

Electricity and magnetism

IGCSE Physics 0625 · Unit 4 revision notes

Magnets and fields, charge, current, p.d. and resistance, circuits and safety, then induction, motors, generators and transformers.

55 definitions to learn word for word, 21 equations in their own column, 33 diagrams and graphs. Read it, cover it, test yourself.

1. 4.1 Simple phenomena of magnetism
2. 4.2a Electric charge
3. 4.2b Electric current
4. 4.2c Electromotive force and potential difference
5. 4.2d Resistance
6. 4.2e Electrical energy and electrical power
7. 4.3a Circuit diagrams and circuit components
8. 4.3b Series and parallel circuits
9. 4.3c Action and use of circuit components
10. 4.4 Electrical safety
11. 4.5a Electromagnetic induction
12. 4.5b The a.c. generator
13. 4.5c Magnetic effect of a current
14. 4.5d Force on a current-carrying conductor
15. 4.5e The d.c. motor
16. 4.5f The transformer

■ Definitions (mark-scheme wording) ■ Equations ■ Exam traps **Extended** = Extended tier only

4.1 Simple phenomena of magnetism

Definitions

Magnetic field: a region in which a magnetic pole experiences a force.

Direction of a magnetic field: the direction of the force on the north pole of a magnet at that point.

Magnetic material: a material attracted by a magnet: iron, steel, nickel and cobalt.

Non-magnetic material: a material that is not attracted by a magnet and cannot be magnetised, e.g. copper, aluminium, plastic.

Induced magnetism: magnetism produced in a magnetic material when it is placed in a magnetic field.

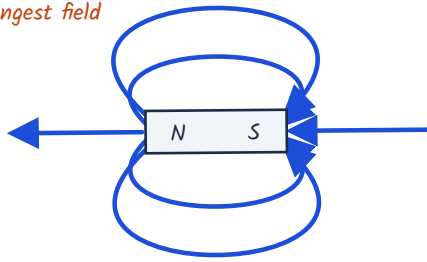
Temporary magnet: a magnet (e.g. soft iron) that loses its magnetism when removed from the field.

Permanent magnet: a magnet (e.g. steel) that keeps its magnetism.

Key points

- ✓ Like poles repel, unlike poles attract; magnetic forces act without contact.
- ✓ A magnet attracts unmagnetised magnetic materials by **inducing** an opposite pole in the near end.
- ✓ **Soft iron** magnetises and demagnetises easily: electromagnet and transformer cores, relays.
- ✓ **Steel** is hard to magnetise but keeps it: permanent magnets (fridge doors, loudspeakers, compasses).
- ✓ Field lines run **N to S** outside the magnet and never cross.
- ✓ Plot a field with a **plotting compass** (mark the needle direction dot to dot) or iron filings.
- ✓ Electromagnets can be switched off and their strength varied: scrapyard cranes, relays, door locks.
- ✓ **Extended** magnetic forces are due to **interactions between magnetic fields**.
- ✓ **Extended** the field is **strongest where the lines are closest together (at the poles)**.

closest lines
= strongest field



Bar magnet field: lines leave N and enter S; crowded lines near the poles mean a stronger field.

N S N S attract

N S S N repel

N S N S attract

soft iron (induced poles)

Attraction, repulsion and induced magnetism: a magnet induces an opposite pole in the near end of soft iron.

Watch out!

- ! Attraction proves nothing: a magnet attracts any iron. Only **repulsion** proves an object is a magnet.
- ! Field lines go **from N to S** outside the magnet; arrows the wrong way lose the mark.

4.2a Electric charge

Definitions

Conductor: a material that allows charge (electrons) to flow through it easily, e.g. metals.

Insulator: a material that does not allow charge to flow through it easily, e.g. plastic, rubber, glass.

Coulomb (C): Extended the unit of electric charge.

Electric field: Extended a region in which an electric charge experiences a force.

Direction of an electric field: Extended the direction of the force on a positive charge at that point.

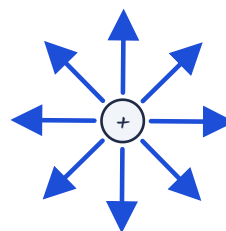
Key points

- ✓ There are two kinds of charge, **positive and negative**. Like charges repel, unlike charges attract.
- ✓ Charging by friction transfers **electrons only**: the object gaining electrons becomes negative, the one losing them positive.
- ✓ Detect charge: a charged rod hung on a thread is repelled by a like-charged rod.
- ✓ Test a conductor: put it in a circuit with a cell and lamp; the lamp lights only if it conducts.
- ✓ Metals conduct because they contain **free (delocalised) electrons**; insulators have none.
- ✓ Extended field lines point **away from positive** and **towards negative**; radial round a point charge or charged conducting sphere, uniform between parallel plates.

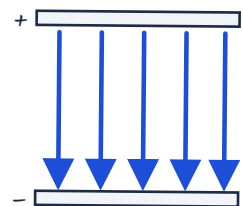


only electrons move, never positive charge

Charging by friction: electrons rub off the cloth onto the polythene rod. Rod negative, cloth positive.



point charge



uniform field

Extended: field lines point away from + and towards -; radial round a point charge, uniform between plates.

