

ESAT

Physics

Electricity

Free lesson notes

Covers

P1.1 to P1.2

Format

Lesson, worked examples, self-check

Price

Free

About this lesson

Electricity is one of the most useful topics in ESAT Physics, because a handful of ideas (charge, current, potential difference, resistance and power) combine in many different ways, and every ESAT question on it can be solved with the same few steps. If you understand *why* the formulae are true, you never need to memorise a separate recipe for each circuit.

This lesson starts from the atom. We explain static electricity (why rubbing moves electrons, why charged objects attract neutral ones, and where static is useful and dangerous). We then define current as the flow of charge and potential difference as energy transferred per unit charge, and use these to derive resistance and Ohm's law. We read the current–voltage graphs of a resistor, a filament lamp, a diode, a thermistor and an LDR. We *derive* the rules for resistors in series and in parallel instead of just quoting them, build potential dividers, and finish with electrical power and energy, including the habit of checking units and scaling that ESAT rewards. There is no calculator in the real exam, so the examples use friendly numbers.

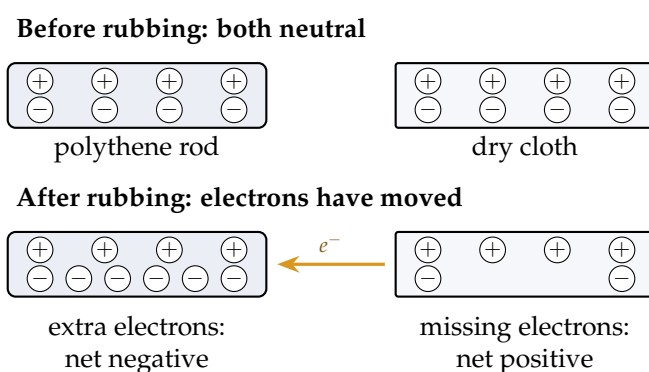
How to use it. Read each idea, then cover the worked example and try it yourself first. Draw the circuit every time. Finish with the self-check and then the practice set. Specification codes: P1.1 (electrostatics) and P1.2 (circuits).

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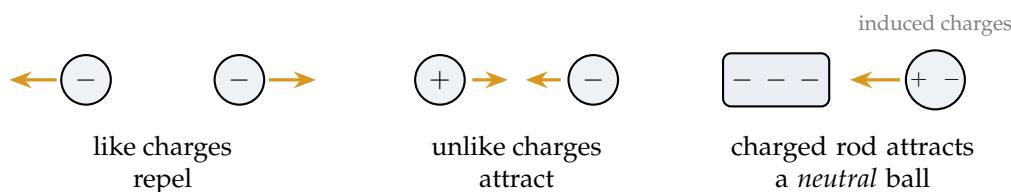
1 Static electricity

Where charge comes from. Every atom has a tiny positive nucleus (protons and neutrons) surrounded by electrons. Protons carry positive charge, electrons carry an equal amount of negative charge, and neutrons carry none. An ordinary object is *neutral* because it has the same number of protons as electrons, so the charges cancel. The protons are locked inside nuclei; only electrons can move from one object to another. So an object becomes **negatively charged** by gaining electrons and **positively charged** by losing electrons. (Never say it “gains protons”.)

Charging by friction. When two different insulators are rubbed together, electrons are pulled off the surface of one and stick to the other. The material that gains electrons ends up negative; the one that loses them ends up positive, and the two charges are *equal and opposite*: the total charge is the same before and after (*conservation of charge*). Insulators are used because the extra charge cannot flow away; on a conductor held in your hand it would drain through you to the ground.



Forces between charges. Experiments show two rules: **like charges repel, unlike charges attract**. The force gets stronger as the charges get closer together.



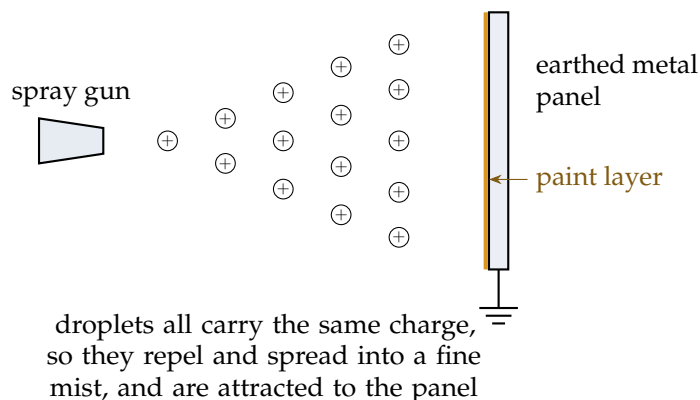
Why does a charged rod attract a neutral object? The third picture is the surprising one. A negatively charged rod is held near a neutral piece of paper or a foil-coated ball. The rod pushes the ball's mobile electrons to the far side, so the near side is left slightly positive and the far side slightly negative. Nothing has been added to or removed from the ball (its net charge is still zero), but the *positive* side is closer to the rod than the negative side, so the attraction is stronger than the repulsion and the ball moves towards the rod. This is called *induced charge*. If the ball then touches the rod, electrons can pass onto it, it becomes negative itself, and it is now repelled.

