IGCSE PHYSICS 0625 · CHAPTER 3 NOTES · ~10 MIN READ

Forces, moments & momentum

Everything that pushes, pulls, turns and crashes — from springs and friction to see-saws and car safety.

Resultant force | Springs & Hooke's law | Friction & drag | F = ma | Circular motion | Moments | Centre of gravity | Momentum & impulse

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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

- A **resultant force** changes motion. Zero resultant = stays at rest or keeps moving at constant velocity.
- **Moment = force × perpendicular distance.** Balanced when clockwise moments = anticlockwise moments.
- EXT **F = ma**, **F = kx** (springs) and **momentum p = mv** (conserved in collisions).
- A low centre of gravity and a wide base make an object stable.

BY THE END YOU CAN

- Combine forces on a line and say what a resultant force does.
- Plot and interpret a load–extension graph and use F = kx. EXT
- Use F = ma and describe circular motion qualitatively. EXT
- Calculate moments and apply the principle of moments.
- Find the centre of gravity of a lamina and judge stability.
- Calculate momentum and impulse and use conservation of momentum. EXT

1 Forces and motion

The effect of forces

- A force is a push or a pull, measured in **newtons (N)**. It can change an object's **size, shape, speed or direction**.
- The **resultant force** is the single force that has the same effect as all the forces together. On a line: add forces in the same direction, subtract forces in opposite directions.
- **Resultant = 0** (balanced forces): an object at rest stays at rest, and a moving object keeps the **same speed in a straight line**.
- **Resultant ≠ 0**: the object speeds up, slows down, or changes direction.

PICTURE IT

In a tug-of-war, if both teams pull with 800 N the rope does not move. If one team pulls with 900 N against 800 N, there is a resultant of 100 N towards the stronger team and the rope accelerates that way.

COMMON MISTAKE

"A moving object always needs a force to keep it moving." No — at constant speed the forces are balanced (resultant zero).

Friction and drag

- **Friction** is a force between surfaces in contact. It opposes motion and makes the surfaces **heat up**.
- **Drag** is friction in a liquid or gas (air resistance). It grows as the speed grows.
- Useful: brakes, grip of shoes and tyres. A nuisance: wasted energy as heat in machines (fixed by oil or lubricant).

Newton's second law

EXTENDED

$$F = m\,a$$

resultant force (N) = mass (kg) × acceleration (m/s²)

- The acceleration is in the **same direction** as the resultant force. 1 N is the force that gives a 1 kg mass an acceleration of 1 m/s².
- Same force on a bigger mass → smaller acceleration.

WORKED EXAMPLE

A 1200 kg car has a driving force of 3500 N and a resistive force of 500 N. Find its acceleration.

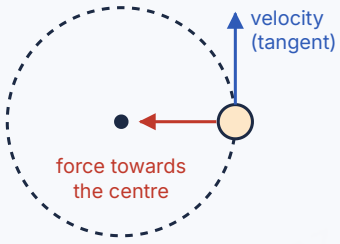
1. Resultant force = 3500 − 500 = 3000 N
2. a = F ÷ m = 3000 ÷ 1200
3. **= 2.5 m/s² in the direction of the driving force**

COMMON MISTAKE

Using the driving force alone in F = ma. Use the RESULTANT force.

Circular motion

EXTENDED



direction keeps changing → a resultant force is needed

The velocity is always along the tangent. A force towards the centre keeps changing the direction.

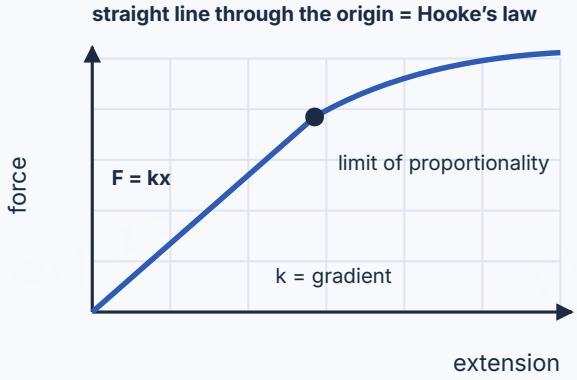
- Moving in a circle at constant speed means the **direction keeps changing**, so the velocity changes and the object is accelerating. A resultant force acts **towards the centre**.
- The force needed is bigger for a **larger mass**, a **higher speed** and a **smaller radius**.
- Examples: the Moon around the Earth (gravity), a car on a bend (friction), a stone on a string (tension).

