Technical Aspects

Fundamental theory

2A1

Understand that the flow of electrons is an electric current.

Recall that a conductor allows electrons to flow easily and that an insulator does not.

Recall that metals such as copper and brass are good conductors, as is carbon. Plastics, rubber, glass and ceramics are regarded as insulators.

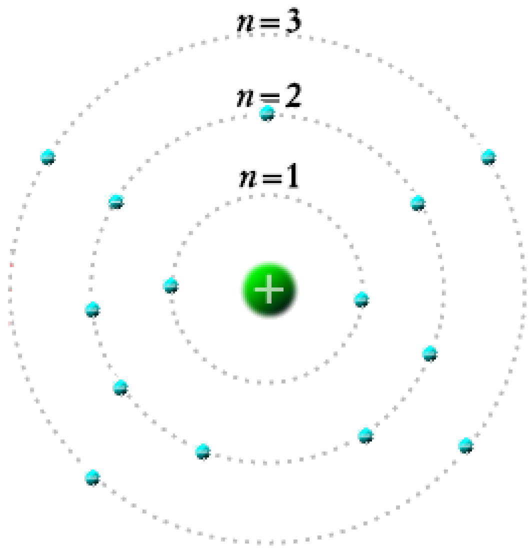
Recall that current can flow across wet insulators.

Recall that the unit of electric current is the Ampere (Amp).

Recall that the unit of electrical potential is the Volt.

All materials are made up of atoms. In elements such as Copper, Gold, Silver or Mercury all of these atoms are identical, in compounds or alloys such as Brass different types of atoms are present.

An atom can be visualised like the solar system. At the centre is a positively charged nucleus containing protons and, usually, neutrons. Orbiting this positively charged nucleus are negatively charged electrons.



In some materials, the outermost electrons are only loosely bound to the central nucleus and the addition of an electrical potential can induce the outermost electrons to move from atom to neighbouring atom resulting in current flowing through the material.

Materials, where the electrons can be induced into moving to neighbouring atoms, are referred to as **conductors**, materials, where the outer electrons are more strongly bound to the nucleus and cannot be induced to move to neighbouring atoms, are referred to as **insulators**.

Conductors	Insulators
<u>All</u> Metals (e.g. Copper, Brass, Gold, Mercury) Carbon	Plastics Rubber Glass Ceramics

The usefulness of conductive materials is plain, without materials that are able to conduct electricity or permit electrons to transfer between atoms there would be no possibility of making electrical circuits. It is perhaps less clear that Insulators are equally valuable as without these materials it would be impossible to separate conducting materials or construct safe enclosures.

The individual properties of different insulators make them useful in different circumstances:

- Ceramic & Glass – high voltage insulators, e.g. at the end of wire aerials because high RF voltages are present when transmitting
- Rubber & Plastic – to cover wires and cables
- Polythene and PTFE – to insulate the centre conductor of coaxial cable, coaxial plugs and sockets
- Plastics – to encase integrated circuits
- Fibreglass – the base material of many printed circuits

Water does conduct electricity. Its natural fluid state makes it less useful than a solid such as Copper but it is important when considering conductive materials, not least because the human body is on average 60% water making us a conductor.

Wet conditions can create situations where it is possible for Voltages and Currents to be present on the outside of wet insulators such as at the end of antenna wires.

In wet conditions **take care**.

Current (I) is measured in Amps or more accurately Amperes abbreviated A and named after André-Marie Ampère (20/01/1775 - 10/06/1836) a French mathematician and physicist who was one of the founders of the science of classical electromagnetism.

Electrical potential (V) or the force that encourages the electrons to move through a conductor is measured in Volts abbreviated V and named after the Italian physicist Alessandro Volta (18/02/1745 - 05/03/1824) who is credited with the invention of the electric battery although you would be hard-pressed to see the link between his Voltaic Pile in 1799 and the current range of Duracell, Varta or Ever Ready (other brands are available) batteries!

In electronics and electrical work it is not uncommon for values to be large; for example power lines often operate at 11,000V, 33,000V and higher. Equally, values can be small, it is not uncommon for some circuits to operate with currents as small as 0.005A. To simplify these large or small values the SI units use prefixes such as micro, milli, kilo, Mega and Giga and you need to be familiar with these and their application to units such as the Amp and the Volt already discussed but also other units such as Frequency (Hertz - Hz), Power (Watt - W), length (metre - m) and mass (gramme - g).

