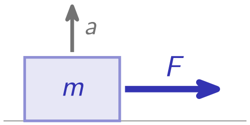
Motion, Forces & Energy

IGCSE Physics ▪ Topic 1

IGCSE Physics



What we will cover

1. Measurement & motion
2. Mass, weight & density
3. Forces & moments
4. Momentum
5. Energy, work & power
6. Pressure

1 Measurement and motion

Measurement

Five SI base units used here:

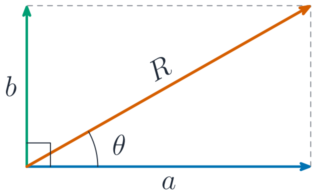
m	kg	s	A	K
length	mass	time	current	temperature

Measure many and divide: 100 pages → one thickness; 20 swings → one **period** 周期. Quote a unit; uncertainty ≈ half the smallest division.

Scalars and vectors

- **scalar** 标量 – size only (distance, speed, mass)
- **vector** 矢量 – size *and* direction (force, velocity)

At right angles, $R = \sqrt{a^2 + b^2}$.



$$R = \sqrt{a^2 + b^2}$$

Speed, velocity and acceleration

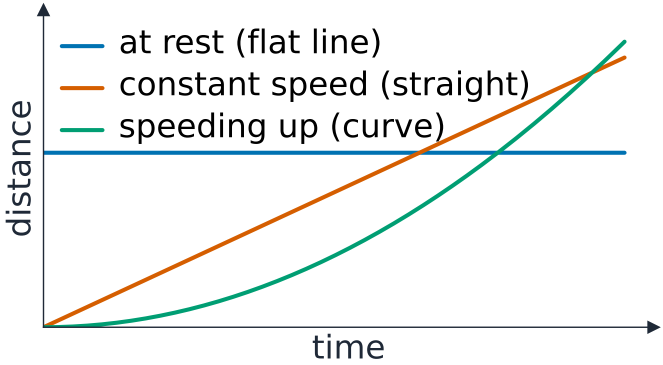
$$v = \frac{s}{t}, \qquad a = \frac{\Delta v}{\Delta t}.$$

Speed is a scalar; **velocity** 速度 is speed in a direction.

Car: $8 \to 20\,\mathrm{m/s}$ **in** $4.0\,\mathrm{s}$

$$a = \frac{20-8}{4.0} = 3.0\,\mathrm{m/s^2}$$

Distance–time: gradient = speed



distance–time: gradient = speed

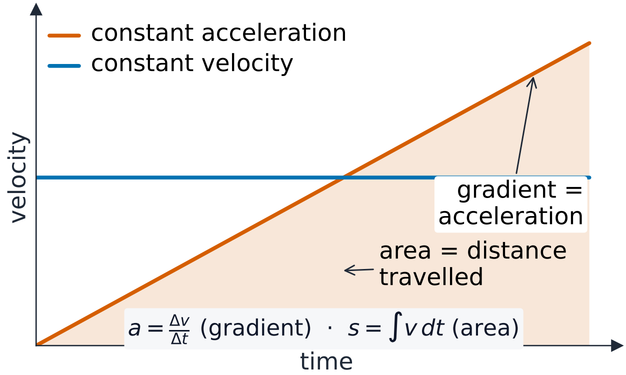
distance–time: gradient = speed

Reading the two motion graphs

Distance–time graph	On a **distance–time graph** the gradient is the speed. A horizontal line means the object is **at rest**; a steeper line means faster.
Speed–time graph	On a **speed–time graph** the gradient is the acceleration – a negative gradient is a **deceleration** 减速.
The area	On a speed–time graph the **area under the line** is the distance travelled. Split it into triangles and rectangles.
The shape	Read the axes first – the same shape means constant speed on one graph and constant acceleration on the other.

> Gradient and area answer different questions. Say which you are taking, and give the unit that comes with it.