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2 Springs and Hooke's law

Load–extension graphs

- **Extension x** = new length − original length.
- Hang masses (the **load**) on a spring and measure the length each time. Subtract the original length to get extension, then plot load (force) against extension.



A straight line through the origin means force is proportional to extension — Hooke's law. The line bends beyond the limit of proportionality.

- Up to the **limit of proportionality** the extension is directly proportional to the load. Beyond it the spring stretches more for each extra newton and may not return to its original length.

EXT $F = k\,x$

k = spring constant (N/m) = gradient of the straight part; x = extension (m)

WORKED EXAMPLE

EXT **A spring has k = 40 N/m. What force gives an extension of 6.0 cm?**

1. Convert: 6.0 cm = 0.060 m
2. F = kx = 40 × 0.060
3. **= 2.4 N**

COMMON MISTAKE

Using the total length instead of the extension.

EXAM TIP

Describing the experiment: measure the original length, add equal masses one at a time, measure the length each time, subtract to get extension, plot the graph. Use a ruler fixed vertically beside the spring and read at eye level.

3 Turning effects

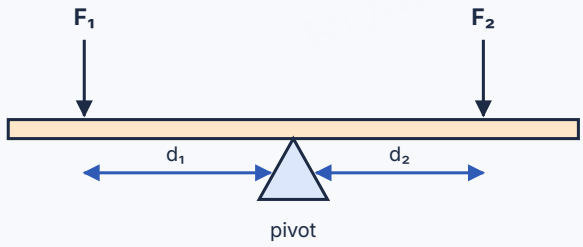
Moments

Moment — the turning effect of a force about a pivot.

$$\text{moment} = F \times d$$

unit N m · d = the PERPENDICULAR distance from the pivot to the line of action of the force

- Examples: pushing a door at the handle (large d) is much easier than near the hinge (small d); a spanner; a see-saw.



balanced when $F_1 \times d_1 = F_2 \times d_2$

A balanced beam: the clockwise moment ($F_2 \times d_2$) equals the anticlockwise moment ($F_1 \times d_1$).

Principle of moments and equilibrium

sum of clockwise moments = sum of anticlockwise moments

when the object is balanced

- An object is in **equilibrium** if the **resultant force is zero** AND the **resultant moment is zero**.
- EXT With several forces on each side, add up all the clockwise moments and all the anticlockwise moments.

WORKED EXAMPLE

A see-saw pivots in the middle. A 300 N child sits 2.0 m from the pivot. Where must a 400 N child sit to balance?

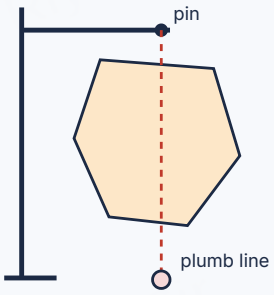
1. Anticlockwise = clockwise
2. 300 × 2.0 = 400 × d
3. 600 = 400d
4. **d = 1.5 m from the pivot**

COMMON MISTAKE

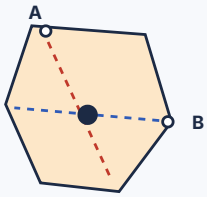
Measuring the distance along a slanted line. d must be perpendicular to the force.

Centre of gravity and stability

Centre of gravity (CG) — the point where the whole weight of an object seems to act.



hang it, mark the plumb line



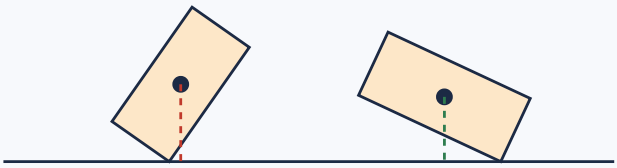
1: from hole A (red)
2: from hole B (blue)

crossing = centre of gravity

Hang the lamina from a pin, mark the plumb line, repeat from another hole. The lines cross at the centre of gravity.

