INTRODUCTION TO MODERN PHYSICS

ATOMIC MODELS

In the 18th and 19th centuries, many scientists attempted to explain the structure of the atom with the help of atomic models. Each of these models had its own merits and demerits and was pivotal to the development of the modern atomic model.

John Dalton's model

The first atomic Model is the John Dalton Model. John Dalton suggested that:

- every matter is made up of atoms.
- atoms are indivisible.
- atoms of the same element are same: specific elements have only one type of atom in them
- each atom has its own constant mass that varies from element to element.
- atoms undergo rearrangement during a chemical reaction.
- atoms can neither be created nor destroyed but can be transformed from one form to another.

Thomson Atomic Model

The second model was postulated by an English Chemist, Sir Joseph John Thomson after the discovery of electrons. He put forth his model describing the atomic structure in the early 1900s. Thomson described the `atomic structure as a positively charged sphere into which negatively charged electrons were embedded. This model is commonly referred to as the "plum pudding model" because it can be visualized as a plum pudding dish where the pudding describes the positively charged atom and the plum pieces describe the electrons.

Rutherford Atomic Model

Rutherford (a student of J. J. Thomson) modified the atomic structure with the discovery of another subatomic particle called "nucleus". His atomic model is based on the alpha ray scattering experiment from which he made the following deductions.

- Most part of the atom is an empty space

- The nucleus is at the centre of an atom, where most of the charge and mass is concentrated.
- The atom is spherical in shape.
- Electrons surround the nucleus of an atom
- Electrons revolve around the nucleus in a circular orbit, like the way planets orbit the sun. This model is also as the Planetary model.

If the electrons revolve with a high speed in circular paths/orbits, they will accelerate, expend energy, and eventually collapse into the nucleus.

Bohr's Atomic Model

After Ruther's model, Neils Bohr put forth his model of the atom in the year 1915. This is the most widely used atomic model to describe the atomic structure of an element. He postulated that the electrons inside atoms are placed in discrete orbits called "stationary orbits". Electrons revolve around the positively charged nucleus in a definite circular path called orbits or shell. A small nucleus surrounded by negative electrons moving around the nucleus in orbits. Electrons move in fixed orbitals shells not anywhere in between; each shell has a fixed energy. Electrons are located some distance away from the nucleus. The farther from the nucleus, the more energy, those closer, have less energy.

Summary of Bohr's theory:

- each orbit (orbital shell) has a fixed energy
- the energy levels of these shells can be represented via quantum numbers (n:1,2.3,4..K, L,M,N..)
- electrons can jump to higher levels by absorbing energy and move to lower energy levels by losing or emitting their energy.
- if an electron stays in its own stationary orbit, there will be no absorption or emission of energy.
- electrons revolve around the nucleus in these stationary orbits only.
- the energy of the stationary orbits is quantized.

ATOMIC STRUCTURE

All matter is composed of elements, while atoms are ultimate building blocks of all matter. Atoms are composed of three main subatomic particles namely, protons, neutrons and electrons.

The atomic structure of an element refers to the constitution of its nucleus and the arrangement of the electrons around it. The **protons and neutrons** make up the nucleus of the atom, which is surrounded by the electrons belonging to the atom (fig. 1).

Electron mass is about $9.109 \times 10^{-31} kg$ and has a negative electrical charge, proton mass is about $1.673 \times 10^{-27} kg$ (almost 2000 times greater than that of electron) and has a positive electrical charge, while neutrons mass is about $1.675 \times 10^{-27} kg$ but electrically neutral.

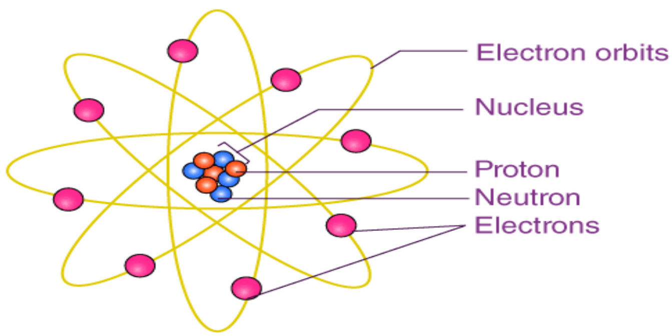

Fig 1. Structure of atom

The conclusion of some experiments in the 1910s is that the magnitude of positive charge in the nucleus of an atom of a particular element is number of protons in the atom. Different elements have different number of protons in their nuclei, number of protons characterises a particular element. The number of protons in the nucleus of an atom is called the **atomic number** (Z). Example atomic numbers for Hydrogen, Helium and Magnesium atoms are as 1, 2 and 12 respectively, which implies that they have 1, 2 and 12 protons in their respective nucleus. Neutral atoms have equal numbers of protons and electrons. The atomic number of an atom also gives the number of electrons in in atom. However, atoms may gain or lose electrons to increase their stability, and the resulting charged entity is called an ion.

