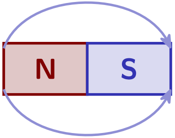
Electricity & Magnetism

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

1 Magnetism and static

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** 北极 and a **south pole** 南极; like poles repel, unlike attract.
Magnetic field lines	**Magnetic field lines** 磁感线 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** 磁性材料 – iron, steel, cobalt, nickel – is attracted by a magnet; everything else is not.
Induced magnetism	**Induced magnetism** 感应磁性: 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** 电子. 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 电子** (tiny negative particles) move from one to the other.

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

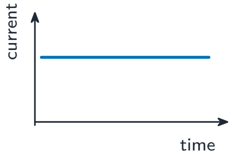
Conductors and insulators

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

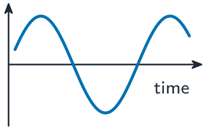
2 Current and resistance

Electric current

d.c. (steady)



a.c. (swaps direction)



Current 电流 $I = \dfrac{Q}{t}$ (A).

Conventional current 常规电流 $+$ to $-$; electrons the other way.

$3.0\,\mathrm{A}$ for $20\,\mathrm{s}$

$Q = It = 60\,\mathrm{C}$

d.c. 直流电 one way; **a.c.** 交流电 swaps direction.

Charge, current and the units

Electric charge	**Electric charge** 电荷 is measured in **coulombs** 库仑 (C). A **negative charge** 负电荷 is an excess of electrons.
Current	Current is the rate of flow of charge, $I = Q/t$, measured in **amperes** 安培 (A). One amp is one coulomb per second.
E.m.f. and p.d.	The **electromotive force** 电动势 of a **power supply** 电源 is the energy given *per coulomb*; potential difference is the energy delivered per coulomb, both in volts. Energy comes in **joules** 焦耳.
Resistance	$R = V/I$, in **ohms** 欧姆 (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.** 电动势 & p.d.: $V = \dfrac{W}{Q}$ (volts)
- **resistance** 电阻 $R = \dfrac{V}{I}$ (Ω)
- $R \propto l$, $R \propto \dfrac{1}{A}$

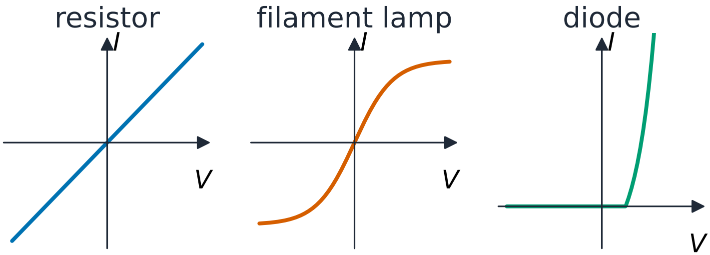
$12\,\mathrm{V}$ drives $0.50\,\mathrm{A}$

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

I–V graphs

- a longer wire has a bigger resistance – resistance is **directly proportional** 成正比 to length, $R \propto l$;
- a thicker wire has a smaller resistance – resistance is **inversely proportional** 成反比 to **cross-sectional area** 横截面积, $R \propto \dfrac{1}{A}$.

I–V graphs, in detail



resistor (ohmic): $V = IR$ straight · filament: resistance rises with heat · diode: one-way

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

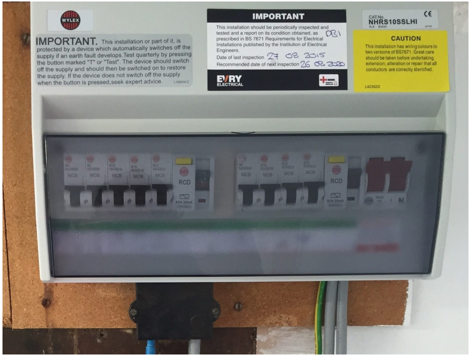
Electrical power and energy

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

$12\,\mathrm{V}$ motor, $2.0\,\mathrm{A}$, $30\,\mathrm{s}$

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

Bills use the **kilowatt-hour** 千瓦时:
$\mathrm{kWh} = \mathrm{kW} \times \mathrm{h}$.



Electrical energy is metered and distributed safely

Hazards

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

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

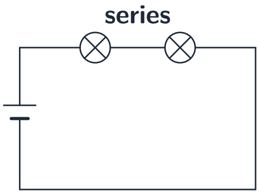
3 Circuits and safety

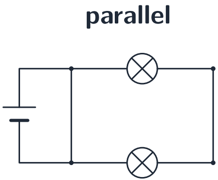
Circuit components

- cell / battery, lamp, switch, resistor, variable resistor
- **thermistor** 热敏电阻 (temperature) and **LDR** 光敏电阻 (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.;
  $$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$6\,\Omega$ and $3\,\Omega$ 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** 分压器 shares the voltage:

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

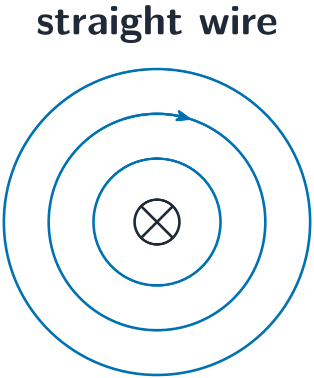
A thermistor/LDR makes the output change with temperature or light.

