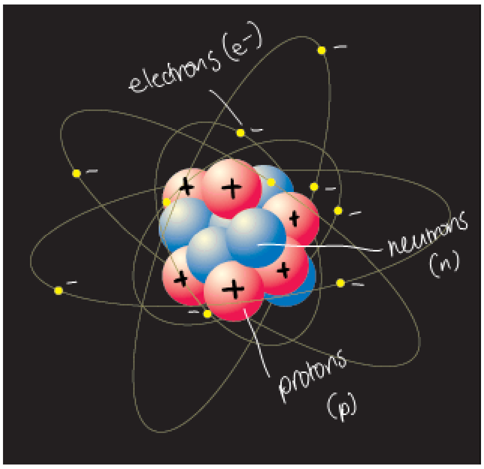
2.1 – The Atom

2.1.1 - State the position of protons, neutrons and electrons in the atom

Atoms are made up of a **nucleus** containing positively charged protons and neutral neutrons, with negatively charged electrons moving around the nucleus in shells.



2.1.2 - State the relative masses and relative charges of protons, neutrons and electrons

	Relative Mass	Relative Charge
Proton	1	1
Neutron	1	0
Electron	5×10^{-4}	-1

2.1.3 - Define the terms *mass number (A)*, *atomic number (Z)* and *isotopes an element*

Mass Number – **A** – Sum of the number of protons and neutrons in the nucleus

mass number = number of protons + number of neutrons

Atomic Number – **Z** – the number of protons in the nucleus. Since atoms are electrically neutral, the number of protons is also equal to the number of electrons.

Isotopes of an Element – Atoms of the same element with the same number of protons, but with a different number of neutrons

2.1.4 - Deduce the symbol for an isotope given its mass number and atomic number

$^{A}_{Z}X$ This is **nuclide notation**, which shows the mass number, atomic number and symbol to represent a particular isotope.

2.1.5 - Calculate the number of protons, neutrons and electrons in atoms and ions from the mass number, atomic number and charge

Protons

Find the atomic number. This is the number of protons

Neutrons

The difference between the mass number and the atomic number

$$\textit{number of neutrons} = \textit{mass number} - \textit{atomic number}$$

Electrons

If the atom is electrically neutral, then the number of electrons is equal to the number of protons.

In an ion, we take the number of protons, and then subtract the charge. For example:

$$(Al^{3+}) \quad n(e^-) = 13 - (+3) = 10$$

$$(Cl^-) \quad n(e^-) = 17 - (-1) = 18$$

2.1.6 - Compare the properties of the isotopes of an element

Chemical properties depend on their outer shell of electrons. Since they still have the same number of electrons, these properties will remain the same.

Physical properties depend on their nuclei. Since the number of neutrons changes, properties such as density, rate of diffusion, melting and boiling change.

The **mass** will also change.

2.1.7 - Discuss the uses of radioisotopes

Many isotopes are **radioactive** because the nuclei are more prone to breaking down spontaneously. Radiation is emitted when this happens. Radioisotopes can occur naturally or be man-made.

^{14}C *Carbon-14*

<u>Radiocarbon dating</u>

In living things, the isotope carbon-14 exists in a set ratio to carbon-12. When the organism dies, the carbon-14 decays, altering the ratio. This is used to estimate the age of the organism, called radiocarbon dating.

These isotopes are very penetrating and can be used to treat cancerous cells.

^{60}Co *Cobalt-60*

<u>Radiotherapy</u>

Cobalt-60, is a powerful **gamma** emitter, making it useful for the treatment of cancer. It has also been used in recent times to stop the immune response to transplanted organs in the body. It is also used in levelling devices and to sterilize foods and spices.

^{131}I *Iodine-131*

<u>Medical tracer</u>

Iodine-131 releases both **gamma** and **beta** radiation. It can treat thyroid cancer, and detect if the thyroid is functioning correctly. The thyroid will take up the iodine and then the radiation will kill part of it.

^{125}I

Iodine-125

<u>Medical tracer</u>

Iodine-125 is a gamma emitter, can treat prostate cancer and brain tumours. It is also taken up by the thyroid gland.

Radioactive cobalt and iodine are dangerous and there is some concern as to whether they could be used to do considerable damage with bombs.

^{241}Am *Americium-241*

This is artificially produced radioisotope used in smoke detectors and detects the presence of smoke or heat sources. These smoke detectors have ionisation chambers and are more effective than ones which detect change in light

Americium has a half-life of 432 years. It is also used as a thickness gauge in the glass industry. It is insoluble and so would simply pass through the body if swallowed. In a soluble form, the radiation of alpha and gamma rays would concentrate in the skeleton.

