D.C. Circuits

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1. Electro-Motive Force and Potential Difference

If current is to flow around a circuit there must be an energy source in the circuit, e.g. a cell. This supplies energy to the charged particles in order to push them around the circuit. The *electro-motive force* (e.m.f.) of an energy source is the amount of energy it imparts per coulomb of charge; ie:

$$e.m.f. = \frac{\text{energy gained by charges}}{\text{charge}}$$

As the charges flow around the circuit shown they lose energy (to light the bulb). The equivalent of emf when energy is lost is potential difference (p.d.) which is the amount of energy lost per coulomg of charge; ie:

$$p.d. = \frac{\text{energy lost by charges}}{\text{charge}}$$

Potential difference is measured using a voltmeter which is connected in parallel with the circuit. These typically have a very high resistance so as not to affect the reading by making the circuit behave like a potential divider.

2. Electric Current

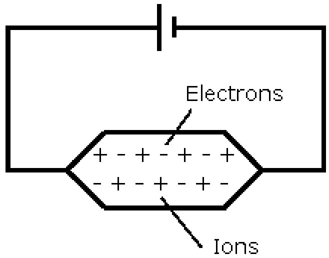


Figure 1 A typical metal. The atoms bind tightly together

- The electrons flow from negative to positive. Conventional current flows in the opposite direction.
- Metals are good conductors because they have a lot of free electrons which break free from their atoms. This leaves the atom ionised (or charged). The atom is called an ion.
- The overall charge of a metal conductor is zero because the charge on the ions and the charge on the electrons cancel each other out.
- In a metal, conduction electrons are free to move around the *fixed* positive ions. The ions are positive because they have positive protons and no electrons to cancel out the charge.

3. Current and Charge

When charges particles flow past a point (in this case, electrons), we say that a current is flowing.

- Electric current is measured in *Amperes* (A). An ampere is a coulomb per second.
- Charge is measured in coulombs. If a current of 1A flows past a point for one second, a charge of 1C has flowed:
- Current is measured by an ammeter which is connected in series with the circuit.

Definition

One coulomb is the amount of charge which flows past a point when a current of one ampere flows for one second.

Equation

$$Charge = Current \times Time$$

$$\Delta Q = I \times \Delta t$$

Exam questions

Question: A current of $10A$ flows through a lamp for 1 hour. How much charge flows through the lamp in this time?

Answer: We need to find the time interval Δt in seconds:

$$\Delta t = 60 \times 60$$
$$\therefore \Delta t = 3600s$$

So the charge which flows is:

$$\Delta Q = I \times \Delta t$$
$$\therefore \Delta Q = 10A \times 3600s$$
$$\therefore \Delta Q = 36000C$$

Question: What current flows if 180C of charge passes a point in a circuit in 2 minutes?

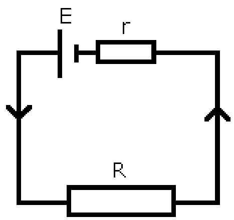
Answer: Rearranging $\Delta Q = I \times \Delta t$ gives:

$$I = \frac{\Delta Q}{\Delta t}$$
$$\therefore I = \frac{180C}{120s}$$
$$\therefore I = 1.5A$$

4. Internal Resistance

A power supply has its own internal resistance. This is due to the wires inside the power supply and in the case of a cell, work is done as the charge flows through the chemical electrolyte and electrodes. When a charge travels through an emf it gains a lot of energy, but it has also lost of what it gained.

The resistance within a source of emf is called the *internal resistance*.



Because R and r are in series, $R_{TOTAL} = R + r$ and I is the same throughout R and r.

$$E = I(R + r) \text{ or } E = IR + Ir$$

We can not measure E directly; a voltmeter can only be connected in parallel across the whole cell. A voltmeter will only measure the terminal p.d.

This will be less than the e.m.f. E by Ir, called the "lost volts":

$$V = E - Ir$$

Exam question

Question: A battery of e.m.f. $5V$ and internal resistance 2Ω is connected to an 8Ω resistor. Calculate the current that flows around the circuit.

Answer: We rearrange the equation $E = I(R + r)$:

$$I = \frac{E}{R + r}$$

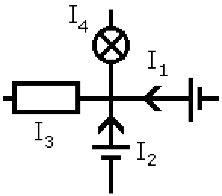
$$\therefore I = \frac{5V}{8\Omega + 2\Omega}$$

$$\therefore I = 0.5A$$

5. Kirchoff's First Law

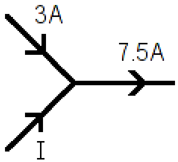
At a junction in a circuit there are some current flowing in and some flowing out. We would expect there to be some balance between the two as charge cannot build up at the junction. This idea of balance is made precise by Kirchoff's First Law, which states that at a junction:

$$\textit{Total Current In} = \textit{Total Current Out}$$



$$I_1 + I_2 = I_3 + I_4$$

Exam question



Question: Use Kirchoff's First Law to deduce the value of I.

Answer: We use the equation $I_1 + I_2 = I_3$:

In this case, $I + 3A = 7.5A$

$$\therefore I = 7.5A - 3A$$

$$\therefore I = 4.5A$$

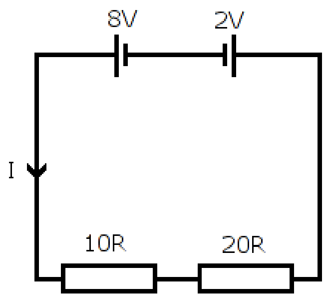
6. Kirchoff's Second Law

Kirchoff's second law states that the sum of the e.m.f.s around any loop in a circuit is equal to the sum of the p.d.s around the loop.

$$E = IR_1 + IR_2$$

Where E is the emf of the power supply and IR_1 and IR_2 are the sums of the p.d.s across the resistors.

Consider:



Calculation of current flowing in the circuit:

$$6V = 10I + 20I$$
$$\therefore 30I = 6V$$
$$\therefore I = 0.2A$$