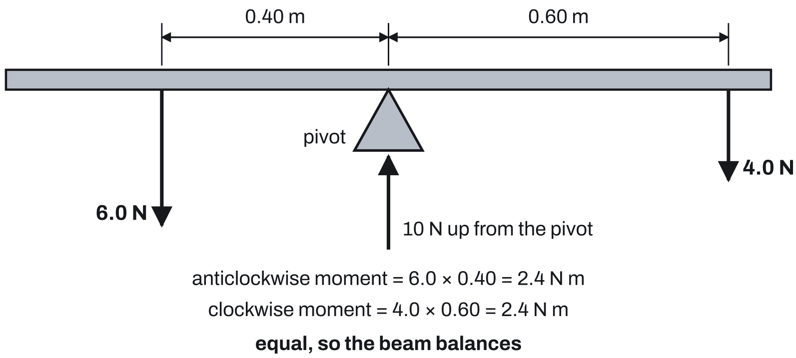
This is why long handles make work easier: with a longer lever, a smaller force gives the same moment.

The principle of moments

A moment turns either **clockwise** or **anticlockwise**. When an object is **balanced** (not turning, or turning at a steady rate):

$$\text{sum of clockwise moments} = \text{sum of anticlockwise moments}$$

about **any** pivot. This is the **principle of moments**.



In the diagram, the 6.0 N weight tries to turn the beam anticlockwise: $6.0 \times 0.40 = 2.4$ N m. The 4.0 N weight tries to turn it clockwise: $4.0 \times 0.60 = 2.4$ N m. They are equal, so the beam balances. A smaller force balances a bigger one by sitting **further** from the pivot.

Extended only: with more than one force on a side, add the moments on each side before comparing. If an extra 2.0 N were hung 0.30 m left of the pivot above, the anticlockwise total would be $2.4 + 0.60 = 3.0$ N m, and the 4.0 N weight would have to move to $3.0 \div 4.0 = 0.75$ m to balance it.

The weight of a **uniform** beam acts at its middle. If the beam is pivoted at its middle, its own weight has no moment about the pivot; if not, include it as one more force.

Equilibrium

An object is in **equilibrium** when both are true:

1. there is **no resultant force** (the forces up equal the forces down, and the forces left equal the forces right), and
2. there is **no resultant moment** (clockwise moments equal anticlockwise moments).

For the beam above, the pivot must push **up** with $6.0 + 4.0 = 10$ N, or there would be a resultant force downwards. Two equal and opposite forces keep an object in equilibrium only if they act **along the same line**: if they are offset, they form a turning pair, and the object rotates.

Extended only: the experiment to show there is no resultant moment on a balanced object:

1. Balance a uniform metre rule at its centre (the 50 cm mark) on a pivot, such as a knife edge.
2. Hang a mass (a known weight) on one side at a measured distance from the pivot.

3. Hang one or more other masses on the other side and slide them until the rule balances horizontally again.
4. Record each weight and its distance from the pivot. Work out force × distance for each, and add the moments on each side.
5. The total clockwise moment equals the total anticlockwise moment. Repeat with different masses and positions (including two masses on one side) to show it always works.

Centre of gravity

Every part of an object has weight. The **centre of gravity** is the point where **all of the weight of the object seems to act**. For a uniform ruler it is the middle; for a uniform rectangle or disc it is the centre. If you balance an object on a single point, that point is directly under the centre of gravity.

