D.C. circuits

Circuit symbols, e.m.f. against p.d., internal resistance, Kirchhoff's laws, resistors in series and parallel, potential dividers, potentiometers, galvanometers and null methods, and sensors using LDRs and thermistors.

10.1 Practical circuits

You must know the circuit symbols in the specification: cell, battery, switch, resistor, variable resistor, thermistor, LDR, lamp, diode, ammeter, voltmeter, galvanometer, potentiometer, capacitor, fuse, and so on, and be able to draw and read circuit diagrams with them.

E.m.f. and p.d.

The **electromotive force (e.m.f.)** of a source is the energy transferred per unit charge in driving charge around a complete circuit.

	Energy change	Where
E.m.f.	other forms (such as chemical) to electrical	in the source
P.d.	electrical to other forms (such as heat)	in a component

Internal resistance

Real sources have **internal resistance** r. Current through it wastes some energy inside the source, so the terminal p.d. V falls below the e.m.f.:

$$E = I(R + r) = V + Ir$$

Ir is sometimes called the "lost volts". The terminal p.d. falls as the current rises.

A graph of V against I is a straight line with **y-intercept** E and **gradient** $-r$.

TRY IT

A cell of e.m.f. 1.5 V and internal resistance 0.50 Ω is connected to a 2.5 Ω resistor. Find the terminal p.d. $I = 1.5/(2.5 + 0.50) = 0.50$ A. $V = IR = 1.25$ V, and the lost volts are 0.25 V.

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10.2 Kirchhoff's laws

The two laws

- **First law:** the sum of the currents into a junction equals the sum of the currents out. This is a consequence of **conservation of charge**.
- **Second law:** around any closed loop, the sum of the e.m.f.s equals the sum of the p.d.s. This is a consequence of **conservation of energy**.

Resistors in series and parallel

In series the current is the same through each resistor, and the second law gives $V = V_1 + V_2 = IR_1 + IR_2$, so:

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

In parallel the p.d. is the same across each, and the first law gives $I = I_1 + I_2 = V/R_1 + V/R_2$, so:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

The total resistance in parallel is always less than the smallest resistor.

Solving circuits with Kirchhoff's laws

1. Label a current in each branch with an assumed direction. A negative answer simply means that it flows the other way.
2. Apply the first law at junctions.
3. Apply the second law around loops. Going round a loop, a cell counts positive if you pass in the direction of its e.m.f., and IR counts positive if you travel with your assumed current.
4. Solve the simultaneous equations.

TRY IT

Two cells of e.m.f. 6.0 V and 2.0 V oppose each other in a single loop with total resistance 4.0 Ω. Find the current. Net e.m.f. $= 6.0 - 2.0 = 4.0$ V, so $I = 4.0/4.0 = 1.0$ A in the direction of the larger cell's e.m.f.

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10.3 Potential dividers

The potential divider

Two resistors in series across a supply share the p.d. in proportion to their resistances:

$$V_{\text{out}} = \frac{R_2}{R_1+R_2} V_{\text{in}}$$

where V_{out} is taken across R_2. Connecting a load across the output adds a parallel resistance, which lowers the output.

Sensors

Replace one resistor with a thermistor or LDR, and the output depends on temperature or light.

> **TRY IT**
>
> **A thermistor and a 2.0 kΩ resistor are in series across 6.0 V, with the output across the resistor. What happens when the temperature rises?** The thermistor's resistance falls, so the fixed resistor gets a larger share of the p.d., and V_{out} rises. Swap the positions and the output falls with temperature instead.

The potentiometer

A **potentiometer** is a long uniform wire with a steady p.d. across it, so the p.d. along it is proportional to the length. It compares two potential differences.

Connect a test cell through a **galvanometer** to a sliding contact. At one position, the **balance point**, the galvanometer reads zero, so the p.d. along that length of wire equals the e.m.f. of the test cell. This is a **null method**. Since no current flows through the test cell, there are no lost volts, so you measure its e.m.f. directly.

For two cells balanced at lengths L_1 and L_2:

$$\frac{E_1}{E_2} = \frac{L_1}{L_2}$$

> **NOTE**
>
> Exam tip: a galvanometer is very sensitive, so a null reading is more precise than reading a voltmeter. It also needs no calibration, because you are only looking for zero.

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