Worked example: a balloon and a wall

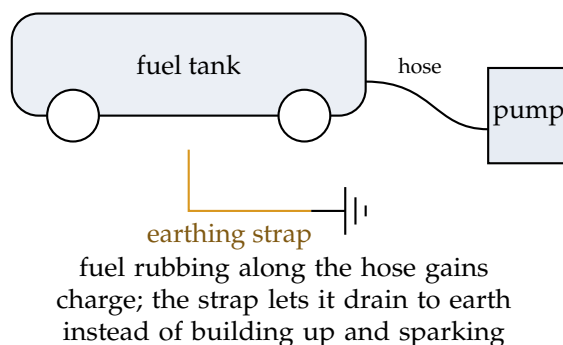
A balloon is rubbed on a woollen jumper and then sticks to a wall. Explain why, and say what happens to the jumper.

Rubbing transfers electrons from the wool to the rubber, so the balloon is negative and the jumper is positive by the same amount. The balloon's electrons repel electrons in the (insulating) wall surface slightly, leaving the surface nearest the balloon positive. Unlike charges attract, and the nearer positive charge wins, so the balloon sticks. The balloon eventually falls as its charge leaks away into the damp air.

Uses of static electricity. Because charged objects attract neutral or oppositely charged ones, charge can be used to steer small particles. In *electrostatic spray painting* the paint droplets are given the same charge, so they repel each other and spread out into a fine, even mist; they are attracted to the earthed metal object being painted, so very little paint is wasted and even the back surface gets coated. Other applications use the same idea: smoke-stack dust precipitators (charged dust sticks to plates), and photocopiers and laser printers (charged powder sticks only to the charged parts of a drum).



Hazards. Charge builds up on insulators and then discharges suddenly as a spark. A static shock from a car door is harmless, but a spark near petrol vapour or in a flour mill could start a fire or explosion, and a lightning strike is a huge discharge. The standard defence is **earthing**: connect the object to the ground with a conductor so that charge drains away steadily. Fuel tankers are earthed for this reason, and aircraft are earthed before refuelling.



Common mistakes

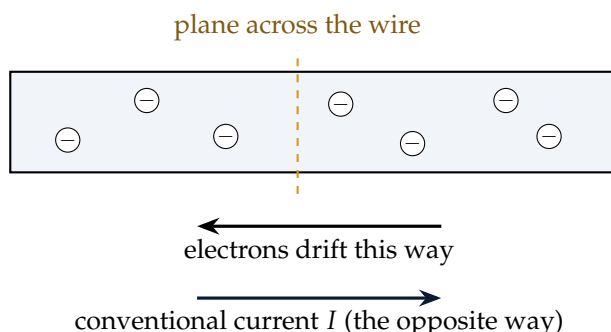
- Saying a rod becomes positive by *gaining protons*. Only electrons move.
- Saying a charged object cannot attract a neutral one. It can, through induced charge.
- Forgetting that the cloth gains the opposite charge to the rod: charge is conserved, so one object cannot be charged without the other.

2 Electric current and charge

Current is a flow of charge. In a metal wire some electrons are free to wander between the atoms (*conductors* have free charge carriers; *insulators* such as plastic, rubber and glass do not). When a cell is connected, these electrons are all pushed one way round the circuit. We define the **current** I as the charge passing a point each second:

$$I = \frac{Q}{t} \quad \text{so} \quad Q = It.$$

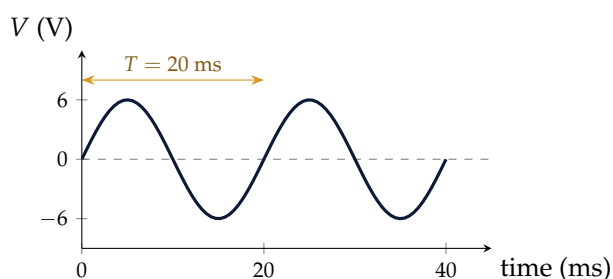
The unit of charge is the coulomb (C) and the unit of current is the ampere (A), where $1 \text{ A} = 1 \text{ C/s}$. Time must be in *seconds*.