Finding the centre of gravity of an irregular flat card (a lamina):

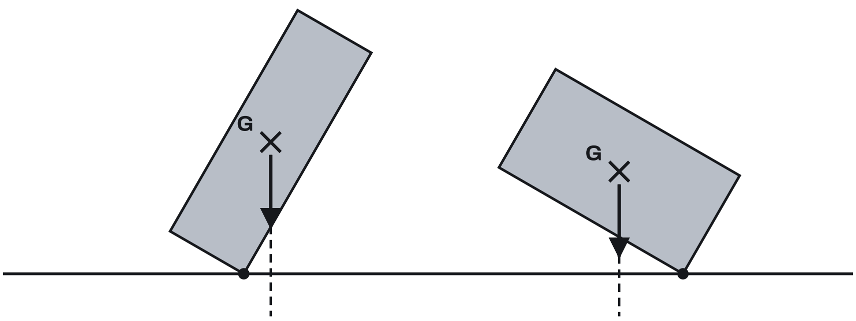
1. Make two or three small holes near the edge of the card, well apart.
2. Hang the card from a pin (or nail) through one hole, held in a clamp, so that it can swing freely. Hang a **plumb line** (a small weight on a thread) from the same pin.
3. When both are still, mark the line of the thread on the card with a pencil and ruler.
4. Hang the card from another hole and draw a second line the same way.
5. The centre of gravity is where the lines **cross**. A third line through the third hole should pass through the same point, which checks it.

It works because a freely hanging object comes to rest with its centre of gravity **directly below** the point of suspension. You do not need a stopwatch or a balance.

Stability

An object tips over when the **vertical line through its centre of gravity** falls **outside its base**. Then its weight has a moment about the edge it is tipping on, which turns it further over. If the line still falls inside the base, the weight's moment turns it **back** onto its base.

both tilted by 30° onto the corner marked with a dot



tall and narrow:
weight line outside the base: topples

low and wide:
weight line inside the base: falls back

So an object is **more stable** when it has:

- a **low centre of gravity** (heavy parts at the bottom), and
- a **wide base**.

Examples: racing cars are low and wide; a table lamp has a heavy, wide base; a bus is less stable when people stand on its top deck, because the centre of gravity rises; a cone standing on its flat base is more stable than a tall cylinder of the same material.

Key facts and formulas

The 0625 papers have no formula sheet, so learn the equations. The value of g is printed on the question paper.

Formula	Status
Resultant along a line: add forces in the same direction, subtract forces in opposite directions	Learn it
Extension $=$ stretched length $-$ unstretched length	Learn it
Extended only: spring constant $k = \dfrac{F}{x}$ (force per unit extension), in N/m or N/cm	Learn it
Extended only: $F = ma$ (F is the resultant force, same direction as a)	Learn it
Moment $=$ force $\times$ perpendicular distance from the pivot, in N m	Learn it
Principle of moments: sum of clockwise moments $=$ sum of anticlockwise moments	Learn it
Equilibrium: no resultant force **and** no resultant moment	Learn it
Weight $W = mg$ (from Mass and weight)	Learn it
$g = 9.8$ N/kg	Given

Resultant force	What happens
zero	stays at rest, or constant speed in a straight line
along the motion	speeds up
against the motion	slows down
at right angles to the motion	changes direction; towards the centre for a circle

How to do it

In the Paper 1 to 4 questions we have tagged for this topic (206 different questions, 2021–2025; 27 more are repeats on other papers), the types came up this often. 26 of the 206 questions mix two or three types, so the counts add up to more than 206.

Question type	Questions
Moments and the principle of moments	67

Question type	Questions
Resultant force and its effect on motion	44
Springs and load–extension graphs	28
Using $F = ma$ (Extended)	25
Equilibrium: conditions and the experiment	20
Centre of gravity and stability	18
Motion in a circle (Extended)	13
Effects of forces, friction and drag	13
Resultant of forces at an angle (Extended)	7

1. Moments and the principle of moments (67 questions)

Calculating a moment:

1. Find the **perpendicular** distance from the pivot to the line of the force. Change units if the answer line asks for them (N m needs metres; N cm needs centimetres).
2. Moment $=$ force $\times$ perpendicular distance.
3. Give the unit: **N m** or **N cm**.