Atoms of different elements have different atomic structures because they contain different number of protons, electrons, and neutrons. This is the reason for the unique characteristics of different elements.

ATOMIC ISOTOPES

Each element has a unique number of protons in it, which is described by its unique atomic number. However, several atomic structures of an element can exist, which differ in the total number of nucleons (Protons plus neutron). This is because same element can have different numbers of neutron. These variants of elements having a different nucleon number (also known as the **mass number A**) are called i**sotopes** of the element. Isotopes of an atom have the same number of protons but differ in the number of neutrons.

The atomic structure of an isotope is described with the chemical symbol of the element, the atomic number Z as a subscript and the mass number A as superscript of the element isotope. For example (fig. 2), there exist three naturally occurring isotopes of hydrogen, namely, protium, deuterium and tritium (${}^{1}H_1$,${}^{2}H_1$ and ${}^{3}H_1$). Isotopes generally have similar chemical behaviour since they hold the same electronic structure, but they vary in stability.

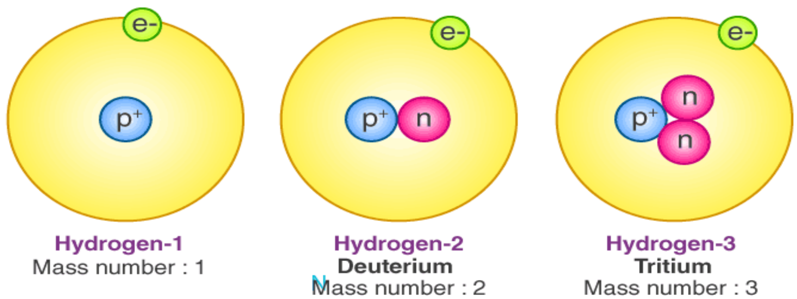

Fig 2. Isotopes of hydrogen

ARRANGEMENT OF ELECTRON (SHELL MODEL)

Electrons go round the nucleus at a certain distance so that their orbits formed shells. An electron shell is the outside part of an atom around the atomic nucleus. It is a group of atomic orbitals with same value of n. Electron shells have one or more electron subshells or sublevels. Each shell contains only a fixed number of electrons, and each shell is associated with a particular range of electron energy. Each inner shell must be completely filled before electron is added to an outer shell. The electrons in the outermost shell determine the chemical properties of the atom. Electrons in the outer shells (valence electrons) have higher energy and determine how atoms behave chemically and as a conductor. Valence electrons like other electrons, can absorb or release energy in the form of photon. Energy gain can cause an electron to jump to an outer shell (atomic excitation) or break free from it shell (ionization +ve ion). If an electron loses energy, it moves to an inner shell causing a photon to be emitted.

The number of valence electrons can be determined by the periodic table group in which the elements is categorized.

ATOMIC ABSORPTION AND EMISSION

The electrons in an atom tend to be arranged in such a way that the energy of the atom is as low as possible. The **ground state** of an atom is the lowest energy state of the atom (fig 3). When those atoms are given energy, the electrons absorb the energy and move to a higher energy level. These energy levels of the electrons in atoms are quantized, meaning, that the electron must move from one energy level to another in discrete steps rather than continuously.

An **excited state** of an atom is a state where its potential energy is higher than the ground state. An atom in the excited state is not stable. When it returns to the ground state, it releases the energy that it had previously gained often in the form of electromagnetic radiation or heat.

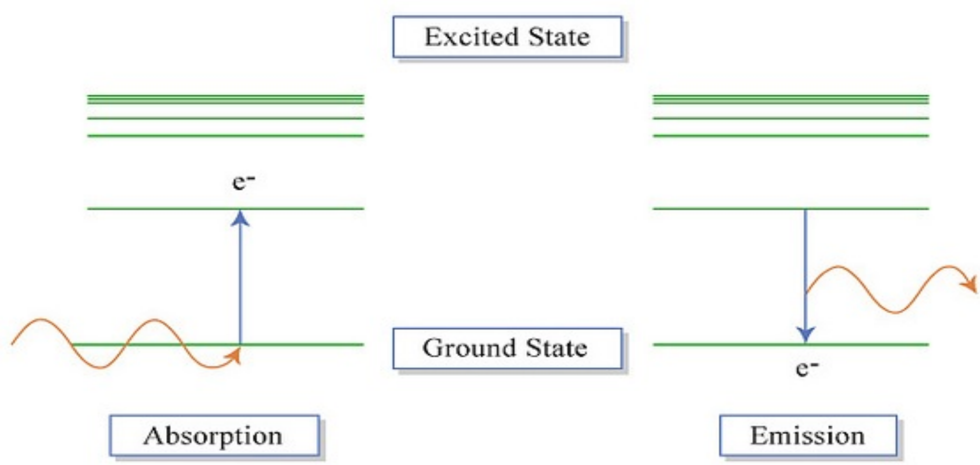

Fig 3. Absorption and emission of photon

ATOMIC SPECTRA

We have seen from Bohr's theory that in an atom, electrons have discrete and specific energies. When an electron transitions from one energy level to a lower energy level, it emits light or photon with a specific wavelength. The collection of all these specific wavelengths of the atom in each set of conditions like pressure, temperature, etc is the atomic spectra of atoms.

