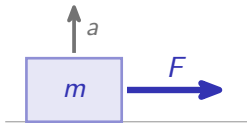


# Motion, Forces & Energy

## 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





# Measurement

Five SI base units used here:

**m**

length

**kg**

mass

**s**

time

**A**

current

**K**

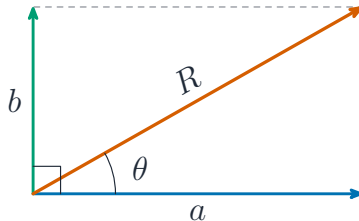
temperature

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

# Scalars and vectors

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

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



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

# Speed, velocity and acceleration

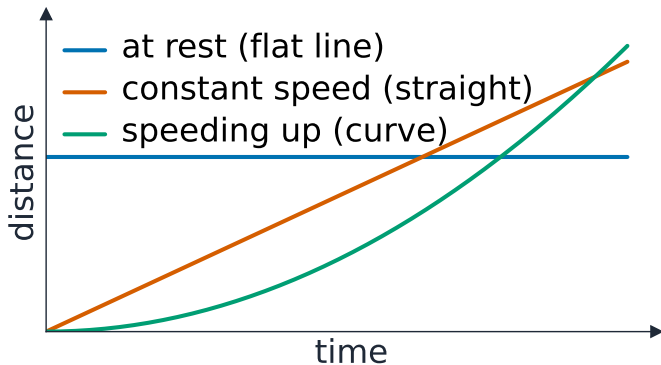
$$v = \frac{s}{t}, \quad a = \frac{\Delta v}{\Delta t}.$$

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

**Car:** 8 → 20 m/s in 4.0 s

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

## 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**.

### The area

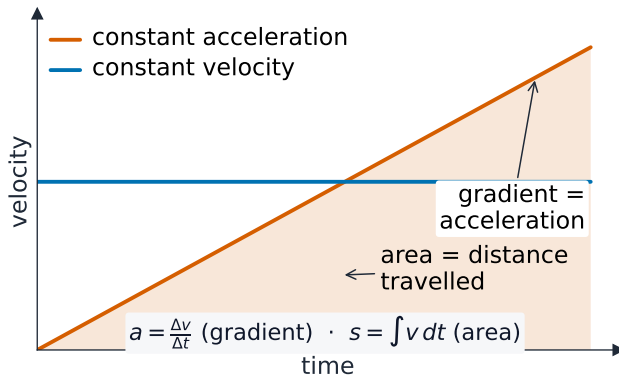
On a speed–time graph the **area under the line** is the distance travelled. Split it into triangles and rectangles.

### 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 = $s$



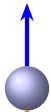
*speed-time: gradient =  $a$ ; area =  $s$*

speed-time: gradient =  $a$ ; area =  $s$

## Falling and terminal velocity

**just released**

air resistance



weight

**speeding up**

**terminal velocity**

air resistance



weight

**steady speed**

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

- **weight** down; **air resistance** up
- drag grows as the object speeds up

**Terminal velocity** : drag = weight, resultant = 0, speed is steady.



# Mass, weight and density

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

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

**Stone** 54 g, **water** 20  $\rightarrow$  40 cm<sup>3</sup>

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

# 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** only; a vector has magnitude *and* direction.

## Named units

The **joule** (J) for energy and **work done**; the **watt** (W) for power, one joule per second; the **pascal** (Pa) for pressure, one newton per square metre.

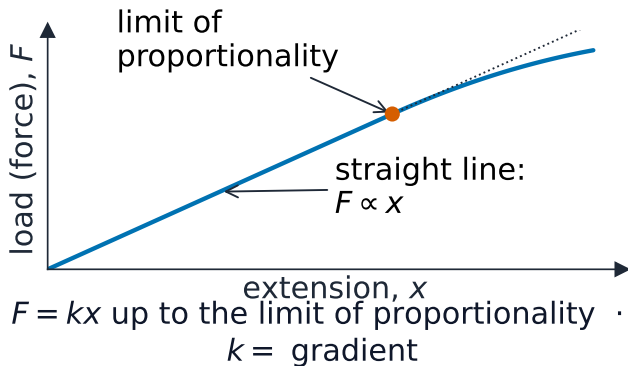
## Hooke's law

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.



# Hooke's law

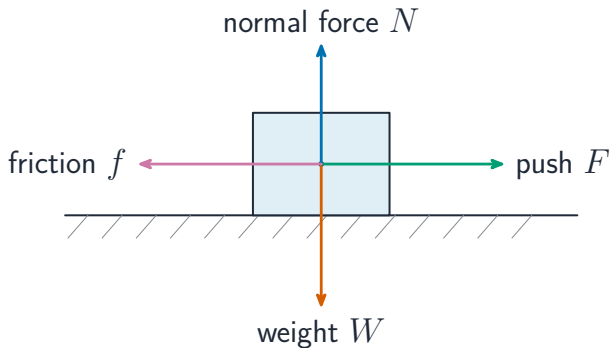


**Extension** is proportional to load up to the **limit of proportionality**.

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

A large **spring constant**  $k$  means a stiff spring.

