Electricity – basic properties

Contents

Introduction

Electricity is NOT a source of energy. It is just a convenient way of TRANSFERRING energy from one place to another with relatively little energy loss.

Introduction

Electric current is a measure of the flow of free electrons.

Electric Potential (a.k.a. Voltage) is a measure of how closely those electrons are packed together.

Free Electrons

The outer electrons orbiting the atoms of metals can be forced out of orbit and made to drift through the atomic lattice.

If a very large number of such electrons all move at once then this forms an electric current.

Electric Current

Electric current is the rate of flow of charge

$$I = \Delta Q/\Delta t$$

1 Ampere (A) is 1 Coulomb (C) per second (s)

$$1\ A = 1\ Cs^{-1}$$

(in metals current is a flow of free electrons. In solutions, it is a flow of ions)

The Coulomb

1 Coulomb is *the amount of electrical charge transferred when a* <u>*constant*</u> *current of 1 Amp flows for 1 second.*

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

Electric Current

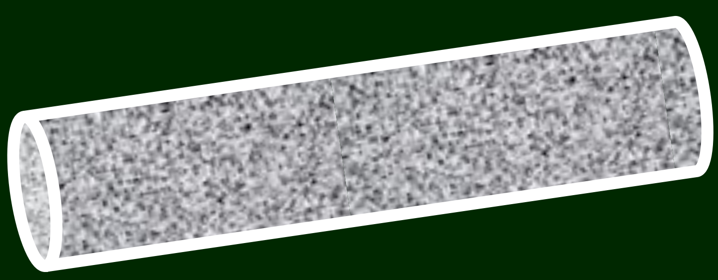
Since each electron has a charge of $1.6 x 10^{-19}$ coulombs (C) then a current of 1 Amp is also a flow of $6.25 x 10^{18}$ electrons passing a fixed point every second.

Electric Current

The direction of electric current flow is defined in terms of the flow of positive charges – this is "conventional current".

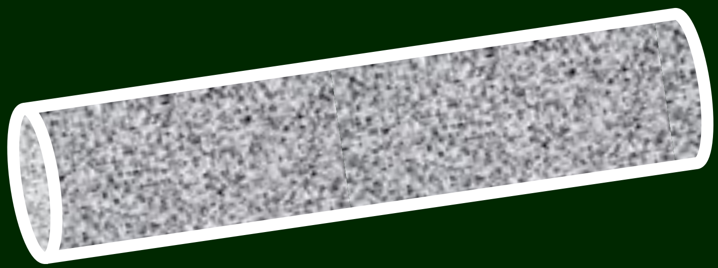
Electrons flow in the opposite direction.

Electric Current



A wire has length L, cross-sectional area A and contains n charge-carriers per unit volume and each has a charge q.

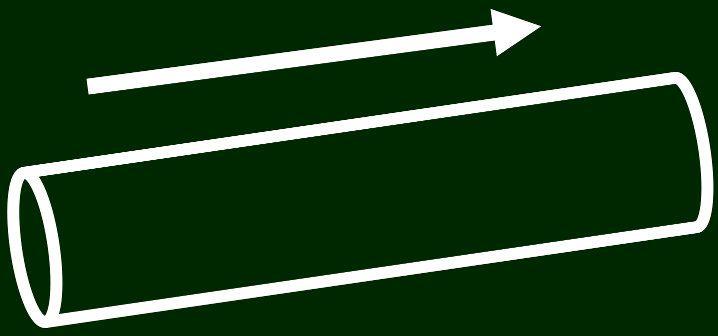
Electric Current



So the total charge, Q contained in this section of wire is nq x volume.

Q=nALq.