Atomic spectra can be defined as the spectrum of the electromagnetic radiation emitted or absorbed by an electron during transitions between different energy levels within an atom.

There are three types of atomic spectra, and they are emission spectra, absorption spectra, and continuous spectra.

Continuous Spectrum contains all wavelengths of light in a certain range, stars emit continuous spectrum of light the broad band emitted depends on its temperature.

Emission Spectrum: light can heat up a cloud of gas exciting the molecules within the gas and causing it to emit light. The spectrum of light that a cloud of gas emits depends on its temperature, density and composition. An emission spectrum consists of a series of coloured lines that corresponds wavelengths emitted by the glowing gas.

Absorption Spectrum

When starlight passes through a cloud of gas, some of the light is absorbed and some transmitted through the gas. The wavelengths of the light that is absorbed depends on the elements and compound it is made of. An absorption spectrum has dark lines or gaps in the spectrum corresponding to wavelengths that are absorbed by the gas.

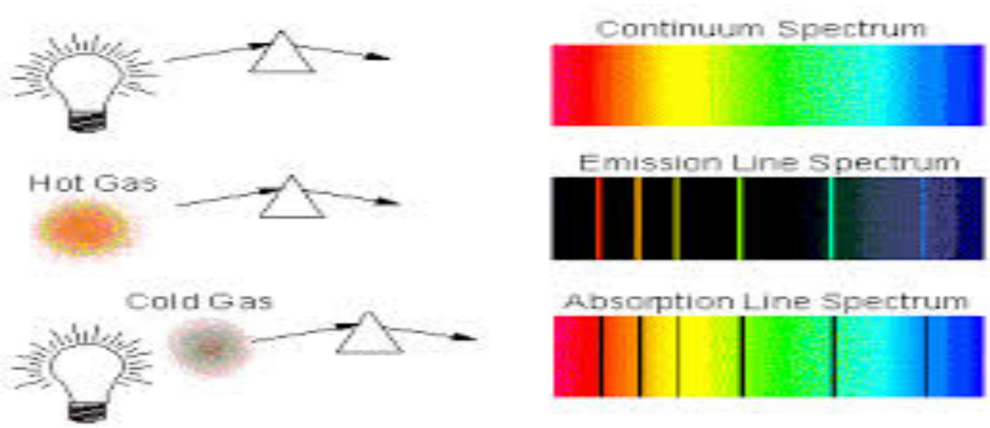

Fig 4 Atomic Spectra

Atoms can gain energy to induce these transitions from various sources. Gases can be excited with the use of electrical current. The atoms in each of noble gases produce distinctive colours that can be used to identify the elements. Each of the species of gases contains a different number of electrons that can undergo different types of excitations. In turn, each gas produces a signature colour.

Flames can also be utilized to excite atoms. Metal chlorides are directly placed into a flame. The intense heat will promote the metal's electrons to an excited state. Upon emission, this extra energy is released in the form of visible light. If a reference panel is provided, the flame colour can be used to identify a metal atom.

ATOMIC SPECTROSCOPY

Atomic spectroscopy is the study of the electromagnetic radiation absorbed or emitted by atoms. There are three types of atomic spectroscopy, and they are:

- **Atomic emission spectroscopy (AES)**: This involves the principle of energy transfer as atoms transit to ground state from an excited state. Excited atoms emit light at characteristic wavelengths as they return to a lower energy state. Application: Environmental samples, metallurgical analysis, biological tissues.
- **Atomic absorption spectroscopy**: For absorption to take place there should be identical energy differences between the lower and higher energy levels. The atomic absorption spectroscopy principle uses the fact that the free electrons generated in an atomizer can absorb radiation at a specific frequency corresponding to electronic transitions. It quantifies the absorption of ground-state atoms in the gaseous state. Application: Heavy metal analysis in water, blood, food.
- **Atomic fluorescence spectroscopy**: Atoms absorb radiation and re-emit it (fluorescence). This is a combination of atomic emission and atomic absorption as it involves radiation of both excitation and de-excitation. Application: Trace analysis of elements like mercury, arsenic, selenium.