^{99}Tc *Technetium-99*

It is used in radiotherapy for cancer and studying metabolic processes. It emits low energy radiation, so can be administered in small doses.

2.2 – The Mass Spectrometer

2.2.1 - Describe and explain the operation of a mass spectrometer

Mass spectrometers are very complex, and are made up of a number of components, each of which performs a particular function. The principle behind it is that the movement of charged particles will be affected as they pass through the magnetic field. Their mass and their charge ($\frac{m}{z}$) ratio determines the degree to which the particles are deflected.

The operation of the mass spectrometer can be broken down into four stages:

Vaporisation - The sample is heated and vaporised, and passed through into an evacuated tube. This separates the particles

Ionisation - The atoms/molecules are then bombarded by a stream of high energy electrons, knocking electrons off the particles, resulting in ions with a 1+ charge (though in some cases 2+)

Acceleration - The positively charged ions are then accelerated along the tube by means of the attraction to negatively charged plates. The ions pass through the slits, which control the direction and velocity of their motion

Deflection - The ions are then passed into a very strong magnetic field, deflecting the ions in a curved path. In the case of a fixed size magnetic field, a lighter ion will be deflected more than a heavier one, and a 2+ ion will be deflected more than a 1+ one of the same mass.

The deflection of the ions depends on the mass/charge ratio

Modern mass spectrometers have a variable strength of magnetic field. The strength can be increased to deflect a heavier ion or one with a lower charge. This can be used when the ions are to be deflected to the same point.

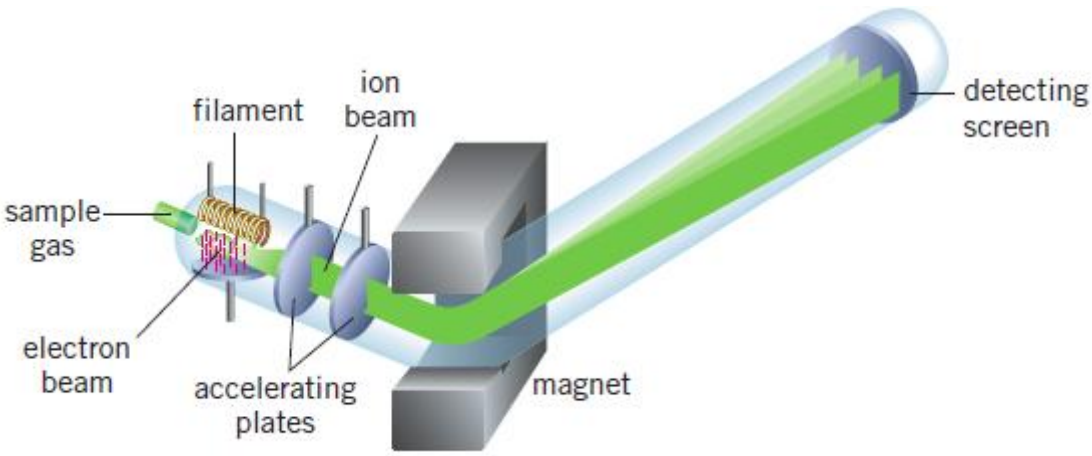
Detection - The ions are detected electronically by a device that measures both the location and the number of particles that collide with it.

Recording - The percentage abundance of the isotopes is recorded as a graph called a spectrum

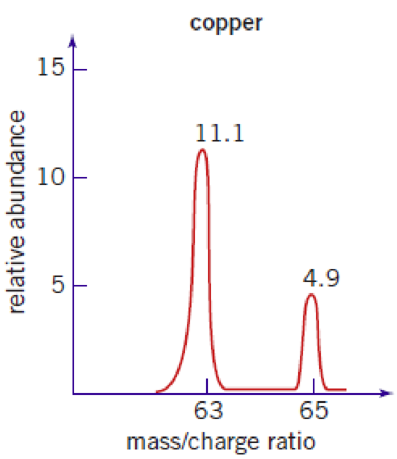
$$\frac{\textit{number of isotopes of a particular type}}{\textit{total number of particles in sample}} \times \frac{100}{1}$$

A peak is produced in the spectrum for each isotope. The peaks along the horizontal axis indicate the ratio:

$$\frac{\textit{mass of ion}}{\textit{charge on ion}}$$



The number of peaks recorded indicates the <u>number of isotopes</u> of the element present and their isotopic masses. The height of the peak indicates the abundance, a higher one meaning more. This is converted into the **percentage abundance** for the calculation of relative atomic mass. This is found by dividing the height of the particular peak by the sum of all the peaks.



$$\frac{11.1}{11.1 + 4.9} = \frac{11.1}{16.0} \times 100 = 69.4\%$$

$$\frac{4.9}{11.1 + 4.9} = \frac{4.9}{16.0} \times 100 = 30.6\%$$

2.2.2 - Describe how the mass spectrometer may be used to determine relative atomic mass using the 12C scale

To generate the relative scale of atomic masses, the carbon-12 isotope is assigned a relative mass of 12 units exactly. This is because carbon is cheap and widely available, it is easy to isolate and purify the isotope and it is in no way toxic. The mass of 12 was chosen to reflect the mass number.

