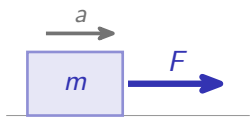
Motion, Forces & Energy

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

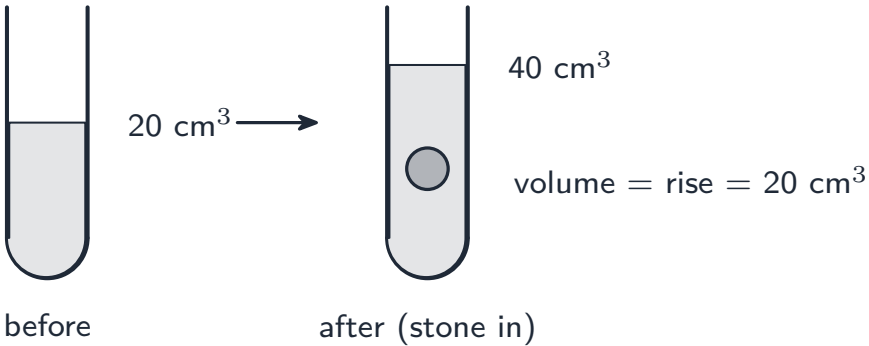
Measurement

Five SI base units used here:

m	**kg**	**s**	**A**	**K**
length	mass	time	current	temperature

Measure many and divide: 100 sheets → one thickness; 20 swings → one **period** 周期. Quote a unit and consider the instrument resolution and the measurement method.

Length and volume



The water an irregular solid pushes up gives its volume

Measuring several to estimate one

Paper and pendulum measurements

A stack of 100 sheets, without covers, is $10.0\,\mathrm{mm}$ thick.

Three timings of 20 complete pendulum oscillations are $31.8\,\mathrm{s}$, $32.2\,\mathrm{s}$ and $32.0\,\mathrm{s}$.

Find the average thickness of one sheet and the mean period of the pendulum. Explain why measuring only one sheet or one oscillation would be less suitable with the same instruments.

Average thickness from a stack

A ruler cannot resolve this individual sheet well. Measuring a stack gives a larger length to read.

$$\text{mean thickness} = \frac{\text{stack thickness}}{\text{number of sheets}}$$

$$\text{mean thickness} = \frac{10.0\,\text{mm}}{100} = 0.100\,\text{mm}$$

Count the sheets, exclude the covers, align the stack and read the ruler at eye level. Avoid gaps or uneven compression. Repeat the measurement to check consistency.

> The result is an average thickness. Dividing does not remove a ruler zero error or a systematic error in the stack measurement.

Mean period from repeated oscillations

Time from a marked position until the pendulum returns to that position in the same direction 20 times. Count complete cycles, not half-swings.

$$\text{mean time} = \frac{t_1 + t_2 + t_3}{3} = \frac{31.8\,\text{s} + 32.2\,\text{s} + 32.0\,\text{s}}{3} = 32.0\,\text{s}$$

$$T = \frac{\text{mean time}}{N} = \frac{32.0\,\text{s}}{20} = 1.60\,\text{s}$$

The **period** 周期 is the time for one complete oscillation. A similar start/stop timing error has a smaller effect per oscillation when a longer interval is divided by 20.

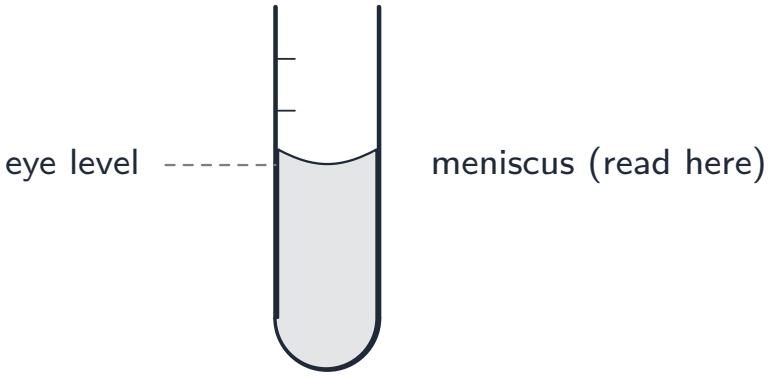
> Timing multiples and repeating trials serve different purposes. Neither repairs a miscount of the oscillations.

