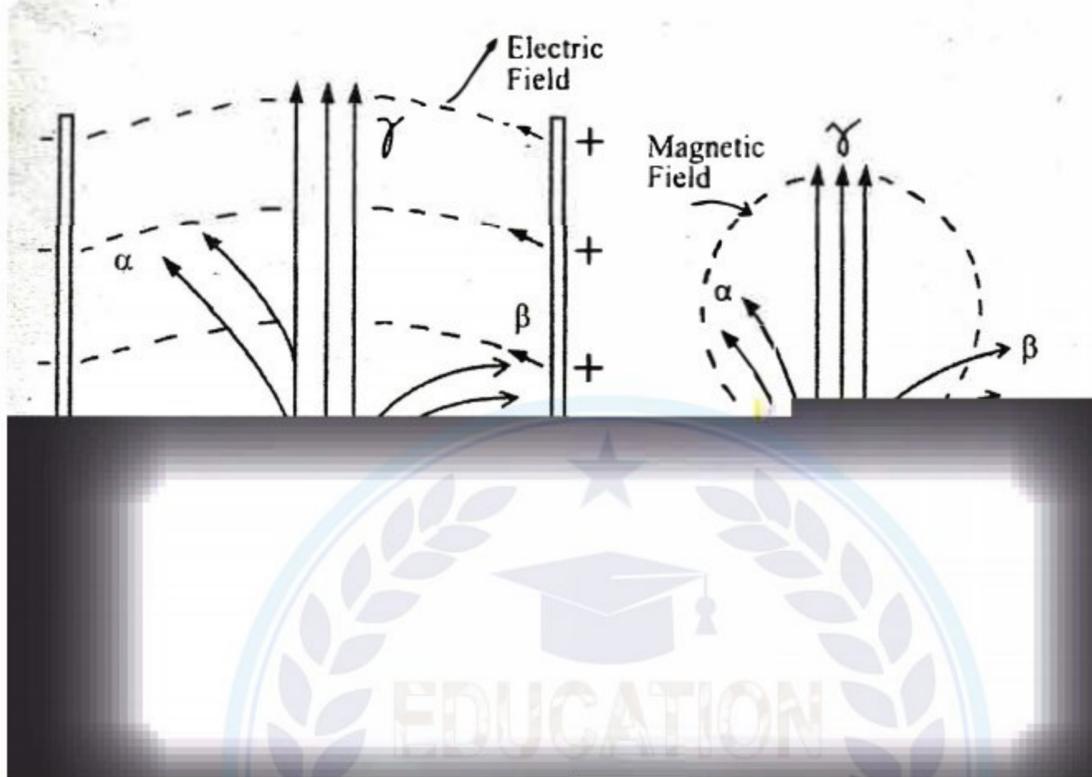# Chapter 19

"The Atomic Nucleus"

Radioactivity

The element whose atomic number is greater than 82 are unstable and emits radiation called α-rays, β-rays and γ-rays. The elements are called radioactive elements. Uranium, polonium and radium are the examples of radioactive elements.
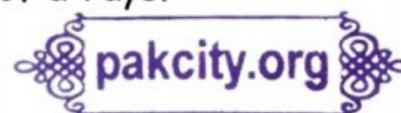

Properties of α-rays

1. The ionization capability of α-rays is very large.
2. Penetration power of α-rays is very small.
3. These rays produce fluorescence in certain substances.
4. These rays can induce artificial radioactivity in certain nuclei.
5. These rays produce burns and sores on human body.
6. α-rays get absorbed after passing through a small distance in air because of high ionization power.
7. When α-rays are absorbed in matter, they produce heating effect.
8. These rays are deflected from electric and magnetic field showing that these rays are positively charge particles.
9. The velocity of these particles very small as comparable to the speed of light.
10. The atomic mass number of α particle is 4 and charge number is 2, e.g. He_2^4.

Properties of β-rays

1. These rays affect the photographic plate.
2. β-rays has smaller in mass than a particles.
3. These rays produce fluorescence easily.

