**CHAPTER 20 NUCLEAR PHYSICS**

**Atomic Nucleus:**

***“The central part of an atom is called nucleus”.*** A nucleus is of the order of 10-15 m. A cloud of electrons surrounds the nucleus. The nucleus contains positively charged protons. The mass of each proton is 1.67310-5 m and its charge is 1.610-19C. The nucleus also contains neutral particles called neutrons. First of all, neutron was discovered by Chadwick in 1932, in the scattering of α-particles from a Be-target. The mass of each neutron is 1.67510-27kg. Protons and neutrons are collectively called as nucleons.

**Atomic Number:**

***“The number of protons in the nucleus of an atom is called atomic number or charge number.”***

It is denoted by Z.

**Atomic Mass Number:**

***“The total number of protons and neutrons present in the nucleus of an atom.”***

**OR**

***“It is the number of nucleons present inside the nucleus of an atom.”***

It is represented by A.

**Nucleus Representation:**

Any nucleus is represented by its chemical symbol ‘X’ with the atomic number ‘Z’ as a subscript to the down left and ‘A’ as a superscript to the top right, as shown:

ZXA

**For example:**

2He4, 11Na23, 6C12, 7N14, 92U235 etc.

**Nuclide:**

***“A nuclide is a particular nucleus with a specified number of protons and neutrons”***

**Isotopes:**

***“Atoms of the same element having same number of protons and different number of neutrons are called isotopes”***

**OR**

***“Atoms of an element having the same atomic number ‘Z’ but different mass number ‘A’ are known as isotopes”***

**Word History:**

The chemist Frederick Soddy suggested the name isotopes (‘iso’ means same, ‘topes’ means place) for elements which are identical in chemical properties and hence occupied the same place in periodic table.

**Explanation:**

Isotopes are two or more nuclides of the same element ‘X’ with the same atomic number ‘Z’ but different number of neutrons and hence different mass number ‘A’.

**For example**:

6C12 and 6C14 both have six protons, but ‘6’ and ‘8’ neutrons respectively.

Similarly, hydrogen is found in three isotopic forms; 1H1, 1H2, 1H3. The nucleus of an ordinary Hydrogen 1H1 contains just one proton and no neutron. The isotope 1H2 has one proton and one neutron. It is called deuterium or heavy hydrogen. Its nucleus has special name deuteron. 1H3, called Tritium, is made up of one proton and two neutrons. Its nucleus is called triton.

Natural uranium contains two isotopes 92U238 (99%) and 92U235 (little less than 1%). 92U235 is used as a fuel in a nuclear reactions and atomic bombs. So, techniques have been developed to separate 92U235 from natural uranium.

**Mass Spectrograph:**

***“A device which is used to separate the isotopes of an element and to measure their masses is known as mass spectrograph.”***

**Principle:**

A mass spectrograph is based on the principle that a beam of ions moving through electric and magnetic field suffers a deflection that depends upon the change and masses of the ions. Hence, ions of various masses are deflected differently.

**Construction:**

The mass spectrometer mainly consists of two parts. The ion source and evacuated chamber, where charges are bent in magnetic field. The vacuum chamber contains a photographic plate as a collection system. The battery is connected between slits S1 and S2 to collimate and accelerate the nuclide before exposing to magnetic field. The arrangement is as shown:

**Working Theory:**

The charged nuclei once produced in the ion chamber, and are collimated with the positive potential applied to S1. The charges are then accelerate due to the potential difference between ‘S1’ and ‘S2’. The potential energy supplied by the battery is converted to K.E i.e.

…………………….. (20.1)

When these ions enter the vacuum chamber having magnetic field perpendicular to the direction of motion of charged particles, they deflect into different paths. The path followed by the charged particles is a circle; therefore it needs centripetal force. The necessary centripetal force is provided by magnetic force i.e.

………………………….. (20.2)

‘B’ and ‘q’ can be determined or known but ‘v’ can’t be determined directly. To find ‘V’, use (20.1)

**Put this value in (20.2),**

**Squaring:**

……………………... (20.3)

………………………….. (20.4)

**From above relation:**

The relation shows that if ‘V’, ‘B’ and ‘q’ are constant, ‘r’ depends upon the mass ‘m’ of the ion. Hence ions of different masses will strike the photographic plate at different places, hence different isotopes can be separated.

**Measurement of Mass:**

Arranging (20.3):

……………………………. (20.5)

The value of ‘r’ can be measured by noting the distance between ‘S1’ and ‘S2’ and the image of the ion formed on the photographic plate. When ions of different masses are present, each produces an image on the photographic plate. From their images, value of ‘r’ can be found and using above relation to find out mass ‘m’:

**Mass defect and Binding energy:**

***“The amount of energy required to disintegrate nucleus into its constituent nucleons is called binding energy.”***

**OR**

***“The difference between the rest mass of the atomic nucleus and the sum of the rest masses of its individual nucleons in the unbounded state is called mass defect and energy associated with this mass defect is known as binding energy.”***

**Explanation:**

Mass spectrometry reveals that the mass of a nucleus is in general not equal to the sum of masses of its constituent protons and neutrons. In fact, mass is less than this sum. The difference in mass determines the binding energy of the nucleons.