CATHODE RAY

Cathode rays are stream of electrons leaving the negative electrode (cathode) in a discharge tube containing a gas at low pressure - electrons emitted by a heated filament in certain electron tubes. These discharge tubes are devices that control the electric current between a potential difference applied to the electrodes in a high vacuum. Cathode rays or streams of electron particles are quite easy to produce, this is because electrons orbit nucleus of every atom and move from atom to atom as electric current. When cathode rays strike certain molecules used to coat a cathode screen, they cause the molecules to emit light. A glow behind the positive electrode (cathode) can be observed when a potential difference (voltage) is applied to the electrodes. The electrons emitted from the cathode is what causes this glow.

Properties of cathode rays

These are some properties of cathode rays:

they are negatively charged,

they travel in a straight route, and

they ionise the gas inside the tube.

Cathode Ray Tube

The cathode ray tube (CRT) was invented in 1897 by the German physicist Karl Ferdinand Braun, is an evacuated glass envelope containing an electron gun a source of electrons and a fluorescent light, usually with internal or external means to accelerate and redirect the electrons.

CRT were previously called gas discharge tubes or Crookes tubes (named after William Crookes whose experiments showed the earliest direct signs of electrons and their charge.

Cathode ray tubes consist of an evacuated glass with two metal electrodes and rarefied gas within the glass. When a potential difference (voltage) is applied across the electrodes, electrons emitted begin to move from the cathode towards the anode and accelerate inside the gas due to the high potential difference. These electrons excite the gas atoms, leading to the emission of electromagnetic radiation. As a result, the route of the electrons becomes visible.

A cathode-ray tube (CRT) is as a specialized vacuum tube in which images are produced when electrons beam strikes a phosphorescent surface. An electron beam, deflected by applied electric or magnetic fields, produces a trace on a fluorescent screen. The electron beam is deflected and modulated in a manner that allows an image to appear on the projector. The function of such cathode ray tube in this case is the conversion of an electrical signal into a visual display.

In a cathode ray tube, when the accelerated electrons hit the far end of the tube, they give up all the energy they carry due to their speed, and this is changed to other forms such as heat.

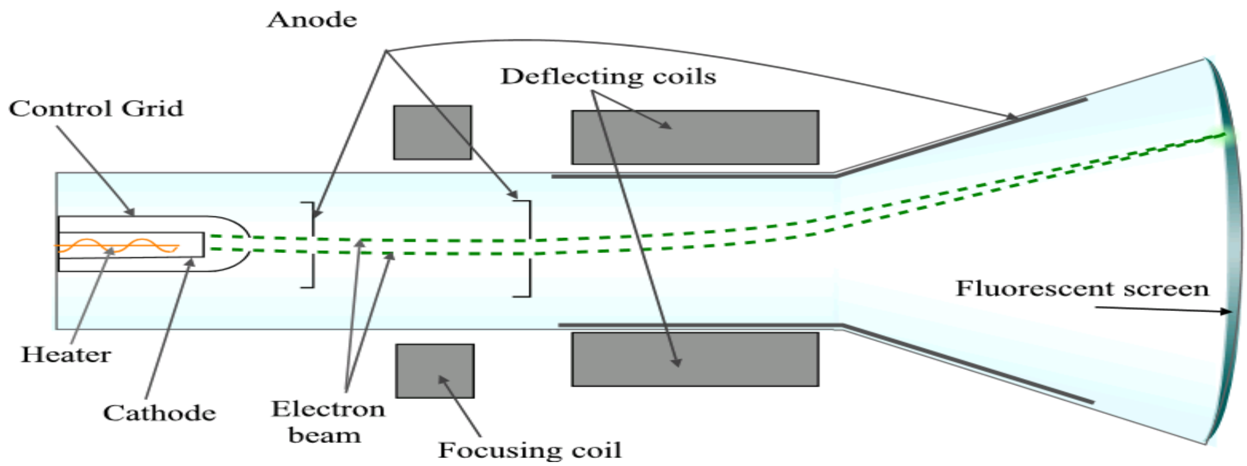

Fig 5. Coolidge tube

A Coolidge tube (Fig. 5) consists of cathode which generates an arrow beam of electrons. Deflecting coils produce an extremely low frequency electromagnetic field that allows for constant adjustment of the direction of the electron beam. The intensity of the beam can be varied. The electron beam produces a tiny, bright visible spot when it strikes the phosphor-coated screen. Light is produced when electrons hit a fluorescent tube. This effect, when coupled with the controlled deflection of a cathode ray by electric or magnetic fields, gives rise to the cathode-ray oscilloscope (cathode-ray tube [CRT]) for monitoring variations and values of an alternating voltage or current and to the picture tube of television and computer monitor and echoes of radar-detected aircraft, and so on. Cathode rays focused on a hard target (anticathode) produce X-rays, when focused on a small object in a vacuum. Cathode ray can generate very high temperatures (cathode-ray furnace).