Finding an unknown force or distance (a balanced beam or see-saw):

1. Say which forces turn **clockwise** and which **anticlockwise** about the pivot.
2. Write the principle: sum of clockwise moments $=$ sum of anticlockwise moments.
3. Put in the numbers, with each force times **its own** distance from the pivot.
4. Solve. For example, a 6.0 N weight at 0.50 m balances a force F at 0.75 m: $F \times 0.75 = 6.0 \times 0.50$, so $F = 4.0$ N.

Variations you will meet:

- **"Define the moment of a force"**: force × **perpendicular** distance from the pivot. **"What does it measure?"** The turning effect of the force. It is not a force, and its unit is N m, not N or N/m.
- **Which change increases the moment?** A bigger force, a bigger distance, or pushing at right angles. A shorter spanner, or pushing along the handle, reduces it. Oiling the nut changes nothing about the moment.
- **Metre rule questions** give positions, not distances. Subtract to get each distance from the pivot: a load at the 20 cm mark with the pivot at 50 cm is 30 cm away.
- **The beam's own weight.** For a uniform beam, it acts at the middle. If the pivot is not at the middle, it has a moment: include it.
- **Extended only: more than one force on a side.** Add all the clockwise moments, add all the anticlockwise moments, then set the totals equal.

- **Force from a pivot or support.** For a beam on two supports, take moments about **one** support to find the force at the other (the force at the pivot you choose has no moment), then use "total up = total down" for the second one.
- **Which direction must a force act?** If the weight turns the beam clockwise, the balancing force must turn it anticlockwise: work out whether that means up or down on that side of the pivot.
- **Why does the beam turn?** One side's moment is bigger. Moving a child away from the pivot increases that child's moment, so that side goes down; balance it again by moving the other child out, or adding weight to the other side.
- **Levers and tools**: scissors, cutters, spanners, crowbars, wheelbarrows. Put the load close to the pivot and your hands far from it to get the biggest turning effect for your effort.
- **See-saw moving up and down**: the distances moved are in the same ratio as the distances from the pivot, so you can still use the principle of moments with the distances from the pivot.

2. Resultant force and its effect on motion (44 questions)

1. **Draw or read the forces** and split them into the direction of motion and against it (and up and down if needed).
2. **Find the resultant**: add those going one way, subtract those going the other. Give its **size and direction**.
3. **Link it to the motion**: zero resultant → at rest or constant speed in a straight line; resultant forwards → speeds up; backwards → slows down.

For example, a boat with a 350 N forward force from its engine and 120 N of water resistance has a resultant of 230 N forwards, so it speeds up.

Variations you will meet:

- **Constant speed means balanced.** "Travels at constant speed" or "terminal velocity" tells you the forces balance: a cyclist moving steadily has friction plus air resistance equal to her driving force; a rocket rising at constant speed has thrust $=$ weight $+$ air resistance, so the air resistance is thrust minus weight, **downwards**.
- **Name a force** on a diagram: the backward force on a car, a boat or a skydiver is air or water resistance (drag) or friction; the downward force is weight.
- **Which object has a resultant force?** Any object that speeds up, slows down or changes direction, including one moving in a circle at constant speed and a ball that has just been dropped. An object at rest or moving steadily in a straight line (even down a slope) has none.
- **What happens when the forces change**, for example the rope towing a car breaks: the truck's resistive forces drop but its driving force doesn't, so the resultant is forwards and it accelerates forwards.
- **Falling objects**: as the speed rises, air resistance rises, the resultant falls and so does the acceleration, until air resistance equals weight (terminal velocity). At a steady fall the upward force equals the weight.
- **A car's top speed**: drag grows with speed until it equals the driving force.
- **Several forces that all balance**: a child sitting on a swing is at rest, so the upward forces add up to her weight and the resultant is 0.
- **Speed–time graphs**: a horizontal section has zero resultant force; a sloping section has a resultant force.