Watch out!

- ! Never say positive charge moves when charging by friction: **only electrons are transferred**.
- ! Extended: field arrows show the force on a **positive** charge, so they point towards the negative plate.

4.2b Electric current

Definitions

Electric current: Extended the charge passing a point per unit time.

Conventional current: Extended current flowing from the positive terminal to the negative terminal of the source.

Direct current (d.c.): current that flows in one direction only.

Alternating current (a.c.): current that repeatedly reverses its direction.

Ampere (A): the unit of current.

Equations

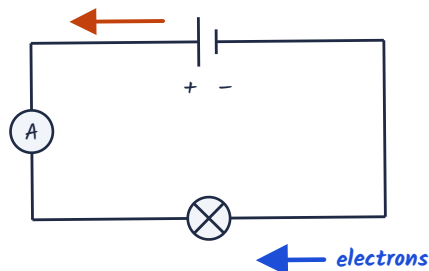
$$I = Q / t$$

Extended current = charge / time
A

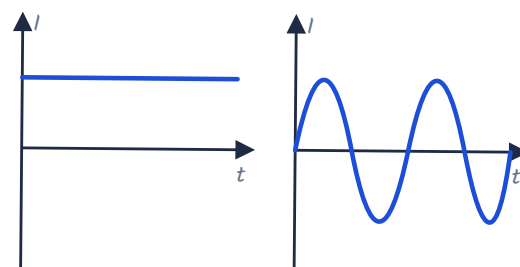
Key points

- ✓ Electric current is a **flow of charge**.
- ✓ Current is measured with an **ammeter in series**; analogue (pointer and scale) or digital, on a suitable range.
- ✓ In metals the current is a flow of **free electrons**.
- ✓ **Extended** conventional current flows from + to -; free electrons flow from - to +.
- ✓ Current is **not used up**: the same current leaves and returns to the cell.
- ✓ Cells and batteries give d.c.; the mains supply is a.c. (50 Hz in the UK).
- ✓ **Extended** charge = current $\times$ time (1 A = 1 C/s), so 2 A for 10 s moves 20 C.

conventional current



Conventional current leaves the + (long) plate; electrons flow the opposite way. The ammeter is in series.



d.c.: one way

a.c.: reverses

d.c. stays in one direction; a.c. reverses direction repeatedly.

Watch out!

- ! Extended: conventional current flows + to -; electron flow is the opposite. Say which one you mean.
- ! Current is the same before and after a lamp: it is **energy** that the lamp transfers, not current.

4.2c Electromotive force and potential difference

Definitions

Electromotive force (e.m.f.): the electrical work done by a source in moving unit charge around a complete circuit.

Potential difference (p.d.): the work done by unit charge passing through a component.

Volt (V): *Extended* one joule per coulomb ($1 \text{ V} = 1 \text{ J/C}$).

Equations

$$E = W / Q$$

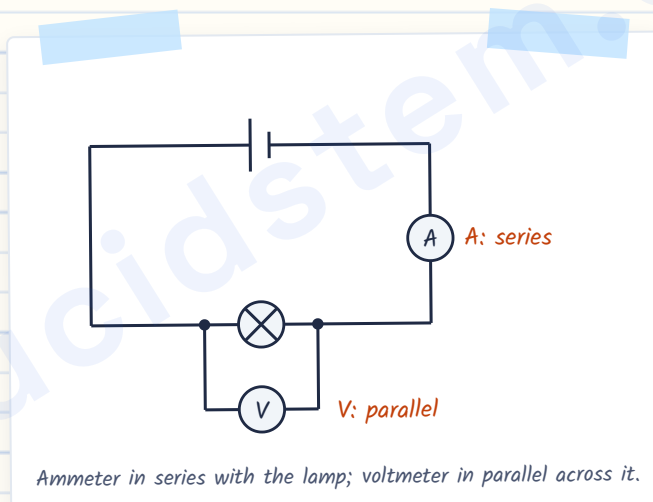
Extended e.m.f. = work done by source / charge
V

$$V = W / Q$$

Extended p.d. = work done / charge
V

Key points

- ✓ Both e.m.f. and p.d. are measured in **volts** with a **voltmeter in parallel** (across the component).
- ✓ e.m.f. is energy **given to** each coulomb by the source; p.d. is energy **transferred from** each coulomb by a component.
- ✓ Voltmeters may be analogue or digital, used on a suitable range; read analogue scales at eye level to avoid parallax.
- ✓ Beyond the syllabus: an ideal voltmeter has a very high resistance so it takes almost no current.
- ✓ *Extended* 1 V means 1 J of work per coulomb; a 12 V battery gives each coulomb 12 J.



Watch out!

- ! Voltmeter **across** (parallel), ammeter **in line** (series). Swapping them is a classic lost mark.
- ! p.d. is **across** a component, current is **through** it. Never say "voltage through".

4.2d Resistance

Definitions

Resistance: the ratio of the p.d. across a component to the current through it ($R = V/I$).

Ohm (Ω): the unit of resistance; $1 \Omega = 1 \text{ V/A}$.