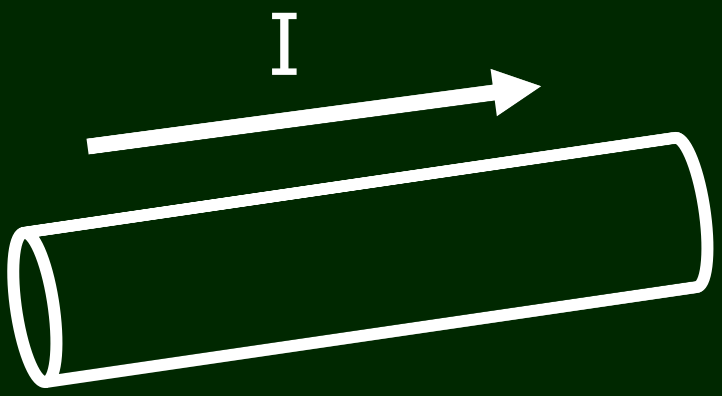
Electric Current



Suppose all of this charge Q flows out of this part of the wire in a time t.

(Obviously, in a real wire, more free electrons would drift in from the left to replace them)

Electric Current



The Current flow I will be:

$I=Q/t$

So $I=nALq/t$

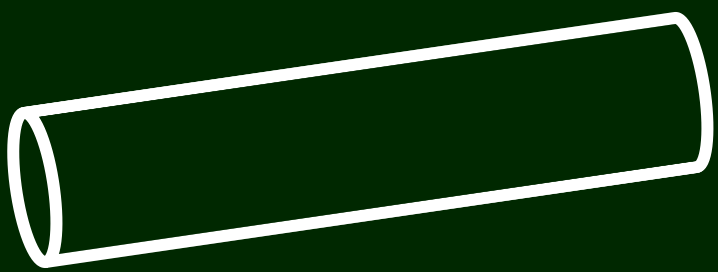
Electric Current

But we can write this as

$I = nAq \times L/t$

But $L/t = v$, the drift velocity,

Electric Current



So

$$I = nAvq$$

Electric Current

$$I = nAvq$$

If the charge carriers are ions (in electrolytes).

$$I = nAve$$

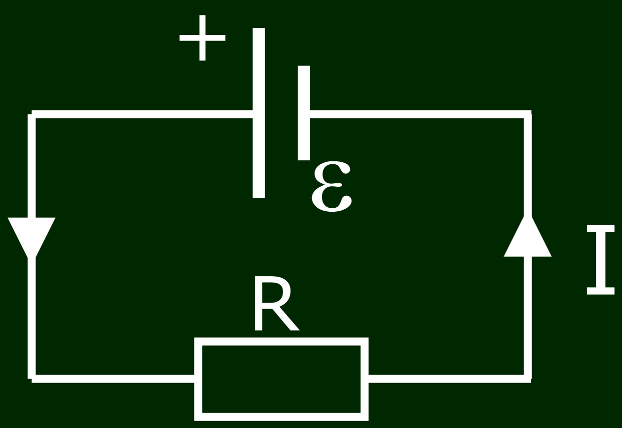
If the charge carriers are free electrons (in metals).

Carrier density

$$I = nAve$$

Values of n vary from 10^{28} m^{-3} for conductors like copper, through semiconductors and down to 10^{15} m^{-3} for insulators like pure silicon.

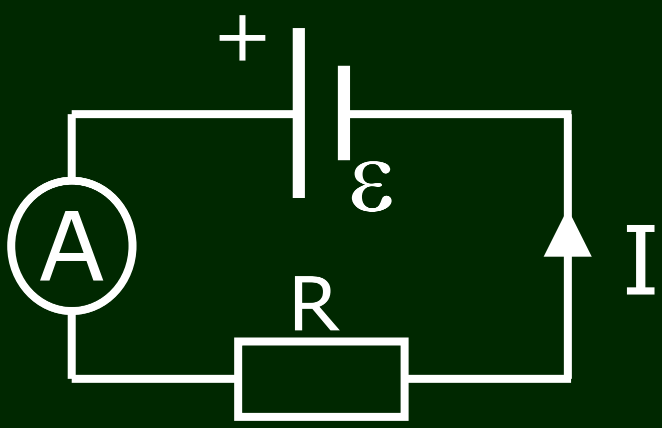
Series circuit



The electric current is the <u>same</u> at all points around a series circuit.

Changing the values of R or ε will change I, but whatever its value, I will be the same at any point around a series circuit.

Ammeter



An ammeter is an electrical flow meter. It is always placed in series with other components so that current flows through it.

All ammeters have negligible electrical resistance.