3. Springs and load–extension graphs (28 questions)

1. **Get the extension**, not the length: extension $=$ length $-$ unstretched length. Watch for tables and graphs that give length.
2. **Read the graph carefully**: go up from the load to the line, then across to the axis, and draw these lines on the graph if asked to "show your working".
3. **Extended only:** use $k = \dfrac{F}{x}$ with a point on the **straight** part. Rearrange as $x = \dfrac{F}{k}$ or $F = kx$ when needed, and give the unit (N/cm or N/m).
4. If the question wants a **length**, add the extension back onto the unstretched length.

For example, a spring of unstretched length 5.0 cm with $k = 2.0$ N/cm, loaded with 3.0 N, extends by $3.0 \div 2.0 = 1.5$ cm, so its length is 6.5 cm.

Variations you will meet:

- **Which graph shows proportionality?** A straight line through the origin.
- **Unstretched length from a length–load graph**: extend the straight line back to zero load and read where it meets the length axis.
- **Describe the experiment**: clamp and stand, spring, metre rule (and pointer), loads or a newton meter; measure the unstretched length first; add loads in steps and record the length each time; work out the extensions; plot the graph; k is load ÷ extension on the straight part. You do not need a stopwatch, a balance or a light gate.
- **Extended only: mark the limit of proportionality** where the straight line ends and the graph starts to curve, and say it is the point beyond which extension is no longer proportional to load.
- **Extended only: sketch a graph** with a straight line from the origin to L, then a curve beyond it: bending towards the extension axis on a load–extension graph, and bending up (getting steeper) on an extension–load graph.
- **Which spring suits a job?** Work out each extension with $x = \dfrac{F}{k}$, then check it fits the space or stays below the limit of proportionality.
- **Extended only: a mass bouncing on a spring.** When the mass is pulled down and let go, the spring's upward force (tension) is more than the weight: the resultant is tension minus weight, upwards, and $a = \dfrac{F}{m}$. The spring force is kx if you know the extension.
- **Two objects on identical springs**: the one with the bigger extension has the bigger weight, and so the bigger mass.

4. Using F = ma (Extended, 25 questions)

1. **Find the acceleration** if it isn't given: $a = \dfrac{\Delta v}{\Delta t}$ (from the Motion topic), or the gradient of a speed–time graph.
2. **Find the resultant force**: $F = ma$, with m in kg.

3. **Give the direction** if asked: the same as the acceleration. A deceleration means a resultant force **backwards**.

For example, a 2.5 kg trolley speeding up from 1.0 m/s to 4.0 m/s in 2.0 s has $a = 3.0 \div 2.0 = 1.5$ m/s² and a resultant force of $2.5 \times 1.5 = 3.75 \approx 3.8$ N.

Variations you will meet:

- **Resistive forces as well as a driving force.** $F = ma$ gives the **resultant**. The driving force must be bigger: driving force $=$ resultant $+$ resistive forces. This explains why a train's motors must provide more than the ma value.
- **Acceleration from forces**: subtract to get the resultant, then divide by the mass. $a = \dfrac{\text{driving} - \text{resistive}}{m}$.
- **Braking force** to stop a moving object: find the deceleration from the speed change and the time (or from a graph), then $F = ma$.
- **How does the acceleration change?** If drag grows with speed, the resultant shrinks, so the acceleration decreases even though the driving force stays the same.
- **A bigger change in motion** for the same force comes from a **smaller mass**.
- **Two objects linked by a cord over a pulley**: $F = ma$ for one object gives the resultant force on that object alone. For a hanging object accelerating down, the upward pull of the cord is weight $-ma$.
- **Force from an upward acceleration**: a balloon or rocket with a resultant force upwards accelerates upwards at $a = F \div m$.

5. Equilibrium: conditions and the experiment (20 questions)

1. **State both conditions**: no resultant force **and** no resultant moment. One alone is not enough.
2. **Test a diagram**: do the forces add to zero? Do they act along the same line (or do their moments balance)? If either fails, it is not in equilibrium.
3. **Use equilibrium to find a force**: total upward force $=$ total downward force; the pivot pushes up with the total of everything hanging on the beam, including the beam's weight.