Ohmic conductor: Beyond the syllabus: a conductor whose current is directly proportional to the p.d. across it at constant temperature.

Diode: **Extended** a component that allows current in one direction only.

Equations

$$R = V / I$$

resistance = p.d. / current

Ω

$$R \propto L$$

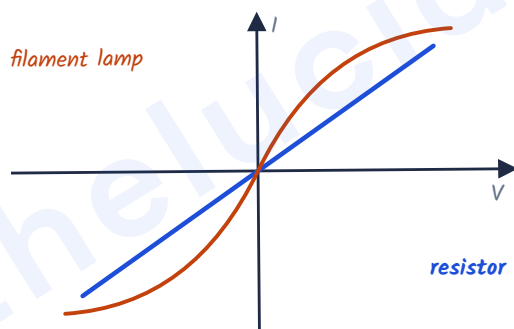
Extended resistance proportional to length

$$R \propto 1/A$$

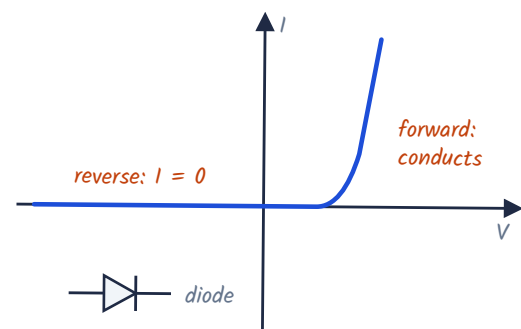
Extended resistance inversely proportional to cross-sectional area

Key points

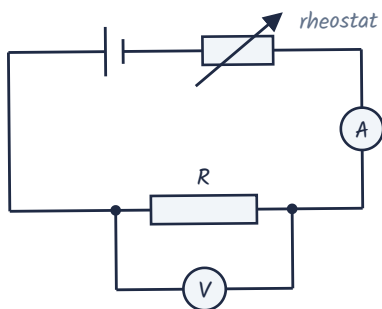
- ✓ Measure R : ammeter in series, voltmeter across the resistor, vary the current with a variable resistor; $R = V/I$.
- ✓ **Extended** fixed resistor (constant temperature): I - V graph is a straight line through the origin.
- ✓ **Extended** filament lamp: curve **flattens**, because the hot filament has **higher resistance**.
- ✓ Longer wire: **more resistance**. Thicker wire (larger cross-sectional area): **less resistance**.
- ✓ **Extended** diode conducts in the **forward** direction only (very high resistance in reverse).
- ✓ **Extended** $R \propto L$ and $R \propto 1/A$: doubling the length doubles R ; doubling the area halves R .



Extended: I - V graphs: a resistor (blue) is a straight line through the origin; the lamp curve (red) flattens as the filament heats up.



Extended: a diode conducts in the forward direction only; in reverse the current is zero.



Measuring resistance: the rheostat varies the current; record V and I and calculate $R = V/I$.

Watch out!

- ! Extended: lamp resistance **increases** with current (hotter filament); do not call the lamp ohmic.
- ! A **thicker** wire has **less** resistance, not more.

4.2e Electrical energy and electrical power

Definitions

Power: the rate of energy transfer (energy transferred per unit time).

Kilowatt-hour (kWh): the energy transferred by a 1 kW appliance in 1 hour ($= 3.6 \times 10^6 \text{ J}$).

Key points

- ✓ Electric circuits transfer energy from the cell or mains to the surroundings via the components.
- ✓ Power of an appliance = **current** $\times$ **p.d.**
- ✓ Energy in joules: use power in **W** and time in **s**.
- ✓ Energy in kWh: use power in **kW** and time in **hours**.
- ✓ Cost = number of kWh (units) $\times$ price per kWh.

Equations

$$P = IV$$

power = current $\times$ p.d.
W

$$E = IVt$$

energy = current $\times$ p.d. $\times$ time
J

$$E = Pt$$

energy (kWh) = power (kW) $\times$ time (h)
kWh

cost = kWh $\times$ price per kWh
cost of electricity used

heater 2000 W
 $= 2 \text{ kW}$

on for 90 min
 $= 1.5 \text{ h}$

$$E = 2 \times 1.5 = 3 \text{ kWh}$$

$$\text{cost} = 3 \times 30\text{p} = 90\text{p}$$

Worked kWh cost: convert watts to kilowatts and minutes to hours before multiplying.

Watch out!

- ! Mixing units: kWh needs kW and hours; joules need W and seconds.
- ! The kWh is a unit of **energy**, not power.

4.3a Circuit diagrams and circuit components

Definitions

Thermistor: a resistor whose resistance decreases as its temperature increases.

Light-dependent resistor (LDR): a resistor whose resistance decreases as the light intensity increases.

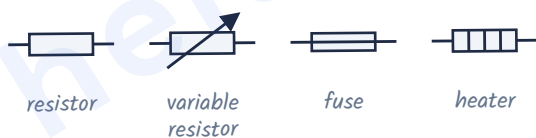
Variable resistor (rheostat): a resistor whose resistance can be changed, used to control the current.

Relay: a switch operated by an electromagnet, so a small current can switch a large current.