Electric Potential

The battery (or power supply) is the device which changes the average free electron spacing.

Its positive terminal is positive simply because fewer free electrons are located there.

Electric Potential

The negative terminal of the battery (or power supply) is negative because a larger number of free electrons are forced together at this terminal.

Electric Potential

Measuring free electron spacing is too difficult. However, changing the average spacing of free electrons stores energy, much like squashing or stretching a spring.

Electric Potential

This energy difference between the terminals of a battery exists all the time, whether it is connected in a circuit or not.

Once connected into a circuit, this energy difference can drive a current.

Electric Potential

But rather than use energy (in Joules) we define a new property; Electric Potential which is simply the energy transferred by each coulomb of charge…

Electric Potential

Electric Potential is *the energy transferred (from electrical to other forms) per unit charge*.

$$V = W/Q$$

1 Volt (V) is 1 Joule per Coulomb.

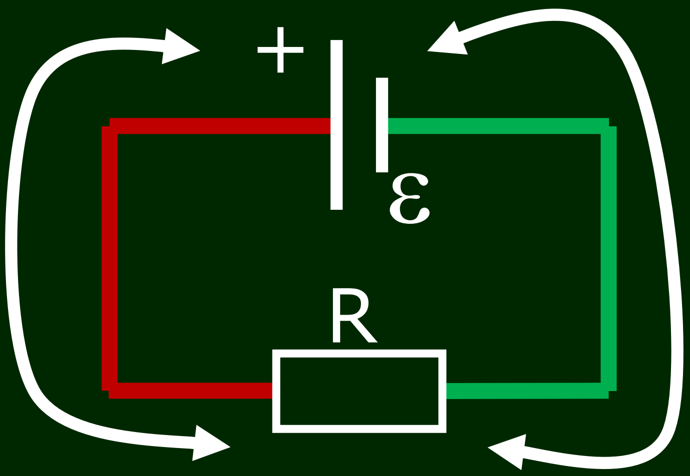
$$1\ V = 1\ JC^{-1}$$

Potential in circuit

If, as they drift through the atomic lattice, the free electrons are pushed closer together then this creates a more negative electric potential.

A wider average spacing of free electrons gives a more positive electric potential.

Series circuit



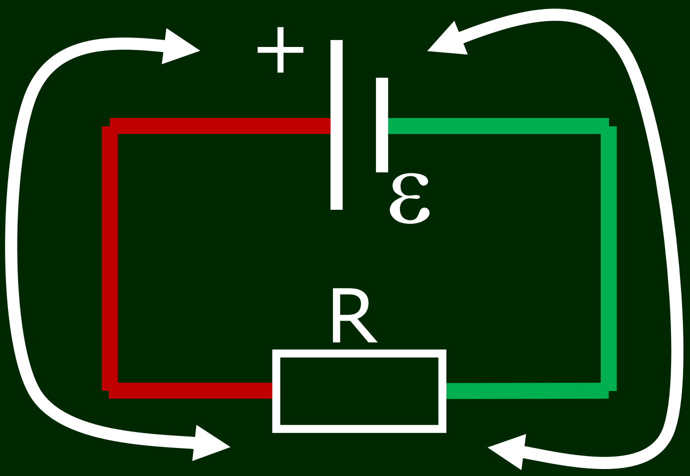
Higher electric potential on this side

(free electrons more widely spaced)

Lower electric potential on this side

(free electrons travel closer together)