We imagine that a stable nucleus is formed when free protons and neutrons combine to form a nucleus under the influence of strong nuclear force. In this reaction tremendous amount of energy is released at the cost of mass. This energy is known as binding energy of the nucleus. If one has to break nucleus into its constituent nucleons, he has to supply this much amount of energy.

**Mathematical Form:**

If ‘’ is the mass defect, then Binding energy ‘E­­B’ will be given by:

EB( …………………………….(20.6)

Now if ‘mp’ is the mass of proton and ‘z’ is the number of protons. ‘mn’ is the mass of neutron and ‘m’ is the mass of nucleus then

mp mn

Put in (20.6)

EBmp mn )

As,

EBmp mn ) ……………… (20.7)

**Binding energy per Nucleon:**

***“The binding energy per nucleon is called binding fraction.”***

It is represented by f. It is given by:

Put value of EB from (2):

…………………………… (20.8)

**Stable and Unstable Nuclei:**

The stability of a nucleus depends upon the binding energy per nucleon of an element.

**Binding Energy Curve:**

A graph between binding energy per nucleon and mass number A, shows variation between them. The binding energy per nucleon is almost constant at about 8.0 MeV between A=30 and A=80. The nucleus in this region has the highest binding energy and most stable.

**Reason of un-stability of lighter Nuclei:**

The decrease in ‘f’ for small ‘A’ is due to surface effect. The nucleons deep inside the nucleus are attracted from all sides by the neighboring nucleons. But nucleons on the surface are attracted from one side only. Smaller the nucleus, larger is the percentage of nucleons at the nuclear surface. This effect reduces the binding energy per nucleon of low ‘A’ and hence stability.

**Reason for low Binding Fraction of Larger nuclei:**

The decrease if ‘f’ for large atomic mass ‘A’, nuclei is due to the fact that large nuclei contain more protons whose repulsive forces oppose the strong nuclear force. Thus repulsive force increases with increasing ‘A’, which results in smaller values of ‘f’. Hence binding fraction decreases for larger ‘A’ and higher nuclei are less stable.

**Consequence:**

The decrease of binding fraction for larger ‘A’ nuclei and small ‘A’ nuclei is responsible for nuclear fission and fusion reaction respectively.

**Natural Radioactivity:**

***“The spontaneous disintegration of heavier elements (Z>82) into its lighter elements along with emission of α, β and γ radiations, is known as radioactivity.”***

OR

***“The natural emission of radiations from unstable nuclei is called radioactivity.”***

**Explanation:**

Radioactivity is a natural process and it is independent of temperature, pressure and physical state of specimen. The heavy nuclei have strong columbic repulsive interaction. This reduces the net attractive force and so the nucleons are loosely bound in a nucleus. These nuclei may emit α, β and γ radiations. α(alpha) rays are doubly positive He-nuclei, β is either (-1e0) electron or positron(+1e0) and γ radiations are high energy photons.

**Emission of α-particles:**

As alpha particle is helium nuclei (2He4), so the emission of α-particle reduces the atomic number of the element by ‘2’ and mass number by ‘4’ i.e.

ZXA Z-2XA-4 + α + Q

where,

‘Q’ is the disintegration energy. Hence element ‘X’ is called parent element and converted to other element by the emission of alpha particle called as daughter element. In this type of reaction, ‘Q’ is always positive as process is spontaneous. The daughter nuclei may also remain unstable and undergo further disintegration till it attains stability.

**Examples of α-decay:**

92U238 90Th234 + 2He4 + Q

88Ra226 86Rn222 + 2He4 + Q

**Beta-Emission:**

As β-particles are either (-1e0) electron or positron (+1e0), so the emission can either increase or decrease the atomic number by 1 i.e.

ZXA Z+1XA+ -1β0 + Q + antineutrino

And

ZXA Z-1XA+ +1β0 + Q + neutrino

**Electron Emission:**

In case of electron emission, there is an increase in atomic number ‘Z’ and no change in mass number. Scientists believe that in this mechanism, a neutron (which is a neutral particle) changes to a proton (charged particle), so obviously charge number which will increase but as neutron and proton both are nucleons and contribute to mass number, so this interconversion (especially in this case, neutron to proton) will not change mass number i-e:

0n1 1P1 + -1β0

**Examples:**

90Th232 91Pa232 + -1β0 + Q + Antineutrino

6C214  7N14 + -1β0 + Q + Antineutrino

82Pb214 83Bi214 + -1β0 + Q + Antineutrino

29Cu64 30Zn64 + -1β0 + Q + Antineutrino

**Positron Emission:**

In case of emission of positive β-particle i-e: a positron, change number decreases by a single unit without any change in mass number A. Scientist believed that in case of positron emission, a proton (charged particle) changes to a neutron(neutral) by the emission of the positron. Hence, due to decrease in proton number, charge number decreases but as the number of nucleons remains same. So, atomic mass number ‘A’ does not change i-e:

1P1 0n1 + +1β0

**Examples of Positron Emission:**

* 29Cu64 changes to Nickel by emission of positron:

29Cu64 28Ni64 + +1β0 + Q + neutrino

* 6C11 5B11 + +1β0 + Q + neutrino

**Neutrino and Antineutrino:**

In 1930, W. Pauli postulated the existence of neutrino. According to him, neutrino is a particle having no charge and its mass is almost zero. Neutrino is emitted in the process of β-decay in order to satisfy the requirements of β-decay. Its spin is ½.

Antineutrino is the antiparticle of neutrino having spin -½.

**Gamma-Emission:**

After the emission of α-particle or β-particle, the daughter nucleus is in excited state, it comes to a stable state by emission of one or more γ-rays. Since γ-rays are photons, so they don’t affect the atomic number or mass number of the nuclei.

Process of γ-decay can be written as:

ZXA ZXA + ZYA + γ-rays

where,

ZX\*A represents excited daughter nucleus.

**Half Life:**

***“The time taken by the atom or radioactive material to decay to half of the original number is called half-life of that material.”***

**Explanation:**

Radioactivity is a spontaneous emission of radiations but it does not mean that all the atoms disintegrate at the same instant. Nobody can predict which atom will disintegrate at what instant. It is a random process. To quantify this property, a special property is introduced called Half-life. It is a nuclear property and is not affected by external parameters like pressure, temperature etc.

**Mathematical Evaluations:**

To explain, let us consider a radioactive material having N0 number of element at a certain instant. After first half life, the remaining atoms will be and decayed will be .

After 2nd half- life, half of the remaining elements will be decayed and atoms left will be:

After 3rd half-life, half of will be decayed and remaining will be .

The result can be summarized for 3 half-life of a material, with original number N0 in the following table:

|  |  |  |
| --- | --- | --- |
| Number of half-life | Number of atom un-decayed | Number of atoms decayed |
| 1st half-life |  |  |
| 2nd half-life |  |  |
| 3rd half-life |  |  |

**Half-life Curve:**

To represent the variation of un-decayed atoms, as a function of time, a graphical method is more suitable as shown:

From the graph, it is clear that number of atoms decreases with ever-decreasing rate but never ends. At start, the rate is more, and decreases as number of half-lives increases.

**Half-life; A characteristic property:**

Half-life is a nuclear characteristic property and using half-life, we can distinguish between different elements. It means that by measuring the half-life of a certain radioactive element, we can identify it.

**Half-life of some elements:**

Half-life of Radium =1000 years

Half-life of Lead = 1.3 years.

Half-life of Uranium = 4.50 years.

**Radioactive Decay Law:**

***“The rate of disintegration of the nuclide at any time is directly proportional to the number of nuclei present at that time.”***

**Mathematical Form:**

If ‘N’ is the number of nuclei in the sample of a radioactive material at a certain time and ‘N’ nuclei decays in time t, then according to the decay law,

Where ‘λ’ is constant of proportionality and is known as decay constant. Its value depends on the nature of radioactivity material. The negative time shows that ‘N’ decreases as time increases. In differential form,

If there are ‘No’ un-decayed at time t=0 and a smaller number ‘N’ at a later time ‘t’ then integrating (1)

Where ‘N’ is the number of atoms at any time ‘t’. ‘e’ is ‘Euler’s number” having value equal to 2.71828.

This equation tells the number of atoms remaining after a time ‘t’.

**Unit of Activity:**

The S.I unit of activity is Becquerel (Bq).

**One Becquerel:**

***“One Becquerel is one disintegration per second.”***

**Other unit:**

Other unit is curie (Ci), named after Pierre Curie and Marie-curie.

**Relationship between Curie and Becquerel:**

The interconversion of curie and Becquerel is:

1Ci = 3.7 Bq

**Decay Constant:**

***“It is the probability per unit time for the decay of each nucleus of a given radioactive material.”***

We know that the instantaneous activity of a radioactive material is proportional to the active nucleus present at that time, so that

In order to attribute physical meaning to the decay constant ‘ we write above relation as:

Thus ‘’ can be interpreted as activity per single nucleus.

**Measurement of Half-Life:**

The half-life of a radioactive material is determined by measuring the activity of a given sample over a period of a time. A count-rate meter such as Geiger counter is used to measure the activity of a given sample. The activity versus time graph gives the decay curve. The half-life of the sample is determined from the decay curve. Note the activity at any time ‘t’, then note the activity at a subsequent time ‘t2’so that the activity has decreased to one half of that found at ‘t1’. The time difference (t2-t1) is then the half-life of the given radioactive sample.

