CAIE Physics A-level

Topic 10: D.C. Circuits

Notes

10 - D.C. Circuits

10.1 - Practical Circuits

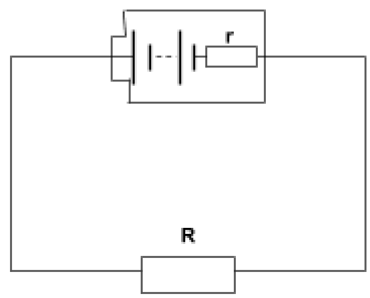
Batteries have an **internal resistance (r)** which is caused by electrons colliding with atoms inside the battery, as this results in some energy being lost before electrons even leave the battery. It is represented as a small resistor inside the battery.

Electromotive force (emf / ε) is the energy transferred by a cell per coulomb of charge that passes through it:

$$\varepsilon = \frac{E}{Q}$$

As you can see in the circuit below, the sum of the internal resistance (r), and load resistance (R) is the total resistance (R_T) in the circuit.

$$R_T = R + r$$



And so the emf is the product of the total resistance and the current of the circuit, because $V = IR$.

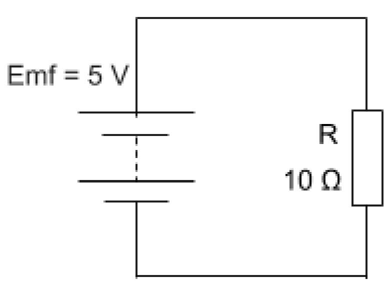
$$\varepsilon = IR + Ir \qquad \varepsilon = I(R + r)$$

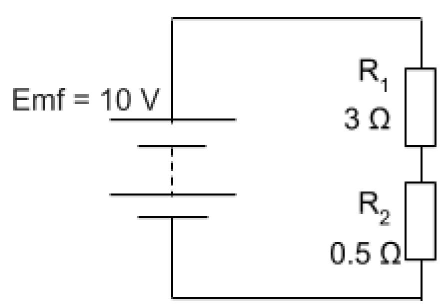
The p.d. across the load resistance R, is known as the **terminal p.d. (V)**, whereas the p.d. across the internal resistance r, is known as **lost volts (v)** because this value is equal to the energy wasted by the cell per coulomb of charge.

$$V = IR \qquad v = Ir$$

Therefore, emf is the sum of the terminal p.d. and lost volts: $\varepsilon = V + v$.

The emf of a battery can be discovered by measuring the voltage across the cell using a voltmeter when there is **no** current running through the cell- where the cell is in an **open circuit**.





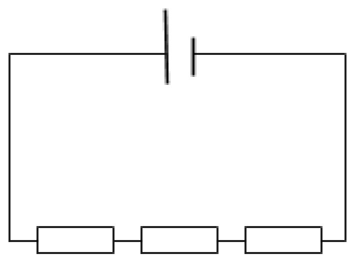
10.2 - Kirchhoff's Laws

In DC circuits, charge and energy are **always** conserved. Kirchhoff's two laws describe how this is achieved:

> **Kirchhoff's first law** - the total current flowing into a junction is **equal** to the current flowing out of that junction. This shows that no charge is lost at any point in the circuit.
> **Kirchhoff's second law** - the **sum** of all the voltages in a **series** circuit is **equal** to the **battery voltage** (or the sum of all the voltages in a loop is zero). This shows that no energy is lost at any point in a circuit.

In a **series** circuit,

- The current is the **same** everywhere in the circuit.
- The battery p.d. is shared across all elements in the circuit, therefore the **total sum of the voltages** across all elements is **equal** to the **supply p.d**.



When joining together battery cells, you can use either a **series** or **parallel** configuration. When joined **in series**, the total voltage across the cells is equal to the sum of the individual voltages of the cells:

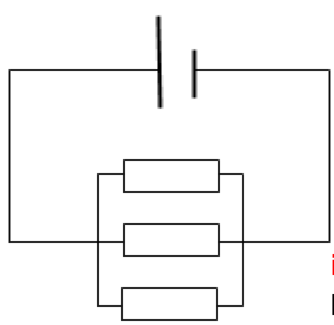
$$V_T = V_1 + V_2 + V_3 + \dots$$

Following from this, the **combined resistance** of several resistors **in series** is:

$$R_T = R_1 + R_2 + R_3 + \dots$$

In a **parallel circuit**,

- The **sum** of the currents in each parallel set of branches is **equal** to the **total current**.
- The potential difference across each branch is the **same**.



