Basic Electrics

Study notes from the Day 1 webinars: the morning course intro and basic electrics, and the afternoon session on circuits, magnetism, transformers, the grid and three-phase. Diagrams are redrawn from the whiteboard, and worked examples use the same numbers as the sessions.

AM Short intro and basic electrics

01 The course and what you need

The route through the course, in order:

1. Attend 14 days of online theory training (webinars).
2. Complete the homework on your portal.
3. Book your exams at your chosen centre, then take them.
4. Once **all** exams are passed, book practical training (weekend or midweek).
5. Attend 10 days of practical training.
6. Book and attend 4 days of final practical assessment.

Theory training covers

- Basic electrics
- Domestic electrical installations
- The wiring regulations
- In-service inspection and testing of electrical equipment
- Initial verification
- Condition reporting
- Circuit design

Practical training covers

- Basic circuit installation
- Cable terminations
- Consumer unit wiring
- In-service inspection and testing
- Initial verification of single and 3-phase installations
- Condition reporting
- Fault finding

Qualifications you receive: Building Regulations (L3) · BS 7671 (L3) · In-service Inspection and Testing of Electrical Equipment (L3) · Fundamental Inspection and Testing (L3) · Initial Verification (L3) · Condition Reporting, periodic inspection and testing (L3).

What they let you do: join a local electrical firm (usually as a trainee at first, because you lack experience), work for yourself, or join an agency and work as a subcontractor. You can work domestically, commercially and industrially.

YOU WILL NEED	NOTES
BS 7671	The wiring regulations
On-Site Guide	
Electrician's Guide to the Building Regulations	
Code of Practice for In-service Inspection and Testing of Electrical Equipment	5th edition
Guidance Note 3	Inspection and testing
Scientific calculator	Casio fx-85GT is recommended
Book marking labels	Tab your books so you can find regulations fast

Exam rules mentioned in the session (check the latest with your course advisor)

- Pass mark is about **65% in every section**. A high score in one section can't make up for a low one in another.
- Portal homework needs **90%**.
- Results can take up to **7 working days**. Resits cost about £50 each.
- Five exams: Building Regs, BS 7671 (18th Edition), Fundamental Inspection & Testing, Initial Verification, Periodic (condition reporting).
- Open book: Building Regs guide, BS 7671 and the in-service inspection code of practice. Guidance Note 3 is expected for the testing exams. Fundamental I&T is believed to be closed book.
- In the books you **can highlight, underline and add tabs**. You **can't write notes** or leave sticky notes with writing on them. Your name on the cover is fine.
- Bring a **non-programmable scientific calculator**. Phones aren't allowed, and taking one out gets you disqualified.
- There's no formula sheet, so learn your formulas by heart.

BUYING BOOKS

Make sure you have the **current editions**: the orange BS 7671 and On-Site Guide, and the green-and-orange Electrician's Guide to the Building Regulations. The brown versions are older amendments. Official IET books have a silver hologram sticker, so a suspiciously cheap copy may be fake or missing pages. A set of tabs makes finding regulations much faster.

HOW TO PASS

Watch each webinar live, ask questions during it, then watch the recording again (recordings go up within about 24 hours). Watch the masterclasses and practical demos, do the mock exams, and learn your way around the books. Use the Tuesday evening Q&A, email your tutor if you're stuck, and study with other students. Sharing notes is encouraged. *"The only people who fail are those who gave up."*

Timetable: webinars run 9–12 and 1–4. Practical training is 10 days, either two weeks Monday to Friday or five weekends. You can't book practical training until all your exams are passed.

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02 Voltage

The session opened with a question: **what three things make up an electrical circuit?** The answer is **voltage, current and resistance**.

Voltage is the electrical **pressure** that pushes electricity around a circuit. It is measured in **volts, V**.

Symbols	`V` in general formulas. `U` is how voltage is written in electrical books like BS 7671.
U_0	The **UK nominal voltage, 230 V** (line to earth).
U	The line-to-line voltage, **400 V** (three-phase).
EMF	**Electromotive force**, the voltage a source produces (battery, generator, transformer winding). Still measured in volts, and written `E` in formulas. Don't think of it as a force in newtons. It's the push that drives electricity round the circuit.
Potential difference	The **difference in voltage between 2 points**. For example, 230 V on the line and 0 V on the neutral gives a PD of 230 V.

WATERFALL ANALOGY

Water at the top of a waterfall has a high potential, and the pool at the bottom a low one. The water only flows because there's a difference and a path between them. Another way to picture it is two cups, one at 230 V and one at 0 V: pour between them and there's a 230 V potential difference. If both cups are at the same level there's no difference, so nothing flows.

Key point: current can only flow when there is a **potential difference**.

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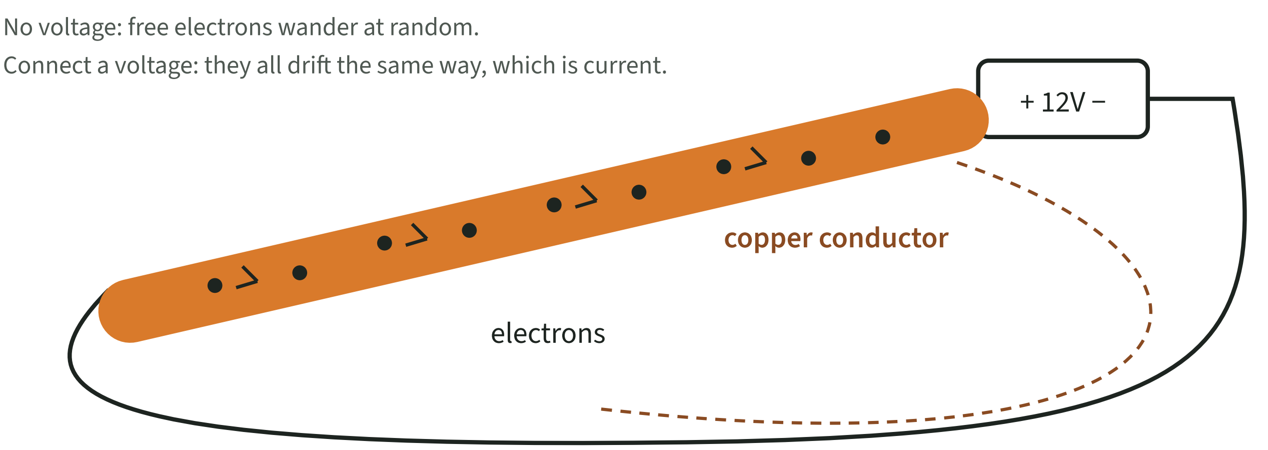
03 Current

Current is the **flow of electrons** through a conductor. It is measured in **amperes (amps), A**. The symbol in formulas is `I`, from the old word "intensity". You'll see I everywhere, for example I_n for a device's rating, `Ib` for design current, and `IΔn` on RCDs and RCBOs.