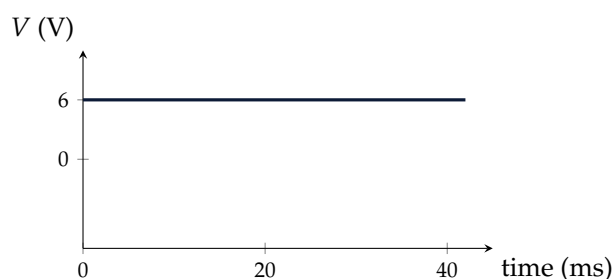
Conventional current. Scientists agreed long before electrons were discovered to draw current from the positive terminal of a cell round to the negative terminal. This *conventional current* is therefore in the *opposite* direction to the movement of the electrons. Arrows on circuit diagrams always show conventional current.

Current is the same all the way round a series loop. Electrons are not used up. The number of electrons entering any component each second equals the number leaving, so an ammeter reads the same current on either side of a lamp. At a junction the charge arriving each second equals the charge leaving each second, so the currents in the branches add up to the current in the main wire.

Direct and alternating current. A cell or battery gives **direct current (d.c.)**: charge always flows the same way. The mains supply is **alternating current (a.c.)**: the direction reverses many times a second. The graph of an a.c. voltage against time is a repeating wave. The time for one full cycle is the *period* T and the number of cycles each second is the *frequency* $f = 1/T$ in hertz. UK mains is about 230 V at 50 Hz, so $T = 1/50 = 20 \text{ ms}$.



a.c.: reverses direction, peak 6 V



d.c.: one direction, constant 6 V

Worked example: charge and electrons

A current of 0.5 A flows through a lamp for 2 minutes. How much charge passes through it? How many electrons is that? (The charge on one electron has magnitude $1.6 \times 10^{-19} \text{ C}$.)

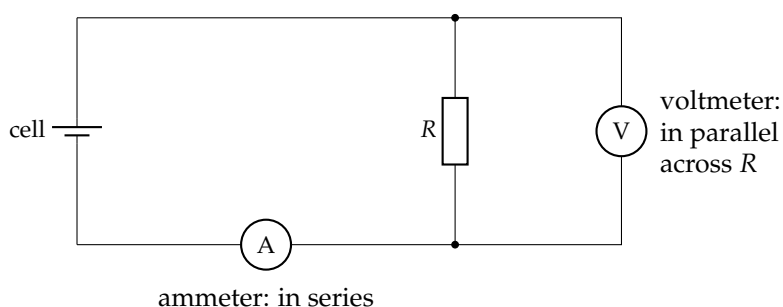
Time = $2 \times 60 = 120$ s. $Q = It = 0.5 \times 120 = 60$ C. Number of electrons = $\frac{60}{1.6 \times 10^{-19}} = 3.75 \times 10^{20}$.

Worked example: a.c. frequency from a trace

An a.c. trace has a period of 0.04 s. What is its frequency, and how many complete cycles occur in 2 s?

$f = \frac{1}{T} = \frac{1}{0.04} = 25$ Hz. In 2 seconds there are $25 \times 2 = 50$ cycles.

Meters. An **ammeter** measures the current through a component, so it must be connected *in series* (the charge has to flow through it) and a good ammeter has very low resistance so that it does not change the current. A **voltmeter** measures the potential difference *across* a component, so it is connected *in parallel* with it and a good voltmeter has very high resistance so that it draws almost no current.



Common mistakes

- Using minutes (or milliamperes) directly in $Q = It$. Convert to seconds and amperes first.
- Drawing current arrows in the direction the electrons move.
- Connecting a voltmeter in series, or an ammeter across a component.
- Thinking current is “used up” by a lamp. Energy is transferred; the current is the same on both sides.

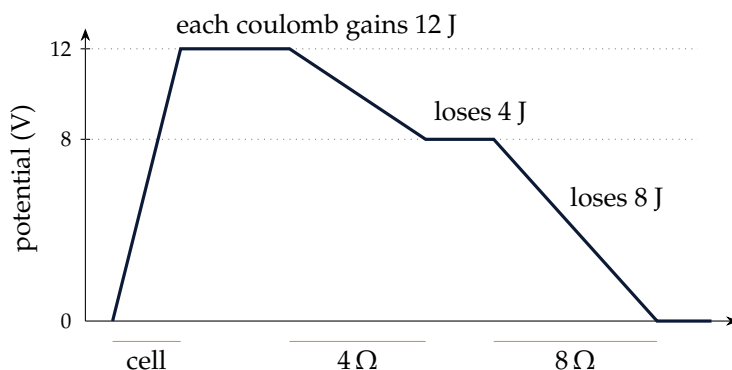
3 Potential difference, energy and resistance

Potential difference (voltage). A cell does work on each charge, giving it energy; a lamp or resistor transfers that energy to the surroundings. The **potential difference** V between two points is the energy transferred per unit charge moving between them:

$$V = \frac{E}{Q} \quad \text{so} \quad E = QV.$$

Its unit is the volt: $1 \text{ V} = 1 \text{ J/C}$. A 12 V battery gives every coulomb that passes through it 12 J. For a source this is called its **electromotive force (e.m.f.)**.