Measuring something too small to measure

Measure many and divide	For a thin sheet or a small mass, use **measure many and divide**: measure a counted stack, then divide; systematic errors can still affect the result.
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.

Reading a measuring cylinder



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

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
- hand timing introduces **reaction time** 反应时间 error
- so time 20 swings of a pendulum and divide by 20

Scalars and vectors

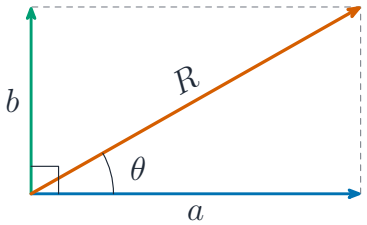
scalar quantity 标量: size only	**vector quantity** 矢量: size and direction
distance	force, weight
speed	velocity
time, mass	acceleration, momentum
energy, temperature	**electric field strength** 电场强度, gravitational field strength

Near the Earth the field is **uniform** 均匀: in free fall all objects share g (air resistance negligible).

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

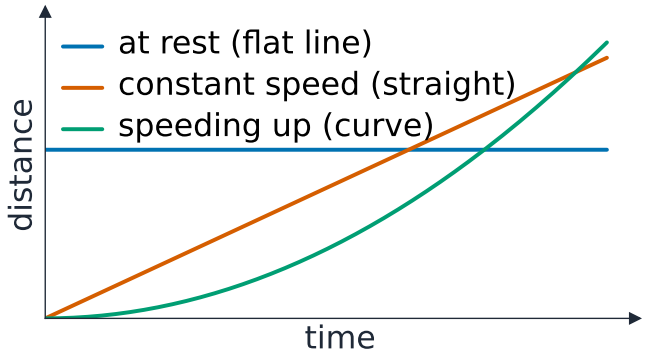
$$v = \frac{s}{t}, \qquad a = \frac{\Delta v}{\Delta t}.$$

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



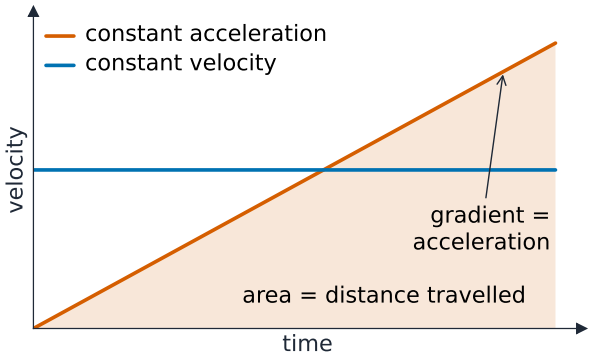
Flat line: at rest. Straight slope: constant speed. Steeper and steeper curve: speeding up.

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.

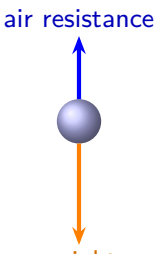
Speed–time: gradient = a; area = s



Flat line: constant speed. The gradient gives the acceleration; the area under the line gives the distance travelled.

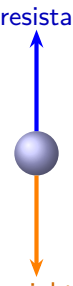
Falling and terminal velocity

just released



speeding up

terminal velocity



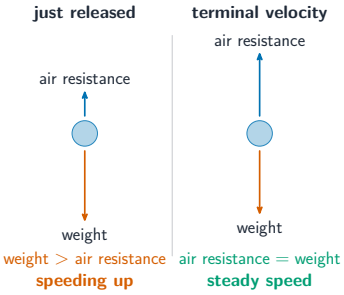
steady speed

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.

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

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.

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 measurements	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 kg/m^3 or 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

Measuring the density of a liquid

1. Measure the mass of the empty measuring cylinder using a balance.
2. Add the liquid and read its volume at the bottom of the meniscus, at eye level.
3. Measure the combined mass. Subtract the empty cylinder's mass to find the liquid's mass.
4. Use $\rho = m/V$, with consistent mass and volume units.

