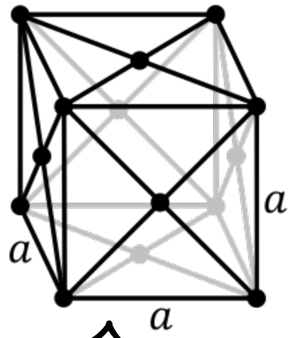
Conductance in Metals



atom at the centre of every plane.

The copper atoms are arranged in a face centred cubic.
Copper has an atomic number of 29. Of those 28 are tightly bound. There is one loosely bound electron in the outermost shell. It is easily delocalised to become free 'conduction electrons'.

Conventional Current

current = rate of flow of charge (Ampere)

$$I = dq/dt \qquad \left(1A = \frac{1C}{1S}\right)$$

A conventional current is treated as the flow of positive charges, regardless of whether the free charges are positive/negative or both.

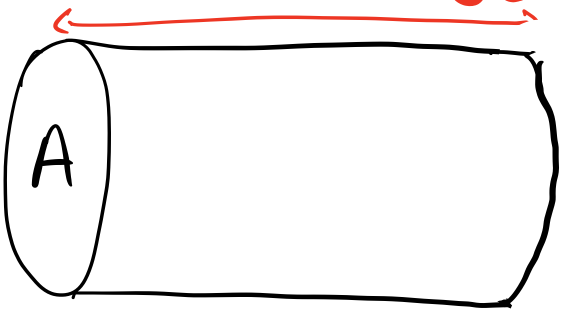
In a metallic conductor, the moving charges are electrons - but the current still points in the direction positive charges would flow. In a salt solution, current is carried by both positive & negative ions. Same occurs in a battery.

Drift Speed

for convience, we always assume the charge carries are positive. The average speed of the charge carriers is called the drift speed.

V_d = drift speed

$$dL = V_d\,dt$$



$$V_d = \frac{dL}{dt}$$

conduction electron density = n = electrons per cubic metre

$$\underset{\text{total charge of } e^- \text{ in conductor}}{dq} = \underbrace{dL \cdot A}_{\text{volume of conductor}} \cdot \underset{e^- \text{ density}}{n} \cdot \underset{e^- \text{ charge}}{e}$$

$$V_d = \frac{dL}{dt} = \frac{dL}{dq}\frac{dq}{dt} = \frac{I}{A \cdot n \cdot e}$$

$(V_d \propto I)$

$(V_d \propto 1/A)$

Collisions between the electrons and the positive ions give rise to resistance. The positive ions undergo random thermal vibrations.

Exercise 1.1

0.00205

0.002025

① $8.45 \times 10^{28}\ e^-/m^3$ ✓

2a $5.5/1.6 \times 10^{-19} = 3.44 \times 10^{19}$ ✓

2b $1.23 \times 10^{-4}\ ms^{-1}$ ✓ $(\approx 0.1\ mms^{-1})$

Potential Difference

If a charge, q, has potential energy, U, the electrical potential is

$$V = \frac{U}{q} \qquad \left(V = \frac{J}{C}\right)$$

If moving q between a and b result in a change in energy then there is a potential difference.

$$V_a - V_b = \frac{U_a - U_b}{q}$$

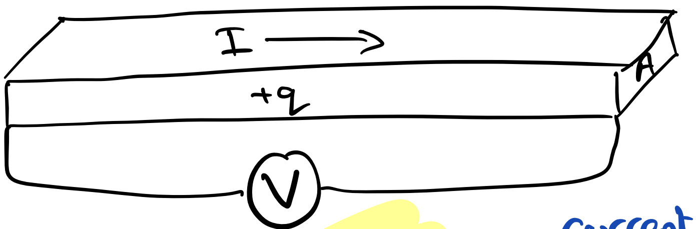
$$\Delta V = \frac{\Delta U}{q}$$

Ohm's Law

The current in a conductor is proportional to the electric field:

current density (A/m²) → $$J = \frac{E}{\rho}$$ ← electric field (V/m)

← resistivity (Vm/A ≡ Ωm)



electric field $E = \dfrac{V}{L}$

current density (A/m²) → $$J = \frac{I}{A}$$ ← current (A), ← area (m²)

we can also find the current density via:

$$\frac{I}{A} = \frac{E}{\rho} = \frac{V}{L\rho}$$

$$R = \frac{V}{I} = \frac{\frac{IL\rho}{A}}{I} = \frac{L\rho}{A}$$

Which gives the equation for resistivity as:

resistivity (Ωm)
length (m)

resistance (Ω) $\rightarrow$ $$R = \frac{\rho L}{A}$$

cross-sectional area (m^2)

- resistivity is a property of the material
- resistance depends on the shape.

Resistivity depends upon temperature. In a metal, increasing temp increases vibrations of the atoms. This causes greater scattering which increases the resistivity of the metal. Carbon (not a metal!) has decreasing resistivity with increasing temp.

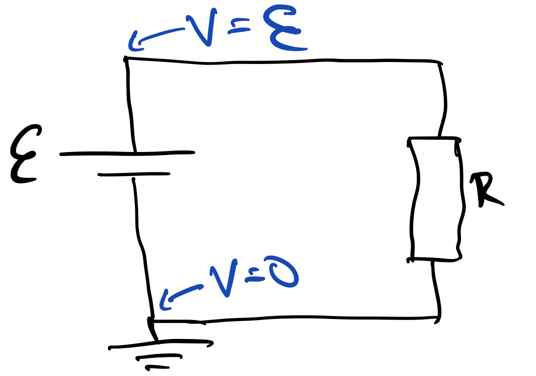
$$\rho(T) = \rho_0\left[1 + \alpha(T - T_0)\right]$$

Resistors & Wires

Usually made from a thin layer of metal/carbon. For circuit analysis we assume the resistance is <u>fixed</u>. Wires are usually made from copper. For circuit analysis we assume they have zero resistance ("ideal").

Ideal Circuit

assume ideal resistors & wires. Ground = 0V. Ideal voltage source.



Electromotive Force

EMF is not a force (has units of volts!). It is the energy gained per unit charge as it passes through the voltage source. EMF causes the charge to flow and creates an electric field. EMF can be generated via e.g. a battery (DC) or a dynamo (AC). The charge in a circuit is conserved.

Voltage Source

Ideal Source	Actual Source
• infinite source of energy	• finite capacity
• zero resistance	• internal resistance
• P.D. is always $\mathcal{E}$	• P.D. depends on the current drawn $V = \mathcal{E} - Ir$

Ground

In a plug, the ground is physically connected to a copper spike in the ground. Ground/Earth is the electrical potential of the planet. We <u>define</u> it to be zero volts for ease. Battery powered circuits don't have a ground. Mains must be grounded (it's the law).

Energy & Power

Energy is conserved.

rate of change of energy.

power $\longrightarrow$ $$P = \frac{dU}{dt} = \frac{dU}{dq}\frac{dq}{dt} = VI = \frac{V^2}{R}$$