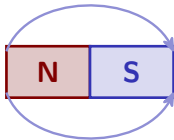


Electricity & Magnetism

IGCSE Physics ■ Topic 4

IGCSE Physics



What we will cover

- 1 Magnetism & static
- 2 Current e.m.f. & resistance
- 3 Power & circuits
- 4 Electrical safety
- 5 Electromagnetic effects
- 6 Recap





Magnets and fields

- field lines run N to S outside a magnet and never cross
- closer lines $\Rightarrow$ stronger field
- like poles repel; unlike poles attract

A plotting compass's N pole points along the field. Iron filings line up on the same lines.

Magnets, poles and field lines

Two poles

Every magnet has a **north pole** and a **south pole** ; like poles repel, unlike attract.

Magnetic field lines

Magnetic field lines run from north to south outside the magnet. Where they are closer together the field is stronger, and they never cross.

Magnetic material

A **magnetic material** – iron, steel, cobalt, nickel – is attracted by a magnet; everything else is not.

Induced magnetism

Induced magnetism : a magnetic material brought near a magnet becomes a magnet itself, which is why a magnet picks up a chain of paper clips.

Attraction is not a test for a magnet – an unmagnetised iron bar attracts too. Only *repulsion* proves both objects are magnets.

Static electricity

Charge is **electrons** . Rubbing transfers them, so one object goes negative and the other positive.

Only electrons move. Like charges repel; unlike attract. A charged object can attract a **neutral** one by induction.

Charging by friction

When you rub two different materials together, **electrons** (tiny negative particles) move from one to the other.

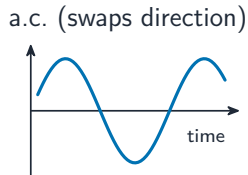
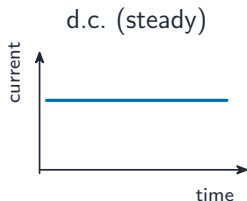
- The material that gains electrons becomes negative.
- The material that loses electrons becomes positive.

Conductors and insulators

- A **conductor** (copper and other metals) lets charge flow through it easily, because it has free electrons that can move.
- An **insulator** (plastic, rubber, glass) does not let charge flow, because its electrons cannot move freely.



Electric current



Current $I = \frac{Q}{t}$ (A).

Conventional current + to -;
electrons the other way.

3.0 A for 20 s

$$Q = It = 60 \text{ C}$$

d.c. one way; **a.c.** swaps
direction.

Charge, current and the units

Electric charge

Electric charge is measured in **coulombs** (C). A **negative charge** is an excess of electrons.

Current

Current is the rate of flow of charge, $I = Q/t$, measured in **amperes** (A). One amp is one coulomb per second.

E.m.f. and p.d.

The **electromotive force** of a **power supply** is the energy given *per coulomb*; potential difference is the energy delivered per coulomb, both in volts. Energy comes in **joules**.

Resistance

$R = V/I$, in **ohms** (Ω).

Current is the same all the way round a series loop – charge is not used up, only energy is.

E.m.f., p.d. and resistance

- **e.m.f.** & p.d.: $V = \frac{W}{Q}$ (volts)
- **resistance** $R = \frac{V}{I}$ (Ω)
- $R \propto l$, $R \propto \frac{1}{A}$