So, the lightest of all elements (H) was found to have deflected 12 times further that carbon-12, while the magnesium-24 isotope deflects half as far. This is why hydrogen's relative mass is close to 1 and magnesium's is approximately 24.

These days, mass spectrometer are used in conjunction with nuclear magnetic resonance (NMR) or infrared (IR) spectrometers for the analysis of substances. The relative isotopic masses of all isotopes have been determined and are readily available

2.2.3 - Calculate non-integer relative atomic masses and abundance of isotopes from given data

The relative atomic mass of an element is the weighted mean of al its naturally occurring isotopes on the scale in which the carbon-12 isotope is 12 units exactly. Its symbol is Ar

To calculate the RAM, we multiply the relative isotopic mass (Ir) of the naturally occurring isotopes by their percentage abundance, then add these values.

$$A_r(X) = \frac{\sum(I_r \times abundance\ fraction)}{100}$$

Isotope	Relative Isotopic Mass	Percentage Abundance
^{24}Mg	23.99	78.70
^{25}Mg	24.99	10.13
^{26}Mg	25.98	11.17

$$A_r(Mg) = \frac{\sum(I_r \times \%\ abundance)}{100}$$

$$= \frac{23.99 \times 78.70}{100} + \frac{24.99 \times 10.13}{100} + \frac{25.98 \times 11.17}{100}$$

$$= 18.88 + 2.53 + 2.90$$

$$= 24.31$$

2.3 - Electron Arrangement

2.3.1 - Describe the electromagnetic spectrum

Light consists of **electromagnetic waves**. Electromagnetic waves can travel through space or matter. A wavelength is the distance between two successive crests. The velocity of travel, c, is related to its wavelength, λ and its frequency, f. The frequency is the number of waves passing a given point second.

$$c = \lambda \times f$$

$$(\text{m s}^{-1}) \quad (\text{m}) \quad (\text{s}^{-1})$$

This radiation is a form of energy. The energy of this radiation is related to its frequency, and Planck's constant