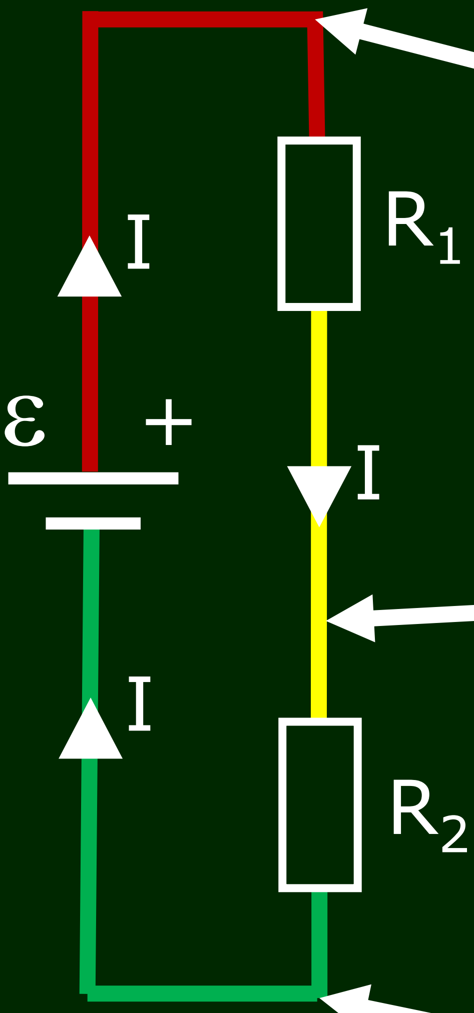
So what about n?



But if n is changing very, very slightly and I=nAve then how can we say that the current in a series circuit is the same at all points?

Answer: if n increases, v reduces and vice versa.

Changing Potential



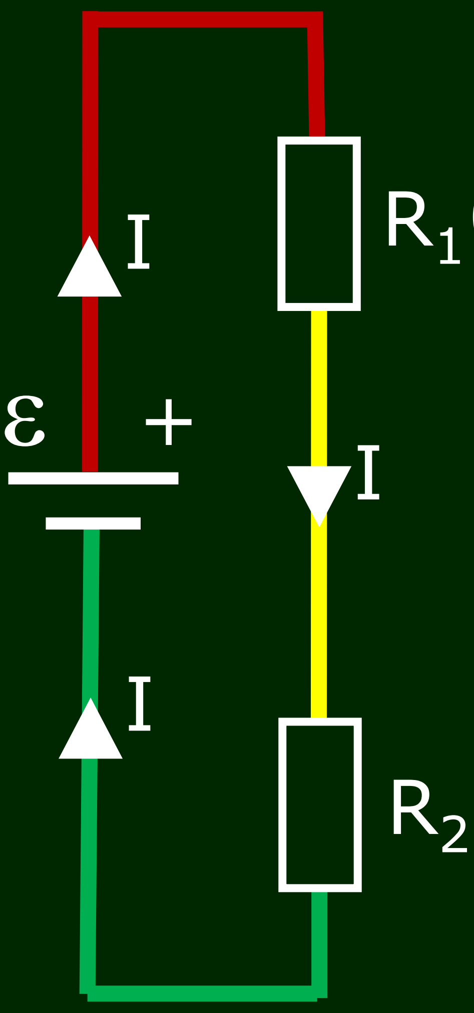
Widest average spacing of free electrons in this wire.

Closer average spacing in this wire.

Closest average free electron spacing in this wire.

Current, I is the <u>same</u> at all points

Changing Potential

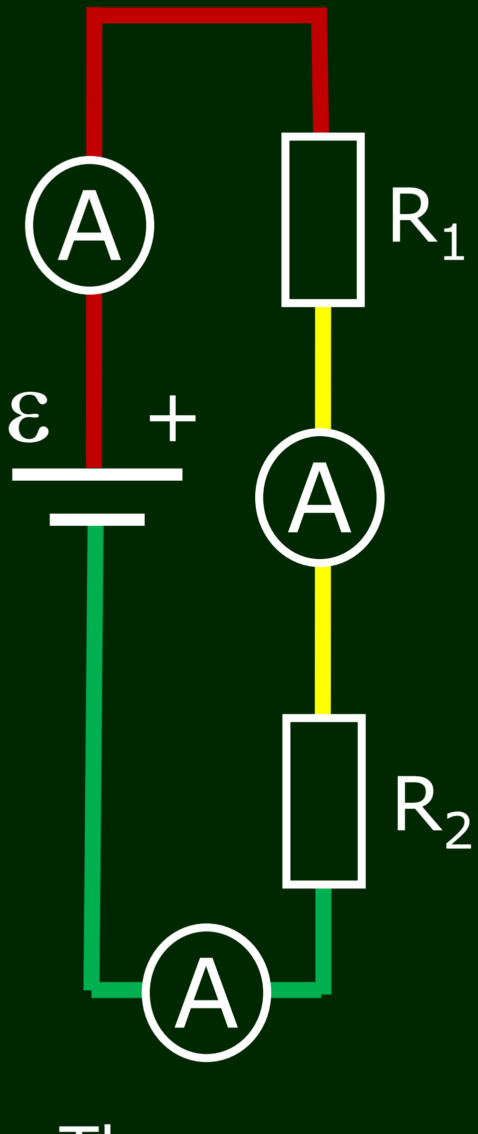


Energy is transferred (electric potential changes) when a current passes through a significant resistance (such as R_1 & R_2)