**Characteristics of Alpha, Beta and Gamma radiations:**

**(A)Properties of α-rays:**

* α -particles are positively charged helium nuclei (2He4).
* They are deflected by electric and magnetic fields.
* They have small penetrating power and can be easily stopped by cardboard or metal. They travel not much greater than a few cm range in air.
* They have large ionizing power.
* α -particles produce fluorescence in certain substances.
* They can induce artificial radioactivity in certain substances.
* They affect photographic plates.

**(B)Properties of β-rays:**

* They are fast moving electrons or positrons.
* They are deflected by electric or magnetic fields.
* They have greater penetrating power as compared to alpha-particles. Their range in metal is **5 to 1** and nearly 1 m in air.
* They show less ionizing power as compared to alpha-particles.
* These rays affect the photographic plate.
* They also produce fluorescence on photographic screen.

**(C)Properties of γ-rays**:

* Gamma rays are electromagnetic waves and travel with speed of light.
* They eject electron when fall on a metal surface.
* These rays have very large penetrating power. It is about hundred times larger than β-particle. They are stopped only by a several cm of lead and have infinite range in air.
* They also produce fluorescence.
* They can be absorbed in various materials.

Interaction of Radiations with Matter:

**Interaction of α-particles and with Matter:**

* When an α-particle interacts with atoms or molecules of a gas, it knocks out the electrons an ionizes the atoms. It is not necessary for α-particles to eject electrons by hitting them but they can emit electrons due to coulombic interaction.
* Since α-particle is about 7000 times more massive than an electron, so it does not suffer any deflection from its straight path, provided it does not approach too closely to the nucleus.
* α-particle continuously produces an intense ionization along its straight pat till it loses all its energy and comes almost to rest. It then captures two electrons from the medium and becomes a neutral He-atom.
* An average of 35eV energy is used to produce one ion-pair. Therefore, a 7.7MeV α-particle emitted from the radium produces as many as 2ion pairs before stopping.
* The range of 7.7MeV α-particle in air is about 7cm and reduces further in a denser medium. The same α-particle will penetrate only 0.04mm in an aluminum foil.

**Interaction of β-particles and with Matter:**

* β -particles also lose energy by producing ionization. However, its ionizing ability is 100 times less than that of alpha-particles. As a result, its range is about 100 times more than alpha-particles.
* β -particles are more easily deflected by collisions than heavy alpha-particles.
* The β-particle suffer frequent deflections during its encounters and therefore, has an erratic path.
* The range of β-particle is measured by the effective depth of penetration into the medium not by length of erratic path. If the density of medium is more through which the particles moves the shorter will be its range.
* Because of lesser ionization, β-particle can penetrate much deeper into matter than can alpha-particle of the same energy.
* Alpha and β-particles both radiate energy as X-rays photons when they are slowed down by electric field of the charged particles in a solid material.

**Interaction of Gamma rays and with Matter:**

γ-rays being uncharged, cause very little ionization. The γ-rays interact with matter in three distinct ways, depending mainly on its energy:

* At low energies (less than about 0.1MeV), the dominant process is photoelectric effect, in which the γ-ray photon provides all its energy to the electron and is completely absorbed.
* If γ-ray photon has energy in the range of 0.1 to 1 MeV, then the dominant process is Compton’s effect in which γ-ray photon is scattered by collision with an electron.
* At higher energies (greater than or equal to 1.02 MeV), the photon transforms into electron-positron pair and hence causes pair-production.

In air γ-rays intensity falls off as the inverse square of the distance from the source, in the same manner as light from a lamp. In solids, intensity decreases exponentially with increasing depth of penetration into the material. The intensity ‘I0’ of a beam after passing through a distance ‘x’ in the medium reduced to the intensity ‘I’ by the relation:

Where,

µ is the linear absorption coefficient of the medium. This coefficient depends on the energy of the photon as well as on properties of matter.

**Fluorescence of α, β and γ radiations:**

***“Fluorescence is a process of absorbing radiant energy of high frequency and re-emitting energy of low frequency in the visible region at electromagnetic spectrum.”***

All properties i.e. α, β and gamma radiations produce fluorescence or glow on striking some substances like ZnS, NaI, or Barium platinocyanide coated screens.

**Interaction of Neutrons with Matters:**

* Neutrons being neutral, are extremely penetrating particles.
* They can be stopped or slowed down by a direct collision with the nucleus.
* The capture of a neutron by a nucleus often results in the formation of a radioisotope. In case of a heavy nucleus, the neutron can also cause fusion.
* Materials such as water or plastic, which contain more low mass nuclei per unit volume are used to stop neutrons.
* Neutrons produce a little indirect ionization, when they interact with materials containing H-atoms and knock out protons.