## Resultant force and $F = ma$



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

$$F = ma.$$

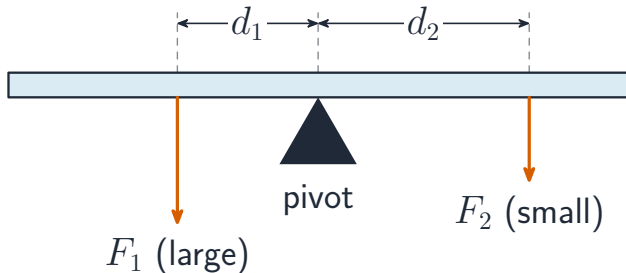
**Friction** opposes motion (or the tendency to move).

**Car** 1200 kg: 3000 – 600 N

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

## Moments – the turning effect

**balanced:**  $F_1 d_1 = F_2 d_2$



**Moment** = force  $\times$   
perpendicular distance.

Balanced: total clockwise  
= total anticlockwise mo-  
ment.

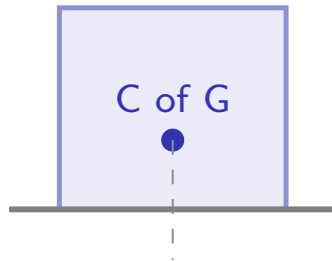
**30 N at 0.20 m vs 20 N**

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

## Centre of gravity and stability

The **centre of gravity** 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  $\times$  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

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.



# Momentum

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

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

**Conservation** : total momentum before  
= after (no outside force).

2.0 kg at 3.0 m/s hits a still  
1.0 kg; they stick

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

# Momentum, impulse and what is conserved

## Momentum

$p = mv$ : a vector, so direction matters and opposite directions carry opposite signs.

## Impulse

**Impulse** 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  $\Delta t$ .



# Energy stores and transfers

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

**Conservation of energy** : 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<sub>2</sub> and pollution

## nuclear fuel

not renewable – huge output and no CO<sub>2</sub>, 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.

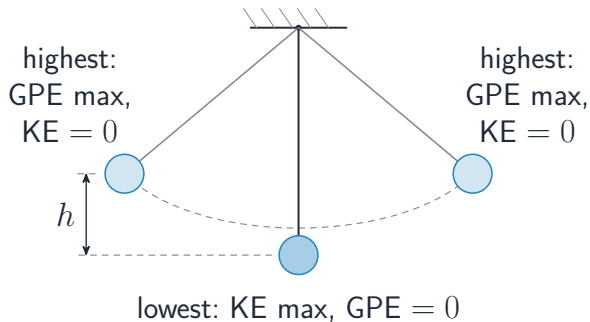
“Renewable” says it will not run out. It says nothing about reliability, and an exam answer usually needs both.

## 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** make electricity directly; solar panels heat water

# Kinetic and potential energy



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

**Conservation of energy** : a falling object turns  $E_p$  into  $E_k$ .

**Drop from 1.8 m ( $g = 10$ )**

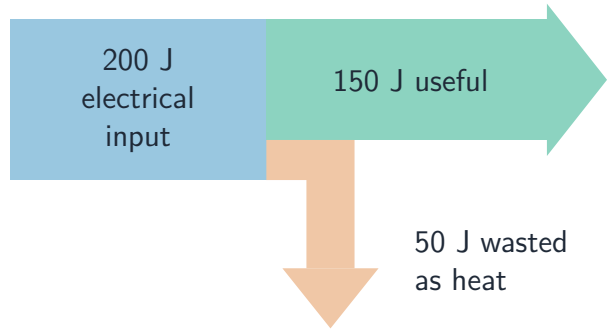
$$v = \sqrt{2g\Delta h} = 6.0 \text{ m/s}$$

# Work, power and efficiency

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

**Motor:** 200 J in, 150 J useful

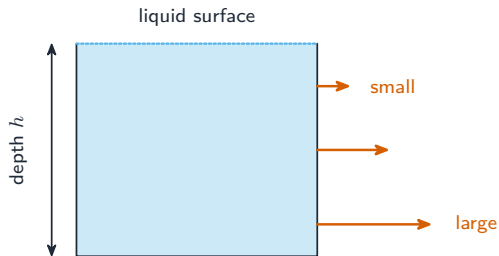
$$\eta = \frac{150}{200} \times 100\% = 75\%$$