With no voltage, the electrons in copper just sit there vibrating. Connect a 12 V battery and they're all pushed the same way round the loop, like F1 cars off the start line. A circuit must be a complete loop for current to flow.

Conventional current	Drawn flowing **positive → negative**. This is the direction everyone assumes on drawings.
Electron flow	What the electrons actually do: **negative → positive**.
DC	Electrons flow in **one direction only**. Batteries are always DC.
AC	Electrons flow **backwards and forwards**. UK mains is AC.

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04 Resistance and impedance

Resistance	**Opposition to current flow.** Measured in **ohms, Ω**. Symbol `R`.
Impedance	Opposition to current in an **AC** circuit only (never DC). Symbol `Z`, also in ohms. It accounts for loads, such as the inductor in a fluorescent fitting, that shift current and voltage out of step. You'll meet **Ze** and **Zs** in fault loop impedance testing, and **R** when testing continuity.

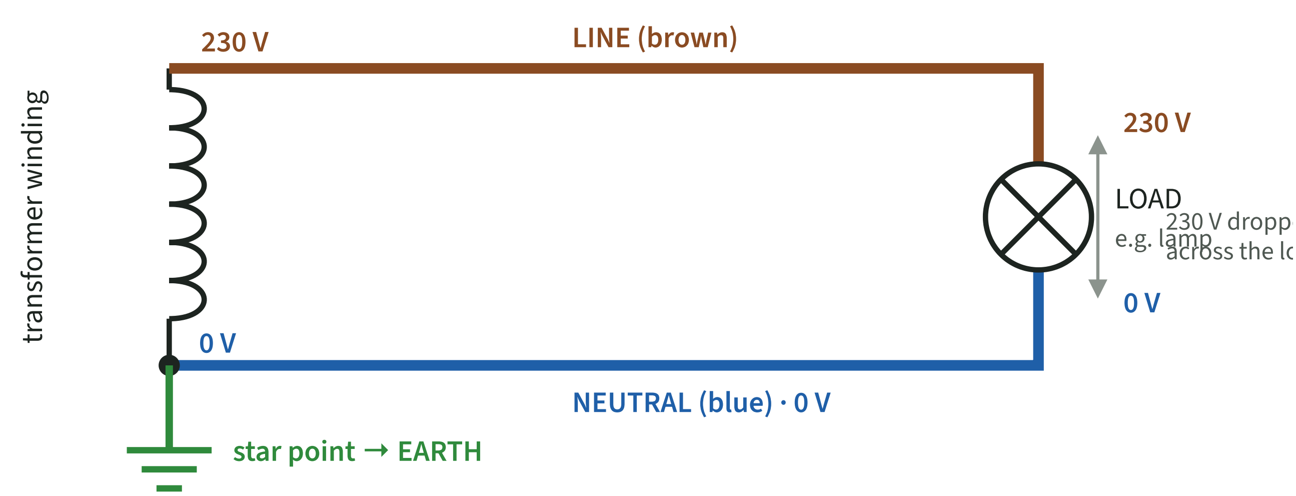
Think of rocks in a stream: the water can't flow straight and fast, so it slows down. Every conductor has resistance, and so do cables, loads and your body. **Increase resistance and current goes down**, as long as the voltage stays the same.

BEST CONDUCTORS	WHY IT MATTERS
1. Silver	Lowest resistance, but far too expensive to use in cable
2. Copper	Second best and cheap, so it's what cables use. Aluminium is also used, for example in concentric supply cables.
3. Gold	Doesn't tarnish, so it's used to plate contacts

- **Low resistance is good** in neutrals and earth conductors (CPCs). If there's a fault, enough current has to flow to trip the protective device quickly.
- Your body has resistance too, and it's **much lower when wet**, for example straight out of the shower. That's why wet skin is so dangerous.
- A protective device (breaker or fuse) is there to **protect the cable** from carrying too much current. More current means more heat.

05 The basic supply circuit

This diagram came up throughout both sessions. It shows where your 230 V actually comes from.



One end of the supply transformer's winding is the **star point**, which is connected to **earth** and held at 0 V. The other end is at 230 V. The line (brown) carries 230 V to the load, and the neutral (blue) returns at 0 V. The full 230 V is dropped across the load.

- The **star point** is where the neutral and earth join at the transformer. From there it goes down into the ground. The electricity doesn't disappear: it's a continuous loop.

- The coil in this drawing is the transformer's **secondary** winding. The secondary side is always **star**.
- A **circle with an X** is the symbol for a lamp. Lamps are **resistive loads**.
- The symbol with three horizontal lines is **earth (ground)**.
- It's called **line** (it used to be called phase), not "live". Both the line and the neutral are live conductors, and you can get a shock from either.

> **Cable colours (current UK harmonised):** Line = brown · Neutral = blue · Earth (CPC) = green/yellow · on 3-phase: L1 brown, L2 black, L3 grey.