**Radiation Detectors:**

Nuclear radiations can’t be detected by our senses. Hence we use some detecting method i.e. interaction of radiation with matter. Most detectors make use of the fact that ionization is produced along the path of the particle. Some are given by:

**(1)Geiger-Muller Counter**:

***“A device used for detecting ionizing radiation to provide a count of individual particles and photons.”***

**History:**

It was first discovered in 1908 by Hans Geiger. Later on Geiger and W.Miller provided on improved version in 1928.

**Apparatus:**

It consists of a small thin walled closed metal tube containing an inert gas such as Argon at a pressure of about 10cm of Hg, with a small quantity of alcohol. A thin wire, insulated from the surrounding tube, in the center of the tube which serves as the anode. The body of the metal acts as cathode. The applied voltage produces a strong electric field in the tube, but smaller than the voltage used for discharge through gases. The particles or photons can enter through a small window usually made by mica.

**Working:**

The radioactive rays i.e. α, β and γ-rays if enters a G.M tube, creates ions and free electrons in the gas through successive collisions with the atoms of the gas. The electrons are accelerated so strongly towards the central positive wire that they further strike the gas atoms, knocking off other electrons and an avalanche of electrons is formed. When this avalanche reaches the positive wire, create a current pulse which is detected by a counting unit such as scalar. For each particle, entering a tube, a pulse is recorded and in this way, Geiger-Muller counter is able to count the particles that come through it.

**Quenching of Discharge:**

***“The process by which the gas in G.M tube is made non-conducting, immediately after each count is known as quenching of discharge.”***

During the process, the heavy and slowly moving positive ions may release electrons on reaching at the cathode. These electrons could reach the anode and may upset the recording of the incident particle. To avoid such a situation, quenching is done which may be:

**(a)Electronic Quenching:**

As soon as the signal is detected by the counter, quenching is obtained by an external unit which brings the voltage below critical value for ionization. Thus the tube is ready to register the next incoming particle.

**(b)Self-Quenching:**

In this quenching, vapor molecules of alcohol or Bromine is mixed with principal gas. The ionization energy is lower than that of argon and hence the ions arriving at the cathode are alcohol ions and acquire e- from the cathode. The alcohol molecules after the neutralization tends to dissipate energy in dissociation of molecules, rather than to release electrons from cathode. In case of Bromine gas, the molecules when interact with the positive ions spilt into individual atoms. So, positive ions lose their energy and cannot cause electron emission

**Uses:**

A Geiger counter can be used to determine:

***(1) A radioactive material in the region.***

***(2) The penetrating power of β-particles and γ-rays. The reduction of count rate by inserting an aluminum or lead plates between the source tube this helps to estimate the penetration power of the incident particles.***

***(3)The range of ionizing particles***

**Note:**

G.M counter can count up to 10,000 particles per second. But it is not suitable for fast counting. Scintillation counter or solid state detectors are fast enough, more efficient and accurate.

**Solid-state Detector:**

***“These are reverse-biased semiconductor diode which is used to detect nuclear radiation.”***

**Construction:**

The common type of silicon PN-junction detector is shown below. The back of detector is coated with thick layer of P-type, connected to the negative terminal of the battery. The top surface is made of very thin layer of N-type over with a thin layer of gold is coated which serves as anode. The conducting surfaces are connected through a resistor R. the radiations are made incident on N-type and electron hole pairs are formed. Arrangement is as shown:

**Working:**

As it is a PN-junction diode which is reverse biased, due to which thickness of depletion region increases. When an incident particle enters the N-type side, it produces and electron-hole pair. These charge carriers move under the influence of biasing potential. The electrons move towards the side of the junction connected to the positive terminal of the battery and holes are swept towards the negative side. The movement of these charge carriers give rise to an electric current in the external circuit which creates a pulse of voltage across the resistance R. the current pulse is amplified and recorded by an electronic counter.

**Advantages and Uses:**

(1) Solid state detectors are more efficient than other detectors.

(2) Since the size of the voltage pulse produced across R is proportional to the energy absorbed of the incident particle. So the energy needed to produce an electron-hole pair is 3 eV to 4 eV. This makes the device useful for detecting low energy particles.

(3) The collection time for electrons and holes is much less than gas filled counter. So solid state detector can count very fast.

(4) It is much smaller in size and operates at low voltage.

(5) It is useful for detection of α and β-particles, whereas a specifically designed detector having amplifier to detect the γ-rays.