X-rays

X-rays were discovered by Wilhelm Conrad Röntgen a German scientist, in 1895. He named it X-radiation to signify an unknown type of radiation. X-rays are electromagnetic radiation with short wavelength.

Production and properties of X-ray

There are three common mechanisms to produce X-rays: the acceleration of a charged particle (Coolidge tube), atomic transitions between discrete energy levels, and the radioactive decay of some atomic nuclei.

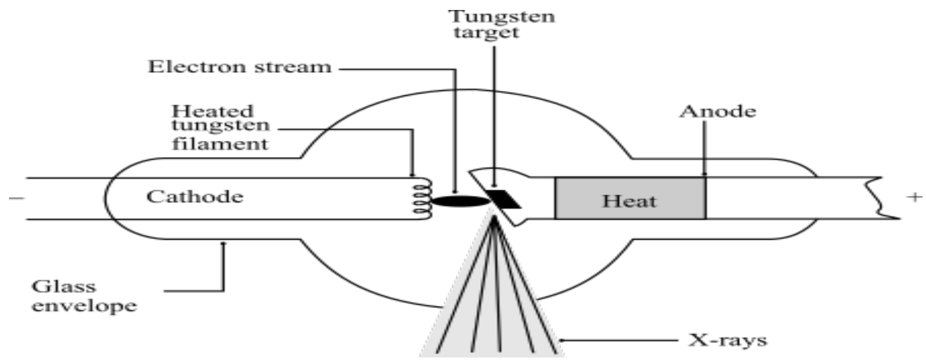

Fig 6. Coolidge tube for X-ray production

X-rays are produced when fast moving electrons are suddenly stopped by a solid target. The cathode consists of tungsten filament heated by a low-tension battery. Thermionic electrons emitted by the filament are accelerated towards the target(tungsten) by a high potential difference (between the filament and the target). The filament is placed inside a metal cup to focus the electrons on to the target (fig 6). The target is made of materials with high melting point and a high atomic number. Materials with high atomic number produce more energetic and intense x-rays when used as targets. Intensity is controlled by the numbers of electrons striking the target per second. Number of emitted electrons is proportional to temperature, which can be varied by current in the filament circuit. The frequency of x-rays emitted also depends on the voltage between cathode and anode.

X-ray can be categorized as either Bremsstrahlung or Characteristic. When electrons hit the anode, they decelerate or brake and emit Bremsstrahlung (meaning braking radiation in German) x-rays. Bremsstrahlung x-rays are produced most effectively when small, charged particles interact with large atoms, such as produced in a Coolidge tube.

When electrons change from one atomic orbit to another, photons emitted are X-rays. The individual photon energies are characteristic of the type of atom and characteristic X-rays can be used to identify very small quantities of a particular element. Radioactivity disintegration of radionuclides is another source of X-rays.

RADIOACTIVITY

Understanding the nucleus occurred with the discovery of the phenomenon known as *radioactivity* in the early 1896 by the French Physicist Henri Becquerel. He discovered that Uranium salt crystal emits an invisible radiation that can darken a photographic plate even if the plate was covered to exclude light. The radiation did not require any external stimulation; this spontaneous emission of radiation was called *radioactivity*

Radioactivity is described as the spontaneous disintegration of unstable atomic nuclei to form more energetically stable atomic nuclei. It is associated with the unstable nucleus losing different particles or releasing energy as they change.

Properties of Radioactivity

- Spontaneous
- Unaffected by external agent like; temperature, pressure, electric field or magnetic field.
- It is accompanied by emission of electrons e^-, positrons e^+, $^{+4}He_2$ photon of energy and other particles.

Sources of Nuclear Instability

Atoms with large atomic number Z often have more neutrons than protons to overcome the electrostatic repulsion between the protons to keep the nucleus stable. As Z gets larger and larger, a point is reached where increase in the number of neutrons is not sufficient to overcome the electrostatic repulsion between the protons this leads to nuclear instability. Unstable nuclei will eventually break into smaller fragments by ejecting the excess nucleons (protons or neutrons), as well as other particles, or by releasing energy through the process of radioactivity. Radioactive (unstable) nuclei will eventually decay by emitting a particle and transforming the nucleus into another nucleus. Series of decays may have to take place to take an unstable nucleus to a state of stability. During radioactive decay processes, the principle of conservation of energy, momentum, charge and nucleon number apply.