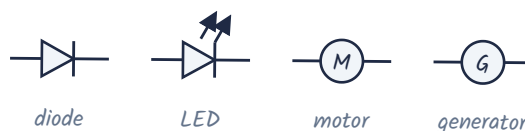
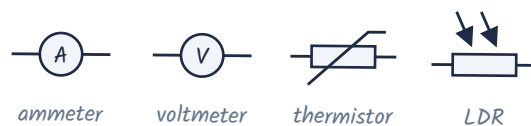
Light-emitting diode (LED): **Extended** a diode that emits light when current flows through it in the forward direction.

Key points

- ✓ Draw circuits with a ruler, **straight wires and square corners**, no gaps at junctions.
- ✓ Mark junctions with a **dot**; wires that cross without a dot are not connected.
- ✓ Cell: the **long plate is positive**. A battery is two or more cells in series.
- ✓ Know the symbols for: cell, battery, switch, lamp, resistor, variable resistor, thermistor, LDR, heater, fuse, ammeter, voltmeter, motor, generator, power supply, potential divider, bell, magnetising coil, relay, transformer.
- ✓ **Extended** know the diode and LED symbols; the diode arrow points in the direction of conventional current it allows.



Circuit symbols (1): sources, switch, lamp and resistors.



Circuit symbols (2): meters, sensors, diodes (Extended), motor and generator.

Watch out!

- ! A lamp symbol is a circle with a **cross**; a circle with a letter is a meter, motor or generator.
- ! Forgetting the junction **dot** where a voltmeter joins the circuit.

4.3b Series and parallel circuits

Definitions

Series circuit: components connected one after another in a single loop, so the same current passes through each.

Parallel circuit: components connected on separate branches between the same two points.

Conservation of charge at a junction: *Extended* the sum of the currents into a junction equals the sum of the currents out of it.

Key points

- ✓ **Series:** the current is the **same at every point**.
- ✓ **Series:** total resistance is the **sum** of the resistances; e.m.f.s of cells in series **add**.
- ✓ **Parallel:** the current from the source is **larger** than the current in any branch.
- ✓ **Parallel:** the combined resistance of two resistors is **less than either** resistor alone.
- ✓ **Lamps in parallel:** each gets the full p.d., and each can be switched **independently**; one failing leaves the rest on.
- ✓ **Extended** in series the p.d.s across the components **add up** to the supply p.d.
- ✓ **Extended** the p.d. across each parallel branch is the **same** as the p.d. across the whole parallel arrangement.
- ✓ **Extended** in parallel the branch currents **add up** to the supply current (charge is conserved).

Equations

$$E = E_1 + E_2$$

combined e.m.f. of cells in series (all the same way round)

V

$$R = R_1 + R_2$$

combined resistance in series

Ω

$$1/R = 1/R_1 + 1/R_2$$

Extended combined resistance of two in parallel

Ω

$$V = V_1 + V_2$$

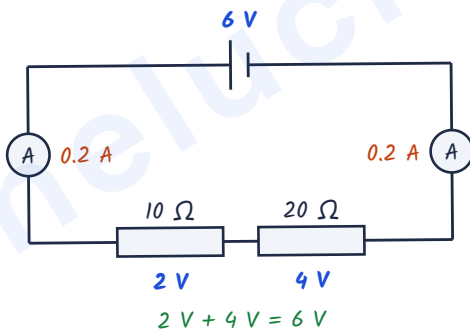
Extended p.d.s in series add to the supply p.d.

V

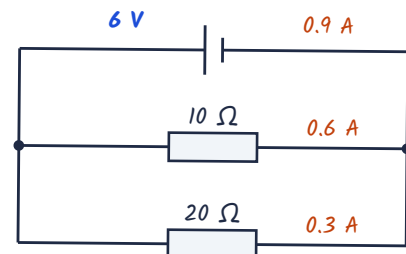
$$I = I_1 + I_2$$

Extended branch currents add to the supply current

A



Series: one current (0.2 A) everywhere; the 6 V supply is shared 2 V + 4 V in the ratio of the resistances.



6 V across each branch

Parallel: each branch gets the full 6 V; branch currents 0.6 A + 0.3 A add to 0.9 A from the cell.

Watch out!

- ! Adding a resistor in **parallel** **lowers** the total resistance: two 10 Ω in parallel make 5 Ω , not 20 Ω .
- ! Current is **not** used up along a series circuit; it is the same before and after each component.

4.3c Action and use of circuit components

Definitions

Potential divider: two resistors in series across a supply, so the supply p.d. is shared between them.

Variable potential divider (potentiometer): *Extended* a potential divider whose output p.d. can be varied continuously, e.g. by a sliding contact.

