Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 19: Electrical and Electronic Principles

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Fundamental Electrical Quantities

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INTRODUCTION

Apply an understanding of fundamental electrical quantities to analyse simple circuits with constant voltages and currents.

Fundamental electrical quantities and concepts:

> **Charge, current, electric field, energy in an electrical context, potential, potential difference, resistance, electromotive force, conductors and insulators.**

Circuit laws:

> **Voltage sources, Ohm's law, resistors in series and parallel, the potential divider.**
>
> **Kirchhoff's and Thevenin's laws; superposition.**

Energy and power:

> **Transfer into the circuit through, for example, battery, solar panel or generator, and out of the circuit as heat or mechanical. Maximum power transfer.**

SIMULATOR DOWNLOADS

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1. Fundamental Electrical Quantities and Concepts

1.1 Charge

Electrical charge is a property of subatomic particles which can cause them to either attract or repel. Like charges repel and opposite charges attract. The electron is deemed to have a negative charge and the proton a positive charge. Not all subatomic particles contain a net charge; the neutron is an example (hence its name).

Electrical charge is given the symbol Q and is measured in Coulombs (C). When examining the electrical charge on an electron or proton it is found that they have the same magnitude of charge, 1.602×10^{-19} C. Since the electron is negatively charged it has a charge of -1.602×10^{-19} C and the proton, being positively charged, has a charge of $+1.602 \times 10^{-19}$ C. It is common to refer to the charge on an electron as '-e' and the charge on a proton as '+e'.

Atoms consist of electrons, protons and neutrons. Usually atoms have an overall charge of zero because they have equal numbers of electrons and protons. However, should an atom lose an electron (perhaps that electron has joined a neighbouring atom) then it will have a net positive charge of +e. You will discover more on this topic when reading workbook 3 for this unit.

1.2 Current

Electrical current in a wire is due to the flow of electrons through the wire. Since electrons are negatively charged they will flow towards a positive destination (perhaps the positive terminal of a battery).

Before electricity and current were properly understood (in the early 1800's) it was wrongly deemed that electrical current flowed from positive to negative. Unfortunately, this convention has stuck around to the present day, and is known as 'conventional current'. You will see conventional current marked on circuit diagrams with an arrow.

To put a figure onto electrical current we must consider how many electrons pass a certain point within 1 second. Put another way, electrical current (I) is given by the number of electrons which have passed by, divided by 1 second…

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

If we now find the reciprocal of the charge on the electron (i.e. 1 over e) we can determine how many electrons need to pass by a point in one second in order to register 1 Amp…

$$1\ Amp = \frac{1}{1.602 \times 10^{19}} \equiv 6.2 \times 10^{18}\ electrons$$

That a lot of electrons; around 6 billion billion electrons per second passing a point within a 1 second timeframe is equivalent to 1 Amp (1 A).

1.3 Electric Field

Since electrons and protons have charge, they produce electric fields. Electric fields are measured in Volts per Metre ($V.m^{-1}$). It is the electric fields emanating from electrons and protons which give rise to the forces of attraction and repulsion between them.

In workbook 2 you will learn that an electric field can also be caused by a varying magnetic field.

1.4 Energy in an Electrical Context

Since the flow of electrons provides a current, and current gives rise to energy, it therefore follows that electrical energy can result from field influences between charges. There is a potential (expectation) that energy will be produced when charges come into close contact.

1.5 Potential and Potential Difference

Electric potential is the amount of work done in moving a unit charge (e) from infinity to a given point in an electric field. A good analogy is the potential for water to flow down from a tap once the tap is opened.

Potential difference is the amount of work done moving a point charge from a point of lower potential to a point of higher potential. There is a potential difference between the positive and negative terminals of a battery, so connecting these with a wire will result in the flow of electrons through the wire (and the battery).

1.6 Resistance

Resistance is the property of materials to block the flow of electrons to some extent. Some atoms have loosely bound outer orbital electrons and can give these up easily when subjected to an electric field (copper, gold for example). Some materials have tightly bound orbital electrons and don't give these up so easily in the presence of an electric field (rubber, ceramic for example).

If a potential difference (voltage) of 1 Volt is applied to a length of material, and, as a result, 1 Amp of current flows, the length of material is said to have a resistance of 1 Ohm (1 Ω).

1.7 Electromotive Force

Electromotive force (e.m.f) is the electrical intensity developed across a device such as a battery, solar cell or generator. It can be considered to be a form of electrical pump which can provide charge (electrons) to circuits, and is measured in Volts.

1.8 Conductors and Insulators

As indicated in section 1.6 above, the nature of a materials' atoms and their orbital outer electrons will dictate the ability of a material to conduct electricity. Conductors have very low resistance, such as silver, iron, copper, gold and mercury, but insulators have very high resistance, such as glass, rubber, Teflon and ceramic.

2. Circuit laws

2.1 Voltage Sources

An *ideal* voltage source (no such thing exists) will deliver a *fixed* voltage across two terminals, regardless of the circuit/load it is delivering the voltage to. In the real world, a voltage source will have a finite internal resistance, so the voltage it delivers will be dependent upon the nature (resistance) of the load. For example, a battery has a finite internal resistance, thus limiting the amount of current it is able to deliver, even if a short (wire) is placed across it (NEVER try this; the battery may explode). Also, very importantly, note; there is no such thing as a short circuit, because even a tiny piece of wire across a battery has some resistance (albeit small).

Of course, batteries are chemical devices, and rely upon human-devised chemical interactions to function. A solar cell can also be considered to be a voltage source – after all, every bit of useful light energy on the earth comes from the Sun. Also, you the reader, are made up of stardust; all of your atoms and energy came from our host star.

The Sun is powerful, yes, but it is not infinitely powerful. If you were to gather all of the energy of the Sun into a battery and place a short circuit across it, you would still not be able to achieve an infinite current (even at absolute zero temperature – for all of you superconductor devotees). Now then, you electrical engineers, listen good, because this point about the finite capacity of an energy (or voltage) source is **infinitely important in your studies of electrical engineering**. There is no such thing as an ideal voltage or current (Norton) source. You heard it here first! However, they are useful concepts when designing circuits, so you must keep them in your designer's box of tricks.

Sometimes you may have heard of voltages being produced by placing rods of different metals inside fruits – a chemical fact. All fruits contain energy, and all this energy was gathered by the fruit as it sunbathed!

2.2 Ohm's Law

I think this was the very first thing I learned in my early studies, and with good reason. It tells us about the relationship between voltage, current and resistance in DC circuits (when considering AC circuits, the topic is somewhat more complicated, but the relationship still holds good once we also consider the frequency involved).

As a student, I was the given the option of learning Ohm's Law via repetition (what an insult), or by fancy triangles (which you may have heard of). I wanted understanding, not poetry, so, after a few decades of getting a feel for Ohm's Law I'd like to present it to you in a nice simple way which you will hopefully never forget…