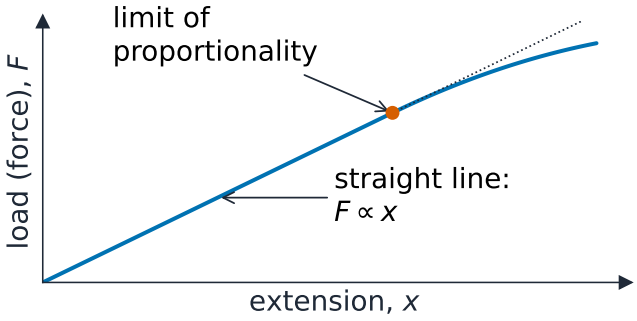
$$\rho = \frac{m_{\text{full}} - m_{\text{empty}}}{V}$$

density 密度 of the liquid

Use the liquid's mass, not the combined mass. Two liquids that do not mix can form layers, with the less dense one above the denser one.

3 Forces and moments

Hooke's law



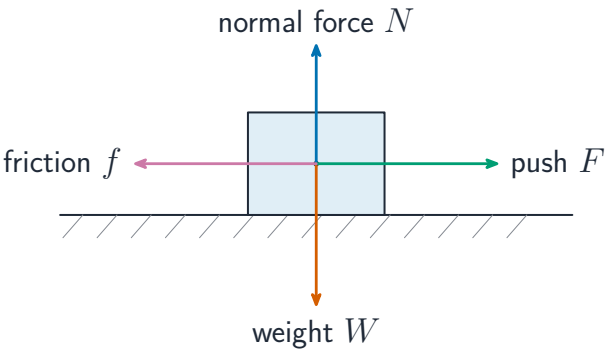
$F = kx$ (straight section)
$k =$ gradient

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

$$F = ma.$$

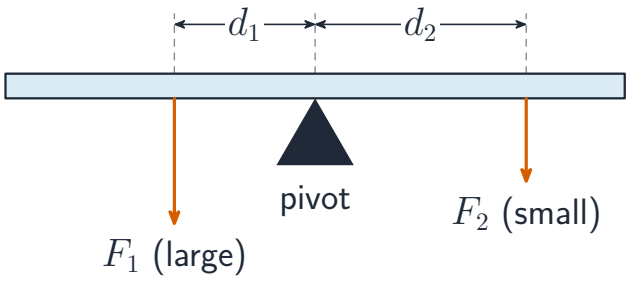
Friction 摩擦 opposes motion (or the tendency to move).

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.

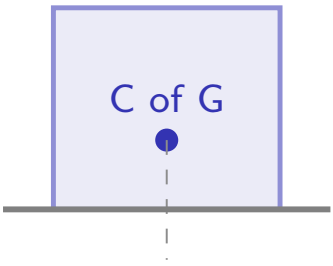
30 N at 0.20 m vs 20 N

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

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.

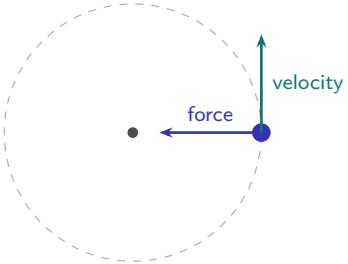


Moments, and finding a centre of gravity

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.

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.

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

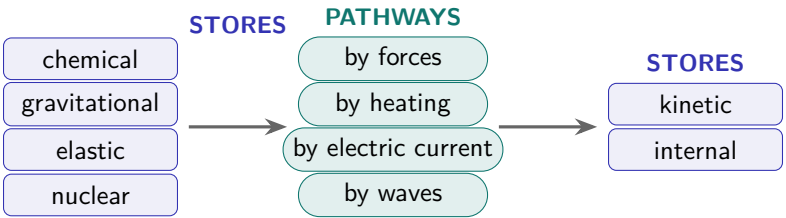
Momentum	$p = mv$: a vector, so direction matters and opposite directions carry opposite signs.
Impulse	**Impulse** 冲量 is $F\Delta t$, and it equals the change in momentum – which is why a longer collision time means a smaller force.
Conservation of momentum	In any collision or explosion with no external 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.