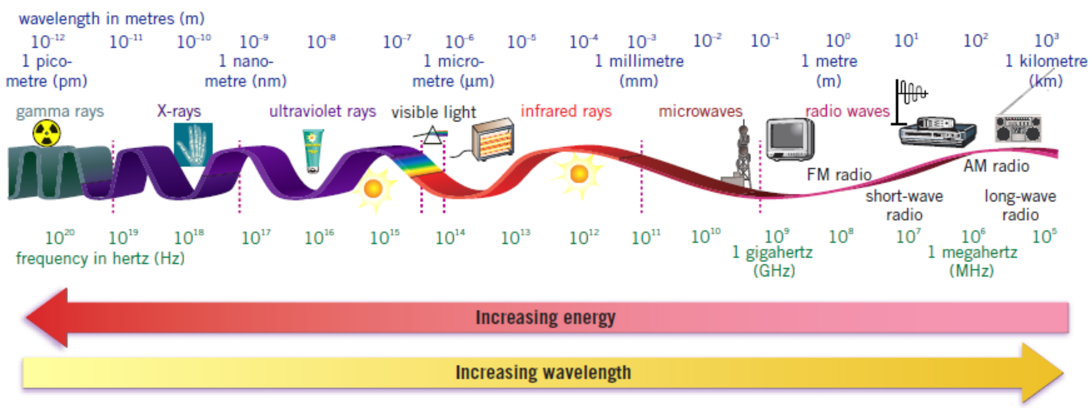
$$E = hf$$

h = Planck's constant

f = frequency

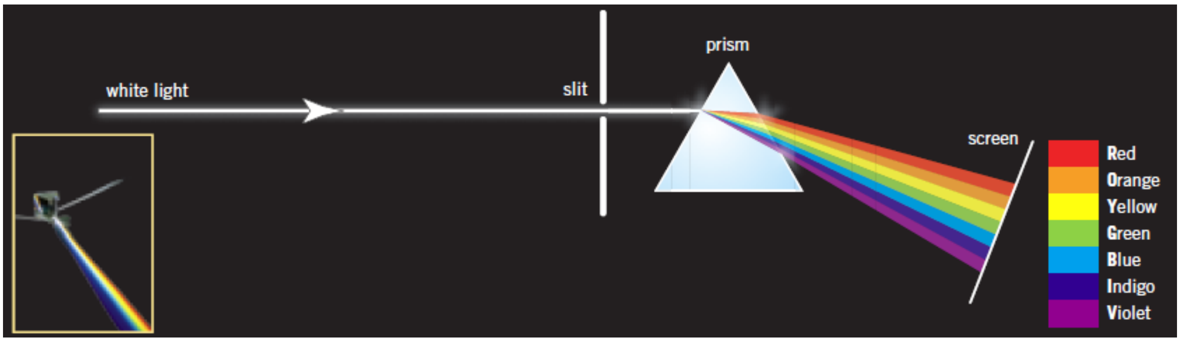
Energy is measured in **joules** and frequency is measured in s^{-1}, so Planck's constant has the unit of J s^{-1}. Its value is 6.63 x 10-34 J s^{-1}

A smaller wavelength has a higher frequency, and possesses more energy. Electromagnetic waves can have a wavelength from low-energy radio waves to very high-energy gamma radiation. Visible light is a narrow part of this spectrum.



As energy increases, so does the **frequency**. So, red light has lower energy than violet light. This is why ultraviolet light is so damaging to our skin, since high energy is more dangerous than low energy. The spectrum includes gamma rays, X-rays, ultraviolet rays, infrared, microwaves and radio waves. The infrared region contains waves with longer wavelengths than visible light.

Sunlight contains all the wavelengths of visible light, so when it passes through a prism, the different wavelengths are bent (or refracted) at different angles, breaking up the light into its components, producing a continuous spectrum of colours.



2.3.2 - Distinguish between a *continuous spectrum* and a *line spectrum*

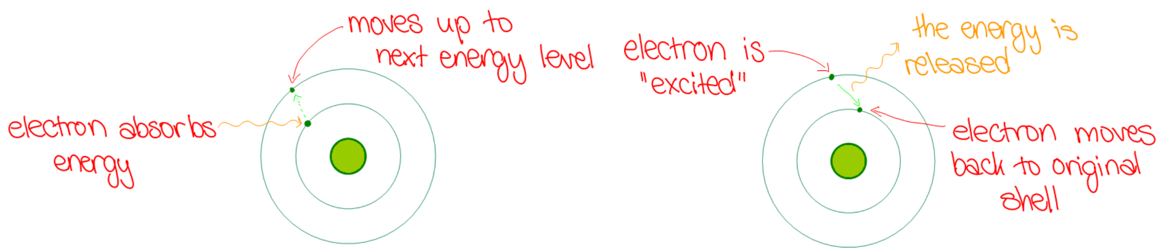
Line spectrum - a representation of light and appears as a series of discrete, coloured lines on a black background.

Continuous spectrum - a spectrum of light in which there are no gaps, so that each region blends directly into the next.

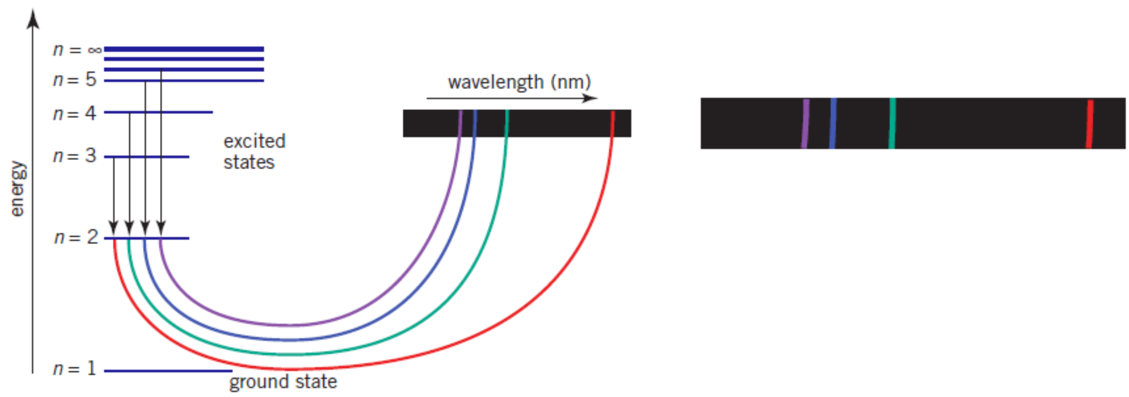
2.3.3 - Explain how the lines on the emission spectrum of hydrogen are related to electron energy levels

Emissions spectra are the emissions of light from atoms that have been provided with energy.