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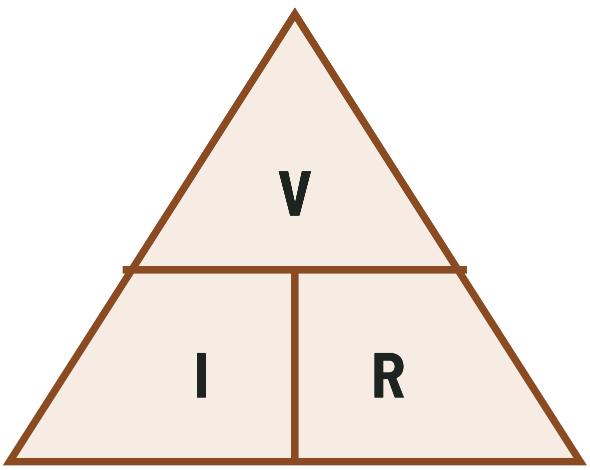
06 Ohm's law



Cover the one you want. A line across means divide, side by side means multiply.

THE THREE FORMS

```
V = I × R     volts = amps × ohms
I = V ÷ R     amps  = volts ÷ ohms
R = V ÷ I     ohms  = volts ÷ amps
```

LEARN THE FORMULAS, NOT JUST THE TRIANGLE

There's no formula sheet in the exam. You can ask for blank paper, but it stays in the room. Write the three formulas out until you know them by heart.

EXAMPLE 1: FIND THE CURRENT

```
Supply 230 V, lamp resistance 6 Ω
I = V ÷ R = 230 ÷ 6 = 38.33 A
```

EXAMPLE 2: FIND THE RESISTANCE

```
Supply 230 V, current measured 12 A
R = V ÷ I = 230 ÷ 12 = 19.17 Ω
```

CASIO FX-85GT TIP

If 230 ÷ 6 comes up as a fraction (115/3), press the `S⇔D` button to switch it to a decimal. On other calculators, look for a FORMAT or decimal setting. Get used to *your own* calculator, because that's the one you'll take into the exam.

A 6 A lighting circuit doesn't mean the lights draw 6 A. They might only draw 2.5 A. The 6 A breaker is sized to **protect the cable**.

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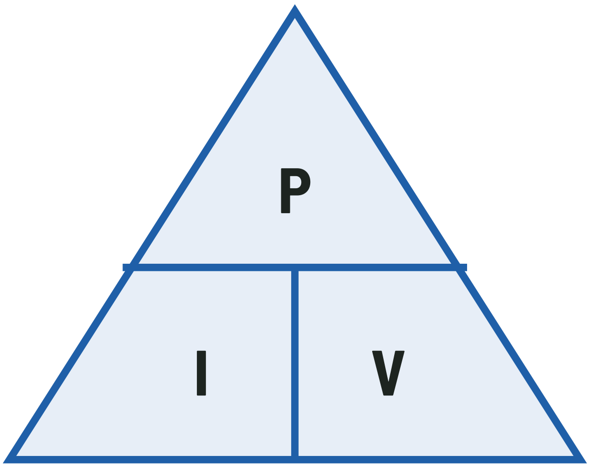
07 The power triangle

Power is the rate at which energy is used. It is measured in **watts, W**, and **1 kW = 1000 W**.



P = watts · I = amps · V = volts

THE THREE FORMS

```
P = I × V      watts = amps × volts
I = P ÷ V      amps  = watts ÷ volts
V = P ÷ I      volts = watts ÷ amps
```

EXAMPLE 1: CURRENT DRAWN BY A 20 W LAMP

```
I = P ÷ V = 20 ÷ 230 = 0.087 A
  → round to 2 decimal places: 0.09 A  (≈ 87 mA)
```

EXAMPLE 2: POWER OF A LOAD DRAWING 16.92 A

```
P = I × V = 16.92 × 230 = 3891.6 W
                         = 3.892 kW
```

- Power is used by the **loads**, not by the cables. To get total power, add up every load. Three 20 W downlights = 60 W.
- Work to **2 decimal places**. If you round, round properly (0.087 → 0.09). Otherwise use the full number.

Which triangle? Read what the question gives you.
Given volts and ohms or amps, or asked for **resistance** → **Ohm's law** (V, I, R).
Given **watts**, or asked for power → **power triangle** (P, I, V).

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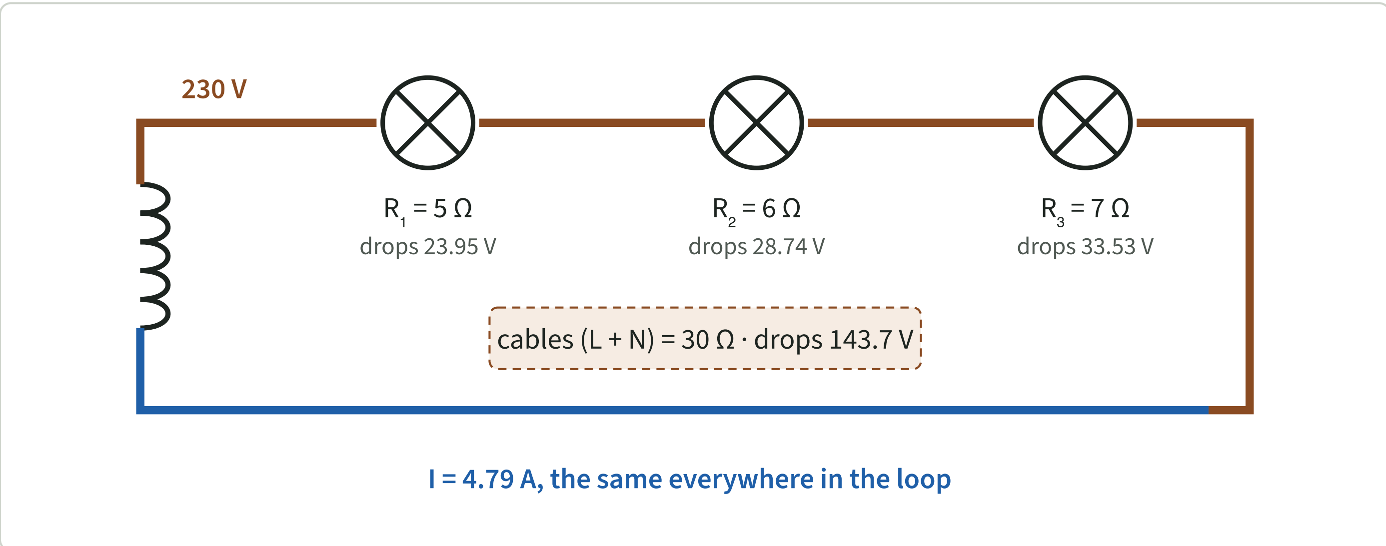
08 Series circuits

In a series circuit the loads are connected **one after another in a single path**. There's only one route for the current. Fairy lights and old Christmas tree lights are the classic example: when one bulb goes, they all go out.