An energy picture of a circuit. Follow one coulomb round the loop. In the cell it gains 12 J. Each resistor then takes some of this energy away, and by the time the coulomb is back at the cell it has none left to spare. The energy gained in the cell equals the sum of the energy transferred in the components, so *the potential differences across components in series add up to the e.m.f.*



Resistance. For a given potential difference, different components allow different currents. We define the **resistance** of a component as the potential difference across it divided by the current through it:

$$R = \frac{V}{I} \quad \text{so} \quad V = IR \quad \text{and} \quad I = \frac{V}{R}.$$

The unit is the ohm (Ω): $1\Omega = 1\text{ V/A}$. A large resistance means a small current for a given voltage. Resistance is caused by the moving charge carriers colliding with the vibrating atoms of the material; this is also why electrical energy becomes thermal energy.

Ohm's law. For some components (metal wires and fixed resistors at constant temperature) the current is proportional to the voltage: doubling V doubles I , so V/I is constant. Such a component is called *ohmic*. For other components V/I changes (next section), and $R = V/I$ is still the resistance *at that voltage*.

Worked example: energy and resistance

A 12 V battery pushes 5 C round a circuit. How much energy does it transfer? A resistor carries 0.5 A when the p.d. across it is 6 V. What is its resistance?

$$E = QV = 5 \times 12 = 60\text{ J}. \quad R = \frac{V}{I} = \frac{6}{0.5} = 12\Omega.$$

Worked example: rearranging in your head

A 4Ω resistor has a current of 3 A. What is the p.d. across it? The same resistor has a p.d. of 10 V; what is the current?

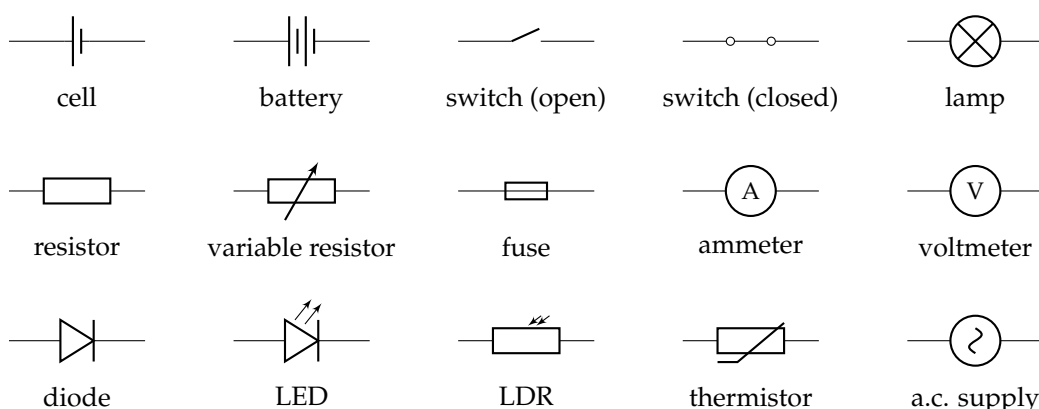
$$V = IR = 3 \times 4 = 12\text{ V}. \quad I = \frac{V}{R} = \frac{10}{4} = 2.5\text{ A}.$$

Common mistakes

- Using joules per second for voltage. Voltage is joules per *coulomb*.
- Thinking potential difference “flows”. Current flows; a p.d. exists *across* a component.
- Calling a component with a large current “high resistance”. It is the opposite: $R = V/I$.

4 Components and current–voltage graphs

A current–voltage graph (an I – V graph, with I on the vertical axis) shows how a component behaves. Careful: the resistance at a point is V/I for that point, which is *not* the gradient unless the graph is a straight line through the origin. The gradient of an I – V graph is $\Delta I/\Delta V = 1/R$, so a steeper line means a *smaller* resistance.

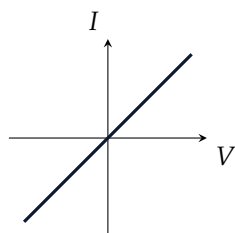


Fixed resistor. A straight line through the origin: $I \propto V$, constant resistance (the temperature stays about constant). The line has the same shape in the negative quadrant because the current simply reverses.