Energy losses in connecting wires are negligible in comparison.

Current, I is the <u>same</u> at all points

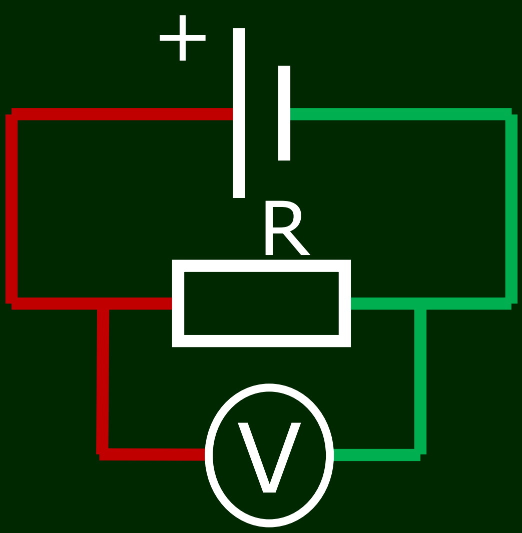
Effect of Ammeters



Like connecting wires, Ammeters are designed to have negligible resistances, so their presence or absence in a circuit does not affect the voltage levels (i.e. free electron spacing)

The same ammeter, moved to different points in the circuit will show the same current reading

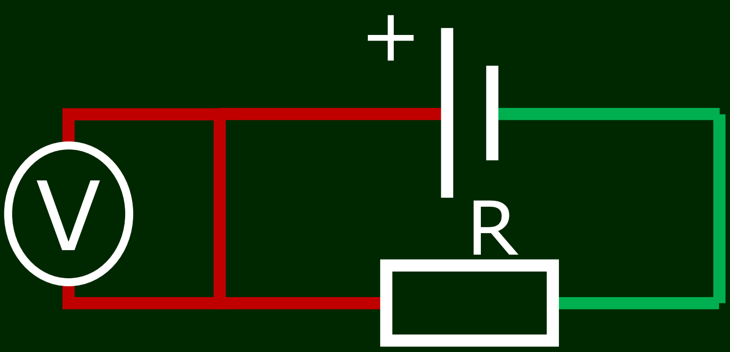
Voltmeter



A voltmeter is a subtraction machine. It measures the potential at each terminal and displays the difference between the two readings.

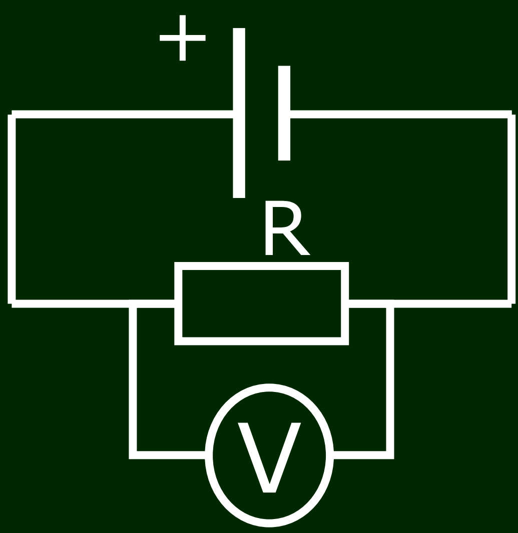
Hence "potential difference" (a.k.a voltage)

