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VCE Physics Unit 3

Area Of Study 2, Electronics And Photonics, Study Notes 1

Electricity is a form of **energy**. It comes from **electrons**. Electrons are tiny particles existing on the outside of the atoms from which all matter is constructed. Electrons are considered to have a **negative** “charge”. For every electron there is a **proton**. Protons are less tiny particles existing in the nuclei of the atoms from which all matter is constructed. Protons are considered to have a **positive** charge.

Materials

In terms of electricity, there are three kinds of materials.

- **Conductors** are materials through which the electrons can flow freely, without being firmly associated with any particular atomic nuclei.

- **Semiconductors** are materials which act as conductors in certain circumstances, such as when a particular amount of light, temperature or voltage (more on voltage later) act on the material.

- **Insulators** are materials through which electrons **cannot** flow freely. The electrons are firmly associated with the material’s atomic nuclei. Electrons can, however, be removed from or attached to the surface of these materials quite easily, usually by rubbing.

Static Electricity

This is electricity that’s not moving; static means **stationary**. Static electricity is contained, as **potential** or “stored” energy. Objects are statically “charged” either by having an excess or deficiency of electrons, meaning that their numbers of protons (positive charges) and electrons (negative charges) are not equal. This occurs through objects encountering contact with other objects and gaining or losing electrons to or from the respective surfaces.

- Too **many** electrons in an object = overall, or “net”, **negative** charge (because there’s more electrons than protons).
- Too **few** electrons in an object = overall, or “net”, **positive** charge (because there’s more protons than electrons).
- Two objects, one negative and the other positive, experience an **attractive** force; **opposite charges attract**.
- Two objects, both negative, experience a **repulsive** force; **like charges repel**.
- Two objects, both positive, experience a **repulsive** force; **like charges repel**.
- Two objects, one negative and the other neutral, experience an **attractive** force; negative objects “want” to give up their excess electrons.
- Two objects, one positive and the other neutral, experience an **attractive** force; positive objects “want” to gain the electrons they’re missing.

Whether a neutrally charged object has the tendency to gain electrons (acquire negative charge) or lose electrons (become positively charged) depends on the substance from which it’s made (the particular type of atoms and/or molecules) and the way in which articles are bonded together. There’s no empirical relationship between these variables, but the **triboelectric series** lists materials in order of their tendency to become positively charged, through to their tendency to become negatively charged.

Examples:
Static electricity is best demonstrated with insulators, because they don’t easily “lose” their charge to other objects with which they contact.

- A rubber balloon (inflated) rubbed against a woollen jumper. The wool loses electrons which the balloon gains. The balloon should then be attracted and “stick” to a neutral wall.
- Rayon or polyester fabric (cheap shirts are made from these) rubbed against glass. The glass loses electrons which the fabric gains. Light neutral objects (such as bean bag beans or small pieces of tissue paper) should be attracted to and “stick” to both the glass and the fabric.
- Nylon or silk fabric rubbed against acetate. The fabric loses electrons to the acetate. The acetate should then attract light neutral objects (such as bean bag beans or small pieces of tissue paper).

Charge

This is a measurable quantity of electricity. An amount electrical charge is measured in Coulomb, C.

- One electron has -1.6×10^{-19}C.

The negative sign indicates that the charge is negative, not that the charge is less than zero.

- $1C = (1.6 \times 10^{-19})^{-1} = 6.25 \times 10^{18}$ electrons

Current Electricity

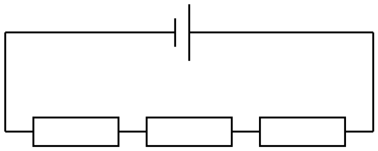
This is electricity that involves electrons **moving** through **conductors** (as opposed to static electricity, which involves electrons remaining fixed in insulators). This is useful, because it allows the energy of electrons to be converted into forms other than electricity, such as light, heat or motion.