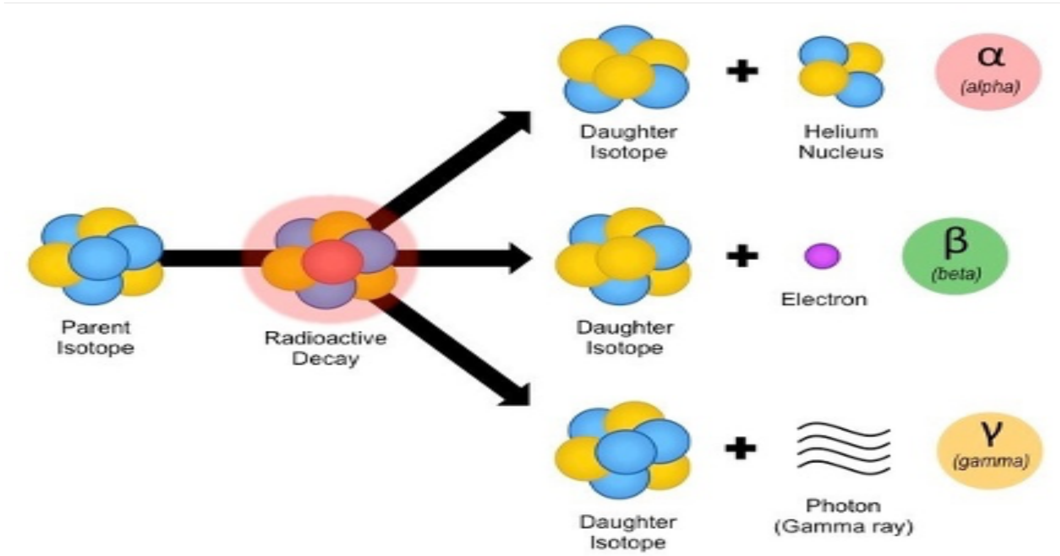

Fig 7. Different channels of radioactive decay

An unstable nucleus decays majorly by going through one or more of the following: emitting an alpha particle (alpha decay), beta particle (beta decay) or gamma particle (gamma decay) fig 7.

Alpha decay: emission of α particle (2 protons + 2 neutrons).
An unstable nucleus (parent) disintegrates into a lighter nucleus (daughter) and an alpha particle ($^4He_2$).
Generally, alpha decay is represented by equation 1

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha({}^{4}_{2}He) \text{ --------------------------- } 1$$

The parent nucleus loses two protons and two neutrons. The atomic number Z of the daughter Y nucleus therefore decreases by two while the mass number A decreases by 4. The parent nucleus X is a different chemical element to Y.

Beta Decay: emission of beta β particle.

In beta decay, electron (negative or positive) is emitted. Here , there's a change in the Z number of the parent nucleus, but the nucleon number A remains unchanged. In this group we have beta plus, beta minus decay, and electron capture.

Beta minus Decay

Light nuclei with excess neutron convert the excess neutron into proton emitting a beta β– particle. The emitted particles were later discovered to be electrons. Note that the emitted electron is not one of the orbital electrons.

β– decay is generally expressed with the equation 2:

$${}^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + \beta^{-}({}_{-1}^{0}e) \text{ -------------------------- } 2$$

Neutron is converted to proton therefore; nucleon number A remains the same but proton number Z increases by 1 as a proton has been gained.

Example $^{12}B_5 \rightarrow {}^{12}C_6 + \beta^- + \upsilon^-$ $\quad$ $^{1}n_0 \rightarrow {}^{1}P_1 + {}^{0}e_{-1} + \upsilon^-$

Beta plus Decay

Light nuclei with excess protons emit β^+ (positron) to converts protons to neutrons. β^+ decay is generally written as equation 3

$${}^{A}_{Z}X \rightarrow {}_{Z-1}{}^{A}Y + \beta^{+}({}_{1}^{0}e) \text{ -------------------- } 3$$

Example $^{12}N_7 \rightarrow {}^{12}C_6 + \beta^+ + \upsilon$ $\quad$ $^{1}P_1 \rightarrow {}^{1}n_0 + {}^{0}e_1 + \upsilon$

Emission of β^+ particle is only possible when the atomic mass of parent nucleus m_x is greater than that of daughter nucleus m_y by at least two electronic masses (the equivalent of 1.02MeV of energy).

Electron Capture

In the case of excess protons, where there's no sufficient energy for β^+ decay to take place, an alternative process called *electron capture* can occur. For electron capture, an inner shell atomic electron is captured by the nucleus to convert a proton into a neutron.

Generally, electron capture is written as equation 4

$$^{A}_{Z}X + {}^{0}_{-1}e \rightarrow {}_{Z-1}^{A}Y \quad \text{---------------------------- } 4$$

$$^{1}P_{1} + {}^{0}e_{-1} \rightarrow {}^{1}n_{0} + \upsilon$$

Example: $^{7}Be_{4}$ + electron ${}^{0}_{-1}e \rightarrow {}^{7}Li_{3}$ -------------------- 4

Whenever an atom is transformed by orbital electron capture, an electron from an outer orbit falls into the energy level that had been occupied by the captured electron. X-ray of the characteristic of the daughter element is then emitted (production of X-rays from radioactive nuclei).