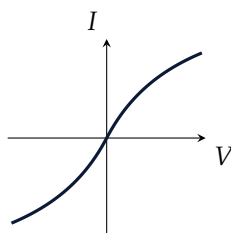
Filament lamp. The graph is a curve that flattens out at higher voltage. As the current rises the thin metal filament heats up (to well over a thousand degrees); the metal ions vibrate more, collide more often with the charge carriers, and the resistance rises. So V/I *increases* with V (the graph gets less steep).

Diode. A diode lets current flow in one direction only. In the forward direction almost no current flows until the voltage reaches about 0.6 V, after which the current rises very steeply (small resistance). In the reverse direction the current

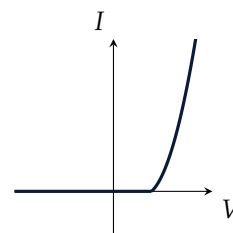
is essentially zero (very large resistance) until the diode breaks down at a large voltage. A light-emitting diode (LED) behaves in the same way and also gives out light; it needs a resistor in series to limit the current.



fixed resistor:
straight line

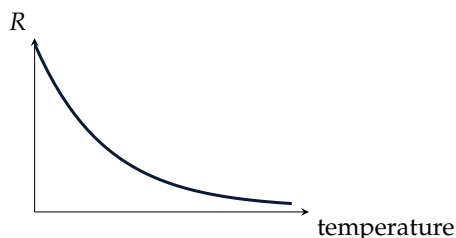


filament lamp:
curve flattens

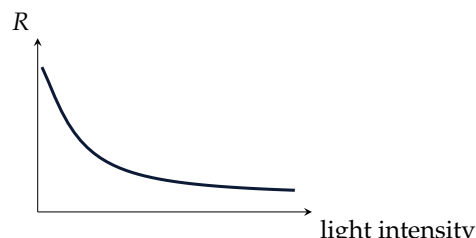


diode:
one-way

Thermistor (NTC) and LDR. In a negative-temperature-coefficient thermistor the resistance *falls* as the temperature rises, because heating frees more charge carriers. A light-dependent resistor (LDR) has a resistance that is large in the dark and falls as the light intensity increases (light also frees charge carriers). They make good sensors: a thermistor for a thermostat or fire alarm, an LDR for a light-operated switch.



thermistor (NTC):
 R falls as it gets hotter



LDR:
 R falls as light gets brighter

Worked example: reading a lamp graph

A filament lamp has a current of 0.50 A at 2 V and 1.0 A at 6 V. Find its resistance at each voltage and comment.

At 2 V: $R = \frac{2}{0.50} = 4 \Omega$. At 6 V: $R = \frac{6}{1.0} = 6 \Omega$. The voltage tripled but the current only doubled, so the resistance increased: the filament is hotter at the higher voltage.

Worked example: a diode in a circuit

An ideal diode (zero resistance forward, infinite resistance in reverse) is connected in series with a 3Ω resistor and a 6 V cell. What is the current when the diode is (a) forward-biased and (b) reversed?

(a) The diode acts like a wire, so $I = 6/3 = 2$ A. (b) No current can pass: $I = 0$ A and the whole 6 V appears across the diode. (A real silicon diode would drop about 0.6 V in the forward direction.)

Common mistakes

- Using the gradient of a curved I - V graph as the resistance, or forgetting that the gradient is $1/R$ for a straight line. Always use V/I at the point.
- Mixing up which graph axis is which: if V is on the vertical axis a steeper line means a *larger* resistance.
- Saying a thermistor's resistance rises with temperature (that is the metal wire; the NTC thermistor is the opposite).

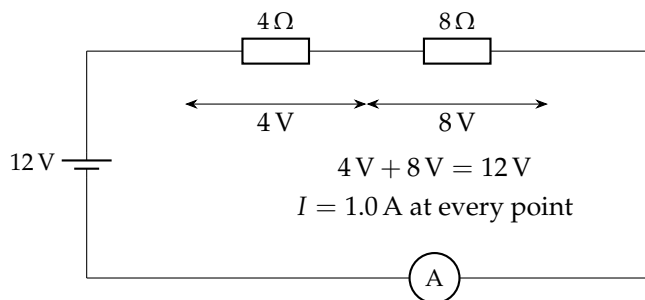
5 Series circuits

In a **series** circuit the components are in a single loop, one after another, with no branches. We can *derive* what two resistors R_1 and R_2 in series are equivalent to.

Because there is only one path, the **same current** I flows through both. The potential differences add up to the e.m.f.: $V = V_1 + V_2$. Using $V = IR$ for each,

$$IR_{\text{total}} = IR_1 + IR_2 \Rightarrow R_{\text{total}} = R_1 + R_2.$$

The I cancels because it is the same in each term. So resistances in series simply add, and the total is always bigger than the largest one.



