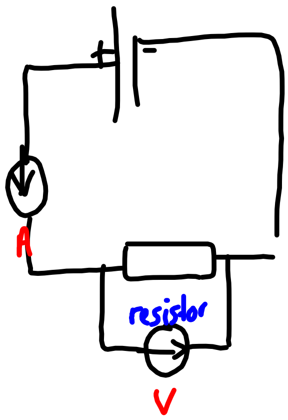
Resistor

- impedes the flow of charge.
- work is done; charges lose potential energy → thermal; so there is a potential difference across the resistor.



If the pot. diff across the resistor is V then each coulomb of charge passing through it loses V joules of its electrical potential energy

(if the potential diff. is 100V, then 1C of charge loses 100J of pot. energy.)

If the current through the resistor is I then I coulombs of charge pass through every second

(If the current is 5.0 A, then 5.0 C pass through the resistor in 1 second)

Resistance

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

scalar quantity

units: $V A^{-1}$ Ω ohm (Ω)

* NOTE that this is NOT a statement of ohm's Law

Example

A potential difference of 12V exists across a resistor and the current through the resistor is 3.0A. Determine the resistance of the resistor.

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

$$R = \frac{12V}{3.0A}$$

$$R = 4.0\,\Omega$$

Example

A small heating element has a resistance of 100 Ω and 5.0V is applied across it. Determine the amount of charge which flows through the element in 1.0 minutes and the power that it develops in that time.

find the current: $R = \frac{V}{I}$

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

$$I = \frac{5.0\cancel{V}}{100\,\Omega} \quad \cancel{V}A^{-1}$$

$$I = 0.050\,A$$

change in 1 min: $I = \frac{\Delta q}{\Delta t}$

$$\Delta q = I\Delta t$$

$$\Delta q = 0.050A\,(60s)$$

$$\Delta q = 3.0\,C$$

Recall: $\Delta E = qV$ $\left(V = \frac{\Delta E}{q}\right)$

$$\Delta E = I(\Delta t)V$$

now $P = \frac{\Delta E}{\Delta t}$

$$P = \frac{I\cancel{(\Delta t)}V}{\cancel{\Delta t}}$$

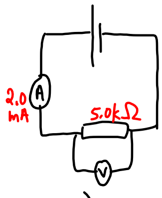
$$P = IV$$

$$P = (0.050A)(5.0V)$$

$$P = 0.25W$$

Example

In the circuit shown, the ammeter reads 2.0mA and the resistance of the resistor is 5.0 kΩ. What is the reading on the voltmeter?



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

$$V = IR$$

$$V = (2.0 \times 10^{-3}A)(5.0 \times 10^{3}\,\Omega) \quad VA^{-1}$$

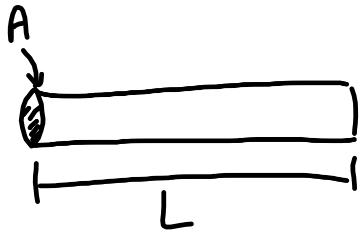
$$V = 10 \times 10^{0}\,V$$

$$V = 10\,V$$

Resistivity

$R \propto L$

$R \propto \frac{1}{A}$



ρ rho

depends on the nature of the material used.

$R \propto \frac{L}{A}$

$$\boxed{R = \frac{\rho L}{A}}$$

where ρ is the constant of proportionality (depends on the material)

ρ is called the resistivity of the material that the conductor is made of.

- scalar; units are $\Omega\,m$

Definition of resistivity (see handout)

↳ resistance of the material 1m long with a cross sectional area of $1m^2$

$$\rho = \frac{RA}{L}$$

where R is the resistance (Ω)

A is the cross sectional area (m^2) ($A = \pi r^2$)

L is the length (m)

Example

The resistivity of constantan is $4.9\times10^{-7}\ \Omega\,m$. Calculate the length of constantan resistance wire which has a resistance of $5.0\ \Omega$ and a radius of 0.12 mm.

$$R=\frac{\rho L}{A}$$

$$L=\frac{RA}{\rho} \qquad A=\pi r^2$$

$$L=\frac{(5.0\cancel{\Omega})(\pi)(0.12\times10^{-3}\,m)^2}{4.9\times10^{-7}\ \cancel{\Omega}m}$$

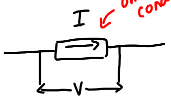
$$\boxed{L=0.46\ m}$$

The resistivity is a small value since the resistance is is small and a small area (radius)

$$\rho=\frac{RA}{L}$$

For a particular material, if the radius of the wire is increased, the the resistance decreases for the same length.

Ohm's Law



$$\underbrace{I\propto V}_{\text{true If}}$$

- ohmic conductor
- temperature is constant

ohmic conductor → metallic conductors + most resistors

non-ohmic conductor → filament lamps, ionic solutions + semi conductor devices such as diodes

Ohm's Law and Resistance

For an ohmic conductor at constant temperature:

$$I\propto V$$

and recall our definition of resistance: $R=\frac{V}{I}$

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

$$I=\left(\frac{1}{R}\right)V$$

$\frac{1}{R}$ is the constant of proportionality for $I\propto V$

For an ohmic conductor at constant temp:

ohm's Law or ($I\propto V$) → $I=\frac{V}{R}$

or $V=IR$ (← not a statement of ohm's Law)