Table 1 - SI Prefixes				
Prefix	**Symbol**	**Scale**	**Multiplier**	**$x10^n$**
micro	µ	Millionth	0.000001	$x10^{-6}$
milli	m	Thousandth	0.001	$x10^{-3}$
None	-	-	1	$x10^{0}$
kilo	k	Thousand	1,000	$x10^{3}$
Mega	M	Million	1,000,000	$x10^{6}$
Giga	G	Billion (US)	1,000,000,000	$x10^{9}$

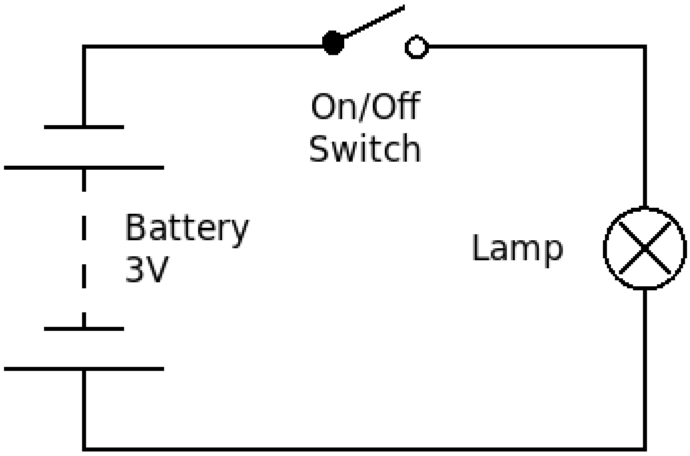
2A2

Recall that a circuit is needed to allow current to flow, and that circuit will include a source of electrical energy.

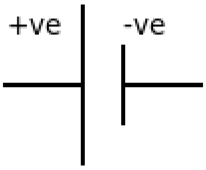
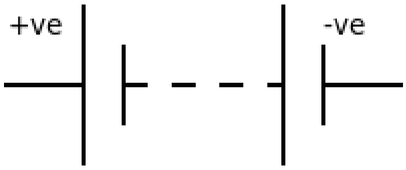
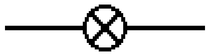
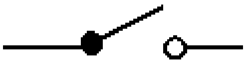
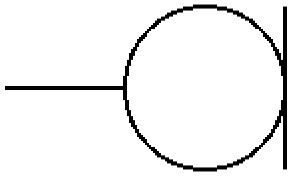
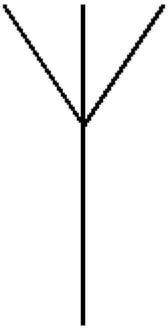
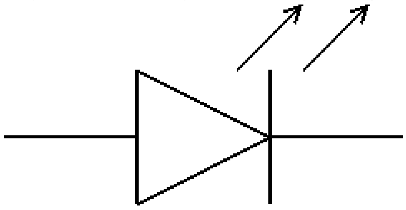
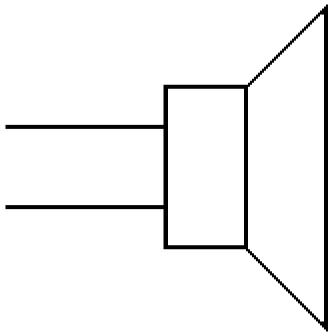
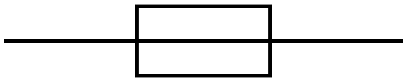
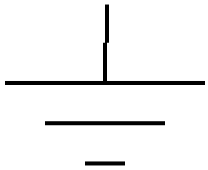
Recall that current in all parts of a series circuit has the same value.

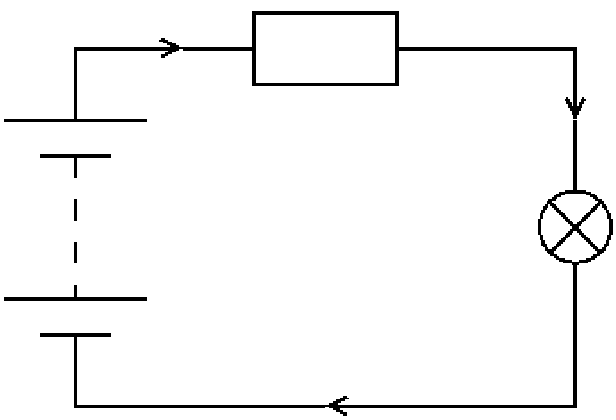
Recall that the potential differences across items in parallel are the same.

Every electrical circuit requires a source of energy, this could be: a generator, solar panel or wind turbine but is more likely to be a battery of some description or a power supply which takes mains voltages (typically 230V AC - more on this later) and transforms them into lower voltages (typically 13.8V DC - more on this later) suitable for use with typical radio equipment. The source of energy must be connected to the circuit with a complete and uninterrupted loop between the positive (+ve) and negative (-ve) poles or terminals of the energy source. The circuit diagram below shows a typical torch with a battery providing the source of energy and the switch being used to complete the circuit and turn the lamp on/off as required by the user.

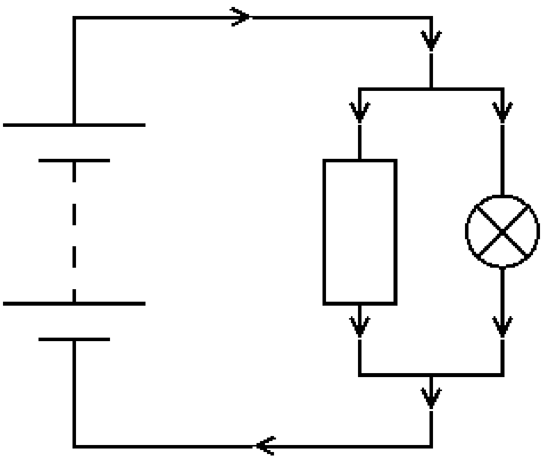


There is a range of components that we will mention and draw in simple circuit diagrams so now is the time to introduce these.