**Nuclear Reactions:**

***“Any reaction in which there is any change in nucleus of an atom is called nuclear reaction.”***

**OR**

***“The change in nucleus of an atom due to the absorption or emission of nucleons is called nuclear reactions.”***

**Explanation:**

Based on the cause, nuclear reactions are divided into two types:-

**(1)Spontaneous Reactions:**

***“The type of nuclear reaction in which the nucleus emits nucleons or radiations on its own accord and either converted into other nuclei or change to the normal state from excited state.”***

**Mathematically:**

ZYA ─────────> Z YA` + nucleon

**OR**

(ZXA)`────────> ZXA + Radiation

**Examples:**

The natural radioactivity of the heaviest elements is an example of spontaneous or non-induced nuclear reaction.

e. g. Radium changes to radon by emission of α-particle

88Ra226 ────────> 86Rn222 + 2He4

**(2)Induced Nuclear Reactions:**

***“If a nucleon or nucleus is bombarded on a certain nucleus and changes occur in the nucleus or its state. The process is called an induced nuclear reaction.***”

The first induced reaction was discovered by Rutherford in 1918 when he bombarded an α-particle on nitrogen and obtained 8O17 and a proton.

Induced reactions are of many types; based on the types of incident particles:-

**(I)Neutron capture:**

As neutron is neutral particles so it does not experience any columbic repulsive force when bombarded on the nucleus. Therefore neutron is considered as an ideal projectile for induced nuclear reaction .it is called neutron capture. B/c energy of neutron is negligibly small compared to any nuclear reaction caused by the charged particle.

If thermal neutrons (very slow neutrons) are bombarded following reaction can be produced with the release of large amount of energy i.e.

1H1 + 0n1 ─────────> 1H2 + γ

Similarly

6C12 + 0n1 ─────────> 6C11 + 2 0n1

**(ii)Proton Induced Reactions:**

Here a charged proton is bombarded on a nucleus to bring changes in the nucleus. Proton is a charged particle and must have a high energy to reach the target nucleus and cause a transmutation.

7N14 + 1H1 ─────────>6C11 + 2He4

A proton captures a neutron and forms a deuteron by nuclear reaction and emits γ rays.

1H1 + 0n1 ─────────> 1H2 + γ-ray

**(iii)Deuteron Induced Reactions:**

Deuteron is also a positively charged particle and must have high energy to cause transmutation and nuclear reaction.

25Mn55 + 1H2 ─────────> 26Fe56 + 0n1

**(iv)Alpha Induced Reactions:**

Alpha particles are helium nuclei and are double positively charged.

The first nuclear transmutation was observed by Rutherford was the following:-

7N14 + 2H4 ─────────> 8O17 + 1H1

**(v)Proton (γ-ray) Induced Reactions:**

γ-rays can also be used to cause induced nuclear reactions.

4Be9 + γ ─────────> 2 2He4 + 2 2He4 + 0n1

1H2 + γ ─────────> 1H1 + 0n1

**Energy in Nuclear Reactions:**

Consider the following reaction:

7N14 + 2He4 ─────────> 8O17 + 1H1 + Q

The energy equivalence of the difference between the rest masses of the elements on the L.H.S and those on the R.H.S is called the nuclear reaction energy and is denoted by ‘Q’. Basically ‘Q’ represents the energy absorbed or evolved in a reaction. If ‘Q’ is negative, energy is absorbed in the reaction (endothermic reaction) and if ‘Q’ is positive, energy is evolved in the reaction (exothermic reaction). If ‘Q’ is negative, the energy required by the chemical reaction to complete is usually provided by the K.E of the incoming particles.

**Nuclear Fission:**

***“The splitting up of a heavy nucleus into two nuclei of comparable size with the emission of a large amount of energy is called Nuclear Fission.”***

**History:**

Fermi and his co-workers (1934) attempted to produce the elements beyond Uranium (Z>92) which at that time was the last element in the periodic table. They bombarded the Uranium with neutrons and found that the β-particles with different half lines were emitted. Therefore, they concluded that the elements with Z>92 i.e. the elements heavier than uranium, had been formed.

Hahn and Stresemann made similar experiments in 1939. After the chemical analysis of the products, they concluded that one of the product nuclei is barium and not a heavier element as predicted earlier. They predicted that the bombardment of neutrons can cause a nucleus to break apart, producing two or more fragments of moderate and comparable size. This process was called Nuclear Fission. Further, they found that the reaction is much more pronounced with thermal neutron.

**Explanation:**

We know from the binding energy curve that as the elements gets heavier, the binding energy per nucleon reduces. The reduction in the binding energy per nucleon is due to the effectiveness of Coulomb’s force with the increase of the size of the nucleus, the nuclear forces due to their short range are counter balanced by the Coulomb’s repulsive force. In normal Uranium nucleus; the two forces are in competition but when a neutron is bombarded, the deformation in the nucleus is produced. This deformation favor’s the Coulomb’s repulsive force and hence the Uranium nucleus is divided into two nearly equal parts. According to Bohr and Wheeler, ***the conflict between the Coulomb’s repulsive force and nuclear short range attractive force is resolved by the bombardment of a slow neutron.***

The two forces according to this theory are:

* The nucleus surface tension due to the short range nucleon force; trying to restore the nucleus to its original shape.
* The Coulomb’s repulsive force, due to the charge on the opposite ends of the dumbbell shape, trying to break up the nucleus into two halves.