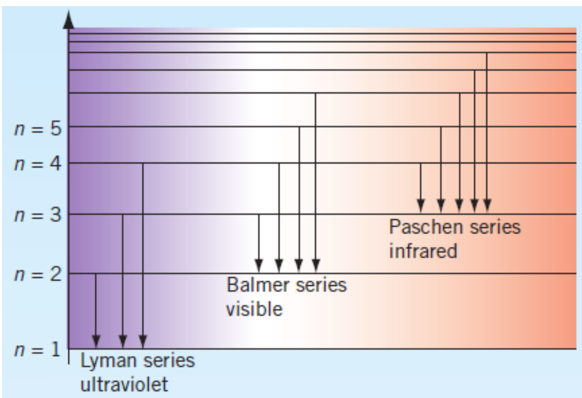
Bohr suggested that when atoms are provided with large amounts of energy, the electrons can **change energy levels**. The electrons jump to levels further from the nucleus than usual, and the atom is said to be excited. When the atom moves to ground state, the energy is released as light. The electrons will make specific jumps, depending on the ground states involved, so the light released has a specific wavelength. The light, a line (or emission) spectrum, looks like coloured lines on a black background. These emissions are not always visible to the naked eye. Studying these emissions is called **emission spectroscopy**



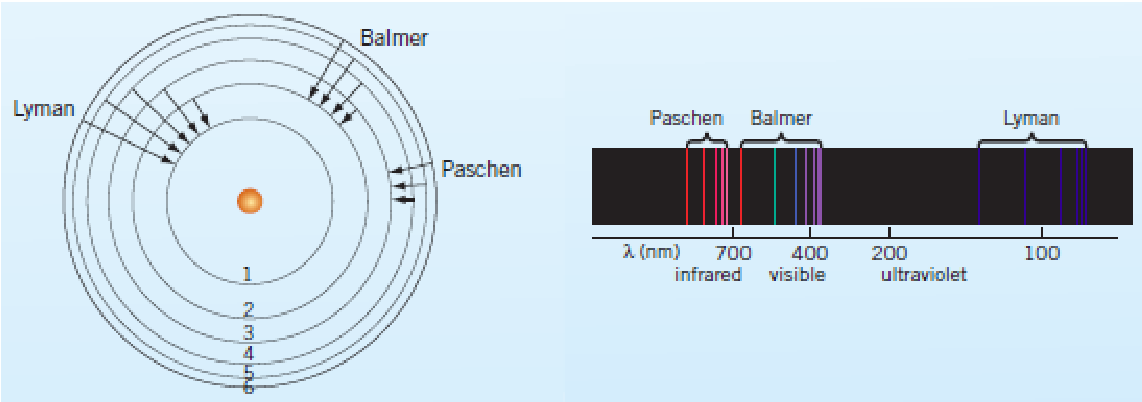
Bohr's model works the best for hydrogen.



It has been discovered that the energy of the lines on the continuous spectrum corresponds to the difference in energies between energy levels.



This all supports Bohr's theory of electron shells of specific energy. With each set of lines, the lines become closer to each other, or converge, as the wavelength decreases.



2.3.4 - Deduce the electron arrangement for atoms and ions up to Z = 20

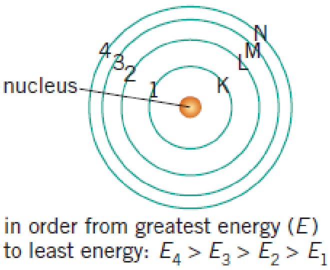
i.e. Z = 17 = 2,8,7

The electron arrangement or configuration for an atom or ion is written showing the electrons in order **from closest to the nucleus, outwards**. Each electron shell can hold a maximum of $2n^2$ electrons (n being the shell number)

The electron shells of an atom are also known as energy levels. The shells nearer the nucleus are of low energy levels, the ones further out being of higher energy levels. The shells are numbered from the nucleus (1, 2, 3...), or are identified by the letters K, L, M... Electrons move around the nucleus in these shells in pathways called orbits

The electron(s) in the outer shell of the atoms are called the **valence electrons**.

The lowest energy state of an atom is when all of the electrons are as close to the nucleus as possible, also known as its **ground state**.



Atoms may also be represented diagrammatically. In the Bohr model, the atom is drawn showing the protons, neutrons and electrons.

The electron arrangement of an ion will be different from its parent atom.