Resistance

When electrons, or other electric charge carriers (e.g. ions in a solution), are forced to move through a medium by an applied electric field (which can also be described by a potential difference (voltage), V), their motion is in most cases retarded by scattering from imperfections (impurities) and vibrating atoms in the medium. This resistance to the movement of charge is defined as

$$R = \frac{V}{I}$$

where V is the voltage, or *potential difference*, applied across the material and I is the current, or *rate of the movement of electric charge* (electrons) in the material. The resistance R of a medium (resistor) is dependent on its chemical properties, geometry, external magnetic field, temperature (the magnitude of atomic vibrations increases with temperature), etc.

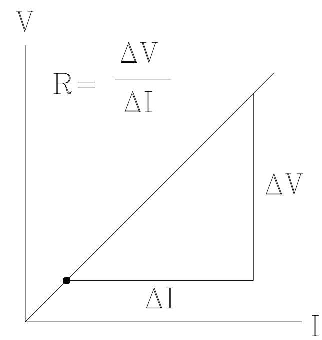

Figure 3.3: IV relationship for Ohmic resistor

The value of resistance may also depend on the *magnitude* and *polarity* of the voltage V applied across its terminals, as is observed with a device made of *semiconducting* material. Semiconductor resistance decreases with temperature, an effect known as thermal runaway.

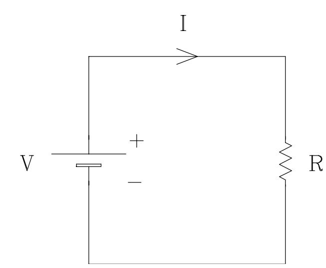

Figure 3.4: Basic resistor circuit

A resistor that is independent of the voltage applied across it is called an Ohmic resistor after George Simon Ohm (1787–1854) who described mathematically the electrical characteristics of such a device. Ohm's law states that the electric current I that flows in a conductor is *proportional* to the potential difference V between the ends of the conductor, and is inversely proportional to its resistance R.

$$I = \frac{V}{R} \tag{3.1}$$

The unit for resistance is the *ohm* (Ω), and is derived from the units of voltage and current:

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}.$$

For an Ohmic resistor, a graph of V vs. I is a straight line, with the slope equal to the resistance R, as shown in Figure 3.3. By varying the voltage across a resistor and recording the current in each case, a graph of V vs. I can be plotted, and from that graph, the resistance of an unknown resistor can be established. A schematic representation of the simplest electric circuit is given in Figure 3.4.

Ohmic resistors are used primarily to *limit the current flow* in an electric circuit. Several methods are used in their construction. For example, some resistors consist of a fine wire wound on an insulating core. The ones that you will use are formed from various carbon compounds.

Kirchhoff's laws

The behaviour of any electric circuit can be examined with the aid of two rules developed by Gustav Kirchhoff (1824–1887). These rules arise from the application of fundamental physical laws to electric circuits, and have been verified by numerous experiments.

Kirchhoff's voltage law, or loop rule, states that the total work done on an electron by the voltage sources in a circuit equals the total work extracted from the electron while traversing the circuit. In following any such closed circuit loop, the gains in potential energy will be equal to the losses, so that $\sum \Delta V = 0$. This is the principle of conservation of energy.

A junction is a point in a circuit where a number of wires are connected together. *Kirchhoff's current law*, or junction rule, states that the total electric current entering a junction, or node, equals the total electric current leaving the junction, $\sum I = 0$. In effect, it states that no electrons are created or destroyed. This is the principle of conservation of electric charge.

Effective resistance of resistors in series

The effective resistance for R_1 and R_2 connected in series is represented by R_S. Applying Kirchhoff's voltage law (starting at O, traversing the loop clockwise) to the closed circuit loop in Figure 3.5 yields:

$$\begin{aligned} V - IR_1 - IR_2 &= 0 \\ V &= IR_1 + IR_2 \\ \frac{V}{I} &= R_S = R_1 + R_2. \end{aligned}$$

Therefore, for two resistors connected in series,

$$R_S = R_1 + R_2. \tag{3.2}$$

and for any number N of resistors in series

$$R_S = R_1 + R_2 + \cdots + R_N = \sum_{i=1}^{N} R_i \tag{3.3}$$

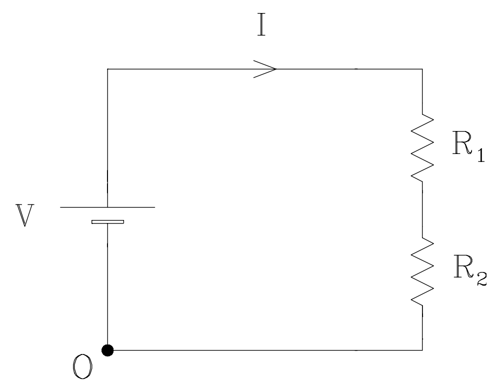

Figure 3.5: Resistors in series

Effective resistance of resistors in parallel

The effective resistance R_P of resistors R_1 and R_2 in Figure 3.6 can be determined by noting that the voltage V is the same across both resistors and applying Kirchhoff's current law at junction O:

$$I - I_1 - I_2 = 0$$

Then, for two resistors connected in parallel:

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}. \tag{3.4}$$

and for any number N of resistors in parallel

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N} = \sum_{i=1}^{N} \frac{1}{R_i}. \tag{3.5}$$

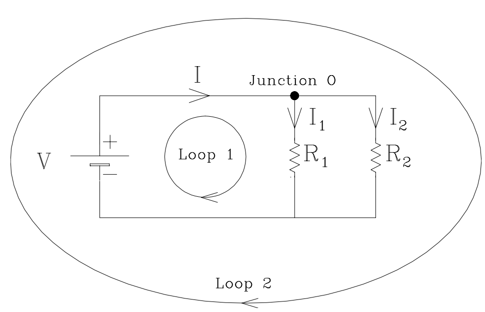

Figure 3.6: Resistors in parallel