Electricians don't wire circuits in series. It isn't efficient, one fault kills everything, and if the loads are different they don't all get the same voltage, so they aren't all equally bright.



WORKED EXAMPLE FROM THE SESSION

```
Given: 230 V supply · cables (line + neutral) = 30 Ω
       lamps = 5 Ω, 6 Ω, 7 Ω

1) Total resistance (add everything, cables included)
   Rt = 30 + 5 + 6 + 7 = 48 Ω

2) Total current (Ohm's law)
   I = V ÷ Rt = 230 ÷ 48 = 4.79 A

3) Voltage dropped across each part (V = I × R)
   Lamp 1:  4.79 × 5  =  23.95 V
   Lamp 2:  4.79 × 6  =  28.74 V
   Lamp 3:  4.79 × 7  =  33.53 V   → lamps total 86.22 V
   Cables:  4.79 × 30 = 143.70 V

   Check: 86.22 + 143.70 = 229.92 ≈ 230 V ✓  (Kirchhoff's voltage law)
```

PICTURE THE VOLTAGE BEING USED UP

230 V arrives at the first lamp. Suppose it's 10 Ω with 4 A flowing: it uses 4 × 10 = 40 V, leaving 190 V for the rest. A 20 Ω lamp next would use 80 V. Each load takes its share, and the shares always add back up to the supply. If they don't, there's a fault somewhere.

Series rules

Current is **constant**: the same everywhere.

Voltage is **dropped across each load**, and the drops add up to the supply voltage.

$R_t = R_1 + R_2 + R_3 \ldots$ $V_t = V_1 + V_2 + V_3 \ldots$

Rt = total resistance · Vt = total (supply) voltage

PM Basic electrics (continued)

09 Series recap: three 12 Ω lamps

The afternoon opened with a practice question using this method: **1.** find total resistance → **2.** find total current → **3.** calculate the voltage dropped across each lamp.

THREE 12 Ω LAMPS IN SERIES ON 230 V

```
Rt = 12 + 12 + 12 = 36 Ω
I  = V ÷ Rt = 230 ÷ 36 = 6.38 A
V per lamp = I × R = 6.38 × 12 = 76.66 V
Check: 76.66 × 3 ≈ 230 V ✓
```

When all the loads are the same, you can shortcut: 230 ÷ 3 = 76.67 V each. When they're different, you can't, and you have to do V = I × R for each one.

The tutor put a cross on one lamp. Because there's only one path, **a break anywhere, even after the last lamp, stops current to every lamp.** That's the big weakness of series wiring, and it's why the circuits in a building are wired in parallel.

> **REAL SUPPLIES AREN'T EXACTLY 230 V**
> The UK supply is allowed to vary by **+10% / −6%**, so you'll never measure exactly 230 V (or 400 V) at a property. Answers that come out at 229.8 V are fine. That's just rounding.

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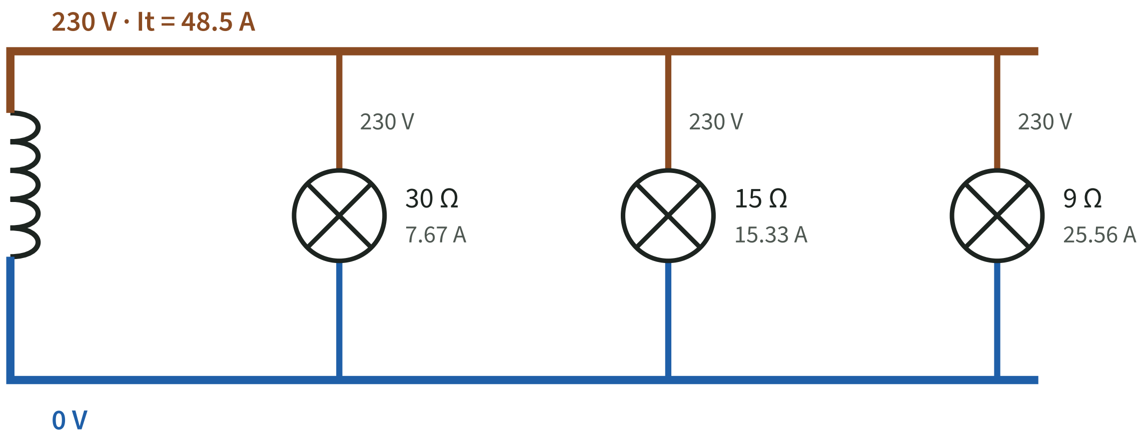
10 Parallel circuits

Each load gets its own connection **directly across line and neutral**, so each one sees the full 230 V. **This is how electricians wire circuits** in buildings.

Open circuit	There's a break in the path, so there's no potential difference and **no current flows**.
Closed circuit	The path is complete, so current can flow.

In parallel, if the cable to one lamp breaks, the other lamps still have their own path to line and neutral, so **they stay on**. A blown bulb in the bedroom doesn't put out every light in the house.



Every branch has the full 230 V across it. The current splits between the branches, and the lowest resistance takes the most current.

Parallel rules

Voltage is **constant**: every load gets the full supply voltage.

Current **divides** between the branches, and the branch currents add up to the total.

$1/R_t = 1/R_1 + 1/R_2 + 1/R_3 \ldots$

Total resistance is **always lower than the lowest resistor**. Use that to check your answer.