Cell 	Battery 	Lamp 
Switch 	Resistor 	Microphone 
Antenna 	Light Emitting Diode (LED) 	Speaker 
	Fuse 	Earth 



Series Circuit



Parallel Circuit

The circuit on the left is a SERIES circuit, the current flowing around the circuit has to pass first through the resistor and then through the lamp. The same amount of current passes through both the resistor and the lamp and the supply Voltage is the sum of the individual Voltages across each component

The circuit on the right is a PARALLEL circuit, the current divides and different amounts pass simultaneously through both the resistor and the lamp. The Voltage across both the resistor and the lamp is the same and the total current flowing in the circuit is the sum of the currents in each component.

Power

2B1

Recall that power is measured in Watts (W).

Recall that a current through a resistor results in conversion of electrical energy to heat energy in the resistor.

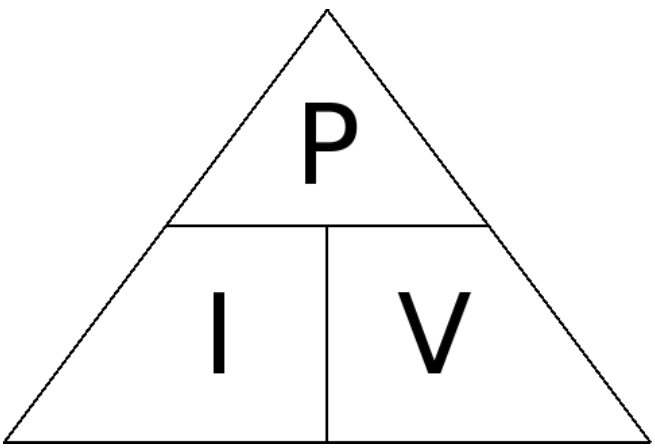
Understand that Power (Watts) in a circuit is the product of the Potential Difference (Voltage) and the Current (Amps) ie $P=V\times I$.

Calculate the unknown quantity given the numerical value of the other two.

Power (P) is measured in Watts, abbreviated W, named after James Watt (30/01/1736 - 25/08/1819) the Scottish mechanical engineer whose steam engine enhancements effectively ushered in the Industrial Revolution.

Current passing through a resistor creates heat in the resistor as electrical energy is converted into heat energy. Resistors have a power rating and it is important that the correct ratings are employed.

This is a variant of Joule's First Law developed by James Prescott Joule (24/12/1818 - 11/10/1889) an English physicist. There is a mnemonic triangle to assist in remembering the form of the equation and to ease the need to rearrange the formula to allow it to be used to determine any one of the three components (Power, Voltage or Current), this is shown below:



The technique for using this triangle is to mask or cover up the unknown quantity and what remains will identify the mathematical function required to determine the unknown or masked quantity.

If the remaining unmasked quantities are on the same line then the two quantities are multiplied together. If the remaining unmasked quantities are one above the other then the top quantity is divided by the bottom quantity or the bottom quantity is divided into the top quantity (which amounts to the same thing).

This is summarised as:

$P = I \times V$	$I = \frac{P}{V}$ or $I = P \div V$	$V = \frac{P}{I}$ or $V = P \div I$

Resistance

2C1

Understand that resistance is the property of a material that opposes the flow of electricity.

Recall that the unit of resistance is the Ohm (Ω).

Recall that the current (I) through a resistor (R) is proportional to the voltage (V) across that resistor.

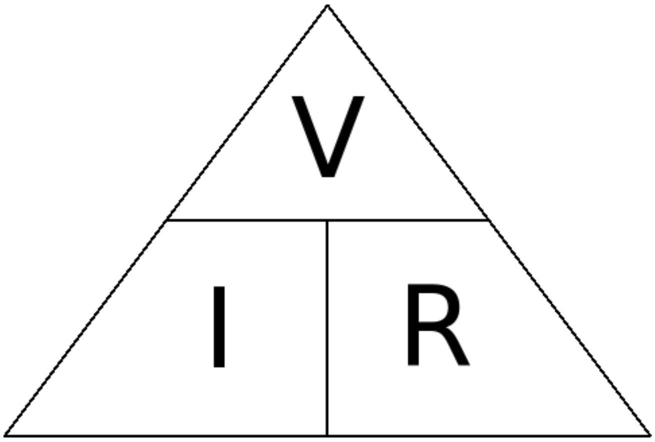
Use Ohm's law to calculate the value of any one of the three quantities (voltage V, current, I and resistance R) given the other two.

Understand that where a supply feeds more than one component or device the total current is the sum of the currents in the individual items when connected in parallel.

Whilst all components present some form of resistance, resistors are specifically designed to present a known amount of resistance and are used to limit current or to divide current.

Resistance (R) is measured in Ohms with the symbol Ω (the Greek letter Omega), named after Georg Simon Ohm (16/03/1789 – 06/07/1854) a German physicist and mathematician who developed Ohm's Law, the relationship between Voltage (V), Current (I) and Resistance (R).

