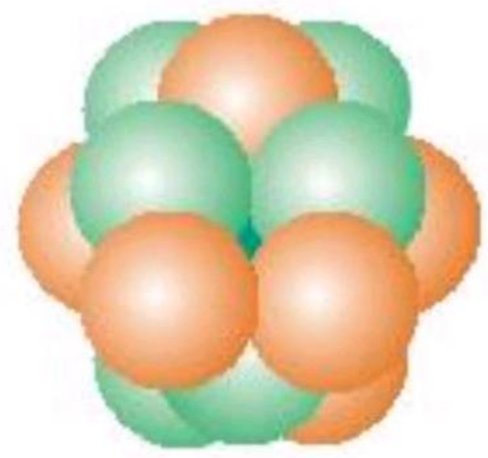
Chapter = 19

# Atomic Nucleus



## Nuclear Structure:



The nucleus consists of protons and neutrons. A proton is a positively charged particle having mass $1.6726 \times 10^{-27}$ kg and charge $1.6 \times 10 - 19$coulomb. The charge of the proton is equal in magnitude of the charge of an electron, but opposite to it in sign. Neutrons have no charge. Its mass is $1.6750 \times 10^{-27} Kg$. The mass of proton is 1836 times the mass of an electron.

## Mass Number:

The sum of the number of protons and neutrons in a nucleus is called Mass Number. It is denoted by 'A'. This number is also called Nucleus Number.

## Atomic Number:

The number of protons in a nucleus is called Atomic Number or proton number or charge number. It is denoted by 'Z'.

## Neutron Number:

The difference between mass number and atomic number is called Neutron Number. It is denoted by 'N' and is given by

$$N = A - Z$$

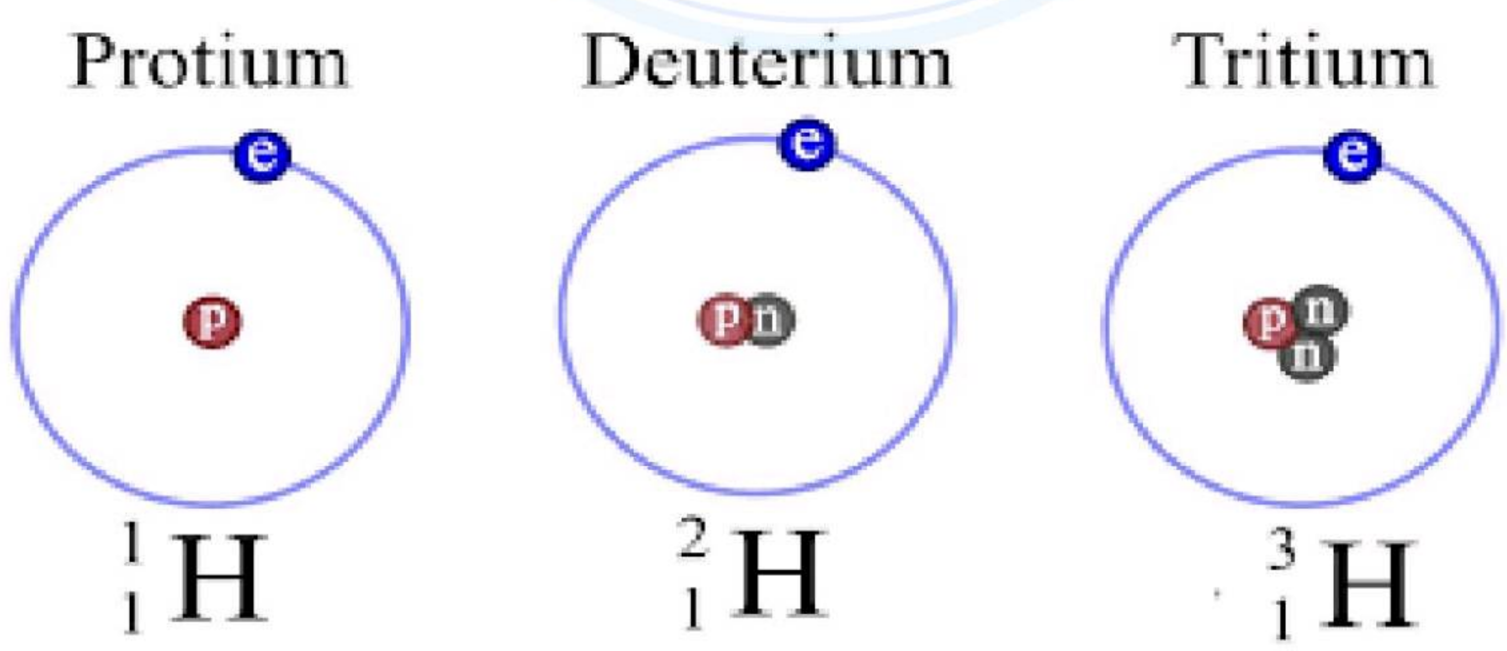
## Representation of an Element:

An element X having mass number A and atomic number Z is represented by the symbol.

$$X_Z^A$$

## Isotopes:

The elements having same atomic number, but different mass number or neutrons number are called isotopes. Example hydrogen deuterium and tritium



## Radioactivity:

The phenomenon of spontaneous disintegration of nucleus of atoms is known as radioactivity.