WORKED EXAMPLE: 30 Ω, 15 Ω AND 9 Ω IN PARALLEL ON 230 V

```
1) Total resistance
   1/Rt = 1/30 + 1/15 + 1/9
        = 0.0333 + 0.0667 + 0.1111 = 0.2111
   Rt   = 1 ÷ 0.2111 = 4.74 Ω     (lower than 9 Ω ✓)

2) Total current (Ohm's law)
   It = V ÷ Rt = 230 ÷ 4.74 = 48.52 A

3) Branch currents (Kirchhoff's current law check)
   I₁ = 230 ÷ 30 =  7.67 A
   I₂ = 230 ÷ 15 = 15.33 A
   I₃ = 230 ÷ 9  = 25.56 A
   Total ≈ 48.5 A ✓
```

MORE PRACTICE FROM THE SESSION

```
20 Ω, 10 Ω, 121 Ω:
   1/Rt = 0.05 + 0.1 + 0.0083 = 0.1583 → Rt = 6.32 Ω

7 Ω, 11 Ω, 36 Ω:
   1/Rt = 0.1429 + 0.0909 + 0.0278 = 0.2615 → Rt = 3.82 Ω

25 Ω, 42 Ω, 21 Ω  (try it yourself first)
   1/Rt = 0.04 + 0.0238 + 0.0476 = 0.1114 → Rt = 8.97 Ω
```

CALCULATOR METHOD (FX-85GT)

The `x⁻¹` key means "1 over". Type `30 x⁻¹ + 15 x⁻¹ + 9 x⁻¹ =`. If it shows a fraction, press `S⇔D` to get 0.2111. **That's 1/Rt, not your answer.** Press `x⁻¹ =` again to flip it: **4.74 Ω**. Forgetting that last flip is the most common mistake. Keep the full numbers in the calculator until the end, because rounding halfway through gives you answers that are slightly off.

WHY "1 OVER"? THE BATH ANALOGY

There's **one** bath (the whole circuit). A series circuit is like a single plug hole with more plugs stacked under it, so the water drains slowly. A parallel circuit is like a plug with **several holes**, so the water has lots of paths out at once. More paths means more flow, which means less total resistance.

ONLY TWO RESISTORS? You can use product over sum: $Rt = (R_1 \times R_2) \div (R_1 + R_2)$. With three or more, use the 1/Rt formula. That's the one the awarding body expects.

A **voltmeter** is always connected **across** a load, in parallel with it, because voltage is constant in parallel.

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11 Power ratings and 4 A per kW

Working out current from an appliance's power rating is how you **size protective devices and cables** in domestic installations.

HOW MUCH CURRENT DOES A 10,000 W COOKER DRAW ON 230 V?

```
I = P ÷ V = 10,000 ÷ 230 = 43.48 A
```

> **Rule of thumb:** at 230 V, **1 kW ≈ 4 A** (1000 ÷ 230 = 4.35 A). A 3 kW immersion heater draws about 12–13 A, and a 10 kW cooker about 43 A. It's a good starting point when you work out cable and protective device sizes.

Later in the course this feeds into choosing a cable's **CSA** (cross-sectional area). That depends on the current, but also on the cable's length and how it's installed.

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12 Number systems and prefixes

PREFIX	SYMBOL	MULTIPLIER	MEANS	EXAMPLE
Tera	T	$\times 10^{12}$	trillion	
Giga	G	$\times 10^{9}$	thousand million	1 GW = 1,000,000,000 W
Mega	M	$\times 10^{6}$	million	1 MΩ = 1,000,000 Ω
Kilo	k	$\times 10^{3}$	thousand	2 kW = 2000 W
base unit: V, A, Ω, W				
milli	m	$\times 10^{-3}$	thousandth	30 mA = 0.030 A
micro	μ	$\times 10^{-6}$	millionth	1 μA = 0.000001 A
nano	n	$\times 10^{-9}$	thousand-millionth	
pico	p	$\times 10^{-12}$	trillionth	

This is **engineering notation**: electricians work in **powers of 3**, so each step is **×1000**. Moving to a **bigger** prefix makes the number smaller, and moving to a **smaller** prefix makes it bigger.

- **Positive power** (10^{6}): the zeros go *before* the decimal point, so it's a big number. **Negative power** (10^{-6}): the zeros go *after* the decimal point, so it's a tiny number.
- **Capital M = mega** (million) and **small m = milli** (thousandth). Mixing them up is a big mistake.
- You'll see **MΩ** when insulation resistance testing, and **Ω** when continuity testing.

CONVERSIONS FROM THE SLIDES

8.4 kW	in watts	→ 8400 W	
100 mA	in amps	→ 0.1 A	
0.03 A	in milliamps	→ 30 mA	
0.5 MΩ	in kilo-ohms	→ 500 kΩ	
80 mA	in amps	→ 0.08 A	$(= 80 \times 10^{-3})$

CALCULATOR

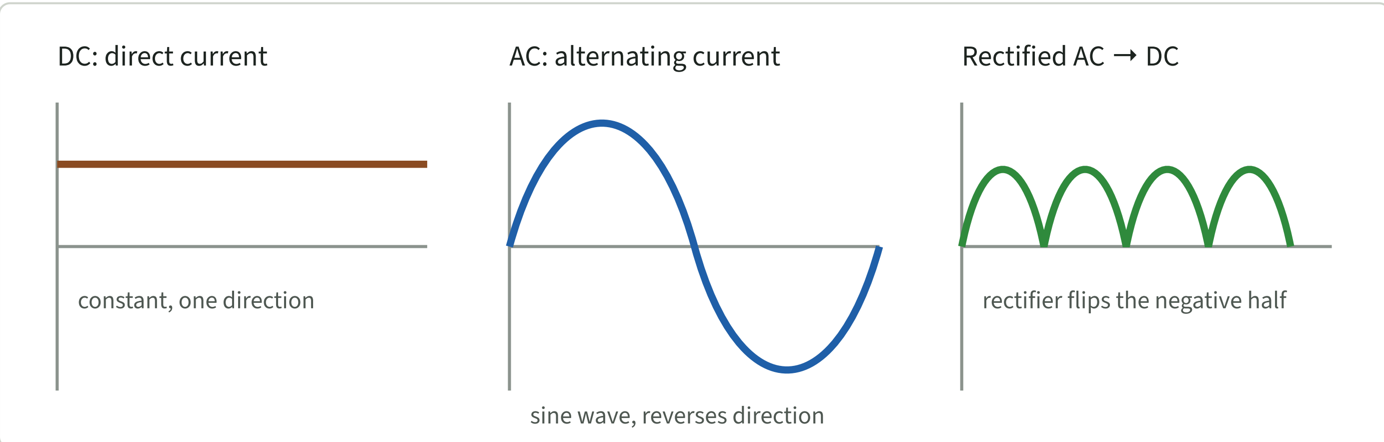
Use the $\times 10^{x}$ key. For 80 mA, type `80` $\times 10^{x}$ `-3`. Also, 30 mA is the trip rating of an RCD, so you'll see that number a lot.