Equations

$$V_1 / V_2 = R_1 / R_2$$

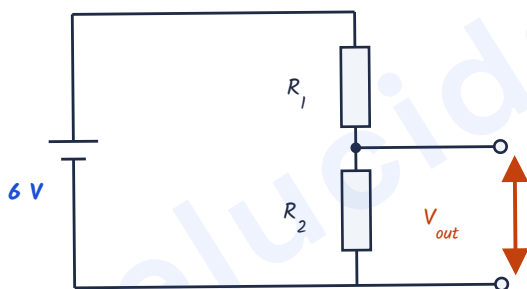
Extended p.d.s share in the ratio of the resistances

$$V_{out} = V_{in} \times R_2 / (R_1 + R_2)$$

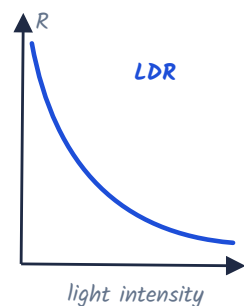
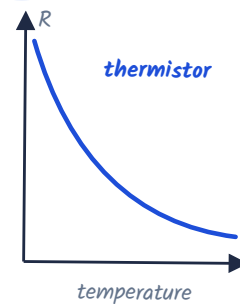
Extended output across R_2
V

Key points

- ✓ For a **constant current**, the p.d. across a conductor **increases** as its resistance increases.
- ✓ In a potential divider the **larger resistor takes the larger share** of the supply p.d.
- ✓ *Extended* moving the slider of a variable potential divider varies V_{out} from 0 to the full supply p.d.
- ✓ Heat a thermistor: its R falls, so its share of the p.d. **falls** (and the other resistor's rises).
- ✓ Light on an LDR: its R falls, so its share of the p.d. falls. Used for automatic street lights.
- ✓ *Extended* $V_1/V_2 = R_1/R_2$; the output can switch a relay or LED at a set temperature or light level.



Potential divider: V_{out} is the p.d. across R_2 . Replace R_2 with a thermistor or LDR to make a sensor.



Sensor resistors: a thermistor's resistance falls as temperature rises; an LDR's falls as light intensity rises.

Watch out!

- ! The **bigger** resistor gets the **bigger** p.d., not the smaller one.
- ! Hot thermistor or bright LDR means **lower** resistance, not higher.

4.4 Electrical safety

Definitions

Fuse: a thin wire in the live wire that melts and breaks the circuit when the current exceeds its rating.

Circuit breaker (trip switch): an automatic switch that breaks the circuit when the current is too large; it can be reset.

Earth wire: a low-resistance path to earth, connected to the metal case of an appliance.

Double insulation: an appliance with a non-conducting outer case and no exposed metal, so it needs no earth wire.

Equations

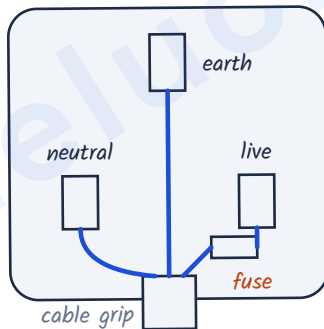
$$I = P / V$$

working current, used to choose the fuse rating

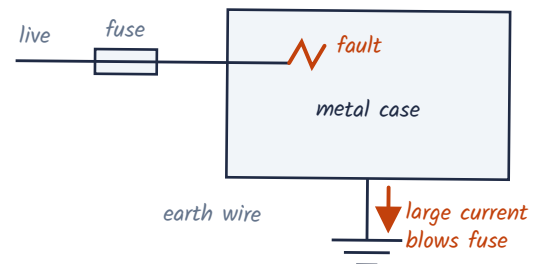
A

Key points

- ✓ **Hazards:** damaged insulation, overheated cables (current too high), damp conditions, overloaded plugs and sockets.
- ✓ Mains wires: **live** (brown, at high p.d.), **neutral** (blue, near 0 V), **earth** (green and yellow).
- ✓ Fuses and switches go in the **live** wire, so the appliance is disconnected from the high p.d. when off or blown.
- ✓ Fault: live touches a metal case, a large current flows to earth and **the fuse melts**, so the case is never live.
- ✓ Choose the fuse rating (or trip-switch setting) **just above** the normal working current (common fuse ratings 3 A, 5 A, 13 A).
- ✓ Circuit breakers act faster than fuses and are reset, not replaced.
- ✓ For a **double-insulated** appliance (no earth wire), the fuse still protects the **circuit and the cabling**.



Three-pin plug: the fuse sits in the live wire; the earth pin connects to the metal case.



Earthing: if the live wire touches the metal case, a large current flows to earth and blows the fuse.

Watch out!

- ! A fuse rated far above the working current gives no protection: a 2.6 A lamp needs a **3 A** fuse, not 13 A.
- ! The fuse must be in the **live** wire; in the neutral the appliance stays live after it blows.