Variations you will meet:

- **Pairs of equal forces on a block**: equal and opposite along the **same line** is equilibrium; equal and opposite but offset makes it turn, so it is not.
- **"Which must be true?"** An object in equilibrium need not be at rest: a spacecraft drifting at constant velocity with no resultant force or moment is in equilibrium.
- **Moments about any point are balanced** for an object in equilibrium, not only about the pivot, so the total moment about either end of a balanced rule is zero.
- **Extended only: describe the experiment** (see "Understand it"): rule balanced at its centre, masses hung on both sides, adjust until it balances, measure distances, show that total clockwise moment $=$ total anticlockwise moment. A labelled sketch helps.

- **Extended only: three forces**, such as a drawbridge held by a cable and a hinge: the unknown force must cancel what's left of the others, so its direction is fixed by the other two.

6. Centre of gravity and stability (18 questions)

1. **Definition**: the point where the whole weight of the object seems to act.
2. **Stability**: lower centre of gravity and wider base → more stable. Explain with the line of the weight: it stays inside the base for longer when the object is tilted.
3. **Experiment**: hang from a pin, plumb line, draw the line, repeat from another hole, the centre of gravity is where the lines cross.

Variations you will meet:

- **Which object falls over most easily?** The one with the highest centre of gravity and the narrowest base, such as a letter T block (heavy at the top, narrow at the bottom) rather than an A or an M.
- **A freely hanging object** comes to rest with its centre of gravity **vertically below** the point of suspension.
- **A symmetrical shape**: the centre of gravity lies on every line of symmetry, so it is where they cross. For a uniform metre rule it is the 50 cm mark.
- **Suggest how to make something more stable**: make the base wider or heavier (lowering the centre of gravity), or keep heavy things low.
- **Moment of an object's weight** about a corner: weight × horizontal distance from the corner to the vertical line through the centre of gravity.
- **Which apparatus is not needed** for the experiment? A stopwatch (and a balance).

7. Motion in a circle (Extended, 13 questions)

1. **Direction of the resultant force**: towards the **centre** of the circle, at right angles to the direction of motion. Draw the arrow from the object pointing at the centre.
2. **Why is there a force at constant speed?** The direction of motion changes, so the velocity changes, so there must be a resultant force.
3. **How big?** Bigger for more speed, a smaller radius or a bigger mass.

Variations you will meet:

- **Satellites and moons**: the resultant force is gravity, towards the centre of the planet.
- **A car on a bend or roundabout**: friction between tyres and road provides the force. A tighter corner at the same speed needs a **bigger** force.
- **Why does a car slide off?** Too fast, too tight a bend, too little friction (wet, icy or oily road, worn tyres), or too much mass for the friction available.
- **The acceleration** of the object also points **towards the centre**, because acceleration is in the direction of the resultant force.

8. Effects of forces, friction and drag (13 questions)

1. **What forces can change**: size, shape, speed, direction of motion. Never **mass**.
2. **Friction**: acts between surfaces, opposes motion, produces **heating**.
3. **Drag**: friction in a liquid or gas; air resistance points opposite to the motion.

Variations you will meet:

- **"State two changes a resultant force can make to a moving object"**: its speed and its direction of motion. For a stationary object, it can also change its size or shape.
- **Which is an example of friction?** Air resistance or water resistance; not weight, and not the tension in a spring.
- **Which way does air resistance act?** Opposite to the direction the object is moving, whatever the object is.
- **Why is a rocket or racing car pointed and smooth?** To reduce the air resistance.
- **Energy**: work done against friction heats the surfaces, so the energy ends up as thermal energy.