13 Conductors and insulators

- A voltage is put **across** a circuit or load. Current flows **through** it.
- A **conductor** is any material that allows current to flow through it. Good conductors (copper, aluminium, most metals) have **low resistance**.
- An **insulator** is any material that doesn't allow current to flow. Good insulators (plastics, rubber, wood, glass) have **very high resistance**.

A cable uses both: copper conductors to carry current, and PVC insulation and sheath to keep it where it should be.

14 DC and AC



Direct current (DC) flows in **one direction** at a steady level. The three most common sources:

1. a battery of cells
2. a DC generator
3. electronics, using a **rectifier**, which converts AC to DC

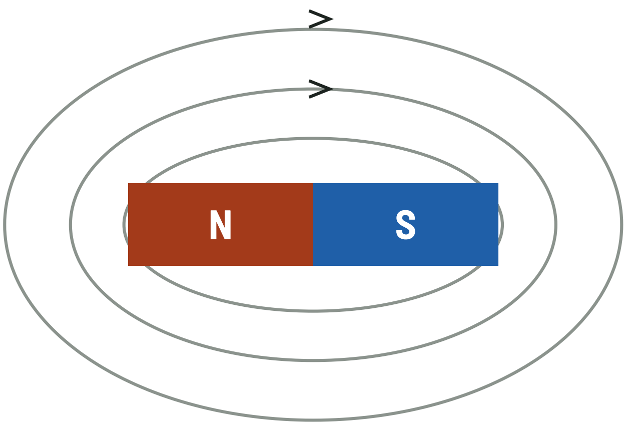
A battery produces pure DC as long as it has energy left in it.

Alternating current (AC) constantly reverses direction, following a sine wave. The UK mains is AC at **50 Hz**, which is 50 complete cycles a second. AC is what the grid generates and what transformers need.

Rectifier	Converts **AC → DC**. Your phone charger has a small **bridge rectifier** inside the plug to charge the DC battery from AC mains.
Inverter	Converts **DC → AC**. Solar panels produce DC, and an inverter turns it into AC for the home.

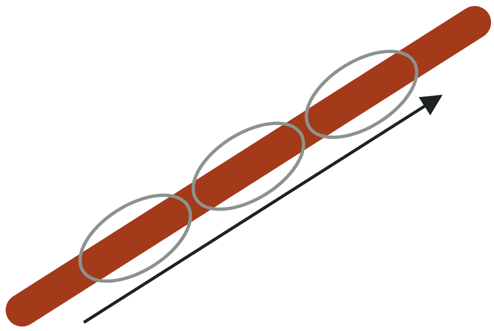
If DC isn't fully smoothed you get a **rectified** waveform: humps that stay on one side of zero, because the current never reverses.

15 Magnetism and induction



flux leaves N, enters S (outside the magnet)

Current-carrying conductor


field is circular, all along the conductor

- **Like poles repel, unlike poles attract.** With two N poles together the flux lines push outwards away from each other. With N and S together the flux lines run straight between them, and they attract.
- The lines of **magnetic flux** run from the North pole round the outside into the South pole.
- **Flux density** is the amount of flux in a given area. Lines close together mean a strong field, and lines far apart mean a weak one.
- **When a conductor carries a current, a magnetic field forms around it.** The field is circular and runs the whole length of the conductor. It goes clockwise or anticlockwise depending on the **direction of the current**. Motors and

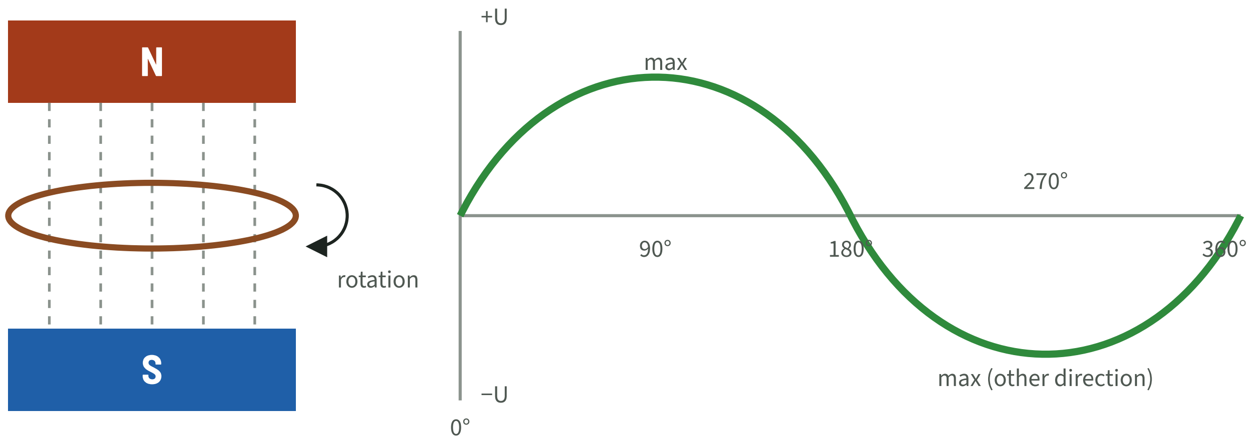
transformers both rely on this.

- Flux lines are invisible. Sprinkle iron filings over a magnet (Faraday's school-physics experiment) and you can see their shape.