**Reactions:**

The different possible reactions are;

92U235 + 0n1 ─────────> 92U236 ───> 56Ba141 + 36Kr92 + 3 0n1 + Q

92U235 + 0n1 ─────────> 92U236 ───> 54Xe140 + 38Sr94 + 2 0n1 + Q

**Fission Energy:**

***“The energy emitted due to the conversion of the mass into energy doing the nuclear fission is called nuclear fission energy.”***

The reason for the emission of this form of energy was the decline in the binding energy per nucleon in the binding energy curve. For heavy nuclei like Uranium, the nuclei were bound by less mass of energy. When intermediate nuclei were formed, the nucleons were bound together very tightly and the difference was emitted as energy in the nuclear reaction.

**Calculations:**

**Initial masses**:

U235 = 235.439v

0n1 = 1.0087u

= 236.0526u

**Final masses:**

Ba141 =140.9139u

Kr92 = 91.8973u

3 0n1 = 3.0261u

=235.837u

The decrease in mass = 0.2150

So,

Q = 0.2150 x 931Mev = 200 MeV

Therefore when one atom of U235 undergoes fission 200Mev of energy is released. If 1 g of naturally occurring uranium which has about 1019 atom of U235 undergoes fission the total energy released would be 200 x 1019 MeV = 3.2 x 108. It is found that 1 kg of uranium delivers as much energy as the combustion of about 3000 tons of coal.

**Chain Reaction:**

***“Self-sustaining fission reaction started with a single neutron in uranium with the emission of three neutrons in each reaction is called fission chain reaction.”***

**Explanation:**

It is well known that along with the splitting of U235 into smaller fragments, a lot of heat and three neutrons per fission also produced he production of 3 neutron per fission rises the possibility of having a chain reaction in which fission neutrons are further fission and the reaction keeps going on if the conditions are correct then these neutron will produce fission in other three uranium atoms and emits nine neutrons these nine neutrons will cause fission in nine more uranium nuclei and producing 27 neutrons with the release of energy thus a chain reaction can be setup as shown:

The numbers of neutrons goes on increasing and a large amount of energy is released in a short time. An uncontrolled chain reaction releases a large amount of energy in the atomic bomb which results in atomic bomb explosion.

**Critical Size:**

To sustain the fission process we need the nucleon per fission to be capable to carry out next fission. The mass of the material needed for this purpose is called critical mass and its size is called critical size. If the mass of the material is less than the critical mass the fission process will die down and if mass is equal or greater than the critical mass the fission reaction will sustain.

**Nuclear Reactor:**

***“A device which has a controlled and sustainable nuclear reaction for any of several purpose to produce power to supply neuron, to induce nuclear reactions, to prepare radio isotopes, or to breed fissionable material from certain “fertile” materials.”***

**Explanation:**

The nuclear reactors are divided into two types on the basis of neutrons:-

**(1)Thermal Reactors:**

***“Those reactors which use the slow moving neutrons and uranium (U235) as fuel are called thermal reactors”.***

These reactors use natural uranium or slightly enriched uranium as a fuel. (The uranium having greater percentage of U235 than natural uranium is known as enriched uranium). There are several designs of thermal reactors. Pressurized water reactors are widely used in the today world. In this type of reactor, water is prevented from boiling kept under high pressure. This hot water is used to boil around another circuit of water which produces steam for running a turbine and generates electricity.

**(2)Fast Reactors:**

***“Those reactors in which we use fast moving neutrons and 92U238 as a fuel are called fast reactors.”***

Here, each 92U238 nucleus absorbs a fast neutron and changes into Plutonium (94Pu239)

92U238 +0 n1 ─────────> 93Np239 + -1βo

93Np239 ─────────> 94Pu239 + -1βo

Plutonium can be fissioned by fast neutrons hence; moderator is not needed in fast reactors. The core of fast reactor consists of a mixture of Plutonium and Uranium dioxides surrounded by blanket of U238. Neutrons that escape from the core interact with U238 in the blanket, producing thereby 93Pu239. Thus more platinum fuel is bred in this way and uranium is used more effectively.

**Principle of a Nuclear Reactor:**

Controlled fission chain reaction is the principle of a nuclear reactor. This is achieved by controlling a number of neutrons produced in the fission event in such a way that one and only one neutron trigger another fission event. In this way the rate of energy generation is maintained at a constant level.

**Construction:**

Basically, a reactor consists of five parts:

1. Core of nuclear fuel
2. Moderator
3. Control rods
4. Heat exchanger

(V) Radiation shielding

**(I)Core of the nuclear fuel:**

This is the most important part of the reactor. It contains fuel which is a material that can be fissioned by thermal neutrons.