4.5a Electromagnetic induction

Definitions

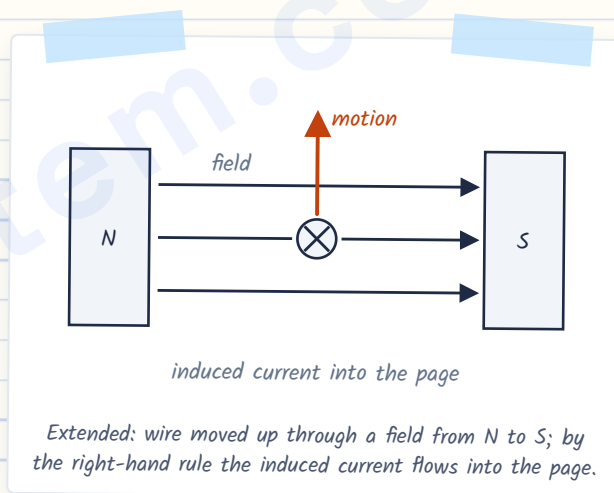
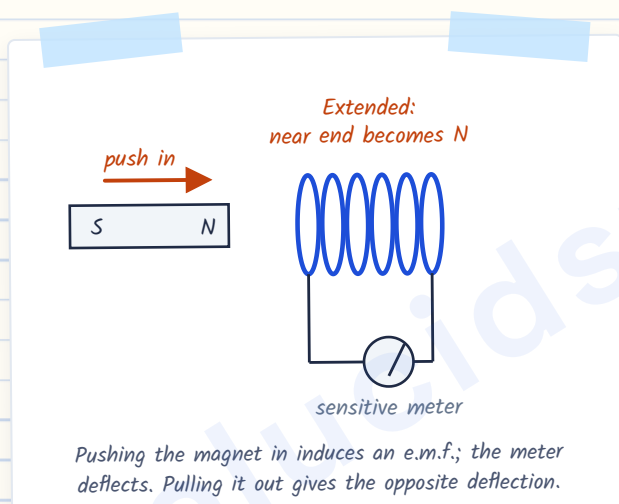
Electromagnetic induction: the production of an e.m.f. in a conductor when it cuts magnetic field lines or when the magnetic field through it changes.

Direction of induced e.m.f. (Lenz): Extended the induced e.m.f. (and current) is in a direction that opposes the change producing it.

Fleming's right-hand rule: Extended thumb = motion, first finger = field, second finger = induced current (generators).

Key points

- ✓ Move a magnet into a coil, or a wire through a field: a sensitive meter **deflects**.
- ✓ No relative movement (no change in field) means **no e.m.f.**
- ✓ Reversing the motion or the magnet's poles **reverses** the e.m.f.
- ✓ Bigger e.m.f.: **faster movement**, **stronger magnet**, **more turns** on the coil.
- ✓ Extended pushing N into a coil makes the near end of the coil an **N pole**, which repels the magnet (opposes the change).
- ✓ Extended work done against this opposing force is transferred as electrical energy.



Watch out!

- ! A **stationary** magnet inside a coil induces nothing: the field must be **changing**.
- ! Extended: the induced pole **opposes** the motion (N facing an approaching N), never helps it.

4.5b The a.c. generator Extended

Definitions

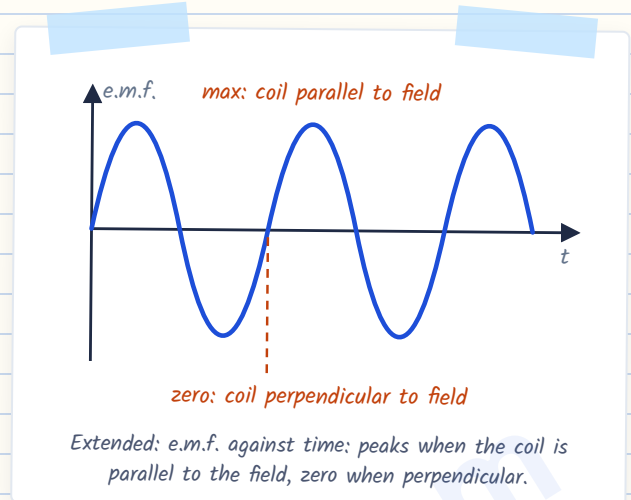
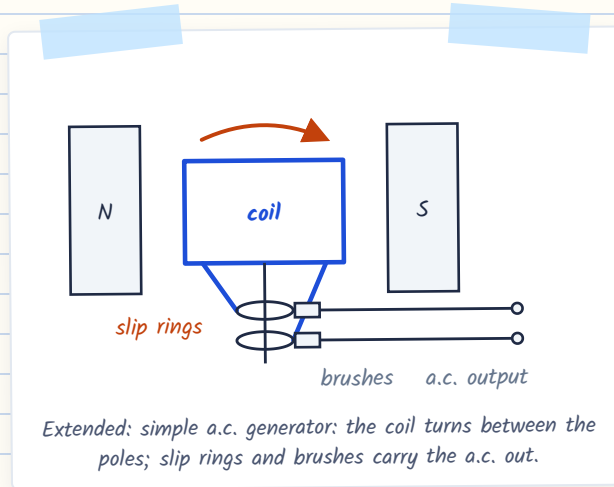
a.c. generator: Extended a coil rotating in a magnetic field, connected to the external circuit through slip rings and brushes, producing an alternating e.m.f.

Slip rings: Extended two complete rings on the axle, each connected to one end of the coil, that keep the coil in contact with the brushes.

Key points

- ✓ Extended rotating coil **cuts field lines**, so an e.m.f. is induced.

- ✓ **Extended** each side of the coil moves up then down every turn, so the e.m.f. **reverses every half turn**: a.c.
- ✓ **Extended** slip rings and carbon **brushes** connect the rotating coil to the outside circuit.
- ✓ **Extended** faster rotation: **larger peak e.m.f.** and **higher frequency**. Stronger field or more turns: larger peak.
- ✓ **Extended** e.m.f. is **maximum** when the coil plane is **parallel** to the field (sides cut lines fastest).
- ✓ **Extended** e.m.f. is **zero** when the coil plane is **perpendicular** to the field (sides move along the lines).