### Explanation:

Radioactivity is a self-disrupting activity exhibited by some naturally occurring elements. It has been found, that the elements with atomic number greater than 83 are unstable and emit certain type of radiations. Such substances (e.g. Uranium, Radium, and Thorium) are called Radio-active substances and the radiations emitted from their nuclei are called radioactive radiations and the phenomenon is known as Radioactivity.



## Radioactive Decay:

The phenomenon in which unstable nuclei disintegrated in to stable nuclei with emission of radiation is called Radioactive decay.

There are three types of radioactive decay:

- Alpha Decay
- Beta Decay
- Gamma Decay

## Alpha Decay($\alpha - Decay$):



The phenomenon in which parent nuclei is converted in to daughter nuclei with the emission of helium nuclei ($\alpha - particle$)is called Alpha decay. In alpha decay charge number (z) decreases by 2 and mass number (A) decreases by 4.

$$X_z^A \rightarrow Y_{z-2}^{A-4} + He_2^4$$

$$_{92}U^{238} \rightarrow {_2He^4} + {_{90}Th^{234}}$$

## Beta Decay ($\beta - Decay$):

The phenomenon in which parent nuclei is converted in to daughter nuclei with the emission of electron or positron is called beta decay.

There are two types of beta decay

1. $+\beta - decay$ (Positron Emission)
2. $-\beta - decay$ (Electron Emission)

### $+\beta - decay$ (Positron Emission):

The phenomenon in which parent nuclei is converted in to daughter nuclei with the emission of positron is called$+\beta - decay$. In positron emission a proton transforms itself in a neutron that is why the charge number (Z) is decreased by 1 and mass number remain unchanged.

$$X_z^A \rightarrow Y_{z-1}^A + e^+ + \nu$$

$${}_{11}Na^{22} \rightarrow {}_{10}Ne^{22} + \beta_+ + \nu_e$$

**$-\beta - decay$ (Electron Emission):**

The phenomenon in which parent nuclei is converted in to daughter nuclei with the emission of electrons are called $-\beta - decay$. In electron emission a neutron transforms itself in a proton that is why the charge number (Z) is increased by 1 and mass number remain unchanged.



$$X_z^A \rightarrow Y_{z+1}^A + e^- + \bar{\nu}$$

$${}_{27}Co^{60} \rightarrow {}_{28}Ni^{60} + \beta^- + \bar{\nu}_e$$

## Gamma Decay($\gamma - decay$):

After the beta or alpha emission daughter nuclei obtain is in the exited state and comes to ground state after emission of gamma ray photons. Since, photons are mass fewer neutral particles that are why the charge and mass number of nuclei remain unaltered.

$$X_z^A \rightarrow X_z^A + \gamma$$

# Law of Radioactive Decay:

## Statement:

*"The rate of decay in a radioactive process is directly proportional to the number of parent nuclides, present in the unstable nuclides of the given species."*

## Mathematical Expression:

If N is the number of unstable nuclide present in a given species then

$$\Delta N \propto N$$

$$\Delta N \propto \Delta t$$

$$\Delta N \propto N\Delta t$$

$$\Delta N = -\lambda N\Delta t$$

Here $\lambda$ is constant of proportionality called decay constant

$$\boxed{\frac{\Delta N}{\Delta t} = -\lambda N}$$

Term $\lambda N$ is called activity **A**

I-e

$$\boxed{A = \lambda N}$$

## Exponential form:

Since,

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

Applying limit $\Delta t \to 0$ on both sides we get;



$$\lim_{\Delta t \to 0} \frac{\Delta N}{\Delta t} = \lim_{\Delta t \to 0} -\lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\frac{dN}{N} = -\lambda dt$$