Electromagnetism is how UK electricity is made: in a power station, a coil rotates inside magnetic fields, generating at about **25,000 V**.

Magnetic induction: how a generator makes AC

Magnetic induction is one of the main sources of EMF. A loop of wire is **mechanically rotated** between the N and S poles of a magnet. As it cuts the lines of flux, a voltage is induced, which is the electrical output.



The coil starts where no flux is being cut, at 0 V. It rises to a maximum at 90° as it cuts the most flux, back to zero at 180°, to a maximum in the other direction at 270°, and back to zero at 360°. One full turn gives one complete sine wave.

- One full turn gives **one cycle**. At 50 Hz the loop turns **50 times a second**, giving 50 cycles and **100 peaks** (one each way per cycle).
- That's why lights sometimes flicker when you look at them through a phone camera. The camera is catching the 50 Hz cycle.
- The peaks at 90° and 270° are current going one way, then back the other way. It isn't "positive then negative electricity".

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16 Transformers and impedance

A transformer converts an **alternating voltage at one level to an alternating voltage at a higher or lower level** (step up or step down). It uses **mutual induction**. A continually changing flux in the primary winding induces a voltage in the secondary winding. That's why a transformer **only works on AC**: DC doesn't produce a changing flux.

The tutor's example: 50 windings on the primary at 110 V and 25 windings on the secondary gives 55 V. Half the turns means half the voltage, which is a step-down transformer.

TURNS RATIO

$$V_1 / V_2 = N_1 / N_2$$

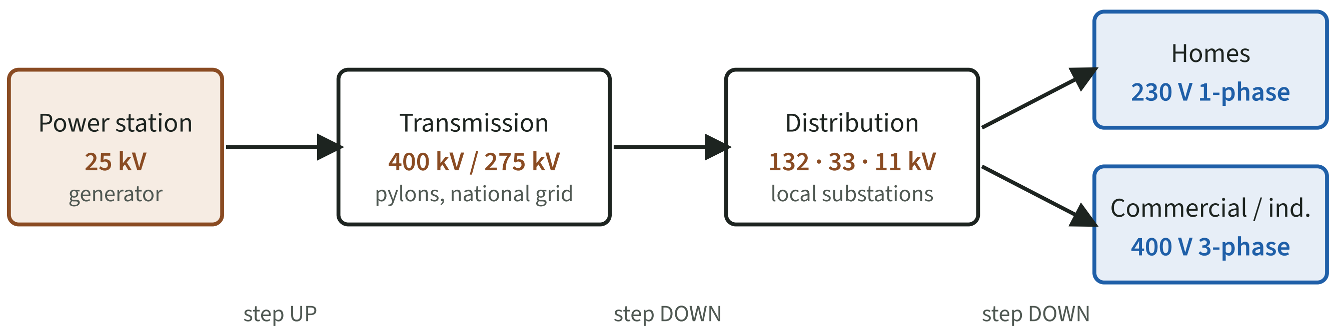
$$110 / V_2 = 50 / 25 \quad \rightarrow \quad V_2 = 55\ V$$

- **Fewer turns on the secondary means step down, and more turns means step up.** You can tell which one a transformer is by comparing the windings.
- On drawings, the **primary** is usually on the **left** and the **secondary** on the **right**.
- The two coils **never touch**. The voltage is induced across through the magnetic field in the core.
- The core is **laminated** (thin lacquered layers) to reduce losses.

Types you'll see: step-up, step-down and **isolating** transformers. An isolating transformer separates you from earth, so there's no path through your body to earth. A bathroom **shaver socket** has one inside. You'll also see pole-mounted three-phase transformers, current transformers (CTs), potential transformers, and the big fenced-off "Danger, high voltage" substations near housing estates.

> **Impedance (Z)** is resistance in an **AC** circuit (in DC it's just called resistance). It's still opposition to current and still measured in ohms. It comes from the resistance of the conductors *plus* the effect of inductance in the supply transformers. You can swap Z in for R in Ohm's law.
> `Ze` = **external** impedance: the transformer and supply cable up to your property.
> `Zs` = **total** earth fault loop impedance: Ze *plus* the resistance of the circuit you installed. You'll test this later in the course.

17 Generation, transmission and distribution



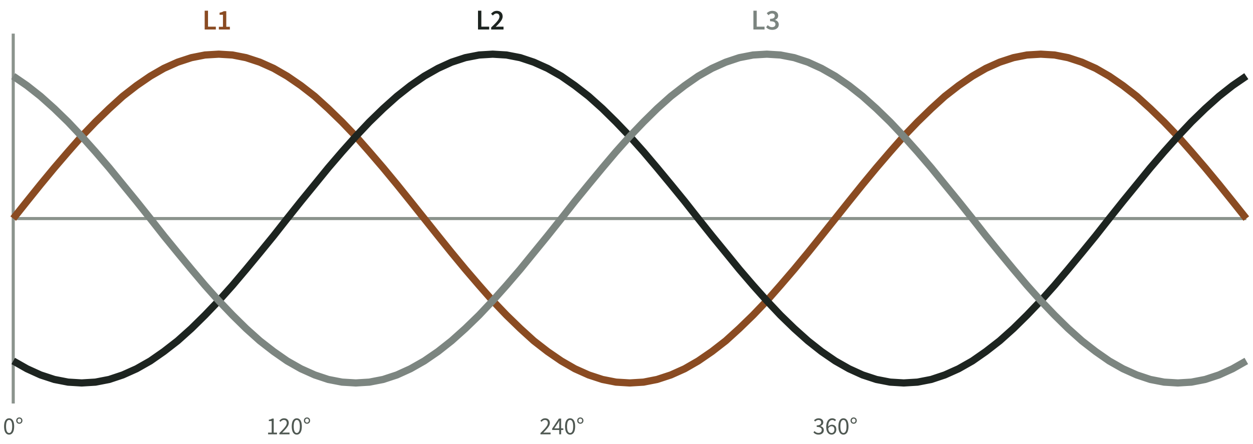
1. **Generate:** fossil fuels or nuclear energy make steam, which drives a turbine and generator at about **25 kV**. Solar and hydro are other sources.
2. **Step up** to **400 kV** (275 kV is also used) to transmit across the country, say from Cornwall to Birmingham. A higher voltage means lower current for the same power, so thinner cables and smaller losses.
3. **Regional transformers** step down to **132 kV**, then local ones to **33 kV or 11 kV**. This is distribution. A big factory might take 11 kV directly.
4. **Step down again** for streets: **230 V** for domestic, and **400 V** for commercial and industrial properties (shops, schools, factories).