4. These rays are easily scattered by nucleus of atoms as comparable to α particles because of their small mass.
5. The velocity of β-rays much greater than the velocity of α particles but less than the speed of light.
6. The penetration power of β-rays much larger than the penetration power of α-rays.
7. The ionization power of β-rays is small.
8. The atomic mass number of β-rays is 0 and the charge number is -1, e_{-1}^0.
9. These rays are deflected by electric and magnetic field showing that these rays are of negative charge.
10. These rays also produce heating effect when absorbed by matter.

Properties of γ-rays
1. γ-rays produce feeble fluorescence.
2. The eject electron when incident on atom.
3. These rays also get absorbed in various elements.
4. Penetration power of γ-rays is very large.
5. These rays can penetrate even through a human body.
6. These rays are not deflected by electric and magnetic field showing their neutral nature.
7. These rays are dangerous can cause damage human cell.
8. They can also used to destroy can cell in human body.
9. They are diffracted by crystals like X-rays.
10. The ionization power is negligible.

Uses and applications of radioactive substance
1. In industry radio isotopes are used widely to check whether the thickness of a material is constant or not.

2.   In industry CO-60 emits high energy gamma radiation and it can be used to detect cracks in welded joints.

3.   In agriculture radio isotopes are used to kill bacteria and preserved food stuff.

4.   In the field of agriculture radio isotopes determine the optimum amount of fertilizers.

5.   In the field of medicine they have also helped in the diagnosis and cure of many complicated diseases.

6.   Phosphoru-32 and indine-131 are used as tracer to trace out the path of an element in the body or plant, animal or human being.

7.   In geology as a radioactive dating the age of rocks, organism etc can be estimate.

8.   Radioactive rays are widely used in science research laboratories.

Radioactive decay:

When radiation is emitted out of any radioactive element it always change into a new element and this phenomenon is called radioactive decay or radioactive transformation or radioactive transmutation.

Daughter Element and Parent Element

The new element found due to the process radioactive decay is called daughter element and the original was parent element.

Alpha decay

When a particle is emit out of any nucleus the mass number of the nucleus decrease by number 4 and the charge number is decrease by number 2.
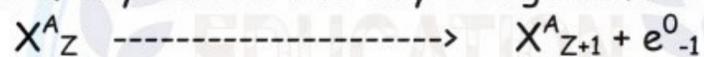
$$X^A_Z \text{ -----------------} \rightarrow X^{A-4}_{Z-2} + He^4_2$$
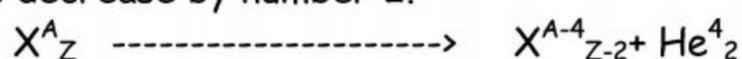
Example

When alpha particle is emit out from the nucleus of radium Ra^{226}_{88} the element changes into a radon gas Rn^{222}_{86}

$$Ra^{226}_{88} \text{ -----------------} \rightarrow Rn^{222}_{86} + He^4_2$$

Beta decay

When a β particle is emit out of any nucleus the only charge number is increase by one

$$X^A_Z \text{ -----------------} \rightarrow X^A_{Z+1} + e^0_{-1}$$

Example

$$n^1_0 \text{ -----------------} \rightarrow H^1_1 + e^0_{-1}$$

Thorium changes into protactinium emitting beta particle

$$Th^{234}_{90} \text{ -----------------} \rightarrow Pa^{234}_{91} + e^0_{-1}$$

Gamma decay

When gamma radiation is emitting out of the nucleus then the charge number and mass number of the element remains same. When a nucleus is excited by absorbing energy and after when it de-excite and coming back to the ground state because it is unstable so it produce gamma rays.
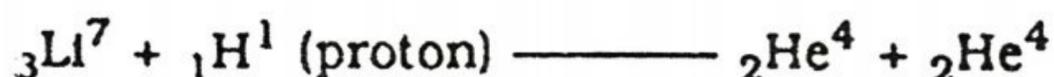
$$X^A_Z{}^* \text{-----------------------} \rightarrow X^A_Z + \gamma\text{-rays}$$

Where

$X^A_Z{}^*$ represent excited state and X^A_Z represent ground state.

1. Protons - Induced Reactions

If lithium absorb a proton, two alpha particles are found to be produced in the reaction.