Integrating on both sides

$$\int_{N_o}^{N} \frac{dN}{N} = \int_{0}^{t} -\lambda dt$$

$$\ln N - \ln N_o = -\lambda t$$

Since $\ln x - \ln y = \ln\left(\frac{x}{y}\right)$

$$\ln\left(\frac{N}{N_o}\right) = -\lambda t$$

Taking exponential on both side

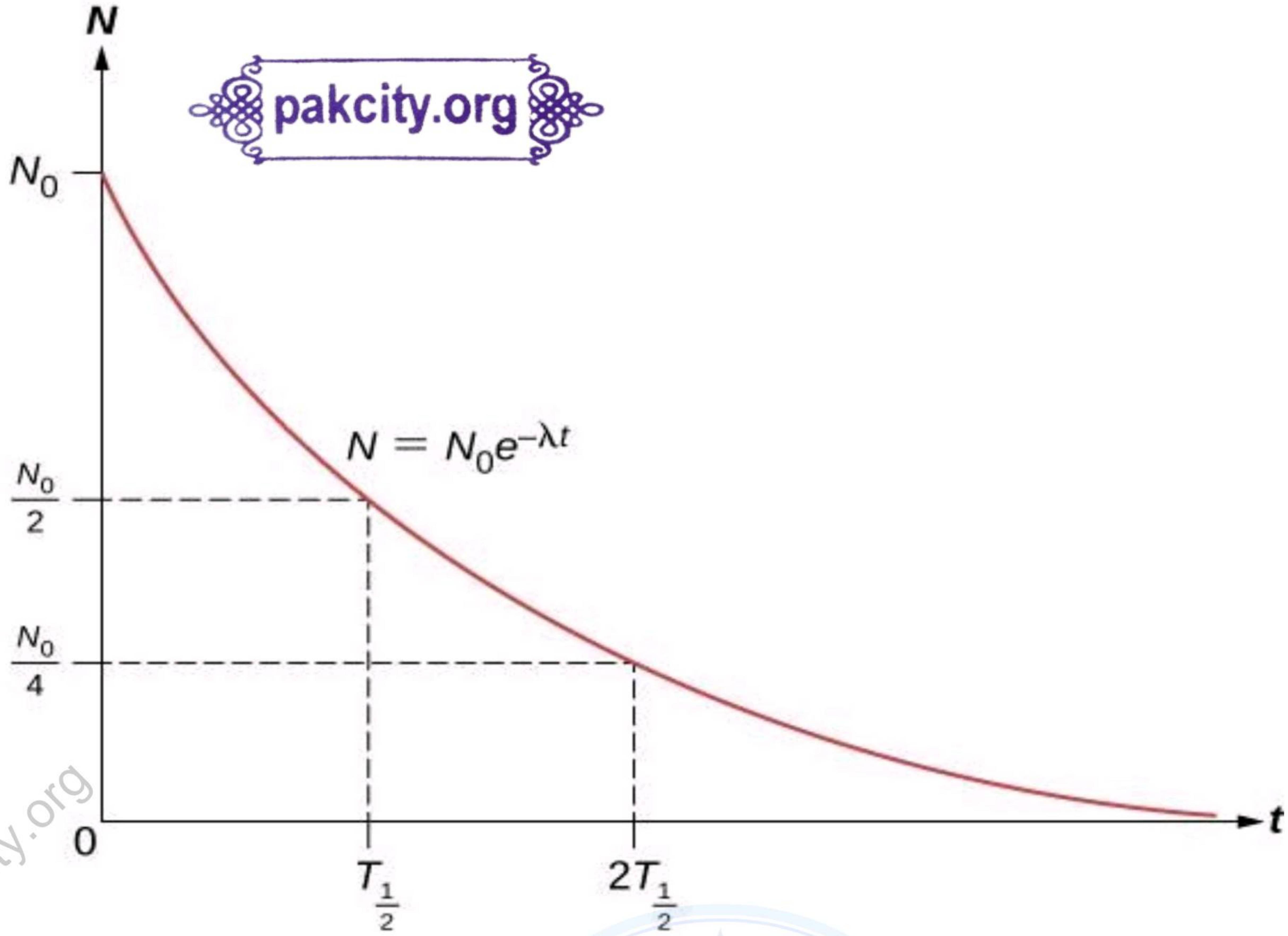
$$\frac{N}{N_o} = e^{-\lambda t}$$

Now in exponential form law of radioactive decay can be written as

$$\boxed{N = N_o e^{-\lambda t}}$$

Here N is the present number of unstable nuclei in the species after time t and $N_o$ is the total number of nuclei present.

## Graphical Representation:




## Half Life of Element:

It is the time in which half of radioactive elements decays from parent element to daughter element. It is denoted by $T_{\frac{1}{2}}$.