Voltmeter



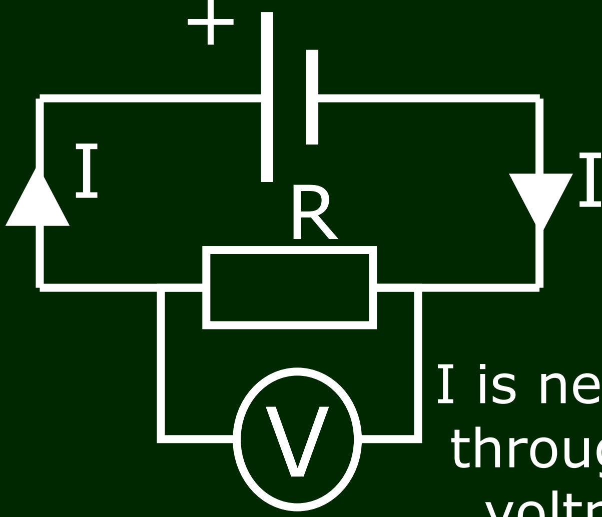
Here the voltmeter reads zero, NOT because the potential really is zero but because there is no difference between the two readings.

Voltmeter



Voltmeters are always connected in <u>parallel</u> with other components (resistors, batteries, lamps etc).

Effect of Voltmeters



Voltmeters are designed to have very large electrical resistances.

So any voltmeter added <u>in parallel</u> to a circuit will not affect the current.

Ohm's Law

The current through a component is directly proportional to the potential difference across its ends providing other physical properties (e.g. length, temperature) remain constant.

I V Characteristics

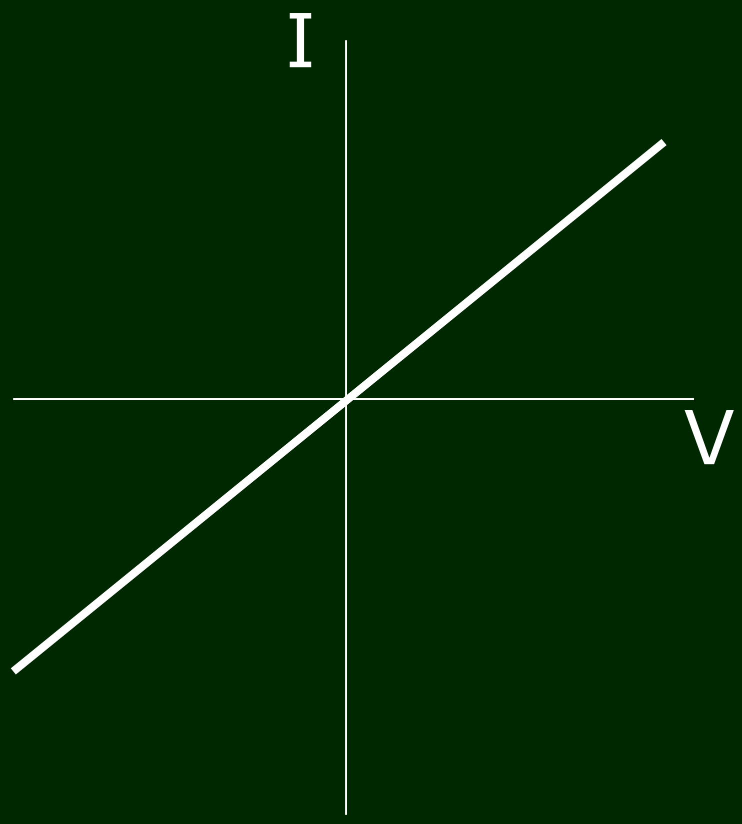
You can identify particular electrical components from the graphs of current vs potential difference.

These particular graph shapes are called IV Characteristics.

You are expected to know them and how they would be measured.

