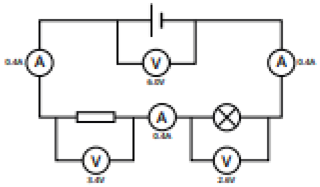
Module 4 Section 1: Electricity

Circuit Diagrams

Series circuits:



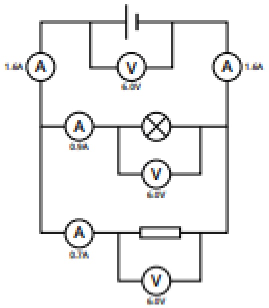
Note:

- The **current is equal** at every point in the circuit. This obeys the law of **conservation of charge**.
- The total potential difference input is **equal to the sum** of the potential differences across the components. This obeys the law of **conservation of energy**.

Parallel circuits:

Note:

- The total current input is equal to the current through each branch of the circuit. This obeys the law of **conservation of charge**.
- The potential difference across each component is equal. This obeys the law of **conservation of energy**.



Conservation of charge:

As current is the rate of flow of charge, the total current through a circuit must be constant as the total charge per second through the circuit is constant.

Current and Charge

A current flowing through a conductor means there are charged particles moving through it. The current is defined as the rate of flow of charge.

Current can be calculated using the following equation:

$$I = \frac{\Delta Q}{\Delta t}$$

Using S.I. units this will give a current in A which is equivalent to Cs^{-1}.

Charge:

Particles can be neutral, positively or negatively charged. The unit of charge is the Coulomb (C).

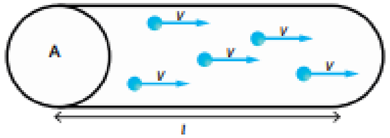
If an object is charged it has gained or lost electrons. A positively charged object has lost electrons and a negatively charged object has gained electrons.

An electron has a very small charge, 1.6×10^{-19}C (given in the data booklet), therefore a charge of **1C is equivalent to**:

$$\frac{1}{e} = \frac{1}{1.6 \times 10^{-19}} =$$

Mean Drift Velocity

I = Anev



When a potential difference is applied across a wire the electrons will move a distance l along the wire in a certain time. This can be used to calculate the **drift velocity** of the electrons.

Remember, rearranging the equation for velocity will give the displacement l as vt.

The following steps can be used to derivate the equation above.

Step 1: calculate the **volume** of the cylindrical wire.

$Volume = A \times vt$

Step 2: calculate the **number of free electrons** in the wire.

$Number\ of\ free\ electrons = n \times Avt$

Where n = the number of free electrons **per m³**.

Step 3: calculate the total **charge**

$Charge, Q = nAvt \times e$

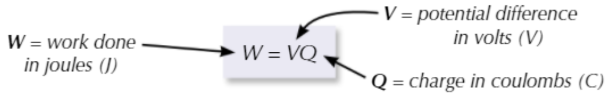
Where e is the charge of 1 electron (= 1.6×10^{-19}C.)

Step 4: calculate the current (I)

$$I = \frac{\Delta Q}{\Delta t} = \frac{nAvte}{t} = nAve$$

Potential Difference

Potential difference is the **energy** transferred from electrical energy to another form for **each unit of charge** that passes. It is measured in colts where, $1V = 1JC^{-1}$



W = work done in joules (J)

$W = VQ$

V = potential difference in volts (V)

Q = charge in coulombs (C)

The potential difference across a component is 1 volt when 1 coulomb of charge does 1 joule of work to pass through the component.

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

Resistance and Resistivity

Resistance is caused by **collisions** between the free **electrons and the ions** in the conductor. These collisions cause some **energy to transfer** from the electrons to the ions in the form of heat energy.

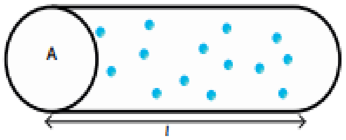
Power:

Electrical power can be calculated using the following equations:

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

Power is the energy transferred per second in Js^{-1} or Watts (W).

Resistivity:



The resistance of a wire is determined by these factors; the length (l), the cross-sectional area (A) and the resistivity of the material (ρ). The resistivity is measured in Ωm and is a constant for each different material.

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

The resistance can be calculated using this equation

Remember:

Calculate the area correctly, if it has a circular cross section, use the equation $A = \pi\frac{d^2}{4}$

Be consistent with units, convert to meters before calculating to ensure the area is in m².