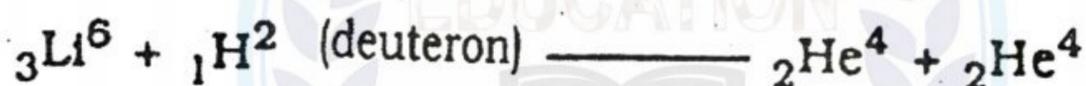$$_3Li^7 + {}_1H^1 \text{ (proton)} \longrightarrow {}_2He^4 + {}_2He^4$$

Two alpha particles.

This reaction is of great historical importance because it provided the earliest experimental verification of the Einstein's mass – energy relationship.

2. Deutron – Induced Reactions

High energy deuterons may be absorbed by $_3L_1^6$ to produce two alpha particles i.e

$$_3Li^6 + {}_1H^2 \text{ (deuteron)} \longrightarrow {}_2He^4 + {}_2He^4$$

3. Gamma – Induced Reactions

High energy gamma rays also have been found to induce nuclear reactions by a process which is usually known as photo disintegration. Examples of such reactions are :

$$_{13}AL^{27} + {}_1H^2 + \gamma \text{ (50 Mev)} \longrightarrow {}_{11}Na^{25} + 2{}_1H^1$$

Sodium   Two
isotope   protons
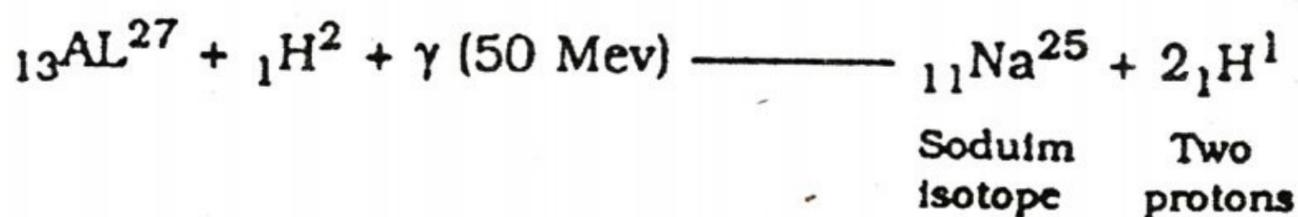
Mass Defect

The mass of the nucleus is always less than the total mass of all the protons neutrons making up the nucleus. The missing mass is called mass defect

$$\Delta m = z m_p + (A-Z) m_n - m_{nuclues}$$

Binding Energy

The missing mass is converted to the energy in the formation of the nucleus called binding energy. It is given by Einstein mass energy relation

$$B.E = (\Delta m)c^2$$

The binding energy is the amount of energy that must be supplied to a nucleus if the nucleus is to be broke up into protons and neutrons.
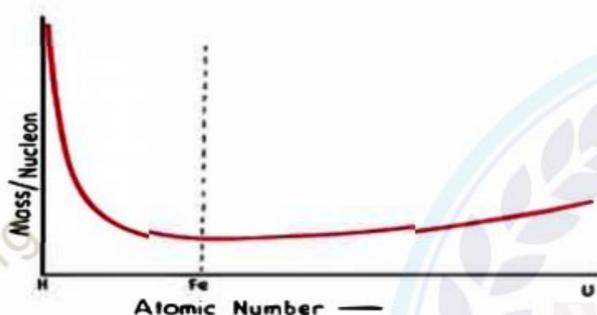
Packing Fraction