*Sankey diagram : useful vs wasted*



# Pressure



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

**2.0 m deep in water**

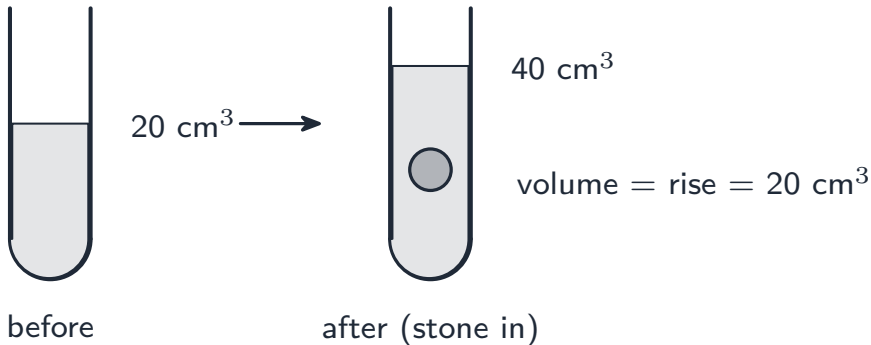
$$\Delta p = 1000 \times 10 \times 2.0 = 2.0 \times 10^4 \text{ Pa}$$

## 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** , measure the time for 20 swings and divide by 20. One full swing is called the **period** .

# 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

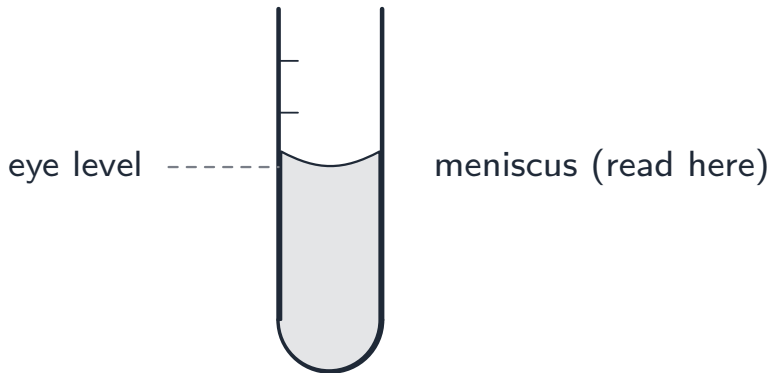
For the volume of an irregular solid, use the **displacement method**: lower it into a measuring cylinder and read the rise, or catch the overflow from a full eureka can.

## 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

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**

## density

$\rho = \frac{m}{V}$ , in kg/m<sup>3</sup> or g/cm<sup>3</sup> –  $\rho$  is the Greek letter “rho”

## finding $V$

a **regular solid** : measure the sides and calculate. An irregular one: displacement in a measuring cylinder

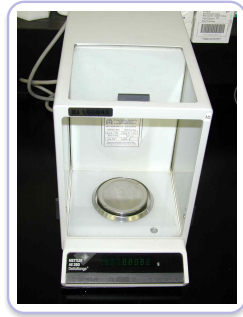
Mass is compared with a balance, weight with a newtonmeter. A balance gives the same reading on the Moon; a newtonmeter does not.

# Density



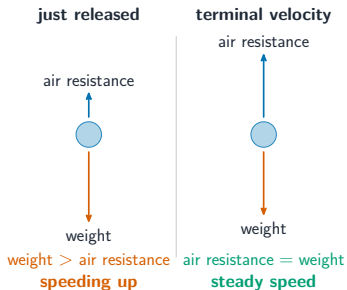
An iceberg floats with most of its volume hidden: ice is slightly less dense than water

# 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

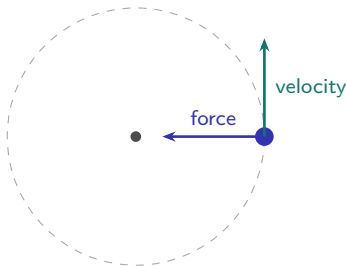
## Measuring time

- long times: a clock
- short intervals: a **stopwatch** or a **digital timer**
- a hand-started stopwatch carries a **reaction time** error of about 0.2 s
- so time 20 swings of a pendulum and divide by 20

## Scalars and vectors

- a **scalar quantity** has size only: distance, speed, time, mass, energy, temperature
- a **vector quantity** has size and direction: force, weight, velocity, acceleration, momentum, **electric field strength**, gravitational field strength
- near the Earth the field is **uniform**: 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** .

- bigger force  $\Rightarrow$  higher speed, same mass and **radius**
- bigger force  $\Rightarrow$  smaller radius, same mass and speed
- bigger mass  $\Rightarrow$  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  $\text{extension} = \text{new length} - \text{original length}$
- 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:  $\text{force} \times \text{distance (left)} = \text{force} \times \text{distance (right)}$

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** : will it run out?
- **availability** : is it always there? wind drops, the Sun sets
- **reliability** : a steady output?
- **scale** : how much energy can it supply?
- **environmental impact** : pollution, CO<sub>2</sub>, 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 → m, g → 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.



# 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 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