This is Ohm's Law mentioned above. There is a mnemonic triangle to assist in remembering the form of the equation and to ease the need to rearrange the formula to allow it to be used to determine any one of the three components (Voltage, Current or resistance), this is shown below:



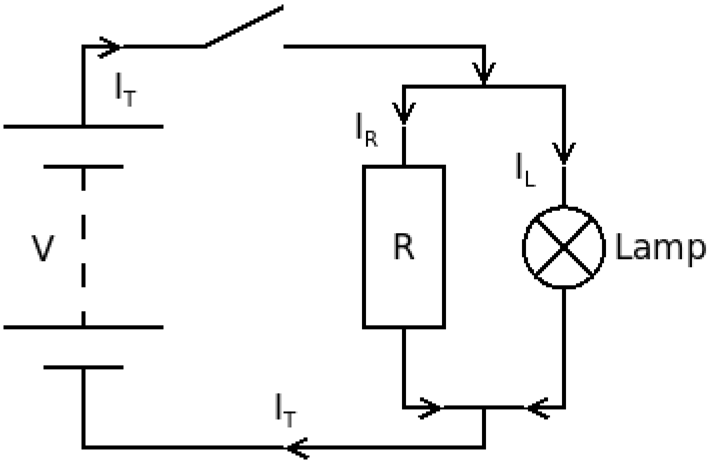
The technique for using this triangle is to mask or cover up the unknown quantity and what remains will identify the mathematical function required to determine the unknown or masked quantity.

If the remaining unmasked quantities are on the same line then the two quantities are multiplied together. If the remaining unmasked quantities are one above the other then the top quantity is divided by the bottom quantity or the bottom quantity is divided into the top quantity (which amounts to the same thing).

This is summarised as:

$V = I \times R$	$I = \frac{V}{R}$ or $I = V \div R$	$R = \frac{V}{I}$ or $R = V \div I$

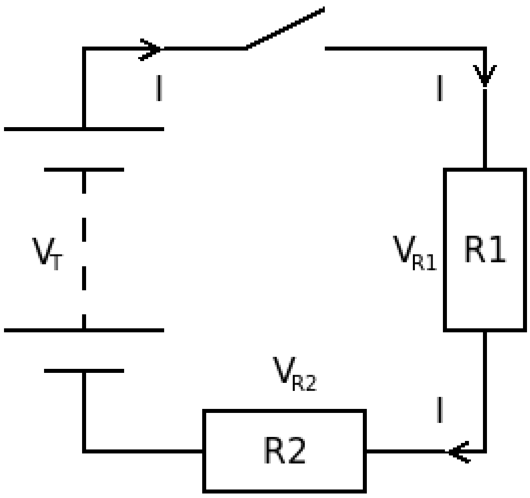
This applies in parallel circuits as we have previously mentioned:



$$I_T = I_R + I_L$$

2C2

Understand that the sum of the voltages across a number of resistors in series equals the supply voltage.

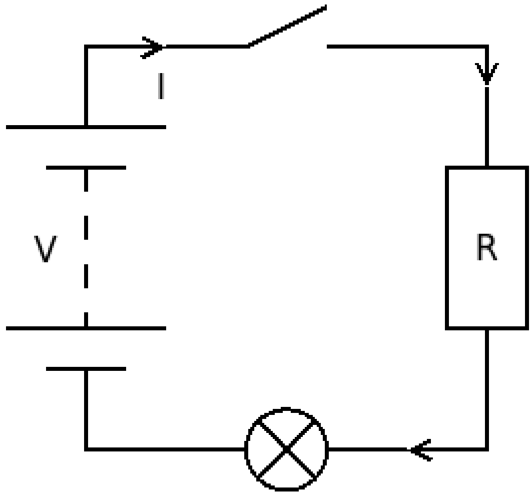


$$V_T = V_{R1} + V_{R2}$$

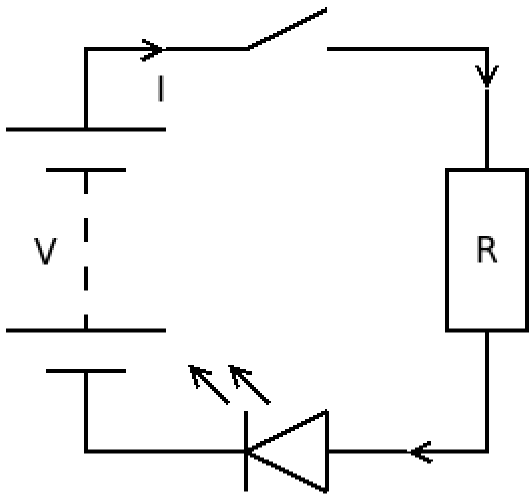
2C4

Recall that polarity must be correct for electronic circuits to function correctly, or damage may be caused.

Returning to the simple torch circuit examined previously; the polarity of the battery is not important, assuming a physical connection can be made then the circuit works equally well whether the current flows clockwise or anticlockwise around the circuit. None of the components are sensitive to polarity.



If the lamp is replaced by a Light Emitting Diode (LED) the situation changes. A LED only works in one direction and as such if the battery were accidentally inserted or connected the wrong way round the circuit would not operate as the current cannot flow through the LED in the wrong direction.



