

Circuit rules, power and mains safety

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: In a series circuit the current is the same everywhere and the voltages add up to the supply; in a parallel circuit every branch has the full supply voltage and the branch currents add up. Electrical power is the energy transferred per second, $P = I V$, which is also $I^2 R$, measured in watts.

Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** GCSE P2, HS-PS3-3

What are the rules for a series circuit?

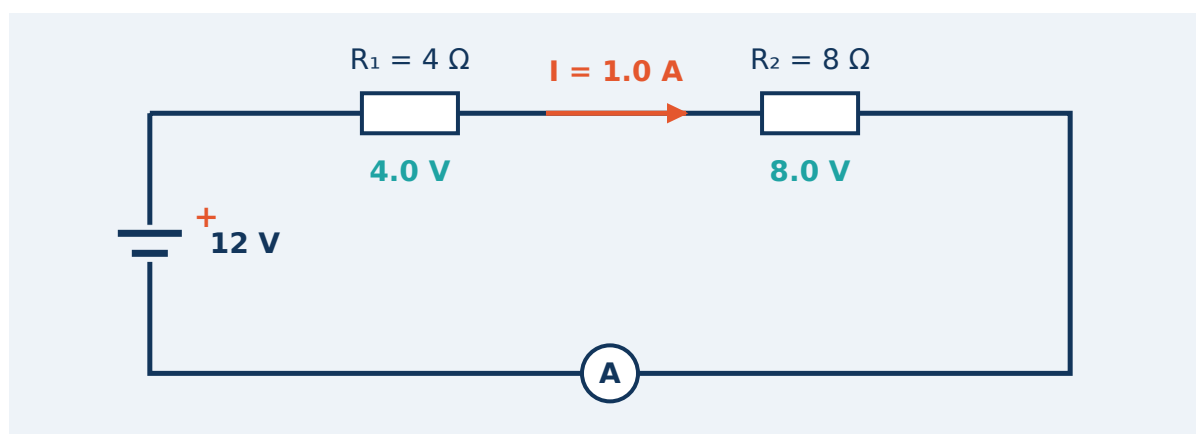
In a **series circuit** the components are joined one after another in a single loop. The charge has only one route, so the same current passes through every component, and a break anywhere stops the whole circuit.

Key law: series

Current: I is the same everywhere.

Voltage: the supply voltage is shared, $V = V_1 + V_2 + \dots$

Resistance: $R = R_1 + R_2 + \dots$



Series circuit: one loop, the same current 1.0 A everywhere, and $4.0 \text{ V} + 8.0 \text{ V} = 12 \text{ V}$.

The figure shows how it works. Together the resistors give $4 \Omega + 8 \Omega = 12 \Omega$, so a 12 V cell drives $I = V \div R = 12 \div 12 = 1.0 \text{ A}$. Each resistor takes a share of the voltage in proportion to its resistance, which is why the larger resistor gets 8.0 V.

What changes in a parallel circuit?

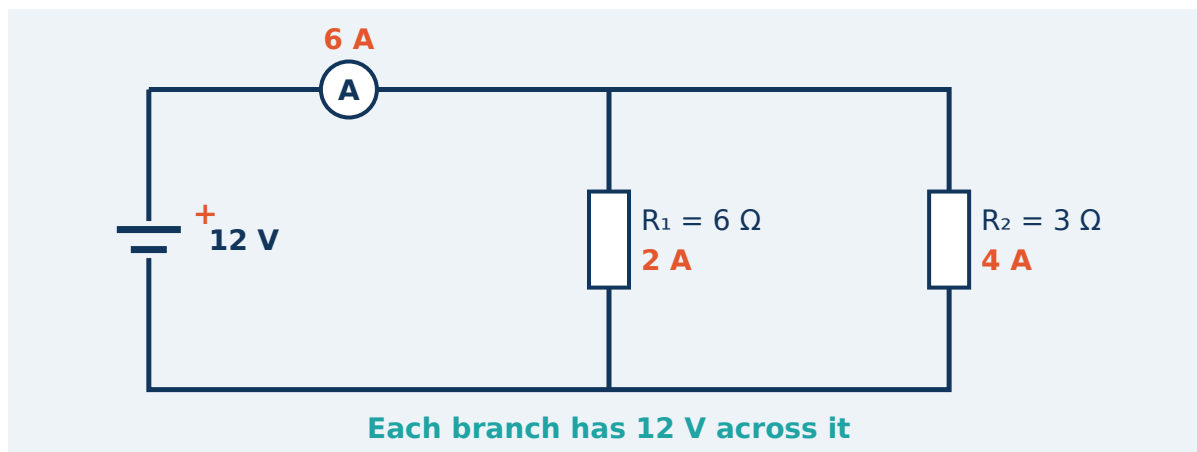
In a **parallel circuit** the components sit on separate branches joined at two points. Each branch is connected straight across the supply, so each one gets the full supply voltage, and the current splits at the junction.