The mass defect per nucleons is called packing fraction.
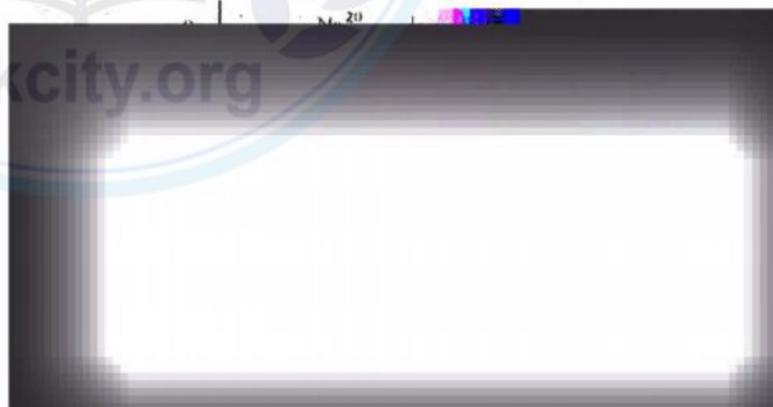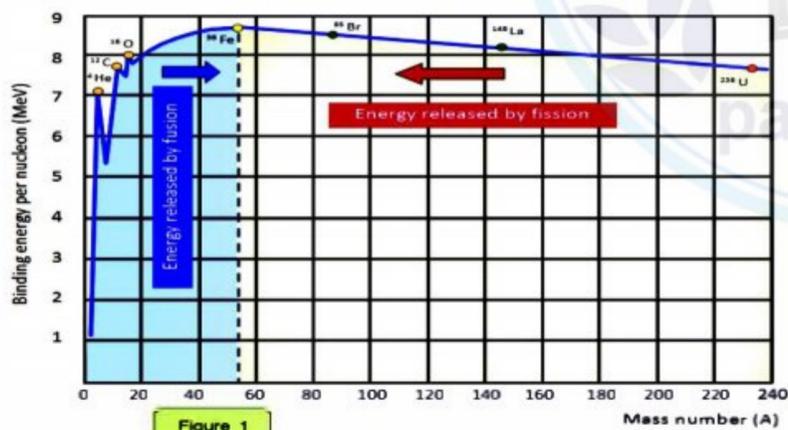
$$F = \Delta m/A$$

Where A is the number of nucleons.

Binding Fraction

The binding energy per nucleons is called binding fraction.

$$f = B.E/A$$

Figure 1

Half Life

The period of time in which half of the atoms of the radioactive substance decay is called half-life of radioactive substance.

Derivation

Let N is the number of atoms present in a radioactive substance and ΔN is the number of decaying atoms. It is proof that the decaying atoms are directly proportional to the time interval Δt and the number of atoms present initially N.

$$\Delta N \, \alpha \, N \text{--------------}(1)$$
$$\Delta N \, \alpha \, \Delta t \text{_____}(2)$$

Comparing (1) and (2)

$$\Delta N = -(constant) \, N\Delta t$$
$$\Delta N = -\lambda N \, \Delta T\text{_____}(3)$$

Where λ is the constant of proportionality and is known as decay constant. The negative sing indicates the decrease in number of atoms.

$$\lambda = -(\Delta N/N) / \Delta t$$

Here $\Delta N/N$ is called fraction of decaying atoms. The decaying constant is defined as the fraction of the decaying atoms per unit time. The S.I unit of decaying constant is s^{-1}.

By using integration the relation can also be written as

$$N = N_0 e^{-\lambda t}\text{_____}(4)$$

N_0 = number of atoms in parent elements at t=0

N = number of atoms in daughter elements

At half life $t = T_{1/2}$ and $N = N_0/2$

Substituting values in (4)

$$N_0/2 = N_0 e^{-\lambda T_{1/2}}$$
$$1/2 = e^{-\lambda T_{1/2}}$$

Tale natural logarithm both sides of the equation

$$\ln(1/2) = \ln e^{-\lambda T_{1/2}}$$

$$\mathbf{T_{1/2} = 0.693/\lambda}$$

By knowing the value of decay constant of radioactive element we can easily estimate the half life of radioactive element.

Activity

The number of decays per unit time is called decay activity.

$$A = \Delta N/ \Delta t$$

We know that $\quad \Delta N/ \Delta t = \lambda N$

So $\quad\quad\quad A = \lambda n$

The S.I unit of activity is Becquerel (Bq), other units are curie and Rutherford.

Radioactive Isotopes

Isotopes of an element have the same atomic number and different atomic mass number i.e. they differ only in the number of neutrons.