Circuits

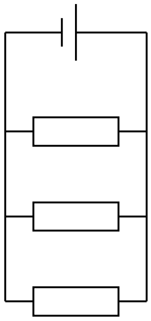
These are arrangements of conducting (and often also semiconducting) components and wires such that electrons can move from, and return to, a source (a battery, for example). Electrons are not lost, as they return to where they came from, but their energy is consumed as they move through the circuit.

There are two ways of connecting components to form circuits:

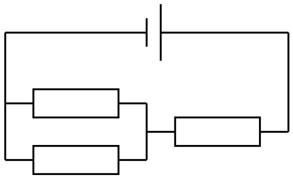
- In **series**, components are connected one after the other.

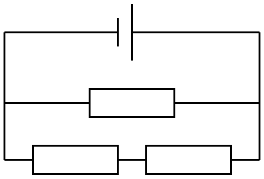


- In **parallel**, components are connected such that current passes through each simultaneously.



Most useful circuits are more complex than simply series or parallel configurations, and are actually a combination, where some sections can be considered as in series, and others in parallel.

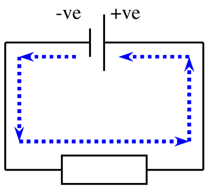




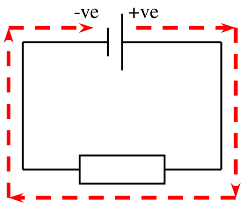
Current

This is the motion of electrons through a **circuit**. It can be considered in two ways.

- **Electron current** is the direction in which electrons, and hence negative charge actually moves in a circuit, from the negative terminal of a battery to the positive.



- **Conventional current** is the direction in which charge is **considered** to move in a circuit. Positive charge is thought of as moving from the positive terminal of a battery to the negative, in the opposite direction to electron current, even though positive charge comes from protons which actually have fixed positions and don't really move. Despite being an incorrect conceptualisation, **conventional current is how all current is always considered**.



Whether thought of as electron or conventional in terms of the direction, there are two methods by which current can move in a circuit.

- **Direct current**, DC. Charge moves only in one direction, through a circuit, from one end of a power supply to the other. This kind of current is usually powered by a battery.

- **Alternating current**, AC. Charge moves in only one direction at a time, but the direction is always changing, cycling back and forth. This kind of current is usually powered by a generator, and is the kind that is supplied by household power points.

Current is defined mathematically as an amount of charge moved per unit of time.

$$I = \frac{q}{t}$$

Where I = current, in Ampere, A
q = charge, in C
t = time, in s

Voltage

This is amount of energy supplied to each coulomb of charge. Mathematically, it is defined as the work done per unit of charge.

$$V = \frac{W}{q}$$

Where V = voltage, in V
W = work done (energy supplied), in J
q = charge, in C

Voltage is often referred to by other terms:

- Potential
- Potential difference
- Potential drop
- EMF, Electro Motive Force, ε

These other terms consider voltage from the perspectives of different points in a circuit. The point to remember is that each of these terms refers to an amount of voltage.

Peak Voltage And RMS Voltage

This is associated with alternating current (AC). Current and voltage are directly proportional (as explained by Ohm's Law, later in these notes). In a circuit, if current is alternating, and therefore cycling back and forth in direction, and up and down in magnitude, then voltage is cycling in the same way. This means that in an AC circuit voltage is **not** constant (because it varies linearly with a non constant current).

The **average** voltage occurring throughout each period of the AC cycle is called the **R**oot **M**ean **S**quare, or **RMS**, voltage. RMS is a mathematical method of averaging a cyclic variance.

The **maximum** voltage occurring throughout each period of the AC cycle is called the **peak** voltage.

$$V_{RMS} = \frac{V_{peak}}{\sqrt{2}}$$

$$V_{peak} = \sqrt{2} \times V_{RMS}$$

Where V_{RMS} = RMS voltage, in V
V_{peak} = peak voltage, in V

Resistance

This is the property of conductors and electronic components to restrict, "impede" and hence **resist** the flow of current. All conductors reduce current due to their resistance. Also due to their resistance, all conductors require an amount of energy to "push" current through them.