12 V drives 0.50 A

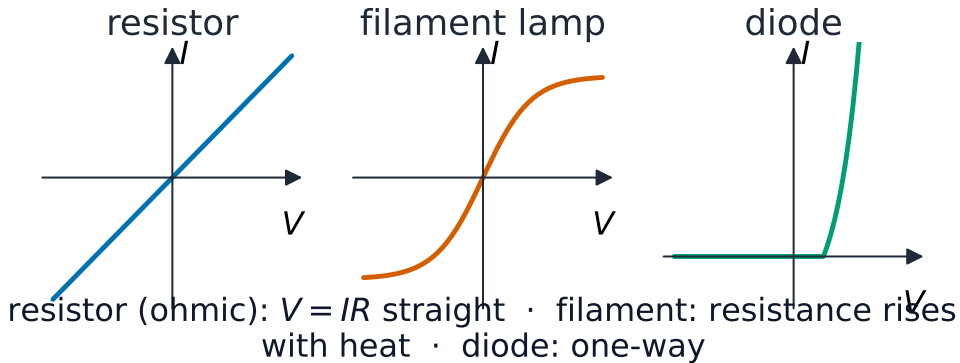
$$R = \frac{12}{0.50} = 24 \Omega$$



I - V graphs

- a longer wire has a bigger resistance – resistance is **directly proportional** to length, $R \propto l$;
- a thicker wire has a smaller resistance – resistance is **inversely proportional** to **cross-sectional area**, $R \propto \frac{1}{A}$.

I - V graphs, in detail



A resistor gives a straight line; a filament lamp curves as it heats up; a diode lets current pass only one way

Electrical power and energy

$$P = IV, \quad E = IVt.$$

12 V **motor**, 2.0 A, 30 s

$$P = 24 \text{ W}, \quad E = Pt = 720 \text{ J}$$

Bills use the **kilowatt-hour** :

$$\text{kWh} = \text{kW} \times \text{h}.$$



Electrical energy is metered and distributed safely

Hazards

These are **hazards** (dangers) with mains electricity:

- damaged **insulation** – bare wires can give a shock or start a fire;
- **overheating** cables – too much current makes a cable hot, which can start a fire;
- **damp** conditions – water lets current pass into a person, raising the risk of a shock;
- **overloading** – plugging too many appliances into one **socket** draws too much current.

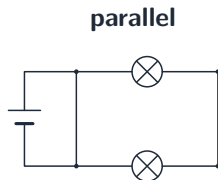
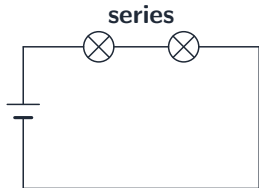


Circuit components

- cell / battery, lamp, switch, resistor, variable resistor
- **thermistor** (temperature) and **LDR** (light)
- ammeter in **series**; voltmeter in **parallel**

$$I = Q/t, \quad V = W/Q, \quad R = V/I.$$

Series and parallel



- series: same current;

$$R = R_1 + R_2$$

- parallel: same p.d.;

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

6 Ω and 3 Ω in parallel

$$\frac{1}{R} = \frac{1}{6} + \frac{1}{3} = \frac{1}{2} \Rightarrow R = 2\ \Omega$$

Potential dividers and safety

A **potential divider** shares the voltage:

$$\frac{R_1}{R_2} = \frac{V_1}{V_2}.$$

A thermistor/LDR makes the output change with temperature or light.

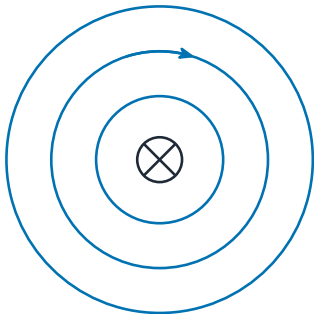
Fuses and circuit breakers protect by cutting the current when it is too large – never rely on the appliance alone.



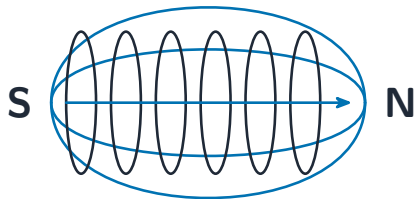
The magnetic effect of a current

A current makes a magnetic field – circles round a wire, bar-magnet-like for a **solenoid** . Stronger with more current, more turns, or a soft-iron core.