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Types of Conductor

Ohm's Law:

Ohm's law states that the **potential difference** across a component is **directly proportional** to the **current** through it, **under constant physical conditions**.

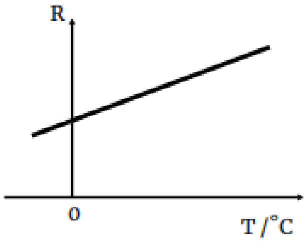
This can be expressed using the equation $V=IR$

Where R is the resistance in Ohms (Ω).

Effect of Temperature:

As temperature increases, resistance increases linearly.

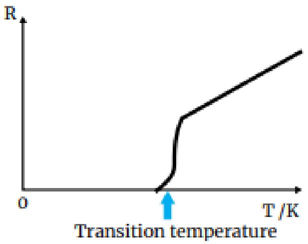
This heat energy causes the **ions to vibrate more** and therefore will cause more **frequent collisions** between the ions and electrons, increasing the resistance.



Superconductivity:

If you were to cool a metal, the resistance would decrease and following a linear pattern would reach 0Ω at -273°C or 0K. For most metals this is not the case.

When cooled the metal will reach its **transition temperature**, where its **resistance drops quickly to 0Ω**. This is superconductivity. For some metals this temperature is a few degrees above 0K, but for others **liquid nitrogen** can be used to cool the material enough to be superconducting. This is very useful in MRI scanners or particle accelerators as **very high currents can flow without any losses due to the heating effect of resistance**.

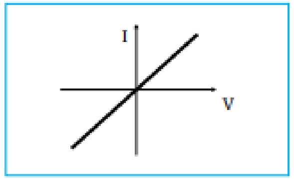


I—V Characteristics

I-V graphs:

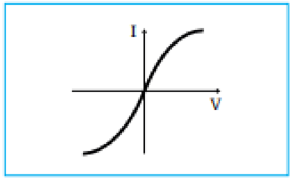
Investigating Ohm's law with different components will give you these graphs. It is important to remember the shape of each graph.

Resistor or wire
(At a constant temperature)



Constant resistance = obeys Ohms law

Filament lamp



Resistance increases at higher voltages

Doesn't obey Ohms law because the temperature of the lamp changes.

The resistance of each component at any point on the graph can be calculated using the gradient of the curve.

$$gradient = \frac{1}{R}$$

Conservation of Charge

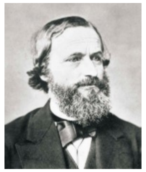
Kirchhoff's first law

The total current entering a junction = the total current leaving it.

Kirchhoff's second law:

The total e.m.f. around a series circuit = the sum of the p.d.s across each component.

This is Kirchhoff's second law in symbols:



$$\varepsilon = \Sigma IR$$

This symbol means 'sum of'.

Electromotive force (e.m.f.) and internal resistance

The total amount of work the battery does on each coulomb of charge is called its **electromotive force** or **e.m.f.** (ε). Be careful — e.m.f. isn't actually a force. It's measured in volts.

$$W = \varepsilon Q$$

W *= work done in joules (J)*
ε *= electromotive force (e.m.f.) in volts (V)*
Q *= charge in coulombs (C)*

Conservation of energy tells us for any electrical circuit:

energy per coulomb supplied by the source = energy per coulomb transferred in load resistance + energy per coulomb wasted in internal resistance

You'll get this equation for e.m.f. in the data and formulae booklet in the exam:

$$\varepsilon = I(R + r)$$

ε *= electromotive force (e.m.f.) in volts (V)*
R *= load resistance in ohms (Ω)*
I *= current in amperes (A)*
r *= internal resistance in ohms (Ω)*

Expanding the brackets of this equation gives: $\varepsilon = IR + Ir$

Then using the equation $V = IR$, you can substitute V and v for IR and Ir...

$$\varepsilon = V + v$$

V *= terminal p.d. in volts (V)*
v *= lost volts in volts (V)*

Rearranging the equation gives the equation for terminal p.d...

$$V = \varepsilon - v$$

And re-substituting v for Ir gives...

$$\varepsilon = V + Ir$$

E.m.f. in series

$$\varepsilon_{total} = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots$$

E.m.f. in parallel

$$\varepsilon_{total} = \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \ldots$$

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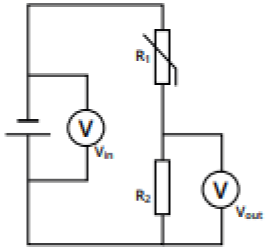
The Potential Divider

Potential dividers:

Potential divider circuits are used when a certain output potential difference is required.