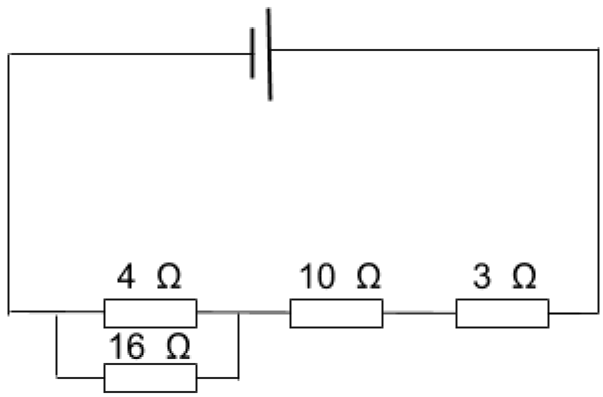
When **identical cells** are joined **in parallel**, the total voltage is equal to the voltage of one cell. This is because the current is split equally between branches, therefore the overall potential difference is the same as if the total current was flowing through a single cell:

$$V_T = V_1 = V_2 = V_3 = \dots$$

Following from this, the **combined resistance** of several resistors **in parallel** is:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

You may need to use both of these rules when calculating the resistance of one circuit. For example, find the resistance of the circuit in the diagram below.



Firstly, find the resistance of the parallel combinations of resistors:

$$\frac{1}{R_T} = \frac{1}{4} + \frac{1}{16} = \frac{5}{16} \qquad R_T = 3.2\ \Omega$$

Then, use the series rule to add the remaining two resistors to the value calculated for the parallel combination.

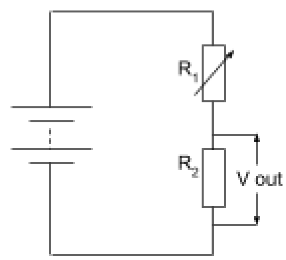
$R_T = 10\ \Omega + 3\ \Omega + 3.2\ \Omega = 16.2\ \Omega$ so the total resistance is **16.2 Ω.**

10.3 - Potential Dividers

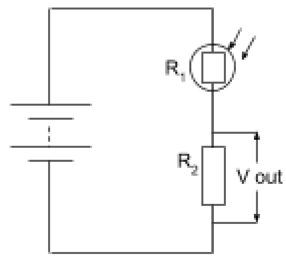
A **potential divider** is a circuit with several resistors in series connected across a voltage source, used to produce a required **fraction** of the source potential difference, which remains constant.

You can also make a potential divider supply a **variable** potential difference by using a **variable resistor** as one of the resistors in series, therefore by varying the resistance across it, you can vary the potential difference output.

For example, in the diagram below, if the resistance across R_1 increases, the output p.d. will decrease as circuit current has decreased and V=IR.

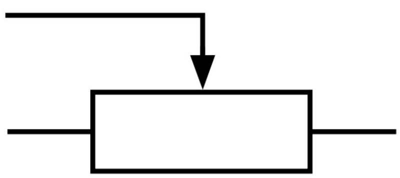


You could replace the variable resistor in the circuit with a thermistor or light dependent resistor (LDR) in order to form a **temperature or light sensor**. A **light dependent resistor's** resistance decreases as light intensity increases.



These types of sensors can be used to **trigger certain events**. For example, in the circuit above, a light dependent resistor is used. If the light intensity falls, resistance across R_1 will increase. This will cause the total circuit resistance to increase and so the circuit current will decrease. Using Ohm's law (**V = IR**), you can see that this means the voltage across R_2 decreases, and so the p.d. out decreases also. If you want this effect to be **reversed**, you can **switch the positions of the LDR and the resistor**, meaning that the p.d. out would increase as light intensity decreases, so this circuit could be used to cause a light bulb to be switched on when it's dark, once a certain threshold voltage (p.d. out) has been met. This is an example of a potential divider circuit dependent on light or temperature.

A **potentiometer** consists of a voltmeter and a three-terminal resistor. They have a control which allows for the resistance between terminals to be adjusted, while the resistance between the two outer terminals remains fixed. Adjusting the resistances allows for the potential difference in parts of the circuit to be compared, so it can also be used as a variable resistor for a potential divider circuit.



Null measurements are used to more accurately measure features of a circuit. Measuring with an ammeter or a voltmeter influences the current flow in the circuit, therefore changing its behaviour.

A **galvanometer** allows for the emf of a circuit to be measured directly by using the following equation for internal resistance and emf:

$$\varepsilon = V + Ir$$

With the current set to zero, the emf can be directly measured as equal to the cell voltage. Then, by knowing the emf and measuring the voltage, a galvanometer can be placed along a length of wire and used to measure its current, allowing the resistance of the wire to be determined.