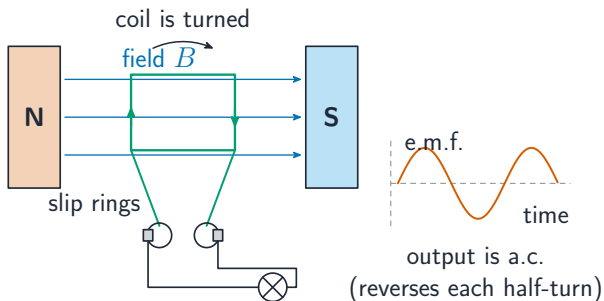
straight wire



solenoid (coil)

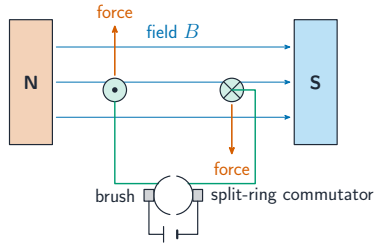


Electromagnetic induction & the generator



Move a wire across a field $\Rightarrow$ an e.m.f. is **induced**. An **a.c. generator** spins a coil in a field; **slip rings** carry the a.c. out. Bigger e.m.f. with a stronger magnet, faster spin, more turns.

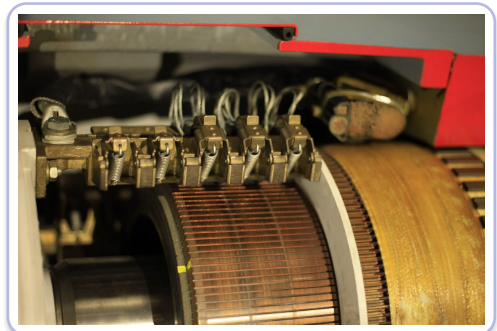
The motor effect and d.c. motor



the two forces form a couple that turns the coil

***commutator** keeps it turning*

Left-hand rule: thumb = force, first finger = field, second = current.



Motors convert electrical energy into motion

The d.c. motor, and the a.c. generator

The d.c. motor

A current-carrying coil in a magnetic field feels a force on each side, so it turns – the **d.c. motor** .

Split-ring commutator

The **split-ring commutator** reverses the current every half turn, so the force keeps pushing the same way round; the **brushes** keep contact as it spins.

The a.c. generator

Turn the coil instead and a voltage is induced: the **a.c. generator** . It uses slip rings, not a commutator, so the output reverses every half turn.

What is induced

The current **deflects** a meter first one way then the other – that is **alternating current** , against the one-way **direct current** of a battery.

Motor and generator are the same machine read in opposite directions: current in → motion out, or motion in → current out.

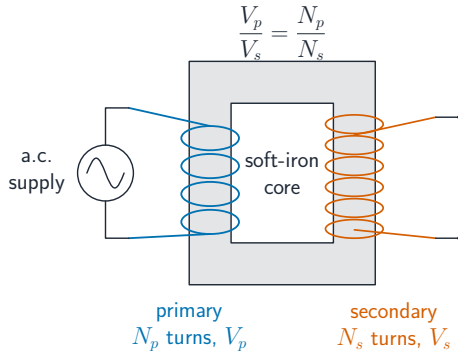
The transformer

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}.$$

$$N_p = 1200, N_s = 100, V_p = 240 \text{ V}$$

$$V_s = \frac{240}{12} = 20 \text{ V (step-down)}$$

The transformer, in detail



The changing field in the core links the two coils; the voltage ratio equals the turns ratio

The transformer, and why the grid uses one

The two coils

A **primary coil** and a **secondary coil** on the same iron core: $\frac{V_s}{V_p} = \frac{N_s}{N_p}$.

Step-up and step-down

A **step-up** transformer raises the voltage and lowers the current; a step-down does the reverse.

Why it saves energy

Power lost in the cables is $I^2 R$, so raising the voltage cuts the current – and the loss falls with the square.

Only a.c.

A transformer needs a *changing* field, so it works on the **mains supply** and not on a battery.

In the home the **live wire** carries the supply, the **neutral wire** completes the circuit, and the earth wire protects the case.