Sharing the voltage. Since $V = IR$ with the same I , the voltage across each resistor is proportional to its resistance: the biggest resistor takes the biggest share. In the diagram $4\Omega : 8\Omega = 1 : 2$ and the voltages are $4\text{ V} : 8\text{ V}$. If one component in a series loop breaks, the loop is broken and the current stops everywhere.

Worked example: three resistors in series

A 12 V cell is connected to resistors of 2Ω , 4Ω and 6Ω in series. Find the current and the p.d. across the 4Ω resistor.

$R_{\text{total}} = 2 + 4 + 6 = 12\Omega$, so $I = \frac{12}{12} = 1\text{ A}$. The 4Ω resistor has $V = IR = 1 \times 4 = 4\text{ V}$. (Check: the voltages are $2 + 4 + 6 = 12$.)

Worked example: a lamp and a resistor in series

A lamp designed to work at 6 V and 0.5 A is run from a 9 V supply. What series resistor is needed?

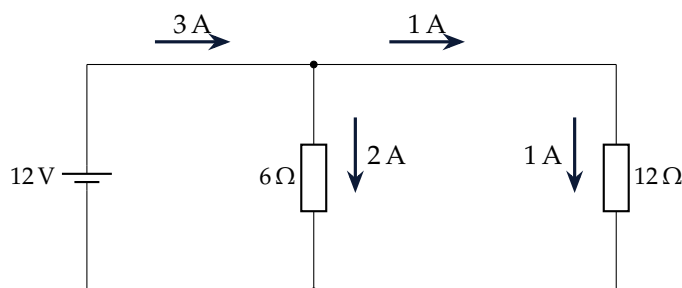
The lamp must have 6 V across it, so the resistor takes the remaining 3 V with the same 0.5 A through it: $R = \frac{3}{0.5} = 6\Omega$.

Common mistakes

- Giving each series resistor the full supply voltage. They *share* it.
- Adding currents in series. The current is the *same*; the voltages add.
- Forgetting that adding a resistor in series increases the total resistance and so reduces the current.

6 Parallel circuits

In a **parallel** circuit the components are on separate branches between the same two points. Each branch is connected directly across the supply, so **the potential difference across every branch is the same**. At the junction charge is conserved, so the branch currents add up to the main current: $I = I_1 + I_2$.



both branches have 12 V across them; the currents add: $2 + 1 = 3\text{ A}$

Deriving the formula. Take two branches R_1 and R_2 across a supply V . The current in each branch is $I_1 = V/R_1$ and $I_2 = V/R_2$. The total current is

$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2}.$$

If one resistor R_{total} replaces the pair, it draws $I = V/R_{\text{total}}$. Equating and cancelling V gives

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2}.$$

Two special cases save time: for *two* resistors $R_{\text{total}} = \frac{R_1 R_2}{R_1 + R_2}$ ("product over sum"), and for *n* identical resistors R the total is R/n .

What this means. The total resistance of resistors in parallel is always *less than the smallest one*: each extra branch gives the charge another route, so adding a branch *reduces* the total resistance and *increases* the current drawn from the cell. That is why the lights in a house are wired in parallel: each has the full mains voltage, and switching one off does not affect the others. Unlike a series loop, the current is shared in *inverse* proportion to the resistance: in the figure the $6\ \Omega$ branch carries twice the current of the $12\ \Omega$ branch.

Worked example: two resistors in parallel

Find the total resistance of $6\ \Omega$ and $12\ \Omega$ in parallel, and the current from a $12\ \text{V}$ cell.

$R = \frac{6 \times 12}{6 + 12} = \frac{72}{18} = 4\ \Omega$ (less than $6\ \Omega$, as it must be). $I = \frac{12}{4} = 3\ \text{A}$. Check by branches: $12/6 = 2$ and $12/12 = 1$, and $2 + 1 = 3$.

Worked example: a mixed network

A $12\ \text{V}$ cell is connected to a $2\ \Omega$ resistor in series with a parallel pair of $6\ \Omega$ and $3\ \Omega$. Find the cell current and the current in the $6\ \Omega$ resistor.

Parallel pair: $\frac{6 \times 3}{6 + 3} = 2\ \Omega$. Total = $2 + 2 = 4\ \Omega$, so the cell current is $12/4 = 3\ \text{A}$. The voltage across the $2\ \Omega$ resistor is $3 \times 2 = 6\ \text{V}$, so the pair has $12 - 6 = 6\ \text{V}$ across it, and the $6\ \Omega$ resistor carries $6/6 = 1\ \text{A}$ (the $3\ \Omega$ carries $2\ \text{A}$; $1 + 2 = 3$).