Key law: parallel

Voltage: the same across every branch, $V = V_1 = V_2$.

Current: the branch currents add up, $I = I_1 + I_2 + \dots$

Resistance: $1/R = 1/R_1 + 1/R_2 + \dots$, so the total is smaller than the smallest branch.



Parallel circuit: both branches have 12 V, the branch currents 2 A + 4 A add up to 6 A.

Adding a branch gives the current one more route, so the total resistance falls and the supply delivers more current. That is why plugging too many appliances into one socket is dangerous.

Quantity	Series	Parallel
Current	same everywhere	splits between branches
Voltage	shared out	same across each branch
Total resistance	bigger than any one resistor	smaller than any one resistor
One lamp fails	all go out	the others stay on

How do you calculate electrical power?

Electrical power tells you how quickly a device transfers energy. A 60 W lamp transfers 60 joules every second.

Definition

Power is the energy transferred per second. One watt (W) is one joule per second.

Formula

$P = I V$ and, using $V = I R$, $P = I^2 R = V^2 / R$

$E = P t$

P is power in watts (W), I is current in amperes (A), V is potential difference in volts (V), R is resistance in ohms (Ω), E is energy in joules (J), t is time in seconds (s).

Worked example 1: series

The 4 Ω and 8 Ω resistors above carry 1.0 A. Find the power in each.

$$P_1 = I^2 R = 1.0^2 \times 4 = 4.0 \text{ W. } P_2 = 1.0^2 \times 8 = 8.0 \text{ W.}$$

Check: total $P = 12 \text{ V} \times 1.0 \text{ A} = 12 \text{ W} = 4.0 \text{ W} + 8.0 \text{ W}$. **Total power 12 W.**

Worked example 2: parallel

A 6Ω and a 3Ω resistor are joined in parallel across 12 V . Find the total resistance and the total current.

$$1/R = 1/6 + 1/3 = 1/6 + 2/6 = 3/6 = 1/2, \text{ so } R = 2 \Omega.$$

$I_1 = 12 \div 6 = 2 \text{ A}$ and $I_2 = 12 \div 3 = 4 \text{ A}$. **Total current 6 A**, which also equals $12 \div 2$.

Worked example 3: energy and cost

A 2.0 kW heater runs on 230 V for 4 hours. Electricity costs 30 p per kWh.

$$I = P \div V = 2000 \div 230 = 8.7 \text{ A, so a } 13 \text{ A fuse is suitable.}$$