In this case, the result of connecting the battery with an opposite polarity (the wrong way round) is that the circuit fails to operate, there is little or no risk of actual damage. However more sophisticated circuits can be damaged by the application of a reverse polarity power source, so **observe the polarity**.

AC theory

2E1

Understand what is meant by Direct Current (DC) and Alternating Current (AC)

All of the circuits examined so far rely on a battery as a source of energy, a battery produces **direct current** (DC). This means that the current only flows in one direction. By contrast **alternating current** (AC) changes direction, flowing first one way and then the other. DC is most useful for powering our equipment but we must rely on AC to create a Radio Frequency (RF) signal. It is also easier to generate AC. The process of converting AC to DC is beyond the scope of this course but is well established and understood and is a component in all bench power supplies.

2E2

Identify the sine wave as a graphical representation of the rise and fall of an alternating current or voltage over time.

Recall the frequency of the mains supply: 50Hz.

Recall the range of frequencies for normal hearing: 20Hz - 15kHz.

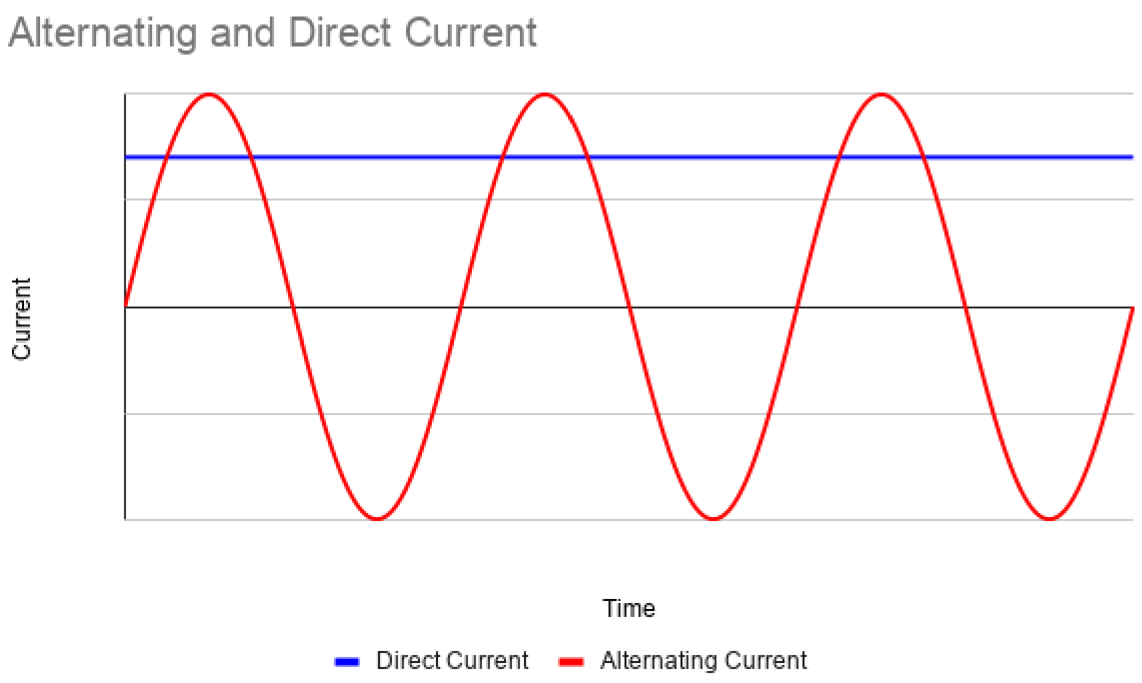
Recall the range of frequencies for audio communication: 300Hz - 3kHz.

Recall that radio frequencies can range from below 30kHz to beyond 3000MHz.

Recall the frequency bands for HF, VHF and UHF radio signals.

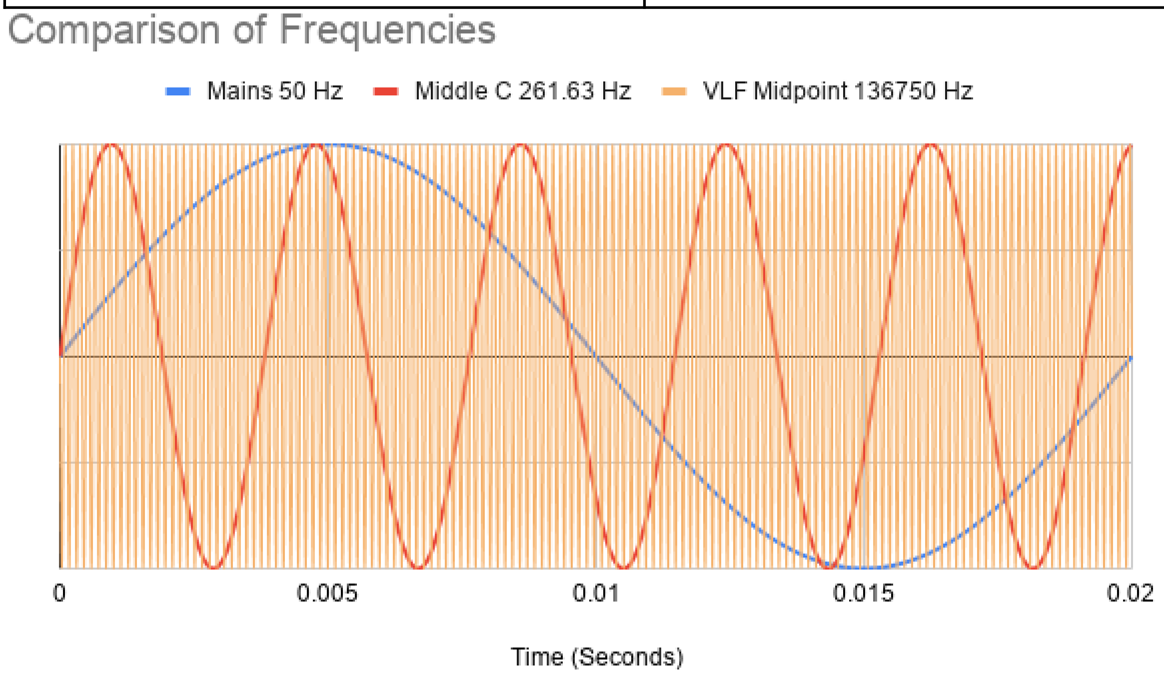
Understand the meaning of the abbreviations RF and AF