Total momentum is conserved when the resultant external force is negligible; kinetic energy may change. 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.

Energy stores



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

The energy resources, compared

fossil fuels	not renewable – reliable and high output, but CO_2 and pollution
nuclear fuel	not renewable – no CO_2 from reactor operation, but radioactive waste
biofuels	replanted crops absorb CO_2; growing and processing cause emissions; land use matters
hydroelectric	renewable – output depends on water supply; a dam floods land
solar and wind	renewable; no fuel burned during operation, but output varies
geothermal and tidal	location-limited; tidal output is predictable, but not continuous

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 renewability, availability, reliability, scale and environmental effects.

> Renewable sources are replenished on a useful timescale. This alone does not guarantee a continuous supply.

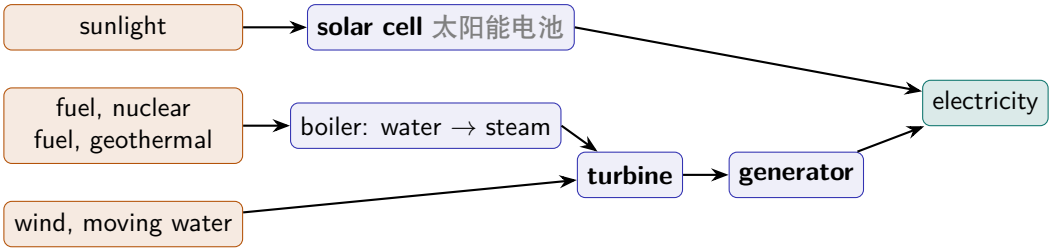
Electric lighting or hot water?

Two solar devices for a school

The school wants electric lighting and hot water. One device is a solar cell connected to an electrical circuit. The other is a solar panel that heats water flowing through it.

Which device directly supplies electrical energy? Which directly heats water? Does either require a steam turbine to do its stated job?

Different routes from the same source



A solar water-heating panel instead transfers solar radiation to the internal energy of water. The energy route determines which components are needed.

> A turbine drives a generator. Solar cells generate electrical power directly, so a turbine is not a required stage in every electricity source.

Tracing a resource back to the Sun

Three resources: wind, geothermal and nuclear fuel

Which gets its energy from solar radiation? Explain the link, then explain why the other two do not belong in the same group.

Tracing a resource back to the Sun

Three resources: wind, geothermal and nuclear fuel

Which gets its energy from solar radiation? Explain the link, then explain why the other two do not belong in the same group.

Solar heating helps drive movement of air, so wind traces back to the Sun. Geothermal energy comes from inside the Earth; nuclear fuel supplies energy through nuclear changes rather than solar heating.

> For 0625/22 May/June 2025 Q9, only wind qualifies (official answer D). Geothermal, nuclear and tidal are the syllabus exceptions; renewability is a separate classification.

A renewable source for a continuous load

A proposed supply for a remote clinic

The clinic needs electrical power both day and night. The proposal uses solar cells with no battery, backup or grid connection. A nearby river might support a hydroelectric scheme, but its flow changes with the season.

Evaluate both proposals. Use availability and reliability, then identify information needed about scale and environmental effects. Is “renewable” enough to justify either choice?

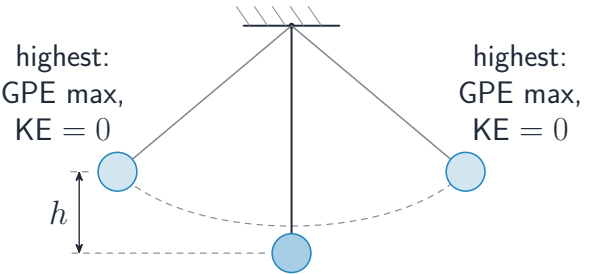
A comparison tied to the demand

A clinic needs power **day and night**. Compare the proposed supplies against that demand:

	solar cells	**hydroelectric scheme**
availability	daylight only: night demand needs another source or stored energy	may supply at night if suitable flow and stored water are available
reliability	output depends on conditions	seasonal flow; renewable does not mean guaranteed continuous output
scale	compare with the clinic's power requirement	check site and scheme capacity
impact	land use	land or habitat changes, especially if a dam is needed

Use **renewability** 可再生性, **availability** 可用性, **reliability** 可靠性, **scale** 规模 and **environmental impact** 环境影响 to explain this choice, rather than listing generic advantages.