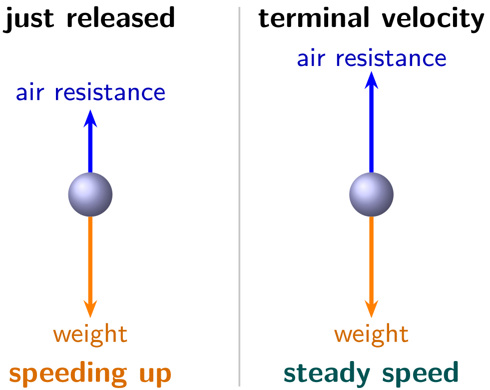
Speed–time: gradient = a; area = s



speed–time: gradient = a; area = s

> speed–time: gradient = a; area = s

Falling and terminal velocity



Near Earth, $g \approx 9.8\,\mathrm{m/s^2}$ for every object.

- **weight** 重力 down; **air resistance** 空气阻力 up
- drag grows as the object speeds up

Terminal velocity 收尾速度: drag $=$ weight, resultant $= 0$, speed is steady.

2 Mass, weight and density

Mass, weight and density

- mass (kg) – amount of **matter** 物质, same everywhere
- weight (N) – gravity's pull, $W = mg$
- **density** 密度 $\rho = \dfrac{m}{V}$

Floats if its density $<$ the liquid's.

Stone $54\,\mathrm{g}$**, water** $20 \to 40\,\mathrm{cm}^3$

$$V = 20\,\mathrm{cm}^3,\ \rho = \frac{54}{20} = 2.7\,\mathrm{g/cm}^3$$

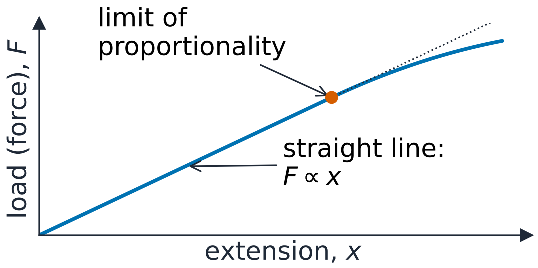
Mass, weight, and the units they use

Gravitational field strength	Weight is $W = mg$, where g is the **gravitational field strength**: 9.8 N/kg on Earth. Mass is the same everywhere; weight is not.
Magnitude	A scalar has **magnitude** 大小 only; a vector has magnitude *and* direction.
Named units	The **joule** 焦耳 (J) for energy and **work done**; the **watt** 瓦特 (W) for power, one joule per second; the **pascal** 帕斯卡 (Pa) for pressure, one newton per square metre.
Hooke's law	On a **load–extension graph** the straight part obeys Hooke's law, and the gradient is the spring constant.

> Every named unit is a shorthand for a combination of the base units. Knowing which combination is often the whole question.

3 Forces and moments

Hooke's law



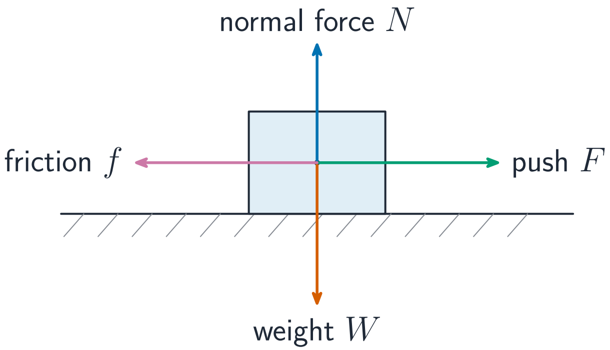
$F = kx$ up to the limit of proportionality · $k =$ gradient

Extension 伸长量 is proportional to load up to the **limit of proportionality** 比例极限.

$$k = \frac{F}{x}.$$

A large **spring constant** 弹簧常数 k means a stiff spring.

Resultant force and $F = ma$



Resultant force 合力 zero $\Rightarrow$ rest or constant velocity. Otherwise

$$F = ma.$$

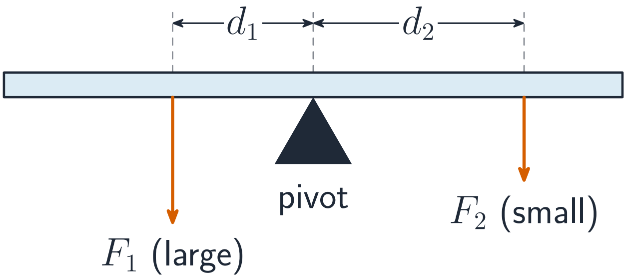
Friction 摩擦 opposes motion (or the tendency to move).