Exam tip

For a network, *reduce* it in stages from the inside outwards (parallel pairs first, then add the series parts), find the cell current, then work *back out* using $V = IR$ branch by branch, checking that currents add at junctions.

Common mistakes

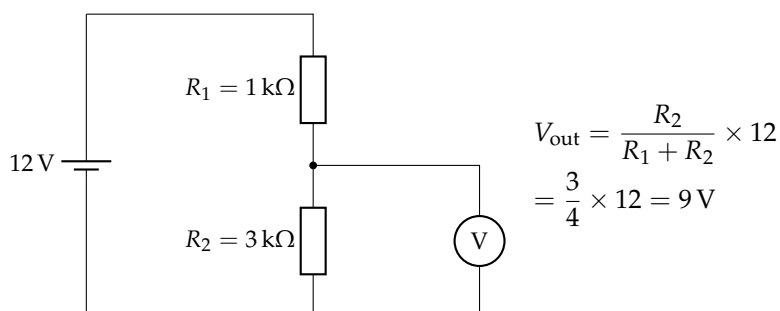
- Adding parallel resistors like series ones. The total must be smaller than the smallest.
- Forgetting the last step: $\frac{1}{R_1} + \frac{1}{R_2}$ gives $\frac{1}{R}$, so flip it.
- Thinking the branch with the biggest resistance carries the biggest current. It carries the *smallest*.
- Believing that removing a lamp in a parallel circuit makes the others dimmer. Each has the same voltage as before.

7 Potential dividers and sensors

Two resistors in series share the supply voltage in proportion to their resistances. This is called a **potential divider**. The same current $I = V/(R_1 + R_2)$ flows through both, so the voltage across R_2 is

$$V_{\text{out}} = IR_2 = \frac{R_2}{R_1 + R_2} V.$$

Check with the figure: $\frac{3}{1+3} \times 12 = 9\ \text{V}$ and R_1 gets the other $3\ \text{V}$.



Sensors. Replace one resistor with a thermistor or an LDR. The output voltage then changes with temperature or light level, and can switch on a heater, a lamp or an alarm. The rule is the one you already know: *the share of the voltage across a component rises when its resistance rises*. If the output voltmeter is across the LDR, a brighter room lowers its resistance, so it takes a smaller share and the output voltage *falls*; if the voltmeter is across the fixed resistor instead, its reading *rises*. In both cases the total resistance falls, so the current increases.

Worked example: a light sensor

A 6 V cell is connected in series with a fixed 2 k Ω resistor and an LDR. A voltmeter is connected across the LDR. In the dark the LDR has resistance 10 k Ω ; in bright light it falls to 2 k Ω . Find the voltmeter reading in each case.

Dark: $V = \frac{10}{2+10} \times 6 = 5 \text{ V}$. Bright: $V = \frac{2}{2+2} \times 6 = 3 \text{ V}$. The reading falls as the light increases, and the fixed resistor's voltage rises from 1 V to 3 V.

Common mistakes

- Taking $V_{\text{out}} = \frac{R_1}{R_1 + R_2} V$ for the voltage across R_2 . The numerator is the resistance of the part you are measuring across.
- Forgetting that a voltmeter must be assumed ideal (very high resistance), otherwise it changes the divider.
- Forgetting that the current changes too when a sensor's resistance changes.

8 Electrical power and energy

Power is the rate of energy transfer, $P = E/t$, measured in watts (1 W = 1 J/s). We can find an electrical formula by combining definitions we already have. The energy transferred when charge Q passes through a p.d. V is $E = QV$, and $Q = It$, so

$$E = VIt \quad \text{and} \quad P = \frac{E}{t} = VI.$$

Now use $V = IR$ to eliminate one quantity:

$$P = VI = I^2 R = \frac{V^2}{R}.$$

All three are the same quantity; choose the form that uses the numbers you have. Use $I^2 R$ when the same current flows (series), and V^2/R when the same voltage is across the components (parallel). Because power appears with I^2 and V^2 , doubling the current through a fixed resistor makes the power *four* times bigger, and so does doubling the voltage across it.

Energy and units. For a device of power P running for time t , $E = Pt$ (in joules with P in watts and t in seconds; electricity bills use kilowatt-hours, where 1 kW · h = 3.6×10^6 J). A useful check: VIt has units V A s = (J/C)(C/s)s = J, and $I^2 R$ has units $\text{A}^2 \Omega = \text{A}^2 \text{ V/A} = \text{V A} = \text{W}$. Whenever you are unsure of a formula, check that its units come out right.

Worked example: a heater

A heater is marked 12 V, 36 W. Find its current and resistance, and the energy it transfers in 5 minutes.