Watch out!

- ! **Extended**: a generator uses **slip rings** (a.c.); a d.c. motor uses a **split-ring commutator**. Do not swap them.
- ! **Extended**: maximum e.m.f. is when the coil is **parallel** (horizontal) to the field, not perpendicular.

4.5c Magnetic effect of a current

Definitions

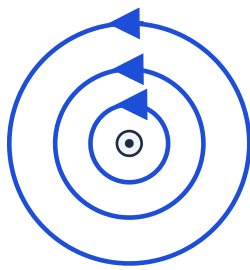
Solenoid: a long coil of wire; when it carries a current its field is like that of a bar magnet.

Electromagnet: a solenoid wound on a soft-iron core, magnetised only while current flows.

Right-hand grip rule: grip the wire with the thumb along the current; the curled fingers give the field direction.

Key points

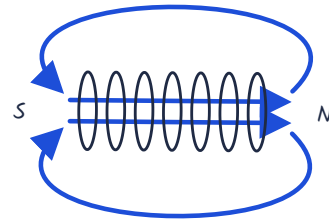
- ✓ Straight wire: field lines are **concentric circles** round the wire.
- ✓ Solenoid: field like a **bar magnet** outside; lines run parallel inside.
- ✓ Find the pattern with **iron filings** or **plotting compasses** on card round the wire or solenoid; compasses give the direction.
- ✓ **Extended** **larger current** gives a stronger field; **reversing the current** reverses the field.
- ✓ More turns and a **soft-iron core** make an electromagnet stronger.
- ✓ Uses: **relays** (small current switches a large one), **loudspeakers** (a.c. in a coil makes the cone vibrate), lifting magnets.
- ✓ **Extended** field of a wire is **weaker further from the wire** (circles spread out).
- ✓ **Extended** solenoid field is strongest (and uniform) inside and weaker outside, especially beyond the ends.



current out
of the page

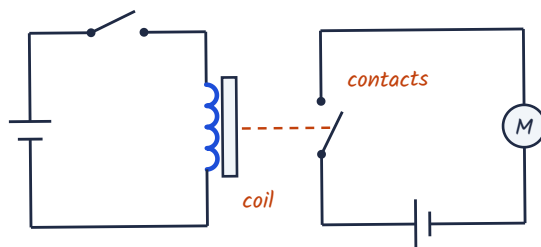
*circles spread
out = weaker*

Straight wire, current out of the page: circular field lines, anticlockwise, spreading out with distance.



uniform field inside

Solenoid: bar-magnet pattern outside, strong uniform field inside. Reverse the current to swap N and S.



low-current circuit

high-current circuit

Relay: closing the switch energises the coil; the iron core pulls the contacts shut and the high-current circuit runs the motor.

Watch out!

- ! Field lines round a wire are **circles**, not lines radiating out from the wire.
- ! An electromagnet core must be **soft iron** (steel would stay magnetised when switched off).

4.5d Force on a current-carrying conductor

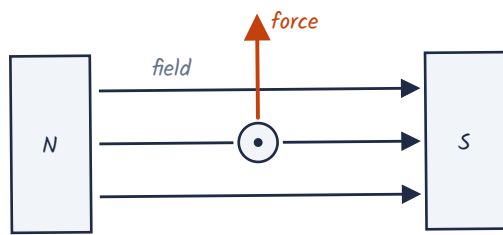
Definitions

Motor effect: a current-carrying conductor in a magnetic field experiences a force.

Fleming's left-hand rule: **Extended** thumb = force (motion), first finger = field (N to S), second finger = current (+ to -).

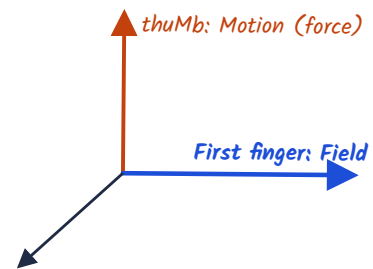
Key points

- ✓ **Extended** force is largest when the current is **perpendicular** to the field; **zero** when parallel.
- ✓ Reversing the **current** or the **field** reverses the force (reversing both leaves it unchanged).
- ✓ Bigger current or stronger field gives a **bigger force**.
- ✓ Demo: a loose wire between the poles of a U-shaped magnet jumps when the current is switched on.
- ✓ **Extended** beams of charged particles are also deflected, since a moving charge is a current.
- ✓ **Extended** for an **electron** beam, the conventional current is **opposite** to the beam direction.

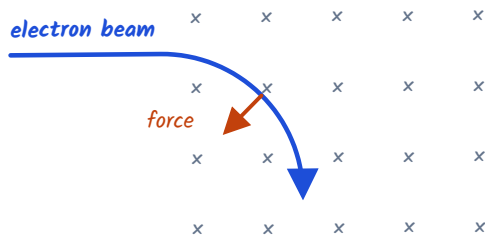


current out of the page

Motor effect: field N to S, current out of the page, so the force on the wire is upwards.