Nuclear Fission

The splitting of a nucleus into fragments with the emission of energy when bombardment by a neutron is called a fission process.
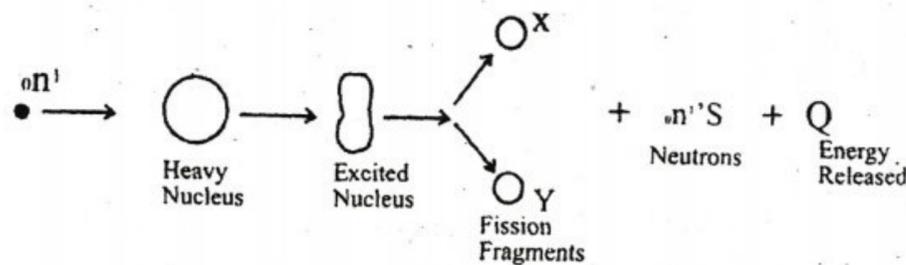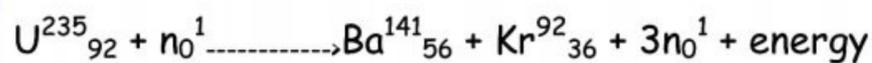
Fig.(19.6)

$$U^{235}_{92} + n_0^1 \longrightarrow Ba^{141}_{56} + Kr^{92}_{36} + 3n_0^1 + energy$$

Where U^{235}_{92} isotope of uranium

Ba^{141}_{56} represent the barium

Kr^{92}_{36} represent krypton nuclei.

Examples

1. The atomic bomb is an example of uncontrolled nuclear fission reaction.

2.   The reaction in nuclear reactors to generate the electricity is an example of controlled fission reaction.

Chain Reaction

In a fission reaction each nucleus emits about two to three neutrons. These neutrons may collide with the other uranium nuclei and cause fission reaction which will emit more neutrons. These neutrons will produce further fission in other nuclei. If this process continuous more and more neutrons are produced and a large amount of energy will released. This is called a nuclear chain reaction.
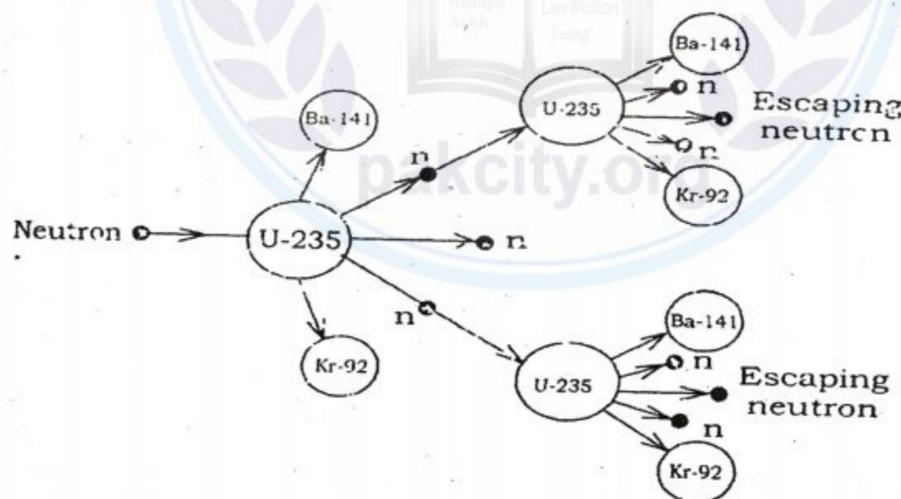

Fig. (19.7)

Controlled Chain Reaction

Basically nuclear chain reaction is uncontrolled fission reaction release large amount of energy. This energy is in the form of heat. If we controlled the chain reaction this heat can be used to run a turbine for the generation of electricity. A system used to control the fission chain reaction is called nuclear reactor.