LEARN THESE	VOLTAGE
Generation voltage	25 kV
Transmission voltage	400 kV (also 275 kV)
Distribution voltages	132 kV · 33 kV · 11 kV
Supply to buildings	400 V 3-phase · 230 V single-phase

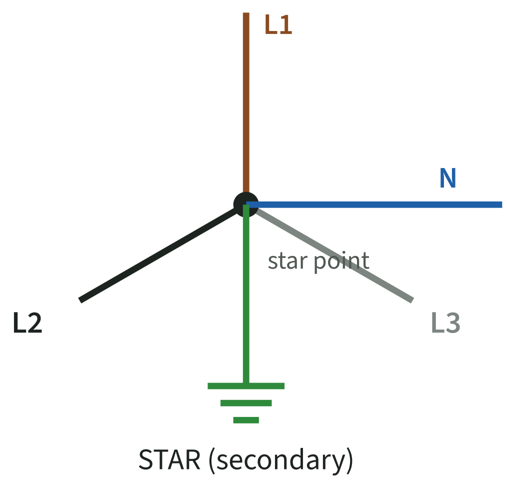
Most houses have a **60, 80 or 100 A** main fuse. Transformers only work on AC.

18 Three-phase supply, star and delta

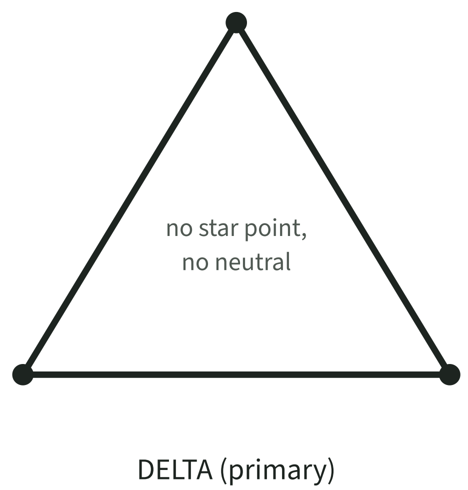
A generator has **three sets of windings**, each creating an EMF set **120° apart**. So a three-phase supply is effectively three supplies all rising and falling at different times.



L1 (brown), L2 (black) and L3 (grey) each peak 120° after the one before.



Star: 4 wires (3 lines + neutral). Line to neutral = **230 V**, line to line = **400 V**.



Delta: 3 wires. The distribution transformer's primary is delta and its secondary is star, which gives you a neutral.

- The star system produces **230 V and 400 V**. 230 V × $\sqrt{3}$ (1.732) ≈ 400 V.
- **Single-phase** houses on a street are each connected to one line plus neutral, spread across L1, L2 and L3 to keep the load balanced. Any line to neutral = 230 V.
- **Three-phase** commercial and industrial supplies use all three lines. Any line to line = 400 V.
- The phases are 120° apart because 360° ÷ 3 = 120°.
- **Why 400 V and not 460 V (230 + 230)?** Two phases never reach their peaks at the same moment. They cross before either one peaks, so the difference between them tops out at 400 V, not double. (415 V is the old figure and no longer used.)
- **Delta** (the primary side) is balanced, with the same current on every line, so it has no neutral and only gives 400 V.

- **Star** (the secondary side) has a neutral. Houses put different loads on each phase, so the phases become **unbalanced**, and the neutral carries that out-of-balance current back.
- Two-phase supplies (two lines plus neutral) exist but are rare, only for very large properties.

19 Kirchhoff's laws

Kirchhoff's voltage law (series)

The voltage across all the loads must **add up to the supply voltage**.

$V_t = V_1 + V_2 + V_3$

Kirchhoff's current law (parallel)

The currents through the loads must **add up to the total current**.

$I_t = I_1 + I_2 + I_3$

20 Formula sheet and self-test

QUANTITY	SYMBOL	UNIT	FORMULAS
Voltage	V, U, U_0	volt (V)	$V = I \times R$ · $V = P \div I$
Current	I	amp (A)	$I = V \div R$ · $I = P \div V$
Resistance	R (Z for AC)	ohm (Ω)	$R = V \div I$
Power	P	watt (W)	$P = I \times V$
Series			$R_t = R_1+R_2+R_3$ · I same · V splits
Parallel			$1/R_t = 1/R_1+1/R_2+1/R_3$ · V same · I splits
Transformer			$V_1/V_2 = N_1/N_2$
Rule of thumb			230 V: 1 kW ≈ 4 A

Test yourself. Answers are under each question.

▼ **A 3 kW heater on 230 V: what current does it draw?**

$I = P \div V = 3000 \div 230 = 13.04$ A

▼ **Four 10 Ω lamps in series on 230 V: total resistance, current, and voltage per lamp?**

$R_t = 40\ \Omega$ · $I = 230 \div 40 = 5.75$ A · V per lamp $= 5.75 \times 10 = 57.5$ V

▼ **10 Ω and 40 Ω in parallel: total resistance?**

$1/R_t = 0.1 + 0.025 = 0.125 \rightarrow R_t = 8\ \Omega$ (lower than 10 Ω ✓)

▼ **Express 0.25 MΩ in kΩ, and 45 mA in amps.**

`250 kΩ · 0.045 A`

▼ **Why do transformers only work on AC?**

```
They need a continually changing magnetic flux in the primary to
induce a voltage in the secondary. DC gives a steady flux, so
nothing is induced.
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▼ **What is the voltage between two lines of a UK three-phase supply, and between a line and neutral?**

`400 V line to line · 230 V line to neutral`

▼ **In a series circuit, what stays the same? And in parallel?**

`Series: current is constant · Parallel: voltage is constant`