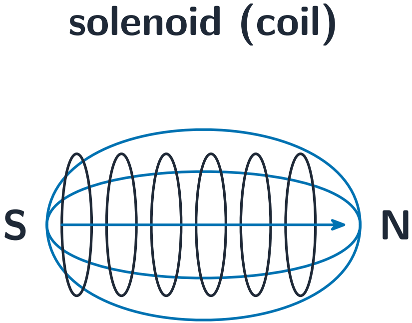
> Fuses and circuit breakers protect by cutting the current when it is too large – never rely on the appliance alone.

4 Electromagnetic effects

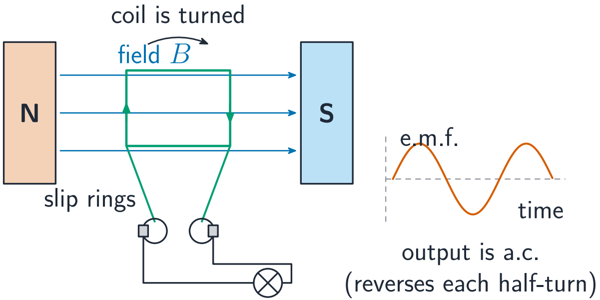
The magnetic effect of a current

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



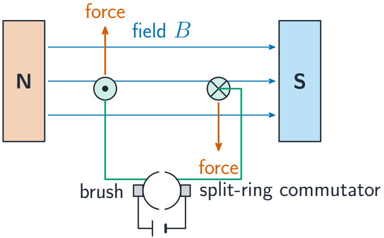


Electromagnetic induction & the generator



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

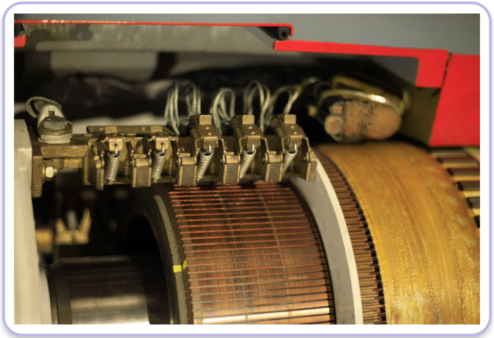
The motor effect and d.c. motor



the two forces form a couple that turns the coil

commutator *换向器 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** 直流电动机.
Split-ring commutator	The **split-ring commutator** 换向器 reverses the current every half turn, so the force keeps pushing the same way round; the **brushes** 电刷 keep contact as it spins.
The a.c. generator	Turn the coil instead and a voltage is induced: the **a.c. generator** 交流发电机. It uses slip rings, not a commutator, so the output reverses every half turn.
What is induced	The current **deflects** 偏转 a meter first one way then the other – that is **alternating current** 交流电, against the one-way **direct current** 直流电 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

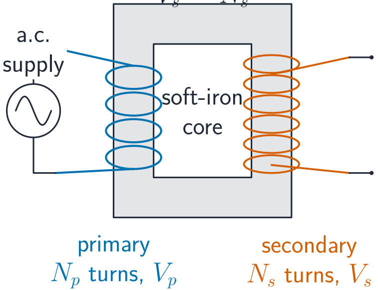
$$\frac{V_p}{V_s} = \frac{N_p}{N_s}.$$

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

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

The transformer, in detail

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



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** 原线圈 and a **secondary coil** 副线圈 on the same iron core: $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p}$.
Step-up and step-down	A **step-up** 升压 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^2R, 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** 市电 and not on a battery.

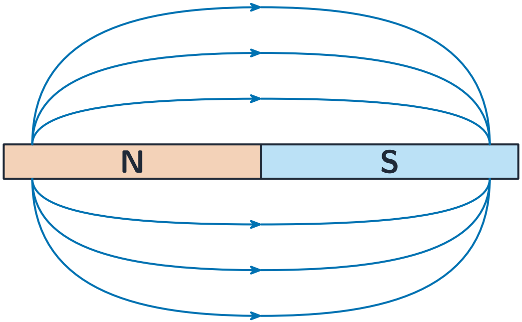
In the home the **live wire** 火线 carries the supply, the **neutral wire** 零线 completes the circuit, and the earth wire protects the case.

High-voltage transmission

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

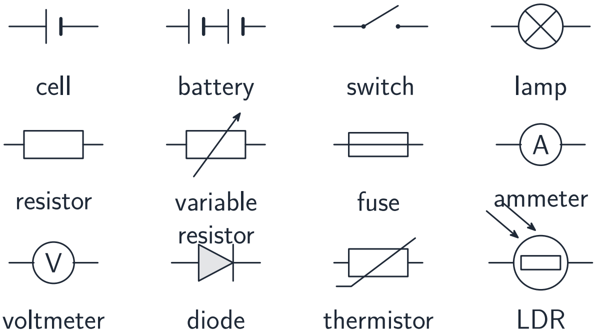
> Step up the voltage $\Rightarrow$ lower current $\Rightarrow$ far less wasted power. Step down again for homes.