$I = \frac{P}{V} = \frac{36}{12} = 3 \text{ A}$. $R = \frac{V}{I} = 4 \Omega$. Check: $I^2 R = 9 \times 4 = 36 \text{ W}$ and $V^2/R = 144/4 = 36 \text{ W}$. Energy = $Pt = 36 \times 300 = 10\,800 \text{ J}$.

Worked example: scaling a power

A resistor dissipates 20 W when connected to a certain cell. The same resistor is connected to a cell of *three* times the voltage. What is the new power?

$P = V^2/R$ with R fixed, so $P \propto V^2$ and the power is $3^2 = 9$ times as big: 180 W. (No need to know the actual values of V or R .)

Worked example: series or parallel: which is brighter?

Two lamps, one of 3 Ω and one of 12 Ω , are connected *in series* to a 15 V supply. Which dissipates more power?

$I = \frac{15}{3+12} = 1 \text{ A}$ through both. $P = I^2 R$ gives 3 W and 12 W. In series the larger resistance gets the larger power. (In parallel it would be the reverse, since then $P = V^2/R$ with the same V .)

Worked example: power lost in a cable

A cable of resistance $2\ \Omega$ carries a current of $10\ \text{A}$. What power is wasted as heat? What if the same power is delivered at 10 times the voltage (so one tenth of the current)?

$P = I^2 R = 100 \times 2 = 200\ \text{W}$. With $1\ \text{A}$: $1 \times 2 = 2\ \text{W}$. A tenth of the current gives a hundredth of the loss. This is the idea behind high-voltage power lines, which you will meet again in the Magnetism lesson.

Problem-solving checklist. (1) Draw the circuit and mark every given value. (2) Decide what is the *same* (current in series, voltage in parallel). (3) Reduce resistances stepwise. (4) Use $V = IR$ and the power formulae with the quantities you know. (5) Check units and ask whether the answer is plausible: series totals are bigger than any single resistor, parallel totals are smaller, and currents add at junctions.

Exam tip

Estimation helps. A kettle is about $2\ \text{kW}$, so on $230\ \text{V}$ it draws roughly $2000/230 \approx 9\ \text{A}$. A phone battery holds about $40\ \text{kJ}$. A lightning flash carries about $20\ \text{C}$ through tens of millions of volts, so around $10^9\ \text{J}$. Quick sanity checks like these catch order-of-magnitude slips.

Common mistakes

- Using $P = VI$ with the wrong V (the supply voltage rather than the voltage across the component).
- Using $P = V^2/R$ for components in series with different voltages across them, or $I^2 R$ across parallel branches without finding each current first.
- Forgetting to convert minutes or kilowatts to seconds and watts before using $E = Pt$.

Check yourself

Try these without looking back, then compare with the answers on the next page.

1. A polythene rod becomes negatively charged when rubbed with a cloth. What has moved, and what charge does the cloth have?
2. A current of $3\ \text{A}$ flows for $20\ \text{s}$. How much charge is that?
3. A $9\ \text{V}$ battery transfers $135\ \text{J}$ to a lamp. How much charge passed through?
4. A lamp has $6\ \text{V}$ across it and $0.3\ \text{A}$ through it. Find its resistance and power.
5. Find the total resistance of $12\ \Omega$ and $4\ \Omega$ (a) in series and (b) in parallel.
6. A $12\ \text{V}$ cell is connected across $6\ \Omega$ and $3\ \Omega$ in parallel. Find the current from the cell.
7. A $10\ \text{V}$ supply is connected to $2\ \text{k}\Omega$ and $3\ \text{k}\Omega$ resistors in series. What is the voltage across the $3\ \text{k}\Omega$ resistor?
8. A resistor dissipates $8\ \text{W}$. The current through it is doubled. What is the new power?

Answers to the self-check

1. Electrons moved from the cloth to the rod. The cloth is positively charged, with the same size of charge.
2. $Q = It = 3 \times 20 = 60 \text{ C}$.
3. $Q = E/V = 135/9 = 15 \text{ C}$.
4. $R = 6/0.3 = 20 \Omega$; $P = VI = 6 \times 0.3 = 1.8 \text{ W}$.
5. (a) 16Ω . (b) $\frac{12 \times 4}{16} = 3 \Omega$.
6. Currents: $12/6 = 2$ and $12/3 = 4$. Total 6 A (equivalent resistance 2Ω , $12/2 = 6$).
7. $\frac{3}{5} \times 10 = 6 \text{ V}$.
8. $P \propto I^2$, so $4 \times 8 = 32 \text{ W}$.

Next step

Heurisco's *ESAT Physics: Electricity Practice Set* has twenty original exam-style questions on this lesson, with circuit diagrams and graphs, in order of difficulty, with a full worked solution for each.