The diagram below shows a comparison of an alternating current and an equivalent direct current.



The alternating current from the mains supply looks similar to the oscillations of the air when an audio signal passes through it and this looks similar to a radio signal when viewed on a 'scope. The difference is the frequency of the oscillations. Typical frequency values are given in the table below, and the figure following the table shows a frequency comparison:

Table 2 - Typical Frequencies	
Source or Signal	**Typical Frequency or Frequency Range**
UK Mains Supply Alternating Current (AC)	50Hz
Typical Hearing Range	20Hz - 15kHz (15,000Hz)
Audio Frequencies in Amateur Transmissions	300Hz - 3kHz (3,000Hz)
Typical Radio Frequencies	Sub 30kHz (30,000Hz) - Above 3GHz (3,000,000,000Hz)
HF (High Frequency Spectrum)	3MHz (3,000,000Hz) - 30MHz (30,000,000Hz)
VHF (Very High Frequency Spectrum)	30MHz (30,000,000Hz) - 300MHz (300,000,000Hz)
UHF (Ultra High Frequency Spectrum)	300MHz (300,000,000Hz) - 3,000MHz (3,000,000,000Hz)



In the chart above the Mains signal and the Middle C signal are in the range of frequencies that can be heard, they are Audio Frequencies commonly abbreviated AF. The VLF signal is well above the range of frequencies that can be heard; it is in the range associated with Radio Frequencies commonly abbreviated RF.

2E7

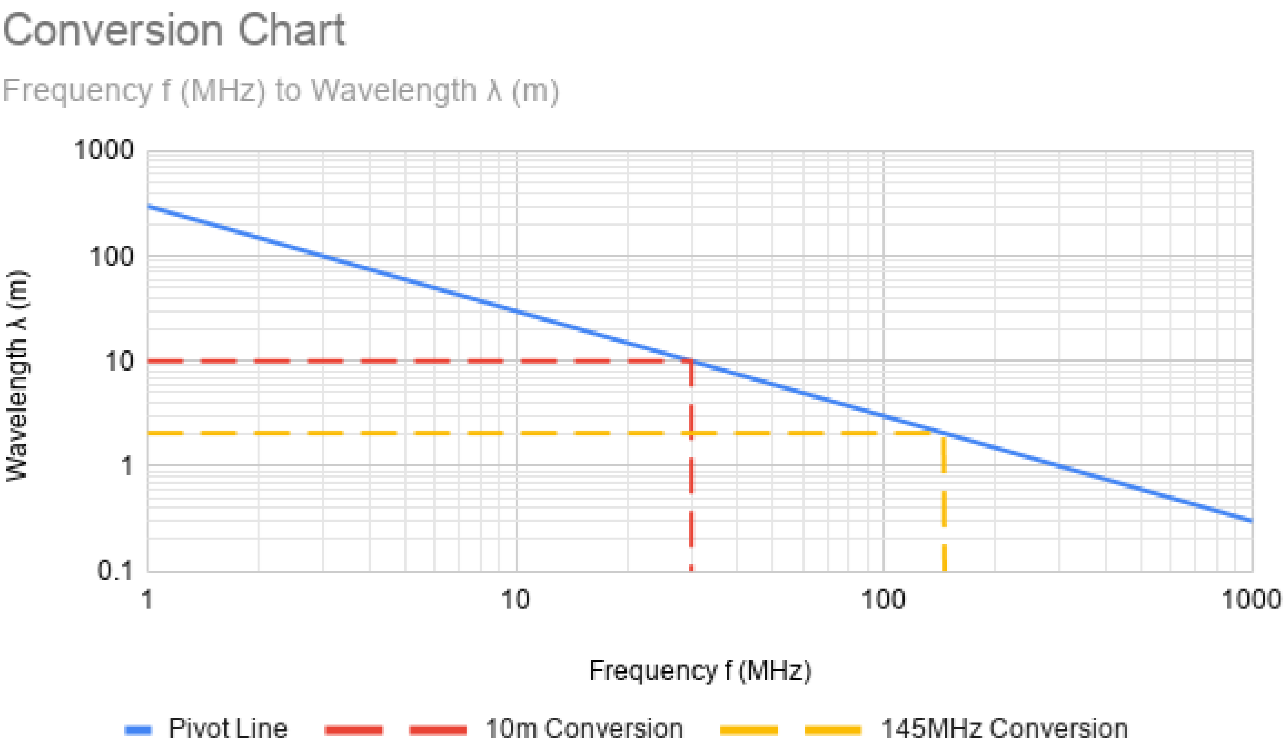
Understand the relationship between frequency (f) and wavelength (λ). Recall the units for frequency (Hz) and wavelength (m).