The equation to calculate the output voltage is:

$$\frac{V}{V_{total}}\left[or\ \frac{V_{OUT}}{V_{IN}}\right]=\frac{R}{R_{total}}$$



Where V is the **output voltage across the resistor R**, in the example above R_2.

These circuits often contain thermistors or LDRs and as such the **total resistance can change**. Remember V_{in} doesn't change, so if the **resistance changes the current will also change**.

$$\frac{V_1}{V_2}=\frac{R_1}{R_2}$$

V_1 = p.d. across resistor 1 (in V)

V_2 = p.d. across resistor 2 (in V)

R_1 = resistance of resistor 1 (in Ω)

R_2 = resistance of resistor 2 (in Ω)

Domestic Electricity

To work out the cost of electricity you need to know how much you've used (in units) and the price of each unit. Then it's a simple matter of multiplying these two numbers together:

Cost = Number of units × Price per unit

Charges for this period

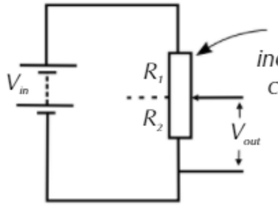
	Previous	Latest	Total
Electricity used	29 125	29 605	480
Unit charge			10.25p
Total for this period			**£49.20**

- The electricity used is given in units (kWh) on an electricity bill.
- The 'previous' value is the reading from the electricity meter in the customer's house from the last time they were billed.
  The 'latest' value is what the electricity meter currently says.
- The total is the difference between the previous and latest values — i.e. the total electricity used in this time.
- The unit charge is the price of one unit of electricity.
- The total cost is found by multiplying the number of units used by the price per unit — 480 × 10.25 = 4920 p or £49.20.

Potentiometers

Potentiometers

A potentiometer has a variable resistor replacing R_1 and R_2 of the potential divider (see Figure 5), but it uses the same idea. You move a slider or turn a knob to adjust the relative sizes of R_1 and R_2, which is useful when you want to change a voltage continuously, like in the volume control of a stereo.



Using a slider, R_1 can be increased or decreased, which changes the voltage out and effectively changes R_2.

Figure 5: *A potentiometer.*

Required Practical 4

Light and temperature sensors

PRACTICAL ACTIVITY GROUP 4

A light-dependent resistor (see p.160) has a very high resistance in the dark, but a lower resistance in the light. An NTC thermistor (page 160) has a high resistance at low temperatures, but a much lower resistance at high temperatures (it varies in the opposite way to a normal resistor and to a much greater extent). By using one of these components in a potential divider, your V_{out} can vary with light or heat, so it works as a light or heat sensor.

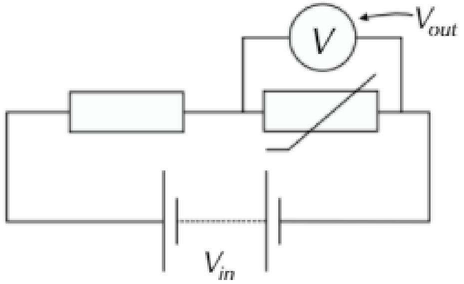


Figure 3: *A heat sensor circuit.*

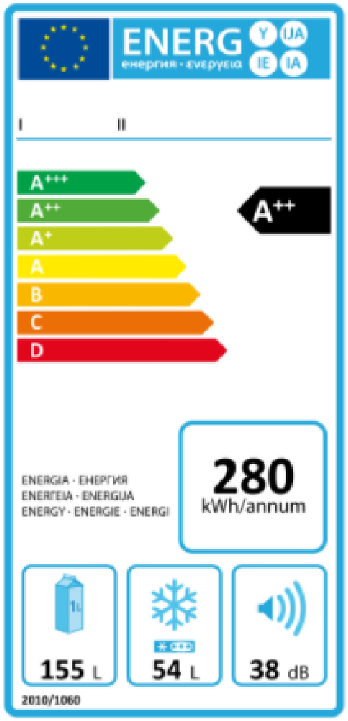


Figure 3: *Energy efficiency labelling, used for domestic appliances within the EU.*