Car $1200\,\mathrm{kg}$**:** $3000 - 600\,\mathrm{N}$

$$a = \frac{2400}{1200} = 2.0\,\mathrm{m/s^2}$$

Moments – the turning effect

balanced: $F_1 d_1 = F_2 d_2$



Moment 力矩 = force × perpendicular distance.

> Balanced: total clockwise = total anticlockwise moment.

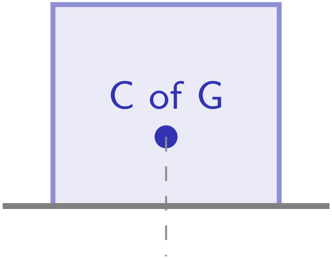
$30\,\mathrm{N}$ at $0.20\,\mathrm{m}$ vs $20\,\mathrm{N}$

$$d = \frac{30 \times 0.20}{20} = 0.30\,\mathrm{m}$$

Centre of gravity and stability

The **centre of gravity** 重心 is where all the weight seems to act.

> More stable with a low centre of gravity and a wide base. It tips when the C of G passes outside the base.



Moments, and finding a centre of gravity

a moment	moment = force × perpendicular distance from the pivot
the unit	the newton metre (N m)
the principle of moments	in equilibrium, total clockwise moment = total anticlockwise moment
the centre of gravity	the single point where all the weight can be taken to act
for a lamina 薄片	hang it from a pin, let it settle, and draw a vertical line down from the pin
then	repeat from a second point – the centre of gravity is where the two lines cross

> An object topples when a vertical line from its centre of gravity falls outside its base. That single rule answers every stability question.

4 Momentum

Momentum

Momentum 动量 $p = mv$ (a vector). Force is the change per unit time:

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

> **Conservation** 动量守恒: total momentum before = after (no outside force).

$2.0\,\mathrm{kg}$ at $3.0\,\mathrm{m/s}$ hits a still $1.0\,\mathrm{kg}$; they stick

$$v = \frac{2.0 \times 3.0}{3.0} = 2.0\,\mathrm{m/s}$$

Momentum, impulse and what is conserved

Momentum	$p = mv$: a vector, so direction matters and opposite directions carry opposite signs.
Impulse	**Impulse** 冲量 is $F\Delta t$, and it equals the change in momentum – which is why a longer collision time means a smaller force.
Conservation of momentum	In any collision or explosion with no external force, the total momentum before equals the total after – the **conservation of momentum**.
Energy too	The **principle of conservation of energy**: energy is never created or destroyed, only transferred between stores.

> Momentum is conserved in every collision; kinetic energy is not. Crumple zones exist to lengthen Δt.

5 Energy, work and power

Energy stores and transfers

Energy is stored (**kinetic** 动能, gravitational, chemical, elastic, nuclear, internal) and transferred by forces, heating, electric current and waves.

> **Conservation of energy** 能量守恒定律: it changes store and path, but the total stays the same.

The energy resources, compared

fossil fuels	not renewable – reliable and high output, but CO_2 and pollution
nuclear fuel	not renewable – huge output and no CO_2, but radioactive waste
biofuels	renewable – roughly carbon-neutral if replanted, but they compete with food for land
hydroelectric	renewable – reliable, but a dam floods land
solar and wind	renewable and clean, but intermittent
geothermal and tidal	renewable and reliable, but limited to certain places

Every row is the same trade in a different form: reliability and output against emissions, land and location. Name which one the question is asking about.

Where the energy came from

Nuclear fusion	Almost every resource traces back to the Sun, whose energy comes from **nuclear fusion** – hydrogen nuclei joining to make helium.
From the Sun	Solar, wind, waves, hydroelectric and biofuels are all sunlight, stored or moved.
Not from the Sun	Geothermal (radioactive decay in the Earth), tidal (the Moon's pull), and nuclear fission (uranium).
The comparison	Compare on the same four axes: renewable or not, reliability, cost, and the environmental effect.