Extended: Fleming's left-hand rule. Hold thumb, first and second fingers at right angles.



Extended: an electron beam in a field into the page curves (here downwards); the force is always at right angles to its motion.

Watch out!

- ! Extended: use the **left** hand for motors (force) and the **right** hand for generators (induced current).
- ! Extended: for electrons point the second finger **opposite** to their motion.

4.5e The d.c. motor

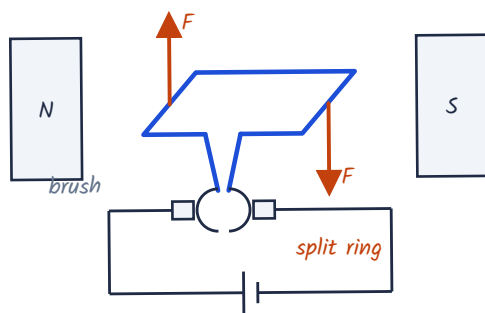
Definitions

Split-ring commutator: Extended a split ring on the axle that reverses the current in the coil every half turn.

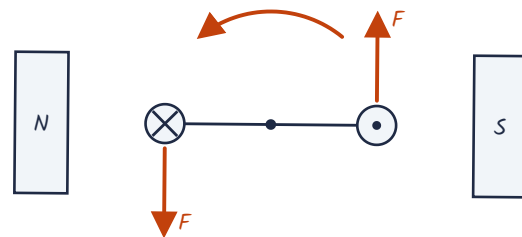
Brushes: Extended carbon contacts that press on the commutator (or slip rings) to connect the rotating coil to the circuit.

Key points

- ✓ Current in a coil in a field: forces on the two sides act in **opposite directions**, giving a **turning effect**.
- ✓ Turning effect increases with **more turns**, **larger current** and a **stronger field**.
- ✓ Reversing the current or the field reverses the direction of rotation.
- ✓ Extended the commutator reverses the current **every half turn** (when the coil is vertical), so the coil keeps turning the same way.
- ✓ Extended momentum carries the coil past the vertical, where the force gives no turning effect.



d.c. motor: forces up on one side and down on the other turn the coil; the split ring and brushes feed the current.



field from N to S

End view: current into the page on the left side, out on the right; forces down and up make the coil turn anticlockwise.

Watch out!

- ! Extended: the commutator reverses the current **in the coil**, not in the external circuit.
- ! Opposite sides of the coil carry current in opposite directions, so the forces are opposite (a turning pair).

4.5f The transformer

Definitions

Transformer: two coils (primary and secondary) wound on a soft-iron core, used to change the size of an alternating voltage.

Step-up transformer: a transformer with more turns on the secondary than the primary, so $V_s > V_p$.

Step-down transformer: a transformer with fewer turns on the secondary than the primary, so $V_s < V_p$.

Equations

$$V_p / V_s = N_p / N_s$$

voltage ratio = turns ratio

$$I_p V_p = I_s V_s$$

Extended power in = power out (100% efficient)

W

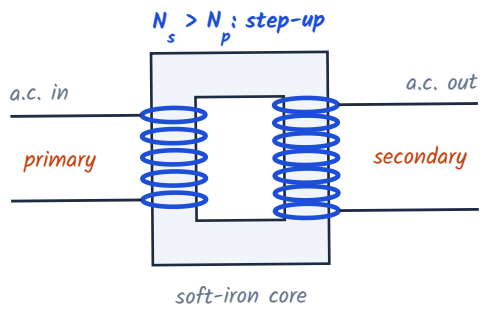
$$P = I^2 R$$

Extended power lost as heat in the cables

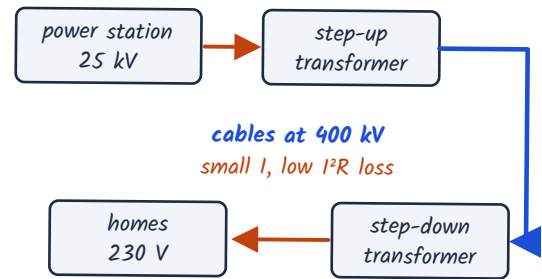
W

Key points

- ✓ Transformers work only on **a.c.**
- ✓ The voltage ratio equals the **turns ratio**.
- ✓ Power is transmitted at **high voltage**: step up at the power station, step down near homes.
- ✓ High voltage means **small current**, so **less energy is lost** as heat in the cables and thinner, cheaper cables can be used.
- ✓ Extended a.c. in the primary makes a **changing magnetic field** in the soft-iron core; this changing field through the secondary **induces** an alternating e.m.f.
- ✓ Extended an ideal (100% efficient) transformer has power in = power out.
- ✓ Extended cable power loss = $I^2 R$, so halving the current quarters the loss.



Step-up transformer: more turns on the secondary, so the output voltage is larger.



The grid: step up for transmission (small current, low I^2R loss), step down for safe use in homes.

Watch out!

- ! A transformer does not work on **d.c.**: a steady current gives a constant field and no induced e.m.f.
- ! Stepping up the voltage steps **down** the current; it does not create energy.