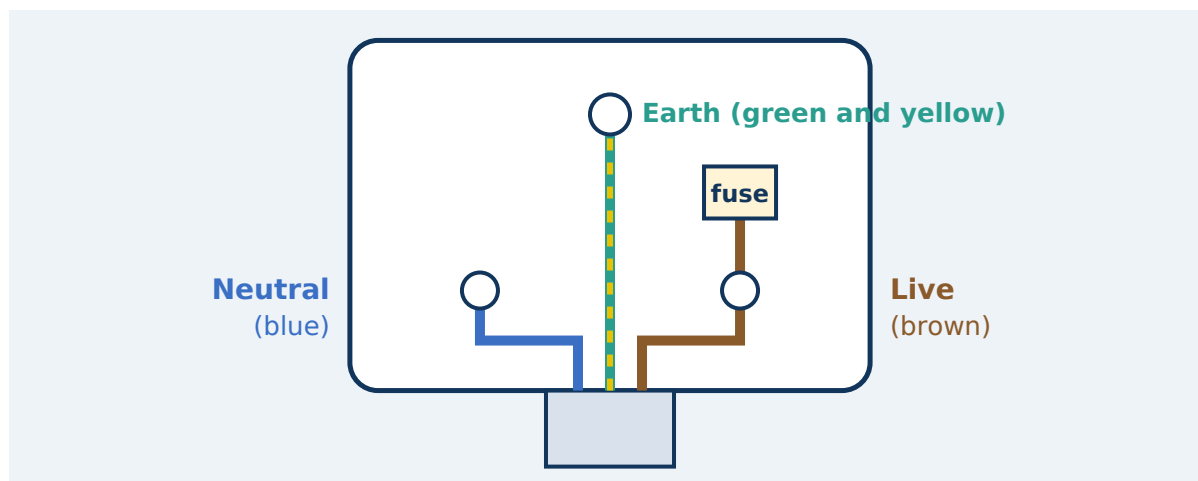
$$E = 2.0 \text{ kW} \times 4 \text{ h} = 8.0 \text{ kWh. Cost} = 8.0 \times 30 \text{ p} = \mathbf{240 \text{ p} = \pounds 2.40}.$$

Common mistake

Do not add resistances in parallel as $5 \Omega + 20 \Omega = 25 \Omega$. The total must be smaller than 5Ω : $1/R = 1/5 + 1/20 = 1/4$, so $R = 4 \Omega$. Also remember that a kilowatt-hour is a unit of energy, not of power.

How is mains electricity made safe?

Mains voltage is dangerous: about 230 V in the UK, India and much of Africa, and 120 V in the USA. A three-core cable carries three wires. The **live** wire (brown) brings the alternating voltage, the **neutral** wire (blue) completes the circuit, and the **earth** wire (green and yellow) connects the metal case to the ground.



Wiring inside a three-pin mains plug: the fuse sits in the live wire, the earth wire connects to the metal parts.

If a loose live wire touches a metal case, a large current flows down the earth wire, the fuse melts and the appliance is cut off before anyone is shocked. A fuse is chosen just above the normal current: for 8.7 A choose 13 A , for 3.3 A choose 5 A . A residual current device (RCD) adds protection by switching off within milliseconds if the live and neutral currents differ. Fuses and switches always go in the live wire so that a switched-off appliance has no live parts.

Lina's tip

Pick the formula by what you know: current and voltage give $P = I V$, current and resistance give $P = I^2 R$, voltage and resistance give $P = V^2/R$. Write the one you choose before you substitute.

Key points to remember

- Series: same current, voltages add, $R = R_1 + R_2$.
- Parallel: same voltage, currents add, $1/R = 1/R_1 + 1/R_2$ (total is smaller).
- Power $P = I V = I^2 R = V^2/R$, in watts ($1 \text{ W} = 1 \text{ J/s}$).
- Energy $E = P t$; $1 \text{ kWh} = 3.6 \text{ MJ}$.
- Fuse and switch go in the live wire; the earth wire protects metal cases.

Circuit rules, power and mains safety: frequently asked questions

Why are home lights wired in parallel?

Each lamp then gets the full mains voltage and can be switched on and off independently. If one bulb fails the others keep working, which would not happen in series.

How do you choose the right fuse for an appliance?

Divide the power by the mains voltage to find the normal current, then choose the next standard fuse above it. For a 920 W appliance on 230 V, $I = 4.0 \text{ A}$, so a 5 A fuse is chosen.

What is the difference between power and energy?

Power is how fast energy is transferred and is measured in watts. Energy is the total transferred, $E = P t$, measured in joules or kilowatt-hours.

Why does adding a parallel branch lower the total resistance?

A new branch gives the charge an extra route, so more current flows for the same voltage. Since $R = V \div I$, a larger total current means a smaller total resistance.

Is the mains voltage the same in every country?

No. Most countries use 220 V to 240 V at 50 Hz, while the USA and Canada use 120 V at 60 Hz. The rules for series, parallel and power are identical everywhere.