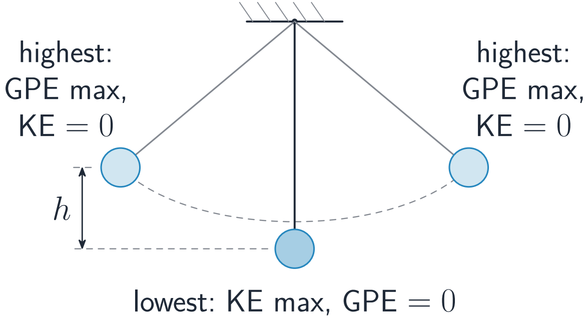
> "Renewable" says it will not run out. It says nothing about reliability, and an exam answer usually needs both.

Energy resources

Most generators spin a turbine. Most traces go back to the Sun – exceptions: geothermal, nuclear, tidal.

- **fossil / nuclear** – not renewable; high output
- **wind / solar / hydro / biofuel** – renewable; often intermittent
- **solar cells** 太阳能电池 make electricity directly; solar panels heat water

Kinetic and potential energy



$$E_k = \frac{1}{2}mv^2, \qquad \Delta E_p = mg\,\Delta h.$$

Conservation of energy 能量守恒定律: a falling object turns E_p into E_k.

Drop from $1.8\,\mathrm{m}$ ($g = 10$)

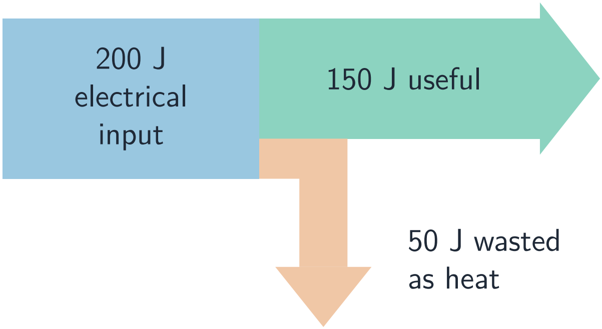
$v = \sqrt{2g\,\Delta h} = 6.0\,\mathrm{m/s}$

Work, power and efficiency

$$W = Fd, \quad P = \frac{W}{t}, \quad \eta = \frac{\text{useful}}{\text{total}} \times 100\%.$$

Motion: $200\,\text{J}$ in, $150\,\text{J}$ useful

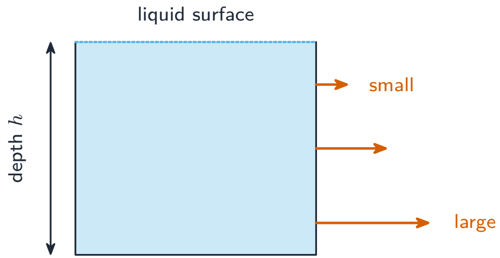
$$\eta = \frac{150}{200} \times 100\% = 75\%$$



Sankey diagram *桑基图: useful vs wasted*

6 Pressure

Pressure



Pressure 压强 $p = \dfrac{F}{A}$ (Pa). A small area gives a large pressure. In a liquid it grows with depth: $\Delta p = \rho g \Delta h$.

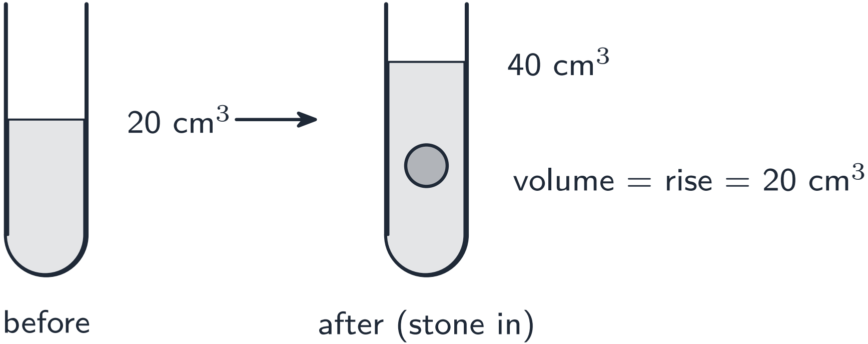
$2.0\,\mathrm{m}$ deep in water

$$\Delta p = 1000 \times 10 \times 2.0 = 2.0 \times 10^4\,\mathrm{Pa}$$

Pressure in a liquid

A real dam is built much thicker at the bottom, because the water pushes hardest where it is deepest

Length and volume



The water an irregular solid pushes up gives its volume

Measuring small amounts

A single small length or a short time is hard to measure well.