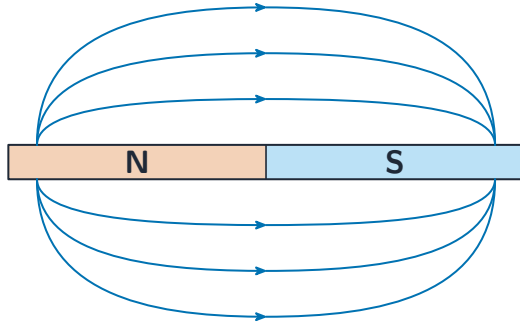
High-voltage transmission



Power lost in cables is $P = I^2 R$.

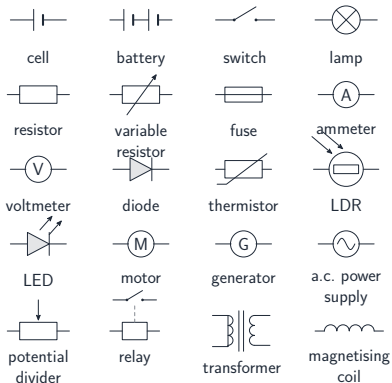
Step **up** the voltage $\Rightarrow$ lower current $\Rightarrow$ far less wasted power. Step down again for homes.

Magnetic fields



The field lines of a bar magnet come out of the N pole and go into the S pole

Circuit components, continued



The standard symbols used to draw circuit diagrams

Two components that respond to their surroundings

Light-dependent resistor

A **light-dependent resistor** (LDR): its resistance **falls** as the light gets brighter.

Thermistor

Resistance falls as the temperature rises – the sensing element in a thermostat.

Light-emitting diode

A **light-emitting diode** (LED) conducts one way only and glows when it does – so it also indicates direction.

In a divider

Put either sensor in a potential divider and its changing resistance changes the output voltage. That is how a sensing circuit works.

At a **junction**, the current in equals the current out. Nothing accumulates at a point in a circuit.

The components, and how resistance depends on the wire

a relay

a switch worked by an electromagnet – a small current controls a big one

a bell

makes a sound, using an electromagnet that repeatedly breaks its own circuit

a diode

lets current pass one way only

a thermistor / LDR

resistance falls as temperature, or light, rises

resistance and length

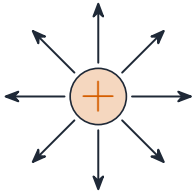
doubling the length doubles the resistance

resistance and area

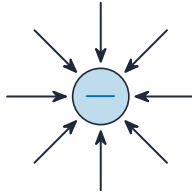
doubling the area halves it – and the area depends on the diameter squared, so a wire twice as thick has a quarter the resistance

An I - V graph identifies a component by its **shape**: a straight line is an ohmic resistor, a curve is a filament lamp, and a one-sided graph is a diode.

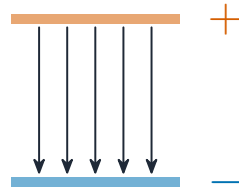
Electric fields and ions



positive charge



negative charge



parallel plates

Electric field lines point away from a positive charge and towards a negative one; between parallel plates the field is uniform

The field around a charge

Electric field

A **region** where a charge feels a force. The lines point the way a *positive* charge would move.

Around a point charge

Radial: out from a positive charge, in towards a negative one.

Between plates

Uniform: evenly spaced parallel lines, from the positive plate to the negative one.

Charging by friction

Rubbing transfers electrons: one object gains a negative charge, the other is left equally positive.

Charge is conserved. Friction never creates it – it only moves electrons from one surface to the other.