- The higher the resistance of an object, the more the current will be reduced.
- The higher the resistance of an object, the more the energy required to push current through.

Resistors are devices designed with specific amounts of resistance for controlling current and voltage in circuits.

Resistors In Series

To find the total resistance of a circuit containing resistors in series.

$$R_T = R_1 + R_2 + R_3 ..... + R_n$$

Where R_T = total resistance of circuit, in Ω
R_1 = first resistance, in Ω
R_2 = second resistance, in Ω
R_3 = third resistance, in Ω
etc.

Resistors In Parallel

To find the total resistance of a circuit containing resistors in parallel.

$$R_T = (R_1^{-1} + R_2^{-1} + R_3^{-1} ..... + R_n^{-1})^{-1}$$

Where R_T = total resistance of circuit, in Ω
R_1 = first resistance, in Ω
R_2 = second resistance, in Ω
R_3 = third resistance, in Ω
etc.

Ohm's Law

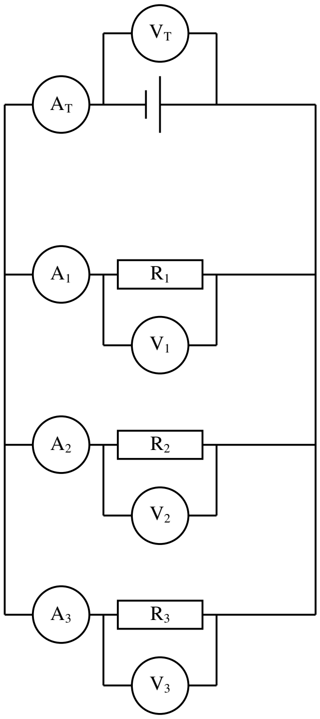
This relates resistance to both voltage and current.

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

Where R = resistance, in Ohm, Ω
V = voltage, in V
I = current, in A

Note that R would the gradient of a V/I graph, showing R to be the constant when resistance is fixed. Ohm's law does not apply to all electronic components.

Current Dividers And KCL



Parallel circuits act as **current dividers**. The total current is divided amongst each of the resistances, according to their value. **Voltage is equal** in all sections of the circuit.

$$I_T = I_1 + I_2 + I_3$$

Where I_T = total current, in A
I_1 = current at A_1, in A
I_2 = current at A_2, in A
I_3 = current at A_3, in A

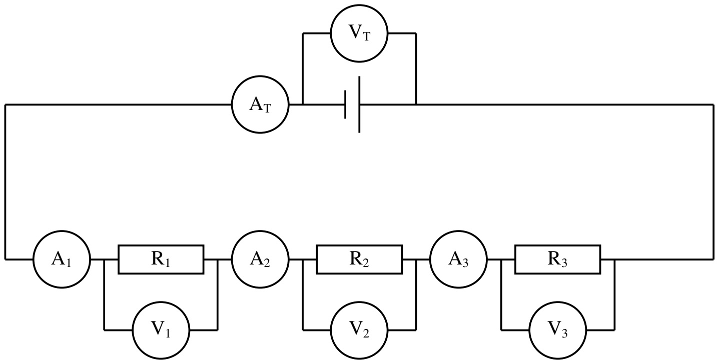
$$V_T = V_1 = V_2 = V_3$$

Where V_T = total voltage, in V
V_1 = voltage at V_1, in V
V_2 = voltage at V_2, in V
V_3 = voltage at V_3, in V

Kirchoff's Current Law (KCL) states that the current going into a circuit is equal to the current coming out. In the above example, current immediately after the positive terminal of the battery is equal to current immediately before the negative terminal, after having been divided among the resistances.

$$I_{in} = I_{out}$$

Voltage Dividers And KVL



Series circuits act as **voltage dividers**. The total voltage is divided amongst each of the resistances, according to their value. **Current is equal** in all sections of the circuit.

$$V_T = V_1 + V_2 + V_3$$

Where V_T = total voltage, in V
V_1 = voltage at V_1, in V
V_2 = voltage at V_2, in V
V_3 = voltage at V_3, in V