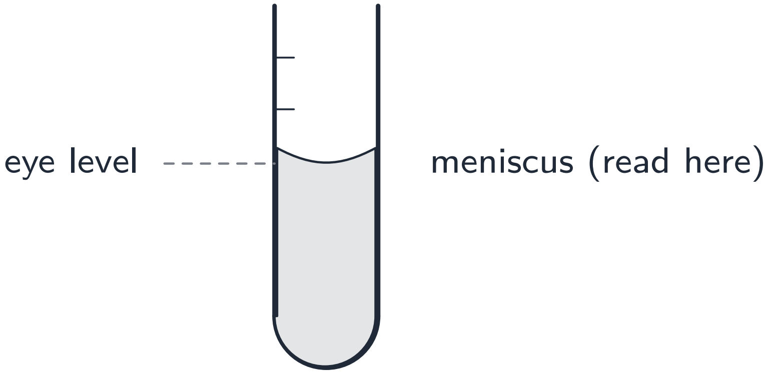
- To find the thickness of one page, measure 100 pages and divide by 100.
- To find the time for one swing of a **pendulum 摆**, measure the time for 20 swings and divide by 20. One full swing is called the **period 周期**.

Measuring something too small to measure

Measure many and divide	For a thin sheet or a small mass, use **measure many and divide**: measure 100 pages, then divide – the uncertainty is divided too.
The displacement method	For the volume of an irregular solid, use the **displacement method**: lower it into a measuring cylinder and read the rise, or catch the overflow from a full eureka can.
Repeat and average	Repeat any reading and take a mean – it reduces random error, though it can never remove a zero error.

> State the instrument, the unit and the precision. "Use a ruler" is not a method; "a 30 cm ruler to the nearest millimetre" is.

Length and volume, continued



> Read a measuring cylinder at the bottom of the meniscus, with your eye level

Measuring length, mass and density

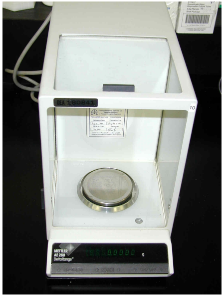
a ruler 直尺	read the scale with your eye straight in front of the mark, to avoid a parallax error
small lengths	measure many together and divide – 100 sheets of paper, or 20 swings of a pendulum
mass and weight	mass in kg is the amount of matter; weight in N is the force of gravity, $W = mg$
g	about 9.8 N/kg – the same number as the **acceleration of free fall 自由落体加速度**
density	$\rho = \frac{m}{V}$, in $\mathrm{kg/m^3}$ or $\mathrm{g/cm^3}$ – ρ is the Greek letter “rho”
finding V	a **regular solid 规则固体**: measure the sides and calculate. An irregular one: displacement in a measuring cylinder

Mass is compared with a balance, weight with a newtonmeter. A balance gives the same reading on the Moon; a newtonmeter does not.

Density 密度

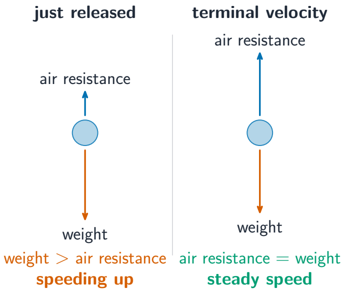
An iceberg floats with most of its volume hidden: ice is slightly less dense than water

Mass and weight



> A laboratory balance measures mass; weight is the gravitational force on that mass

Falling objects



At first the weight is bigger than the air resistance, so the object speeds up; at terminal velocity the two are equal and the speed is steady

Energy stores

Wind turbines transfer energy from the kinetic store of the moving air to electricity

Measuring time, and two kinds of quantity

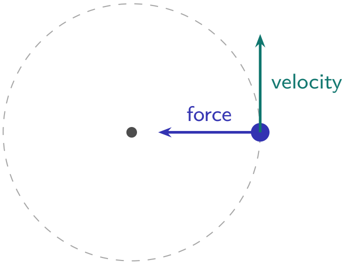
Measuring time

- long times: a clock
- short intervals: a **stopwatch** 秒表 or a **digital timer** 数字计时器
- a hand-started stopwatch carries a **reaction time** 反应时间 error of about $0.2\,\mathrm{s}$
- so time 20 swings of a pendulum and divide by 20