Both the f.λ graph and the velocity of radio waves will be given in the Reference Booklet.

The chart above shows another aspect of frequency. As the frequency rises so the length of the wave reduces. The Greek letter λ (Lambda) is used to denote or signify wavelength. Any given frequency has a corresponding wavelength and vice-versa and it is possible to convert from one to the other which is useful for the purposes of designing antennas. The readout or display on your radio will almost certainly be of frequency, yet to put up a resonant dipole (more on this in subsequent sections) the wavelength must be known.

Wavelength is measured in metres (or in the case of UHF and above bands in centimetres or even millimetres). Frequency is measured in Hertz named after Heinrich Rudolf Hertz (22/02/1857 - 01/01/1894), a German physicist who provided conclusive proof of the existence of electromagnetic waves, and is essentially the number of complete cycles of a wave in 1 second.

The chart below, which is provided in the exam, shows the relationship between frequency and wavelength and contains a couple of worked examples demonstrating how to use the chart.



As a couple of examples, consider the wavelength of 10m. To determine the frequency of a radio wave with a wavelength of 10m:

- First, locate 10m on the vertical axis (wavelength).
- Project this line horizontally to the right, until it reaches the blue conversion or pivot line.
- Once it reaches the conversion or pivot line, project it vertically downwards until it reaches the horizontal-axis (frequency).
- Read off the point on the horizontal axis (frequency) where the line meets the horizontal-axis (frequency), in this case, 30MHz. Note that the frequency is in MegaHertz (MHz)

Now consider the frequency of 144MHz. To determine the wavelength of a radio signal with the frequency of 144MHz:

- First, locate 144MHz on the horizontal axis (frequency). You will see that this is about half-way between 100MHz and the first division mark above (to the right of) 100MHz, which is 200MHz, where the orange dashed line starts.
- Project this line vertically upwards until it reaches the blue conversion or pivot line.
- Once it reaches the conversion or pivot line project it horizontally to the left until it reaches the vertical axis (wavelength)

- Read off the point on the vertical axis (wavelength) where the line meets the vertical axis (wavelength), in this case, 2m. Note that the wavelength is in metres (m)

A copy of this graph will be made available to all candidates in the exam but you will have to know how to use it.

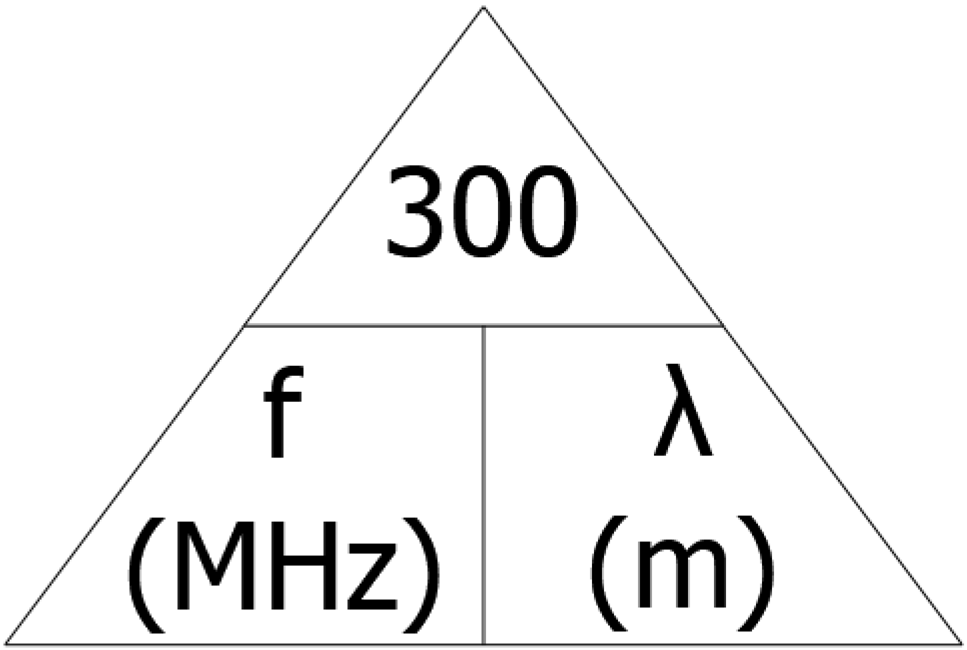
The above chart is produced from the equation for the relationship between frequency and wavelength which is:

$$v = f \times \lambda$$

In this equation:

- v = speed of light in a vacuum (generally approximated to 300,000,000m/s)
- f = frequency of the signal in Hertz (Hz)
- λ = wavelength in metres

To simplify this the speed of light can be reduced to 300 IF the frequency is entered in MegaHertz (MHz), a mnemonic triangle for this, which operates in the same way as the Ohms Law and Joules Law triangles that have been described previously.



