Arrangement of Electrons

Spectroscopy and the Bohr atom (1913)

- Spectroscopy, the study of the light emitted or absorbed by substances, has made a significant contribution towards our current understanding of atomic structure.
- The emission spectrum of hydrogen can be observed by passing an electric current through a sample of hydrogen gas.
- When viewed through a spectroscope it consists of a series of coloured lines against a black background.

Spectroscopy and the Bohr atom (1913)

- Rutherford's nuclear atom helped to explain the basis of the Periodic Table but it appeared to conflict with basic laws of physics:
  - why do the orbiting electrons fall to emit electromagnetic radiation?
  - why do they not lose energy and spiral into the nucleus?
  - why does the emission spectrum of hydrogen exhibit light of specific energies only?

Spectroscopy and the Bohr atom (1913)

- Niels Bohr suggested a model for hydrogen atom which accounted for these anomalies and the observed spectrum.
- He used an idea put forward by Max Planck and Albert Einstein in which electromagnetic radiation (e.g.light) consists of a stream of very small packets or quanta of energy called photons.
- These photons have properties which enable them to behave like particles and like waves:

Spectroscopy and the Bohr atom (1913)

– each line in the emission spectrum represents a specific amount of energy emitted by the hydrogen atom.
– the electron is able to move only in certain fixed orbits or energy levels.
– within one of these fixed orbits the energy of the electron does not change.
– when the electron moves into a higher energy level (further away from the nucleus) a fixed amount of energy is absorbed.

Spectroscopy and the Bohr atom (1913)

  - when the electron moves to a lower energy level (closer to the nucleus) a fixed amount of energy is released (as photons) which appears as a sharp line in emission spectrum.
- Since the electron can only change energy levels by specific amount it does not spiral into the nucleus.
- Each line in the emission spectrum of hydrogen represents an electron transition from a higher energy level to a lower energy level.

Spectroscopy and the Bohr atom (1913)

- The energy of the emitted photons corresponds to the difference in energy between the two levels.
- These ideas were extended and modified to account for the observed emission spectra of more complex atoms.

Using Bohr's ideas to explain the absorption spectrum of hydrogen

- The absorption spectrum of hydrogen appears as black lines against a coloured background.
- It is obtained when a beam of white light is passed through an atomised sample of hydrogen gas and then through a prism.
- The electrons in the hydrogen atoms become excited by absorbing energy in the form of photons of particular energies.

Using Bohr's ideas to explain the absorption spectrum of hydrogen

- Each black line corresponds to an electron transition from a lower energy level to a higher energy level.
- The energy of the absorbed photons corresponds to the difference in energy between the two levels.
- Thus the effect is a series of black lines against a coloured background.

Ionisation energies

- Further evidence concerning the arrangement of electrons in atoms was obtained by comparing the values of the successive ionisation energies of various atoms.
- The ionisation energy of an element is the minimum energy required to remove an electron from the ground state (lowest possible energy state) of an atom' in the gas phase.

Ionisation energies

- Note that the number of ionisation energies for an element is equal to its atomic number.
- Also note that the amount of energy required to remove successive electrons from an atom increases in a particular way.

Electron Shells

- Such measurements suggested that electrons in atoms are arranged in different energy levels or shells.
- Each shell can accomodate only a certain number of electrons.
- The energy associated with each shell increases as the distance from the nucleus increases:

Electron Shells

Shell number	Maximum number of electrons
1	2
2	8
3	18
4	32
n	$2n^2$

Electron Shells

- Hence, the maximum number of electrons allowed per shell is $2n^2$ where n is the shell number.

Modern Atomic Theory

- The quantum mechanical or wave mechanical model of the atom was developed during the 1920s and 1930s principally by Erwin Schrodinger and Werner Heisenberg.
- It is based on the mathematical interpretation of the behaviour of small particles such as the electron.

Modern Atomic Theory

- The principal features are:
  - Nearly all the mass of the atom is concentrated in a very small central nucleus consisting of protons and neutrons.
  - The electrons behave like clouds of negative charge and move in regions of space around the nucleus called orbitals.
  - Electrons within an atom occupy different energy levels which correspond to different regions of space

Modern Atomic Theory

– A main energy level is called a shell and has a principal quantum number, n.
– Each shell is further divided into subshells or sub-energy levels.
– The orbitals in a given shell have similar energies but may not be all of the same type.
– Each subshell has its own unique set of orbitals.

Arrangement of electrons in atoms

- The electronic configuration (or arrangement) of an element describes how the electrons of its atoms are distributed into shells, subshells and orbitals.
- It normally refers to atoms in the ground state or lowest possible energy state.
- The atom is said to be in an excited state if one or more of its electrons are not in their ground state.

Arrangement of electrons in atoms

- Electrons in their ground states occupy orbitals in order of increasing orbital energy levels.
- The principal quantum (shell) number (n) defines the main energy level. The shell is known by this number (n = 1,2,3,4 ...) or by the letters K, L, M, N ...
- A shell can accommodate a maximum of $2n^2$ electrons.

Arrangement of electrons in atoms

- Subshells are described by the letters s, p, d and f each of which has a characteristic shape and a different energy.
- The total number of orbitals in a shell is given by n^2
- The number of different types of subshell within a shell is given by n.

Arrangement of electrons in atoms

- There may be more than one orbital per subshell type. There is only one s-orbital but there can be three p-orbitals, five d-orbitals and seven f-orbitals
- Each orbital cannot accommodate more than two electrons. It can contain 0, 1 or 2 electrons - this is known as the Pauli Exclusion Principle.
- Subshell energy levels increase as follows:
  ls < 2s < 2p < 3s < 3p < 4s < 3d < 4p

Arrangement of electrons in atoms

- Note that the 3d subshell is higher in energy than the 4s subshell.
- This overlapping of subshells occurs more often as their energies increase.
- Electrons occupy subshells in the order shown above.
- The electron configuration for a hydrogen atom is its ground state is represented thus

$$1s^1$$