The kilowatt-hour



A household electricity meter counts the energy used, in kilowatt-hours (kWh) – the number it shows is what you pay for

Paying for electricity

the unit the kilowatt-hour (kW h) – the energy used by a 1 kW appliance in one hour

the calculation energy = power in kW $\times$ time in hours

a heater 2 kW used for 3 hours uses $2 \times 3 = 6$ kW h

the cost multiply by the price per unit

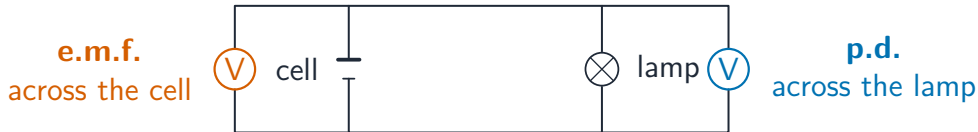
watch the units the power must be in kilowatts and the time in hours – a 500 W lamp is 0.5 kW

the joule $1 \text{ kW h} = 3.6 \times 10^6 \text{ J}$ – large, which is why the bill uses it

The kilowatt-hour is an energy, not a power, despite carrying “watt” in its name. The hour is what converts a rate into a total.

E.m.f. and potential difference

A voltmeter across the



E.m.f. and potential difference

Magnetism



N–S attract



N–N repel

Like poles repel; unlike poles attract

Magnetic fields, continued



Iron filings line up along the field lines, showing the field pattern of a bar magnet

Soft iron or steel, and what each is used for

soft iron

easy to **magnetise** but **loses** its magnetism quickly

steel

harder to magnetise but **keeps** its magnetism – so it makes a **permanent magnet**

the electromagnet core

an **unmagnetised** piece of **soft iron** – it must lose its magnetism the instant the current stops

permanent magnets

fridge door catches, compass needles, loudspeakers

electromagnets

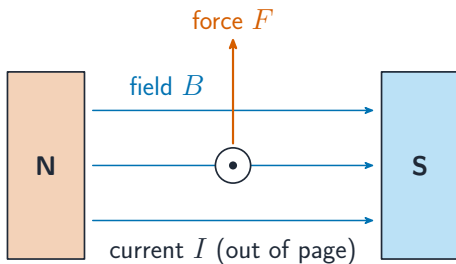
magnetic **only while a current flows**: cranes that lift scrap iron, relays, circuit breakers

the field pattern

around a charged sphere the field spreads out **evenly all around**, like a point charge's

Choose the material by **whether you want the magnetism to stop**. That single question decides soft iron against steel every time.

Force on a current-carrying conductor

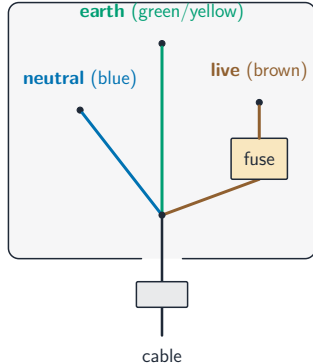


F , B and I are all at 90° (Fleming's left-hand rule)

A current-carrying wire in a magnetic field feels a force at right angles to both the field and the current

Live, neutral and earth

In a three-pin plug the **live** wire carries the supply, the **neutral** completes the circuit, and the **earth** gives a fault current a safe path away.



The earth wire and the fuse work together: a fault sends a large current to earth, and the fuse melts before the case can become live.

Fuses, trip switches and earthing

A fuse is a thin wire that melts if the current gets too big, breaking the circuit before the cable overheats.

- **earthed** : the casing is joined to the earth wire. If a live wire touches the casing, a large current flows to earth and blows the fuse.
- **double-insulated** : the casing is plastic, so it can never become live. Such an appliance needs no earth wire; its fuse still protects the cable.

Mains safety, and the two ways to make a casing safe

the hazard

a home is fed by the mains, and the mains is dangerous if it is used wrongly

a fuse

a thin wire that melts when the current exceeds its rating, breaking the circuit

a trip switch

a circuit breaker – the same job, but it acts faster and can be reset

earthing

a low-resistance path from the metal casing to earth, so a fault blows the fuse at once

double insulation

the alternative: a plastic casing that cannot become live, so no earth wire is needed

in the home

lamps are wired in parallel – each gets the full voltage, and if one fails the others stay on

An appliance's casing must be made safe one of two ways: earthed, or double-insulated. Naming which one applies is the marked step.