9. Resultant of forces at an angle (Extended, 7 questions)

This is syllabus 1.1 (Physical quantities and measurement techniques, Extended), covered in full in the Measurement note; a short reminder follows. When two forces act **at right angles**, draw them tip to tail and use Pythagoras for the size and $\tan$ for the angle, or draw a scale diagram and measure. For 5.0 N east and 12 N north, the resultant is $\sqrt{5.0^2 + 12^2} = 13$ N at $\tan^{-1}\left(\frac{5.0}{12}\right) = 22.6^\circ$ east of north.

Variations you will meet:

- **More than two forces** (four forces on an aircraft): combine the forces along each line first, then add the two results at right angles.
- **Which is the resultant of F_1 and F_2 at right angles?** $\sqrt{F_1^2 + F_2^2}$, not $F_1 + F_2$.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A delivery van moves along a straight, level road. The horizontal forces on it are a driving force of 2600 N forwards, air resistance of 700 N and friction of 400 N.

(a) Calculate the resultant horizontal force on the van, and state its direction. **[2]**

(b) Describe the effect of this resultant force on the motion of the van. **[1]**

(c) Later the van travels at a constant speed. The air resistance is now 900 N and the friction is still 400 N. State the driving force. **[1]**

(d) **Extended only.** The mass of the van is 2500 kg. Calculate the acceleration of the van in (a). **[2]**

(a) Backward forces: $700 + 400 = 1100$ N. Resultant $= 2600 - 1100 = 1500$ N **B1**, forwards **B1**.

(b) The van speeds up (accelerates) forwards. **B1**

(c) Constant speed means the resultant is zero, so the driving force equals the backward forces: $900 + 400 = 1300$ N. **B1**

(d) $a = \dfrac{F}{m}$ **C1** $= \dfrac{1500}{2500} = 0.60$ m/s² **A1**.

Example 2

A uniform plank 4.0 m long, of weight 190 N, is pivoted at its centre to make a see-saw. Child A, of weight 350 N, sits 1.4 m to the left of the pivot. Child B, of weight 280 N, sits on the right so that the plank balances horizontally.

(a) Calculate the moment of child A's weight about the pivot. **[2]**

(b) State the principle of moments and use it to find how far child B is from the pivot. **[3]**

(c) Calculate the upward force of the pivot on the plank. **[2]**

(d) **Extended only.** A toddler of weight 120 N sits on the left, 0.50 m from the pivot. Child B moves so that the plank balances again. Calculate B's new distance from the pivot. **[3]**

(a) Moment $=$ force × perpendicular distance **C1** $= 350 \times 1.4 = 490$ N m **A1**.

(b) For a balanced object, the sum of clockwise moments equals the sum of anticlockwise moments. **B1**

$280 \times d = 490$ **C1**, so $d = 490 \div 280 = 1.75$ m **A1**. (The plank's weight acts at the pivot, so it has no moment.)

(c) No resultant force, so upward force $=$ total downward force **C1** $= 350 + 280 + 190 = 820$ N **A1**.

(d) Anticlockwise moments: $490 + 120 \times 0.50 = 490 + 60 = 550$ N m **C1**.

$280 \times d = 550$ **C1**, so $d = 550 \div 280 = 1.96$ m **A1** (still on the plank, which reaches 2.0 m from the pivot).

Example 3

A student hangs loads from a spring whose unstretched length is 6.0 cm. Her results give the load–extension graph in "Understand it": a straight line through the origin to 6.0 N at 7.5 cm, then a curve.

(a) Describe how she takes her measurements. **[3]**

(b) **Extended only.** Calculate the spring constant of the spring. **[2]**

(c) Calculate the length of the spring when the load is 2.5 N. **[2]**

(d) **Extended only.** A mass of 0.30 kg hangs from the spring. It is pulled down until the tension in the spring is 4.4 N, then released. Calculate the acceleration of the mass just after it is released. **[3]**

(a) Measure the unstretched length of the spring with a metre rule held vertically beside it. **B1** Add loads one at a time, measuring the new length each time (eye level with the pointer). **B1** Work out each extension as length minus unstretched length. **B1**

(b) $k = \frac{F}{x}$ **C1** $= \frac{6.0}{7.5} = 0.80$ N/cm **A1**.