Scalars and vectors

- a **scalar quantity** 标量 has size only: distance, speed, time, mass, energy, temperature
- a **vector quantity** 矢量 has size and direction: force, weight, velocity, acceleration, momentum, **electric field strength** 电场强度, gravitational field strength
- near the Earth the field is **uniform** 均匀: every object falls with the same g

Motion in a circle



the force points to the centre; the speed stays the same

A resultant force at right angles to the motion changes the direction, not the speed: **circular motion** 圆周运动.

- bigger force ⇒ higher speed, same mass and **radius** 半径
- bigger force ⇒ smaller radius, same mass and speed
- bigger mass ⇒ bigger force needed for the same speed and radius

> Examples: a string on a whirling ball; the Sun's gravity on a planet.

Two experiments the exam asks you to describe

Load and extension

1. hang the spring from a clamp, ruler beside it
2. read the bottom of the spring with no load: the original length
3. add loads one at a time; record each new length
4. extension = new length − original length
5. plot load (y) against extension (x)

No resultant moment when balanced

1. pivot a metre rule at its centre
2. hang a known weight each side; slide them until it balances
3. measure each distance from the pivot
4. check: force × distance (left) = force × distance (right)

> The two products agree within the small measurement errors.

Density of a liquid, and which resource to choose

Density of a liquid

1. weigh the empty measuring cylinder
2. pour in the liquid; read its volume
3. weigh again: the difference is the liquid's mass
4. $\rho = m/V$

A liquid floats on another (if they do not mix) when its density is lower: oil on water.

$$\text{efficiency} = \frac{\text{useful power out}}{\text{total power in}} \times 100\%$$

works with power too.

Comparing energy resources

- **renewability** 可再生性: will it run out?
- **availability** 可用性: is it always there? wind drops, the Sun sets
- **reliability** 可靠性: a steady output?
- **scale** 规模: how much energy can it supply?
- **environmental impact** 环境影响: pollution, CO_2, flooded land

Fusion power stations are still research: none yet gives out more energy than it uses.

Exam tips

- On a **distance–time** graph the gradient is the speed; on a **speed–time** graph the gradient is the acceleration and the *area* under the line is the distance travelled. Never read one graph as if it were the other.
- **Mass** (kg) is the amount of matter and is the same everywhere; **weight** (N) is the force of gravity, $W = mg$. On the Moon your mass is unchanged but your weight is smaller.
- **Speed** is a scalar; **velocity** is a vector. Something moving at steady speed around a curve is still accelerating, because its direction keeps changing.

Exam tips (continued)

- In **Hooke's law**, load is proportional to extension only up to the **limit of proportionality**. Use the *extension* (stretched length − original length), never the whole length.
- **Momentum** $p = mv$ is conserved in a collision. Give each velocity a $+$ or $-$ sign for its direction *before* you add them.
- Convert units first (cm $\rightarrow$ m, g $\rightarrow$ kg). Use $p = F/A$ for a solid pressing on a surface, but $p = \rho gh$ for the pressure *inside* a liquid – they are different formulas.

7 Recap

Topic 1 – key takeaways

1 Motion

$v = s/t$, $a = \Delta v/\Delta t$; graphs

2 Forces

$F = ma$; moments balance; $W = mg$

3 Momentum

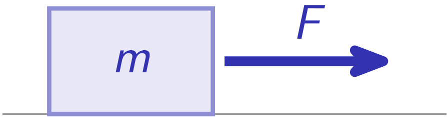
$p = mv$, conserved in collisions

4 Energy

$E_k = \frac{1}{2}mv^2$, $E_p = mgh$; conserved

Check yourself

1. What does the area under a velocity–time graph give?
2. A $2\,\mathrm{kg}$ mass on the Moon – does its mass change?
3. Resultant force at terminal velocity?
4. Why is a knife sharp (small area)?



Answers **1.** the distance **2.** no (weight does) **3.** zero **4.** large pressure from a small area