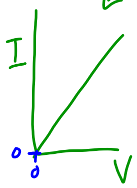
Recall: Ohm's Law is stated

$I \propto V$

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

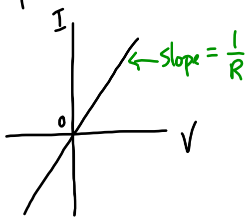
$I = \left(\frac{1}{R}\right) V$

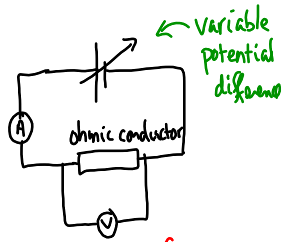
↑ constant of proportionality



Plotting current againts potential difference:

- independent variable is pot. diff | dependent variable is current

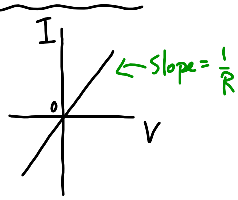




Circuit for verifying Ohm's Law.

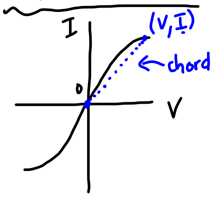
I-V characteristics of an ohmic resistor and a filament lamp

Ohmic behaviour



- ohmic conductor at constant temperature
- constant resistance

Non-ohmic behaviour



- filament lamp
- the resistance increases as the potential diff increases. (or current)

* The resistance is not the reciprocal of the slope to the tangent of the curve. It is simply the value of $\frac{V}{I}$ (non-ohmic)

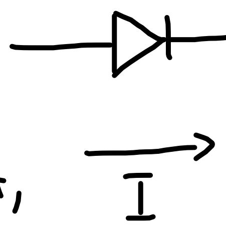
IF the behaviour is ohmic: slope $= \frac{1}{R}$

or $R = \frac{1}{\text{slope}}$

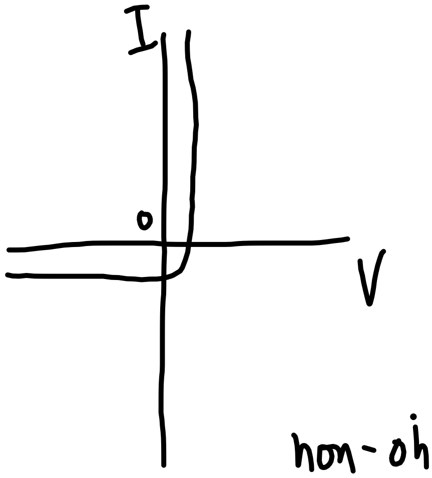
IF the behaviour is non-ohmic, then the slope of the chord drawn between the origin and (V, I) is $\frac{1}{R}$ or $R = \frac{1}{\text{slope (of chord)}}$

I-V characteristic of a diode

diode



A diode is a device which has a low resistance when current flows forwards through it, and a high resistance to current flowing in the opposite direction. ⇒ current essentially can only flow in one direction



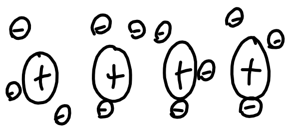
non-ohmic behaviour

Why does the resistance of a metal increase as the temperature increases?

— need to look at the free electron model of conduction in a metal.

Free Electron Model of a Metal

— one or two valence electrons



- free to move from one atom to the next along at conduction band

- think of a metal as a lattice of positive ions in a sea of negative electrons => electrons are free to move around => delocalized electrons.
- overall, the metal is electrically neutral

- apply a potential diffence to the conductor => electric field.
- the electric field applies a force on the electrons so that they migrate in the conduction band to the positive terminal.
- the positive ions are stationary (lattice)

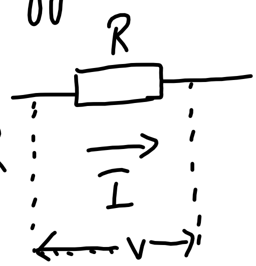
- the motion of the electrons under the action of the electric field is slow (they collide with the positive ions) => net drift of electrons toward the + terminal
- drift velocity is about 1mm per second
- the electron drift is superimposed on the rapid thermal motion of the electrons. (much greater than the drift velocity)
- even though the drift velocity is low, the electrons all start to drift towards the positive terminal at the same time when the circuit is closed.
- when the metal's temperature increases, the the random thermal motion of the electrons increases, thereby impeding the slow drift of the electrons towards the positive terminal.

-> increase the temperature of the resistor => increases the resistance.

Power dissipation in a resistor

For resistor, power refers to the rate at which electrical energy is converted to thermal energy.

When a current I flows through a resistor of resistance R due to a potential difference V, then the power dissipated is:



$$P = \frac{\Delta E_p}{\Delta t}$$ ← loss in electrical potential energy of the charge Δq in time Δt

Recall: $\Delta E_p = \Delta q V$

$$P = \frac{\Delta q}{\Delta t} V$$

$$\boxed{P = IV}$$

Recall: $R = \frac{V}{I}$ → $I = \frac{V}{R}$, $V = IR$

$$P = I(IR) \qquad P = \left(\frac{V}{R}\right)V$$

$$\boxed{P = I^2 R} \qquad \boxed{P = \frac{V^2}{R}}$$

Summary:

$$P = \frac{\Delta E_p}{\Delta t} = \frac{\Delta W}{\Delta t} \qquad P = IV \qquad P = I^2R \qquad P = \frac{V^2}{R}$$