Nuclear Reactor

The fission reaction in a reactor is uranium isotope U^{235}_{92} and is called the fuel element. The neutrons released from fission move with high velocities. These fast moving neutrons are usually lost or absorbed by somewhere in the reactor assembly before producing further fission reaction. The fast moving electrons are slowed down before they are able to cause further fission reaction. The process of slowing down neutrons is called moderation. Heavy water is commonly used as a moderator.
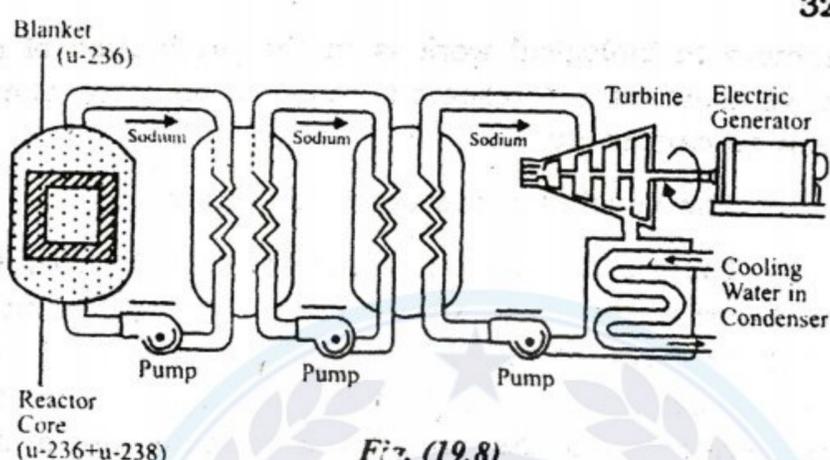
Fig. (19.8)

Control Rods

The rate of a nuclear chain reaction is controlled by inserting some substances that absorbs neutrons. They are called control rods. Boron rods are used as control rods. If too many of the neutrons are absorbed by the control rods the nuclear reaction will stop. To start the chain reaction the control rods are moved out.
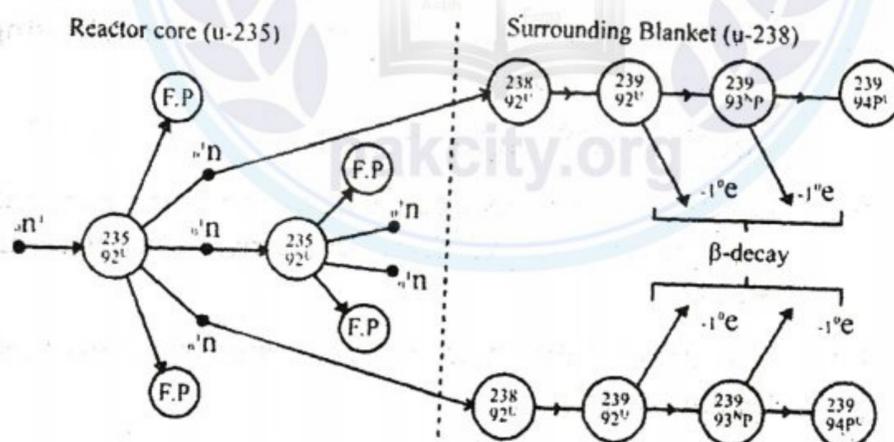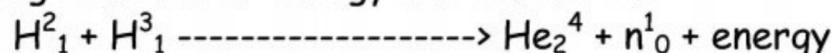

Fig. (19.9)

Nuclear Fusion

When lighter nuclei combined together to form a one heavy nuclei and the amount of energy is release in the process then it is called nuclear fusion reaction.

When deuterium and tritium isotopes of hydrogen are combined together, they form a helium nucleus with the release of large amount of energy and a neutron.

$$H^2_1 + H^3_1 \text{ --------------------> } He_2^4 + n^1_0 + energy$$

In nuclear fusion reaction a large amount of temperature is required to start the reaction greater than one million degree Celsius. In hydrogen bomb fission reaction is used to start the fusion reaction.

Examples

1. The chemical reaction in the stars and sun is nuclear fusion reaction.
2. Hydrogen bomb is also an example of nuclear fusion reaction.

Atomic mass unit (a.m.u)

To indicate the mass of atomic particles, instead of kilogram, unified mass scale (u) is generally used. By definition $1u = 1.67 \times 10^{-27}kg$

Mass of proton is 1.0078 u

Mass of neutron is 1.0086 u

Mass of electron is 0.00055 u

Mass of $_1H^1$ 1.007825 u

Mass of $_1H^2$ 2.014102 u

Mass of $_1H^3$ 3.016049 u

Mass of $_2He^4$ 4.002603 u

Mass of $_2He^3$ 3.016029 u

Mass of $_3Li^7$ 7.016003 u