Gamma decay: emission of gamma γ radiation

A nucleus in an excited state makes a transition to a lower energy state and in the process, a photon called gamma γ ray is emitted. The energy of the γ photon is given by the usual energy equation $hf = E_i - E_f$ where E_i is the energy of nucleus at the excited state, E_f is the energy of the nucleus at the lower energy state. γ carries no charge nor mass. Atomic number and the mass numbers of the nucleus undergoing a gamma decay do not change.

Gamma decay is generally written by the equation 5

$$^{A*}_{Z}X \rightarrow {}^{A}_{Z}X + \gamma \text{ --------------------- } 5$$

$^{A*}_{Z}X$ is the excited nucleus and $^{A}_{Z}X$ is the nucleus in the lower energy level. $^{A*}_{Z}X$ and $^{A}_{Z}X$ are the same nuclide they only differ in energy

BINDING ENERGY AND MASS DEFECT

Suppose we have a proton and electron at rest separated by a large distance. The total energy of this system is the total rest energy of the two particles, $m_pc^2 + m_ec^2$. If the two particles come together to form a hydrogen atom in the ground state, photon of 13.6 eV is emitted. The total energy of the system of the separated electron and proton that forms the hydrogen atom is the rest energy of the hydrogen atom, m_Hc^2 + total photon energy of 13.6eV.

Principle of conservation of rest energy demands that the total energy of the system of isolated particles must equal the total energy of atom plus photons(energy).

For hydrogen atom,

$$m_pc^2 + m_ec^2 = m_Hc^2 + 13.6ev$$

$$m_pc^2 + m_ec^2 - m_Hc^2 = 13.6eV$$

The rest energy of the combined system is less than the rest energy of its constituents by 13.6eV. 13.6 ev is what is called the *binding energy of the atom.*

Binding Energy is therefore defined as the extra energy obtained when an atom is assembled from its components; or the energy that must be supplied to disassemble the atoms into its components.

Mass Defect

Just like that atom and constituents, nuclear particle experiments show that the total mass of a nucleus M_{nucl} is *less* than the sum of the masses of its constituent nucleons (protons and neutrons). $M_{nucl} < Zm_p + Nm_n$. which implies that $M_{nucl} + \Delta m = Zm_p + Nm_n$.

The mass difference (Δm) is known as *mass defect*, given by

$$\Delta m = Zm_p + Nm_n - m_{nucl}$$

where Zm_P is the total mass of the protons, Nm_n is the total mass of the neutrons, and M_{nuc} is the mass of the nucleus. Basically, nuclear binding energy is considered in terms of mass, and that mass becomes "missing". This missing mass is called mass defect.

By Einstein's relation $E = mc^2$, E= Δmc^2 where Δm is mass defect.

Nuclear binding energy is therefore, the energy required to keep the protons and neutrons of a nucleus intact, and the energy that is released during a nuclear fission or fusion in a nuclear power plant.

NUCLEAR FISSION AND FUSION

Nuclear fission is the splitting of a heavy nucleus into two lighter ones. Fission was discovered in 1938 by the German scientists Otto Hahn, Lise Meitner, and Fritz Strassmann, who bombarded a sample of uranium with neutrons to produce new elements. He observed that lighter elements such as barium (Z = 56) were formed during the reaction, and realized that such products had to originate from the neutron-induced fission of uranium-235:

$$^{235}U_{92}+^{1}n_{0} \rightarrow 141Ba_{56}+92Kr_{36}+3\ ^{1}n_{0}$$

The nucleus usually divides asymmetrically rather than into two equal parts, and the fission of a given nuclide does not give the same products every time. In a typical nuclear fission reaction, more than one neutron is released by each dividing nucleus. When these neutrons collide with and induce fission in other neighbouring nuclei, a self-sustaining series of nuclear fission reactions known as a nuclear chain reaction can result.

For example, as seen above, the fission of ^{235}U releases two to three neutrons per fission event. If absorbed by other ^{235}U nuclei, those neutrons induce additional fission events, and the rate of the fission reaction increases geometrically. Each series of events is called a generation (fig 8)..

Experimentally, it is found that some minimum mass of a fissile isotope is required to sustain a nuclear chain reaction; if the mass is too low, too many neutrons can escape without being captured and inducing a fission reaction.