- **Stable** objects: low CG and a wide base. The object topples when the vertical line from the CG falls **outside** the base.

a CG that stays above the base = stable



line from CG falls outside the base → topples ×

line falls inside the base → stable ✓

A tipped object returns if the line from its CG falls inside the base; it topples if the line falls outside.

- Examples: a double-decker bus is tested by tilting it; racing cars are low and wide; a bus with passengers downstairs is safer.

4 Momentum

Momentum and impulse

EXTENDED

$$p = m\,v$$

momentum (kg m/s) = mass (kg) × velocity (m/s) — a vector, same direction as the velocity

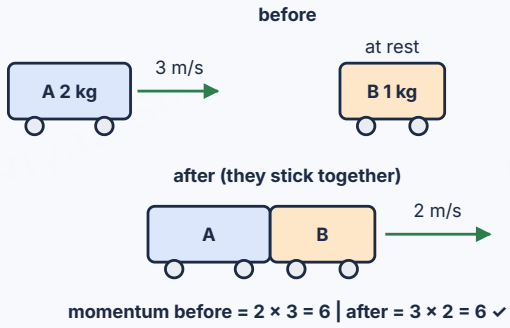
$$\text{impulse} = F\,\Delta t = \Delta(mv)$$

force × time the force acts = change in momentum

$$F = \frac{\Delta p}{\Delta t}$$

resultant force = rate of change of momentum

- **Conservation of momentum:** in a collision with no outside forces, **total momentum before = total momentum after**. Choose one direction as positive.



Momentum is shared out but the total is the same: 6 kg m/s before and after.

WORKED EXAMPLE

A 2.0 kg trolley moving at 3.0 m/s hits a stationary 1.0 kg trolley. They stick together. Find the speed afterwards.

1. Momentum before = 2.0 × 3.0 + 1.0 × 0 = 6.0 kg m/s
2. Momentum after = (2.0 + 1.0) × v = 3.0v
3. 6.0 = 3.0v
4. **v = 2.0 m/s in the original direction**

PICTURE IT

Catching a fast cricket ball: if you pull your hands back, the ball's momentum changes to zero over a longer time, so the force on your hands is smaller.

- **Safety:** crumple zones, air bags, seat belts, padded helmets and playground surfaces all **increase the time** of the collision, so the force is **smaller** for the same change of momentum.

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5 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Resultant of 12 N to the right and 5 N to the left?
2. Moment of a 20 N force acting 0.30 m from a pivot?
3. A 1200 kg car has a resultant force of 3000 N. What is its acceleration?
4. State the unit of momentum.
5. What must be true for an object to be in equilibrium?
6. Why is a car with a low centre of gravity more stable?

EXAM-STYLE

7. A spring is 12.0 cm long. A load of 5.0 N makes it 17.0 cm long. Assuming it obeys Hooke's law, find the spring constant.
8. A uniform 40 N plank rests on a pivot at its centre. A 60 N weight hangs 0.50 m to the left. How far to the right of the pivot must a 20 N weight hang to balance?
9. A 0.60 kg trolley moving at 2.0 m/s collides with a 0.40 kg trolley at rest. They join together. Calculate the speed after the collision.
10. Explain why an air bag reduces injury in a crash. [2]

Show answers

1. 7 N to the right
2. 20 × 0.30 = 6.0 N m
3. 3000 ÷ 1200 = 2.5 m/s² EXT
4. kg m/s EXT
5. resultant force = 0 and resultant moment = 0
6. The line from its CG stays inside the base until the car is tilted much further.
7. extension = 17.0 − 12.0 = 5.0 cm = 0.050 m
   k = F ÷ x = 5.0 ÷ 0.050 = 100 N/m
8. The plank's own weight acts at the pivot, so it adds no moment
   60 × 0.50 = 20 × d
   d = 30 ÷ 20 = 1.5 m
9. momentum before = 0.60 × 2.0 = 1.2 kg m/s
   total mass = 1.0 kg
   v = 1.2 ÷ 1.0 = 1.2 m/s
10. It increases the time taken for the passenger to stop
    so the rate of change of momentum, and hence the force, is smaller

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