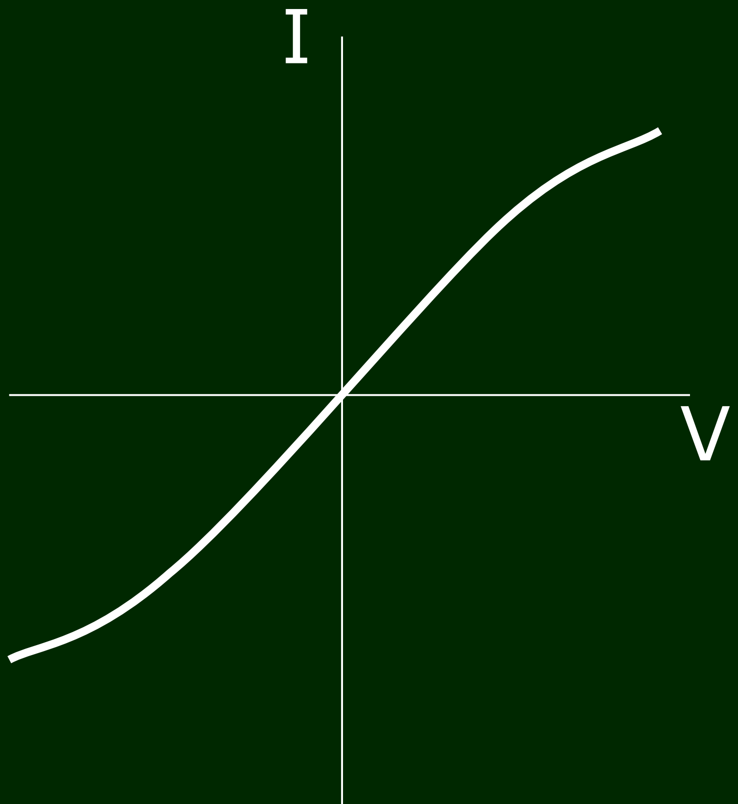
I V Characteristics

Ohmic conductor



I V Characteristics

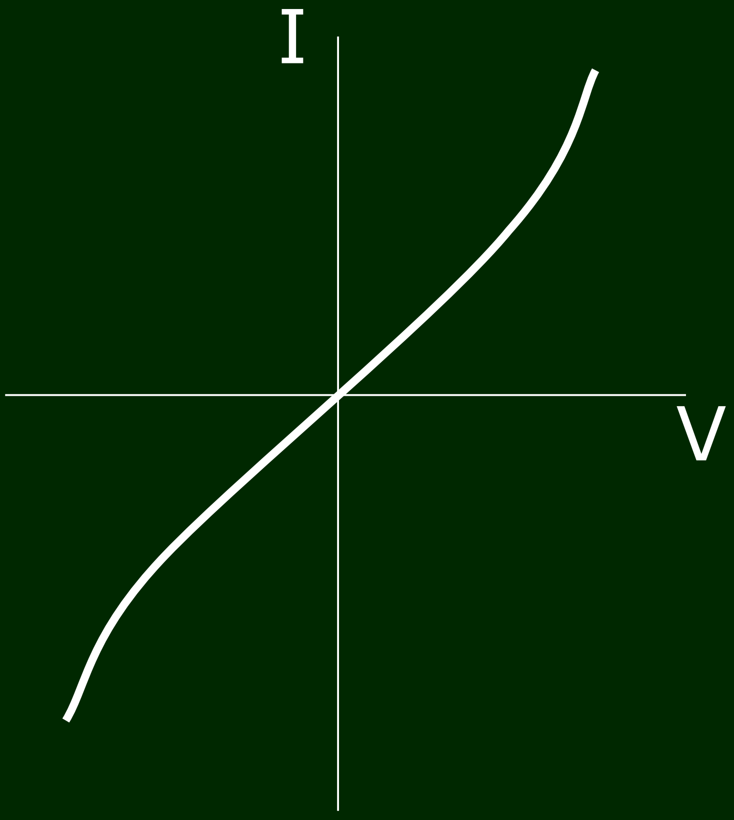
Filament lamp



Resistance increases as temp increases

I V Characteristics

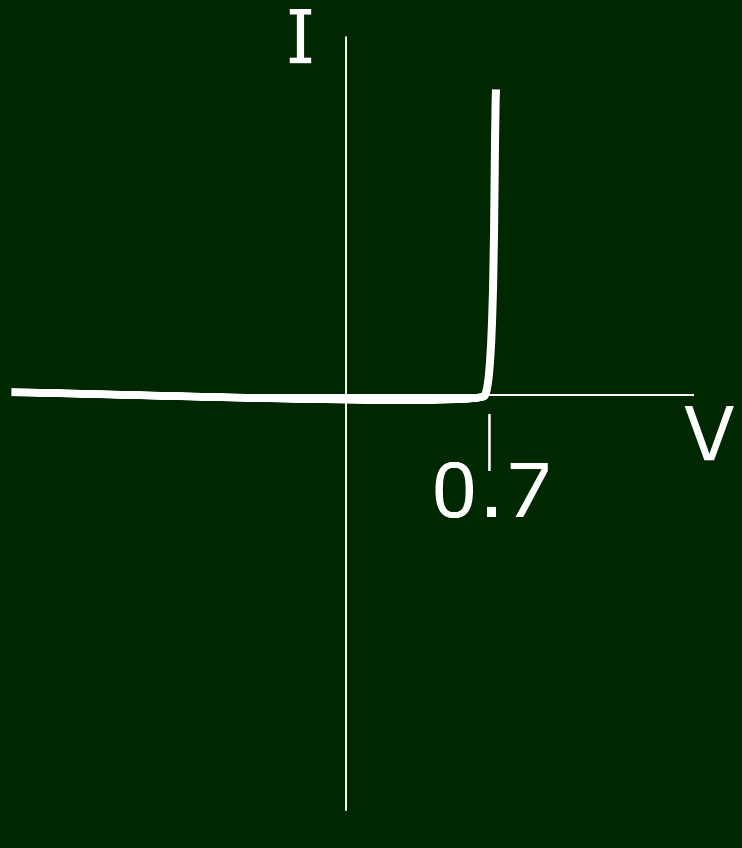
Negative Temp Coefficient Thermistor



Resistance reduces as temp increases

I V Characteristics

L.E.D. or Semiconductor diode



For L.E.Ds, conduction starts between 0.5 and 2V.

Electrical Resistance

The electric potential difference applied across a conductor per unit current flowing through it.

$$R = V/I$$

1 Ohm (Ω) is 1 Volt per Amp

$$1\ \Omega = 1\ VA^{-1}$$

Resistivity

The resistivity of a material is the product of its resistance and its cross-sectional area per unit length.

$$\rho = RA/L$$

Resistivity has the units of Ohm metres (Ωm)

(NOT Ohms per metre)

Quick Clip

TAP HERE

…for a video on Resistivity.

Resistivity

The resistivity of both metals and semiconductors (e.g thermistors) is not fixed but will vary with temperature due to the thermal vibration of the atomic lattice.

Metallic conductors

Increasing the temperature of a metal increases the thermal vibration of the atomic lattice.