**(II)Moderator:**

The function of the moderator is to slow down the neutron produced during fission process, as the neutrons produced are very fast and not suitable for further fission.

**(III)Control rods:**

These rods keep the speed of the fission reaction under control. Usually, these are Cadmium, boron rods, which have the property of absorbing neutrons. By lowering the control rods, the activity of neutrons decreases.

**(IV)Heat Exchanger:**

This is the part of the nuclear reactor where the heat of the fission is transported ordinary through water.

**(V)Radiation Shielding:**

To absorb the harmful radiation produced by the radioactive decay, radiation shielding is used.

**Working:**

When a thermal neutron strikes a uranium atom, it starts the fission process which results in the splitting of uranium atom and the production of more fast neutrons. These fast neutrons are slowed down by moderator. These neutrons have much collision with the materials and come out with thermal energy to strike another fuel can. The material of the moderator should be (i) light (ii) Not to absorb neutrons. Usually Graphite and heavy water (containing Deuterium) are used as moderator.

Sometimes, the chain reaction, once started can liberate an enormous amount of energy and can go out of hand and this can even blow up the reactor. To avoid such a situation, control rods are used. These control rods can be inserted into or drawn out of the reactor fuel core and consists of a material that can absorb neutrons (e.g. Cadmium, Boron or Hafnium). Usually Cadmium rods are used. If these rods are drawn out, the activity of neutron increases and if they are inserted into the fuel core then the activity of the neutron decreases because the neutrons are absorbed by the rods.

The coolant, or heat exchanger, is used to cool the fuel rods and the moderator, and is capable of carrying large amount of energy (heat) generated in the process. If the moderator, fuel rods is not cooled, the heat generated can melt them. The heat carried by the coolant produces steam that can run a turbine, which in turn can run an electric generator.

The last part of the reactor is shielding. Since the neutrons and the fragments in the reactor undergo radioactive decay and produce radiations which are harmful to life, there must be some shielding device to absorb those radiations. For this purpose a concrete wall, this in a few feet thick, is used.

**Nuclear Fusion:**

***“The process in which two light nuclei merge and form a comparatively heavy nucleus is called nuclear Fusion”.***

**Explanation:**

Looking at the binding energy curve, we observe that the binding energy per nucleon increases when the mass no increases and becomes maximum for A=50 to A=60. The maximum value of binding energy is 8.8Mev. On further increasing the mass no the binding energy per nucleon decreases. The initial decrease in the binding fraction favours the fusion process whereas the latter decrease favors fission process. Therefore when smaller nuclei fuse together and form a relatively heavy nucleus, a large amount of heat is generated.

As an example, when a few MeV deuterons are used to bombard a target containing Deuterons, either of the two fusion reactions is observed.

1H2 + 1H2 ─────────> 2H3 + 0n1 + 3.3Mev

1H2 + 1H2 ─────────> 1H3 + 1H1 + 4.0Mev

Another example of fusion reaction releasing energy is the fusion of Deuteron and Triton to form a heavy alpha particle,

1H2 + 1H3 ─────────> 2He4 + 0n1 + 17.6Mev

It is estimated that if fusion process could be used for energy production, it would be six time more efficient than the fission of Uranium. The most promising fusion reactions are either of the above given Deuteron-Deuteron reactions. This is because there is an unlimited and inexpensive supply of Deuterium in the water of lakes and oceans that can be used as a fusion fuel.

**Fusion and Stellar Energy:**

Our sun is smaller than the average stars. Yet it continuously radiates 4×1023 kilowatts of power out into the space and has been doing so for billions of years. Astrophysical evidence shows that the temperature near the interior of the sun is 20 million degrees and the most abundant types of nuclei present in the stars are those of Hydrogen and Helium. It is believed that stars including sun deliver their enormous amount of energy by converting mass into energy, as in the fusion process. Two sets of thermonuclear fusion series reaction taking place at the central core of a star are proposed to be the source of stellar energy.

(1) The proton-proton cycle reactions

(2) The carbon cycle reaction

**(I)Proton-Proton Cycle:**

The possible explanation for the energy emitted from the stars sun etc is the fusion process. One set of fusion reaction which is supposed to be the source of energy from stars and sun is proton-proton cycle i.e.

1H1 + 1H1 ─────────> 1H2 + β+ + υ (neutrino)

1H1 + 1H2 ─────────> 2H3 + γ

1H1 + 2H3 ─────────> 2H4 + β+ + υ

In total,

4H1 ─────────> 2H4 + 2β+ + 2υ + γ

The mass defect for this reaction is ∆m= 0.0265, so

**Q = ∆mc2 = 0.0265 x 931 M e v = 24.7 MeV**

The net effect of this proton –proton sequence of fusion reactions is the conversion of four protons into a alpha particles, two positrons, two neutrinos, and a gamma ray photon. In this process energy of about 24.7 M e v is changed from rest mass into kinetic energy. It is believed that