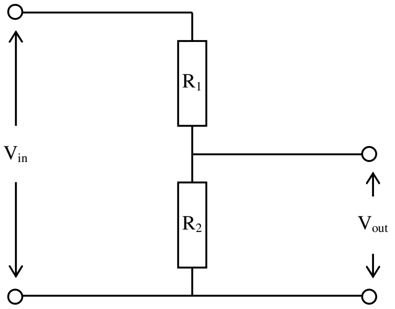
$$I_T = I_1 = I_2 = I_3$$

Where I_T = total current, in A
I_1 = current at A_1, in A
I_2 = current at A_2, in A
I_3 = current at A_3, in A

Kirchoff's Voltage Law (KVL) states that the sum of the voltages across each of the resistances is equal to the voltage supplied to the circuit.

$$V_{\text{supply}} = V_{R_1} + V_{R_2} + V_{R_3}$$

Voltage Dividers In More Detail



The nature of resistors in series is such that they're useful for dividing an amount of supplied ("input") voltage into a smaller specific amount of "output" voltage required for any particular electronic device. An example of this would be powering (or charging) a 3V iPod from a 12V car battery. The ratio between the output and input voltages is equal to the ratio between the resistance across which the output voltage is given (labelled as R_2) and the total resistance of the circuit.

$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_T} = \frac{R_2}{R_1 + R_2}$$

$V_{out} = \frac{V_{in}R_2}{R_T}$..............................re-arranging to make the subject V_{out}

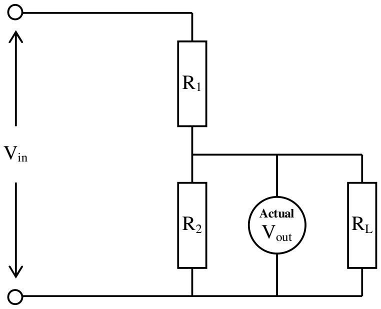
$V_{in} = \frac{V_{out}R_T}{R_2}$............................. re-arranging to make the subject V_{in}

$R_1 = \frac{V_{in}R_2}{V_{out}} - R_2$........................ re-arranging to make the subject R_1

$R_2 = \frac{V_{out}R_1}{V_{in} - V_{out}}$......................... re-arranging to make the subject R_2

Where V_{in} = input voltage, in V
V_{out} = output voltage, in V
R_1 = first resistance, in Ω
R_2 = second resistance, in Ω
R_T = total resistance, R_1+R_2, in Ω

Load Resistance, Effective Resistance And Actual Total Resistance And Output Voltage



All electronic devices have a circuit, and therefore their own total resistance. This resistance, when connected to the output voltage of a voltage dividing circuit, is called a **load resistance** (labelled as R_L), and can be considered as an extra resistor in the voltage dividing circuit.

The problem with voltage dividing circuits is that the load resistance of whatever kind of electronic device is connected to the output voltage is added in parallel to the resistance across which the output voltage is given (labelled as R_2). The **effective resistance** (R_E) of R_2 is therefore compromised, as is the **actual total resistance** (R_T) of the voltage dividing circuit.

Because $R_E \neq R_2$, the **actual output voltage** is different to that calculated without considering the effect of R_L on R_E and R_T.

$R_E = (R_2^{-1} + R_L^{-1})^{-1}$ .... Effective resistance of R_2, because R_2 is in parallel with R_L

$$\begin{aligned} \text{Actual } R_T &= R_1 + R_E \\ &= R_1 + (R_2^{-1} + R_L^{-1})^{-1} \end{aligned}$$

.... Actual R_T, because R_1 is in series with R_E

$$\text{Actual } V_{out} = \frac{V_{in} R_E}{R_{T,\ Actual}}$$

.... Actual V_{out}, substituting R_E for R_2

$$= \frac{V_{in}(R_2^{-1} + R_L^{-1})^{-1}}{R_1 + (R_2^{-1} + R_L^{-1})^{-1}}$$

Where V_{in} = input voltage, in V
V_{out} = output voltage, in V
R_1 = first resistance, in Ω
R_2 = second resistance, in Ω
R_L = load resistance, in Ω
R_E = effective resistance (of R_2 and R_L in parallel), in Ω
R_T = total resistance (considering R_E), in Ω

Power

By definition, power is the rate at which work is done; the change in energy per unit of time. Because voltage is an amount of energy per unit of charge, and current is an amount of charge per unit of time, electrical power is equal to the product of voltage and current. Arrangements of Ohm's Law can then be substituted for voltage or current to show power in terms of resistance.