The drift of electrons through the material is impeded causing a rise in its resistance (e.g filament lamp)

Thermistors

Semiconductor devices are manufactured so that changes in temperatures will have a greater effect on resistance compared with conventional metals.

In semiconductors, thermal vibrations can release more charge carriers so conduction is easier.

Thermistors

Thermistors are used to make temperature sensors.

These temperature sensors can be designed to work over a wider range than the conventional liquid-in-glass thermometers.

Test

State Ohm's Law.

Sketch the four IV characteristic graphs.

Define electrical resistance.

A 10kΩ resistor conducts a 40mA current. Show that the P.d. across it is 400V.

Important

Don’t confuse Ohm’s Law with the definition of electrical resistance.

Online task

Check your understanding by attempting the questions in the following links:

Static Electricity

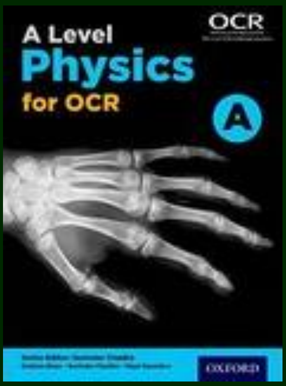
Current and Charge

More detail

Two-year textbook

Pages

122 – 161

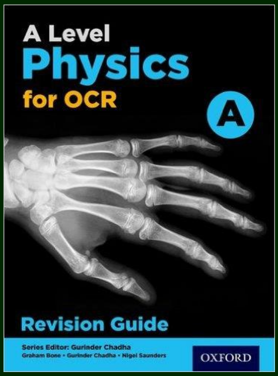


Revision guide

Pages

54 – 58

60 – 65



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