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** 光敏电阻 (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** 发光二极管 (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.

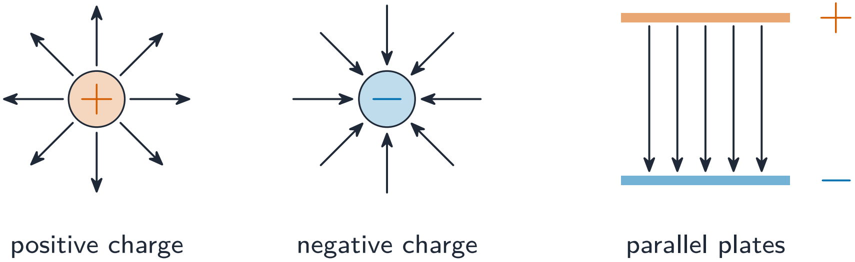
At a **junction** 节点, the current in equals the current out. Nothing accumulates at a point in a circuit.

The components, and how resistance depends on the wire

a relay 继电器	a switch worked by an electromagnet – a small current controls a big one
a bell 电铃	makes a sound, using an electromagnet that repeatedly breaks its own circuit
a diode 二极管	lets current pass one way only
a thermistor 热敏电阻 / LDR 光敏电阻	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



> 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** 区域 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 加热器	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 kW h $= 3.6 \times 10^6$ 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

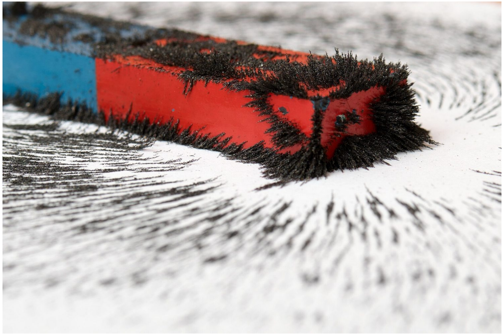
A voltmeter across the

E.m.f. and potential difference

Magnetism

Like poles repel; unlike poles attract

Magnetic fields, continued



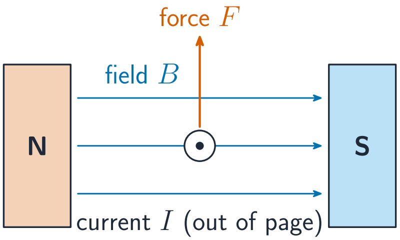
Iron filings line up along the field lines, showing the field pattern of a bar magnet

Soft iron or steel, and what each is used for

soft iron 软铁	easy to **magnetise 磁化** but loses its magnetism quickly
steel 钢	harder to magnetise but keeps its magnetism – so it makes a permanent magnet
the electromagnet core	an **unmagnetised 未磁化** piece of soft iron – it must lose its magnetism the instant the current stops
permanent magnets	fridge door catches, compass needles, loudspeakers
electromagnets 电磁铁	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

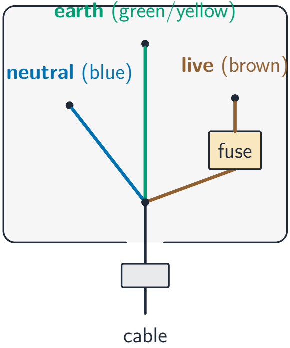


F, B and I are all at $90°$ (Fleming's left-hand rule)

> 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, neutral and earth

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 接地**: 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 双重绝缘**: 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 跳闸开关	a circuit breaker – the same job, but it acts faster and can be reset
earthing	a low-resistance path from the metal **casing** 外壳 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** 模拟 meter has a needle over a scale; a **digital** 数字 meter shows a number
- both come in different **ranges** 量程: 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** 排斥力 is the only sure test; **attraction** 吸引力 also happens with uncharged objects

The relay

- a small current in a coil magnetises a soft-iron core (a **temporary magnet** 临时磁体)
- 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 弗莱明左手定则 (motor effect): thumb = force, first finger = field (N to S), second finger = current.

Fleming's right-hand rule 弗莱明右手定则 (induction): thumb = motion of the wire, first finger = field, second finger = induced current.

A current-carrying coil in a field feels a **turning effect 转动效应**: 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.

5 Recap

Topic 4 – key takeaways

1 Current

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

2 Circuits

series adds R; parallel lowers it

3 Induction

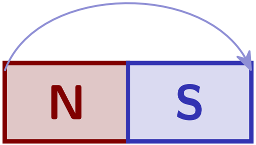
move a wire in a field $\rightarrow$ e.m.f.

4 Transformer

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

Check yourself

1. Charge through a $2\,\mathrm{A}$ lamp in $10\,\mathrm{s}$?
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.** $Q = It = 20\,\mathrm{C}$ **2.** $2\,\Omega$ **3.** the live wire **4.** lower current $\Rightarrow$ less heat lost