Kinetic and potential energy



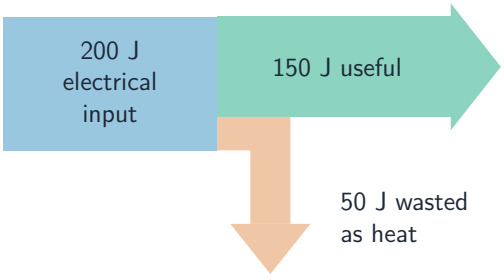
$E_k = \frac{1}{2}mv^2, \qquad \Delta E_p = mg\Delta h.$

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

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

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

A motor's useful and wasted energy



Energy bands: $200\,\mathrm{J}$ *input,* $150\,\mathrm{J}$ *useful output*

Suppose this energy transfer takes $5.0\,\mathrm{s}$

Find the average input power and useful output power. Calculate efficiency using both energy and power. How much energy is transferred to less useful stores?

Input power and useful output power

Power is energy transferred per unit time. Use the same $5.0\,\mathrm{s}$ interval for both transfers.

$$P_{\mathrm{in}} = \frac{E_{\mathrm{in}}}{t} = \frac{200\,\mathrm{J}}{5.0\,\mathrm{s}} = 40\,\mathrm{W}$$

$$P_{\mathrm{useful}} = \frac{E_{\mathrm{useful}}}{t} = \frac{150\,\mathrm{J}}{5.0\,\mathrm{s}} = 30\,\mathrm{W}$$

Power measures the rate of transfer. Mechanical work transfers energy: for a constant force acting along the motion, $W = Fd = \Delta E$.

Efficiency from energy or power

$$\eta = \frac{E_{\text{useful}}}{E_{\text{in}}} \times 100\% = \frac{150\,\text{J}}{200\,\text{J}} \times 100\% = 75\%$$

$$\eta = \frac{P_{\text{useful}}}{P_{\text{in}}} \times 100\% = \frac{30\,\text{W}}{40\,\text{W}} \times 100\% = 75\%$$

The ratios agree because the energy transfers use the same time interval.

$$E_{\text{wasted}} = E_{\text{in}} - E_{\text{useful}} = 200\,\text{J} - 150\,\text{J} = 50\,\text{J}$$

> The wasted energy is transferred to less useful stores. It is not destroyed; the Sankey bands must account for the full input.

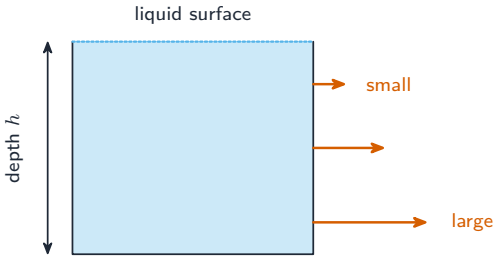
Energy-resource comparison checklist

- **renewability** 可再生性: is the source replenished on a useful timescale?
- **availability** 可用性: is it accessible at this place and time?
- **reliability** 可靠性: can the supply meet the required timing?
- **scale** 规模: can it supply the required power or energy?
- **environmental impact** 环境影响: consider emissions, land and habitats.

> The syllabus also includes research into using nuclear fusion to generate electrical power on a large scale.

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

7 Recap

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.
- Total **momentum** is conserved in a collision when the resultant external force is negligible. Give each velocity a + or − sign for its direction *before* you add them.
- Check that units are consistent. $p = F/A$ defines pressure; $\Delta p = \rho g \Delta h$ gives the change in pressure between depths in a liquid.

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

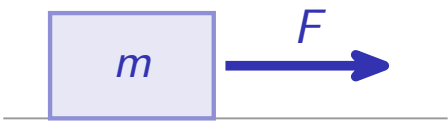
$p = mv$; conserved if external force is negligible

4 Energy

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

Check yourself

1. What does the area under a speed–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