(c) $x = \frac{F}{k} = \frac{2.5}{0.80} = 3.125$ cm **C1**. Length $= 6.0 + 3.125 = 9.1$ cm **A1** (2 s.f.).

(d) Weight $= mg = 0.30 \times 9.8 = 2.94$ N **C1**.

Resultant force $= 4.4 - 2.94 = 1.46$ N upwards **C1**.

$a = \frac{F}{m} = \frac{1.46}{0.30} = 4.9$ m/s² upwards **A1**.

Example 4

Extended only. A cyclist and her bicycle have a total mass of 82 kg. On a straight, level road she speeds up from 3.0 m/s to 7.5 m/s in 5.0 s.

(a) Calculate the resultant force on the cyclist and bicycle. **[3]**

(b) The forward force from the pedals is 120 N. Calculate the total resistive force. **[1]**

(c) She then rides round a circular bend at a constant speed. State the direction of the resultant force on her, and explain why there must be a resultant force even though her speed is constant. **[2]**

(d) She rides round a tighter bend (smaller radius) at the same speed. State how the resultant force needed changes, and suggest what could happen if the road is icy. **[2]**

(a) $a = \frac{\Delta v}{\Delta t} = \frac{7.5 - 3.0}{5.0} = 0.90$ m/s² **C1**.

$F = ma$ **C1** $= 82 \times 0.90 = 73.8 \approx 74$ N **A1**.

(b) Resistive force $= 120 - 73.8 = 46.2 \approx 46$ N. **B1**

(c) Towards the centre of the bend (at right angles to her motion). **B1** Her direction keeps changing, so her velocity changes, and that needs a resultant force. **B1**

(d) A bigger force is needed. **B1** Friction between the tyres and the icy road may not be big enough to provide it, so she slides off the bend (outwards, in a straighter path). **B1**

Common mistakes

- **Calling a moment a force**, or giving it the unit N or N/m. A moment is a turning effect; its unit is N m (or N cm).
- **Using the wrong distance.** The distance must be from the **pivot** and **perpendicular** to the force. On a metre rule, subtract the pivot's position; don't use the mark itself. Examiners often see a force multiplied by a nearby but wrong distance from the diagram.
- **Dividing instead of multiplying** for a moment, or mixing up which forces are clockwise and which anticlockwise. Write "clockwise moment = anticlockwise moment" first, then fill in each side.
- **Balancing forces instead of moments.** On a see-saw with different distances, the weights are **not** equal. Use the principle of moments, not "force left = force right".
- **Forgetting the unstretched length.** A length is not an extension. Subtract the unstretched length to get the extension, and add it back when asked for the new length.
- **Confusing the limit of proportionality** with the elastic limit, or marking it at the end of the graph. It is where the straight line **stops** being straight.
- **Missing units** on the spring constant (N/cm or N/m) or on a moment. Some answer lines don't print the unit, and it costs a mark.
- **Saying "the forces are balanced with the weight"** or "the resultant force is balanced". Say **the resultant force is zero** or **air resistance equals the weight**.
- **Using the driving force in $F = ma$** when there is also friction. F is the **resultant**: subtract the resistive forces first.
- **Thinking a moving object needs a resultant force to keep going.** At constant speed in a straight line, the resultant is zero.
- **Drawing the force on a circling object along the motion or outwards.** It points **towards the centre**. If the force stops, the object goes off in a straight line along the tangent, not outwards.
- **Vague stability answers.** "It is more balanced" earns nothing: say the centre of gravity is **lower** or the base is **wider**. The centre of gravity is a point in the object; it does not stay fixed while the contents move.
- **Leaving steps out of the centre of gravity experiment**: the object must hang freely, you need a plumb line from the **same** pin, and you need at least **two** lines, crossing at the centre of gravity.