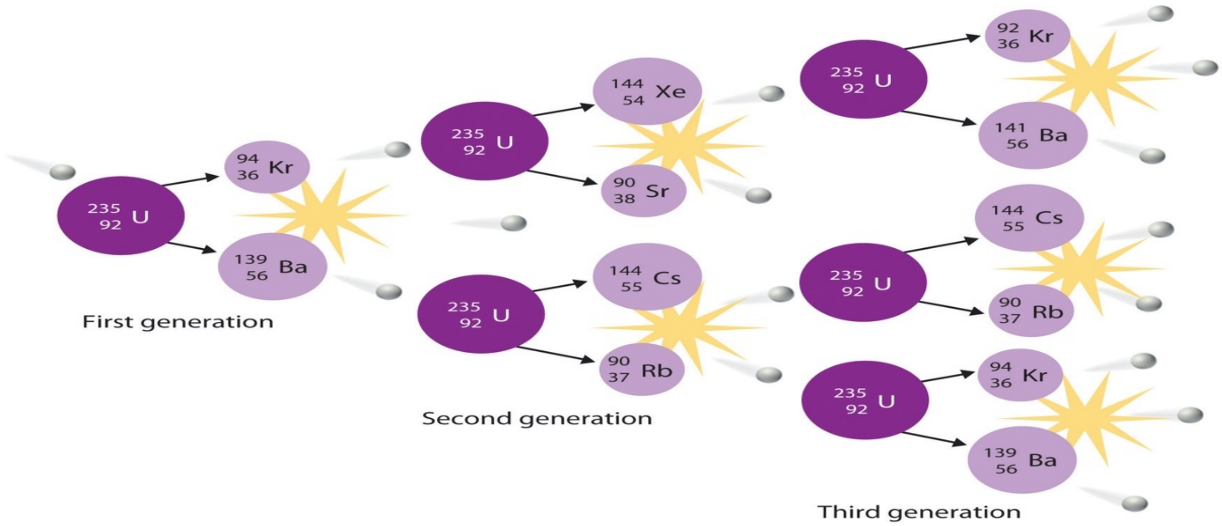

Fig 8 Generations of Nuclear Fission

Nuclear fusion

Nuclear fusion is a process in which two light nuclei combine to produce a heavier, more stable nucleus. The positive charge on two nuclei coming together results in a large electrostatic energy barrier to fusion. This barrier can be overcome if one or both particles have sufficient kinetic energy to overcome the electrostatic repulsions, allowing the two nuclei to approach close enough for a fusion reaction to occur. The principle is like adding heat to increase the rate of a chemical reaction. Fusion reactions are most exothermic for the lightest element e.g source of energy in the sun and stars.

For example, two deuterium atoms combine to produce helium-3, a process known as deuterium–deuterium fusion (D–D fusion):

$$^{2}H_{1} + {}^{2}H_{1} \rightarrow {}^{3}He_{2} + {}^{1}n_{0}$$

Another reaction, a deuterium atom and a tritium atom fuse to produce helium-4 (Fig. 9), a process known as deuterium–tritium fusion (D–T fusion):

$$^{2}H + {}^{3}H \rightarrow {}^{4}He + {}^{1}n$$

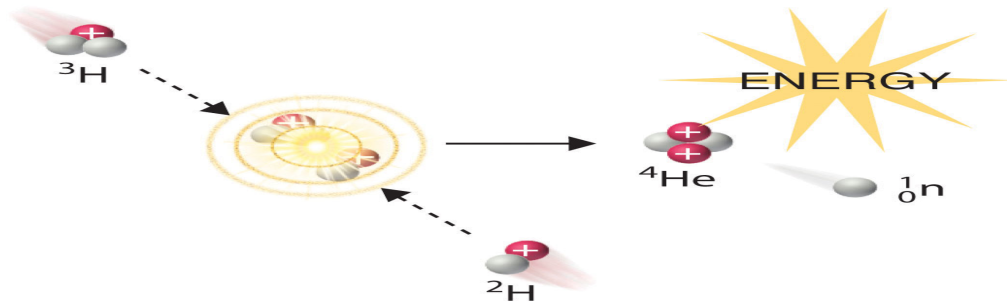

Fig. 9 Deuterium–tritium fusion

As shown in the fusion of ^3H and ^2H to give ^4He and a neutron, fusion processes releases enormous amount of energy. In principle, nuclear fusion can produce much more energy than fission, but very high kinetic energy is required to overcome electrostatic repulsions between the positively charged nuclei and initiate the fusion reaction.

Fission and fusion involve the dispersal and combination of elemental nucleus and isotopes**.** The energy harnessed in nuclei is released in nuclear reactions. Fission is the splitting of a heavy nucleus into lighter nuclei and fusion is the combining of nuclei to form a bigger and heavier nucleus. Adding up the individual masses of each of these subatomic particles of any given element will always give you a greater mass than the mass of the nucleus. The mass of an element's nucleus is less than the total mass of its individual protons and neutrons The consequence of fission or fusion is the absorption or release of energy.