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

$$= VI$$

$= I^2R$.......... substituting IR (from Ohm's Law) for V and simplifying

$= \frac{V^2}{R}$.......... substituting $\frac{V}{R}$ (from Ohm's Law) for I and simplifying

Where P = power, in Watts, W
E = energy, in Joules, J
t = time, in seconds, s
V = voltage, in V
I = current, in A

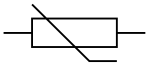
Danger ☠: Don't confuse the pronumeral W for work, with **W** for Watts, the unit of power.

Non Linear, Or Non Ohmic, Resistors

Non Linear resistors exhibit a relationship between the voltage across and the current through them that is **not directly proportional**, and hence **not linear** when graphed. Ohm's Law therefore **does not** apply to these kinds of resistors, so these resistors are also referred to as "**non Ohmic**".

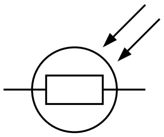
Often these kinds of resistors are made from semiconductive materials, so their resistance varies with certain conditions.

Thermistors, also known as **T**emperature **D**ependant **R**esistors (or TDRs) are non Ohmic resistors whose resistance varies (usually) logarithmically with temperature. Used as R_1 in a voltage dividing circuit, V_{out} changes with temperature. Normally, a thermistor's resistance decreases with increasing temperature.



- cold = high resistance
- hot = low resistance

Light **D**ependant **R**esistors (or **L**DRs) are non Ohmic resistors whose resistance varies (usually) logarithmically with light. Used as R_1 in a voltage dividing circuit, V_{out} changes with intensity of light. Normally, an LDR's resistance decreases with increasing intensity of light.



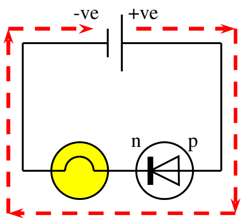
- dark = high resistance
- bright = low resistance

Diodes

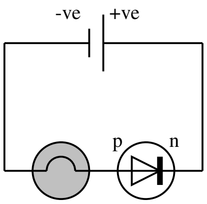
Considered most basically, a diode is an electronic component that allows current to pass in one direction but not the other. It conducts under certain conditions (direction of current), exhibiting semiconductive properties. An **ideal (theoretical) diode** acts as a switch, such that absolutely no current whatsoever passes in one direction, and current passing in the other direction encounters zero resistance.

A diode is said to be **forward biased** when connected to allow current to pass, and **reverse biased** when connected in the opposite direction to not allow current to pass.

A **practical (real) diode** typically operates such that a very small current (in the order of microamps, µA, generally negligible, called "leakage current") is able to pass when reverse biased. When forward biased with about **0.7V** across it, a practical diode conducts freely with very little (negligible) resistance.



Forward biasing.
Current flows,
light globe glows.



Reverse biasing.
No current flows,
light globe **doesn't** glow.

Diodes are usually made from silicon based materials. The silicon is "doped" with other elements, often boron or phosphorous, to create either an overall positive (**p-type**) material, with "electron holes", or an overall negative (**n-type**) material, with "spare electrons". P-type materials allow electrons to move through their electron holes, but don't have free electrons give away, while n-type materials have extra electrons that need to be given away. Where the two materials combine is called a **p-n junction**; this forms a diode, because when voltage is applied in one direction nothing happens, and when it's applied in the other direction current flows.

Light **E**mitting **D**iodes (or LEDs) are diodes that emit light when forward biased.