How to get the marks

- **Calculations** earn a mark for the equation or substitution even if the answer is wrong. Write the equation in words or symbols (moment $=$ force $\times$ distance, $k = F/x$, $F = ma$), then the numbers, then the answer with a unit.

- **"Show that"** questions give the answer. Show every number used and give your value to one more significant figure than the printed one (for example 0.96 for "about 1"), so the examiner can see you didn't copy it.
- **"State and use the principle of moments"** needs the statement in words (sum of clockwise moments $=$ sum of anticlockwise moments) **and** the equation with numbers.
- **Resultant forces** need a **size and a direction**. "40 N" alone loses the direction mark.
- **"Define"**: moment $=$ force × **perpendicular** distance from the pivot; spring constant $=$ force per unit extension; centre of gravity $=$ the point where the whole weight seems to act; limit of proportionality $=$ the point beyond which extension is no longer proportional to load.
- **"Describe an experiment"**: list the apparatus, what you measure, how you measure it, and what you do with the results (how you calculate k, or compare the moments). A labelled diagram earns credit.
- **"Explain"** a change in motion: give the forces (which is bigger), the resultant (and its direction), and then the effect on the speed or acceleration.
- **Graph reading**: draw the lines you use on the graph, and read to half a small square.
- **Significant figures**: give 2 or 3 significant figures, matching the data. Don't round a middle value (like a weight) before using it again.
- **Multiple choice**: work out the answer first. The wrong options use the usual slips: length instead of extension, a non-perpendicular distance, adding forces that should be subtracted, or $F \times d$ swapped for $F \div d$.

Quick check

1. A crate on the floor is pushed with a force of 72 N to the right. Friction on the crate is 26 N. Find the resultant force and describe the crate's motion.
2. A uniform metre rule is balanced at its 50 cm mark. A 2.4 N weight hangs at the 15 cm mark. Where must a 3.5 N weight hang to balance it?
3. **Extended only.** A spring is 9.0 cm long with no load and 11.4 cm long with a 3.6 N load. Calculate its spring constant, and the load that would give an extension of 3.0 cm (within the limit of proportionality).
4. Two identical vans each carry the same heavy boxes. One van carries them on a roof rack, the other on its floor. Which van is more stable? Explain why.
5. **Extended only.** A 1.8 kg trolley is pulled along a bench by a horizontal force of 9.0 N. Friction on it is 2.7 N. Calculate its acceleration.

Answers

1. Resultant $= 72 - 26 = 46$ N to the right. The crate speeds up (accelerates) to the right.
2. Anticlockwise moment $= 2.4 \times (50 - 15) = 84$ N cm. The 3.5 N weight must give 84 N cm clockwise: distance $= 84 \div 3.5 = 24$ cm to the right of the pivot, at the 74 cm mark.
3. Extension $= 11.4 - 9.0 = 2.4$ cm, so $k = 3.6 \div 2.4 = 1.5$ N/cm. Load $= kx = 1.5 \times 3.0 = 4.5$ N.
4. The van with the boxes on the floor. Its centre of gravity is lower, so it has to tilt further before the vertical line through its centre of gravity falls outside its base (its wheels).
5. Resultant force $= 9.0 - 2.7 = 6.3$ N. $a = \frac{F}{m} = \frac{6.3}{1.8} = 3.5$ m/s².

Past questions to try

- **0625/33/M/J/25 Q3**: the principle of moments to find the weight of a block, then a pressure.
- **0625/43/O/N/24 Q2**: the spring constant experiment, the limit of proportionality and choosing a spring (Extended).
- **0625/41/O/N/24 Q3**: the moment of a force, the centre of gravity and the two conditions for equilibrium (Extended).
- **0625/32/F/M/25 Q3**: why a cone is more stable than a cuboid, and the moment of a force that tilts it.