The transformer, continued



A real transformer on a power pole steps the high voltage in the cables down to a safer voltage for homes

Static electricity, continued



Every hair picks up the same charge from the dome, and like charges repel – so the hairs push apart

Meters: analogue, digital, and ranges

- an **analogue** meter has a needle over a scale; a **digital** meter shows a number
- both come in different **ranges** : choose the range just **above** the largest reading you expect
- 0–1 A for about 0.4 A; 0–100 mA for a few milliamps
- ammeter in **series**; voltmeter in **parallel** across the component

Measuring resistance

- 1 component in series with a cell, a switch, an ammeter and a variable resistor; voltmeter across the component
- 2 read I and V ; change the variable resistor for more pairs
- 3 $R = V/I$ for each pair and average, or plot V against I : a straight line through the origin whose gradient is R

Detecting a charge; relays

Is it charged?

- a charged rod picks up small pieces of paper and bends a thin stream of water
- hang one charged rod from a thread; bring another near: same charge, it swings away
- **repulsion** is the only sure test; **attraction** also happens with uncharged objects

The relay

- a small current in a coil magnetises a soft-iron core (a **temporary magnet**)
- the core pulls a switch closed in a **second** circuit that can carry a large current
- so a small switch or a sensor safely controls a motor or a heater: a car's ignition switch starts the motor through a relay

The two hand rules, and the jumping wire

Fleming's left-hand rule (motor effect):

thumb = force, first finger = field (N to S), second finger = current.

Fleming's right-hand rule (induction):

thumb = motion of the wire, first finger = field, second finger = induced current.

A current-carrying coil in a field feels a **turning effect** : more turns, more current or a stronger field make it bigger.

Showing the force on a conductor

- 1 a stiff copper wire (or foil strip) between the poles of a U-magnet, joined to a cell through a switch
- 2 close the switch: the wire **jumps**
- 3 reverse the cell: it jumps the other way
- 4 turn the magnet over: it reverses again
- 5 bigger current or stronger magnet: bigger jump

Exam tips

- **Current** is the same everywhere in a **series** circuit; in a **parallel** circuit it splits between the branches. Voltage (p.d.) is shared out in series, but is the same across every parallel branch.
- Adding resistors in **series** increases the total resistance ($R_1 + R_2$); adding them in **parallel** makes the total *less* than the smallest single resistor.
- An **ammeter** goes in *series* and has very low resistance; a **voltmeter** goes in *parallel* across a component and has very high resistance.

Exam tips (continued)

- In a **transformer** $\frac{V_p}{V_s} = \frac{N_p}{N_s}$: more turns on the secondary steps the voltage *up*, fewer steps it *down*. Transformers only work on a.c.
- Power is sent across country at **high voltage** so the current – and the heat wasted in the cables, $P = I^2 R$ – is small.
- Fit the **switch and the fuse in the live wire**, and choose a fuse rating just above the appliance's normal working current.



Topic 4 – key takeaways

1

Current

$$I = Q/t; R = V/I; P = IV$$

2

Circuits

series adds R ; parallel lowers it

3

Induction

move a wire in a field $\rightarrow$ e.m.f.

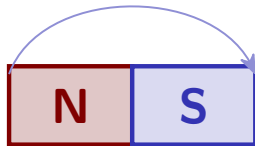
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Transformer

$V_p/V_s = N_p/N_s$; high V for transmission

Check yourself

- 1 Charge through a 2 A lamp in 10 s?
- 2 Two $4\ \Omega$ resistors in parallel – combined R ?
- 3 Which wire holds the switch and fuse?
- 4 Why send power at high voltage?



Answers 1. $Q = It = 20\text{ C}$ 2. $2\ \Omega$ 3. the live wire 4. lower current $\Rightarrow$ less heat lost