The technique for using this triangle is to mask or cover up the unknown quantity and what remains will identify the mathematical function required to determine the unknown or masked quantity.

If the remaining unmasked quantities are on the same line then the two quantities are multiplied together. If the remaining unmasked quantities are one above the other then the top quantity is divided by the bottom quantity or the bottom quantity is divided into the top quantity (which amounts to the same thing).

This is summarised as:

$300 = f \times \lambda$	$f = \frac{300}{\lambda}$ or $f = 300 \div \lambda$	$\lambda = \frac{300}{f}$ or $\lambda = 300 \div f$

Frequency and wavelength are used interchangeably, the table below shows the accepted correlation between frequency and wavelength although some of these are not totally accurate:

Table 3 - Frequency and Wavelength of Amateur Bands	
Frequency Range	**Wavelength or Band**
1.810MHz - 2.000MHz	160m ("Top Band")
3.500MHz - 3.800MHz	80m
7.000MHz - 7.200MHz	40m
10.100MHz - 10.150MHz	30m
14.000MHz - 14.350MHz	20m
18.078MHz - 18.168MHz	17m
21.000MHz - 21.450MHz	15m
24.890MHz - 24.990MHz	12m
28.000MHz - 29.700MHz	10m
50.00MHz - 52.00MHz	6m
70.00MHz - 70.50MHz	4m
144.0MHz - 146.0MHz	2m
430.0MHz - 440.0MHz	70cm (0.7m)

Digital signals

2F1

Recall that analogue signals are constantly changing in amplitude, frequency or both.

Recall that digital signals are a stream of finite values at a specific sampling interval.

Recall that digital signals can be processed by a computing device with suitable software.

The signals shown so far are defined as **analogue** signals, they have constantly changing amplitudes which can adopt any value between 0 and some maximum level set by the system producing them.

By contrast, a **digital signal** is a series of discrete levels, typically 1 or 0, which offer greater resilience to interference and allow more complex processing.

Software Defined Radio, which will be covered in further sections, employs a computer (or tablet) with appropriate software to extract far more information than can be achieved by traditional analogue techniques.

2F2

Recall that an Analogue to Digital Converter (ADC) is a device used to sample an analogue signal and produce a digital representation of it.

Recall the meaning of the term ADC.

Recall that a computing device is required to process digital signals.

Recall that a Digital to Analogue Converter (DAC) is a device used to represent a digital signal in analogue format.

Recall the meaning of the term DAC.

By sampling an analogue signal it is possible to create a digital representation. This sampling takes place in an **Analogue to Digital Converter**, usually abbreviated to ADC. The resulting digital signal can then either be further processed or transmitted as a digital signal with more resilience to interference.

Once the analogue signal has been digitised it is processed through software running on a computer or tablet. It gives the ability to employ filters defined mathematically rather than by physical components and observe signals across a frequency range

A **digital to analogue converter** often abbreviated to DAC is the opposite of the ADC described above. It is employed to recreate an analogue signal from a digital stream. This could be receiving a digital signal off the air and converting it to allow processing in an analogue receiver, or it could be the creation of an analogue audio signal after digital processing and filtering within a software-defined receiver.

Cells and power supplies

2J1

Understand that a battery is a combination of cells (usually in series).

Recall that a battery provides electrical energy from stored chemical energy and has a Potential Difference across its terminals.

Recall that any unwanted battery must be properly disposed of.

Understand that a rechargeable (secondary) battery has a reversible chemical process.

All circuits require a power source or a source of energy. Whilst there are a number of possible sources the most common one is a battery. A battery is a group of cells, a typical cell has a potential difference (PD) of about 1.5V depending on the internal chemistry.

Linking cells together can increase the potential difference between the positive and negative terminal (connecting in series) or can increase the capacity and extend the duration of operation (connecting in parallel).

The internal chemistry stores energy which is released when a reaction takes place within the cell caused by the completion of the connection from positive to negative.

Typical Alkaline cells or batteries, e.g. Duracell, are not rechargeable, once exhausted they must be replaced and the exhausted cell or battery correctly disposed of.

Rechargeable cells have a reversible chemical reaction. When being used as a source of energy the reaction releases energy to the circuit until the chemical reaction has been completed. Unlike primary cells, the chemical reaction can be reversed by recharging the battery. Different chemistries have been used in rechargeable cells but typical ones are:

- Nickel-Cadmium (NiCad)
- Nickel Metal Hydride (NiMH or Mi-MH)
- Lithium-Ion (Li-Ion or LIB)
- Lithium Polymer (LiPo)
- Lithium Iron Phosphate (LiFePo)

The recharging process for some of these batteries needs to be carefully controlled.