Mathematically

Exponential form of law of radioactive decay can be written as

$$N = N_o e^{-\lambda t}$$

After half life $N = \frac{N_o}{2}$ and $t = T_{1/2}$

$$\frac{\cancel{N_o}}{2} = \cancel{N_o} e^{-\lambda T_{1/2}}$$

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

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

Talking natural log on both sides

$$\lambda T_{\frac{1}{2}} = ln2 = 0.693$$

Hence

$$\boxed{\boldsymbol{T_{1/2} = \frac{0.693}{\lambda}}}$$

# Mass Defect, Binding Energy & Packing Fraction:

## Mass Defect:

The mass of the nucleus is always less than the mass of constituent nucleons. This difference in mass is called mass defect



## Mathematically:

$$Mass\ Defect\ =\ Mass\ of\ nucleons - Mass\ of\ nucleus$$

$$\Delta m\ =\ (Nm_n + Zm_p) - m_N$$

## Binding Energy:

The difference in energy between stable nucleus & constituent nucleons is called as binding energy of nucleus

## Mathematically:

$$B.E.\ =\ \Delta m\ C^2$$

When mass is in a.m.u than,

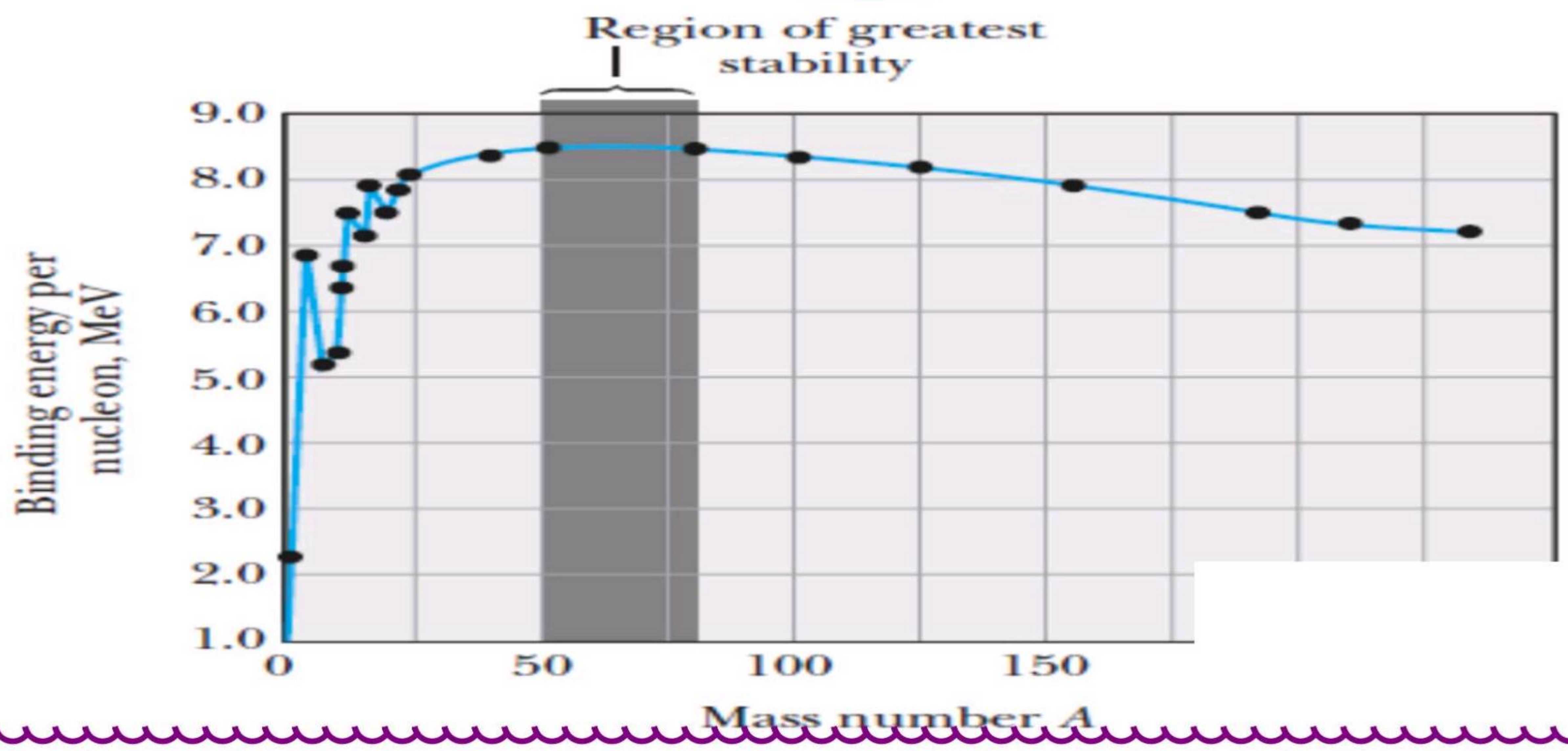
$$B.E.\ =\ \Delta m\ \times 931.5\ MeV$$

## Packing Fraction:

The binding energy per nucleon is called as packing fraction

## Mathematically:

$$P.F.\ =\frac{B.E.}{A}$$



## Nuclear Reactions:

Process in which two nuclei, or else a nucleus of an atom and a subatomic particle (such as a proton, neutron, or high energy electron) from outside the atom, collide to produce one or more nuclides that are different from the nuclide(s) that began the process is called a **Nuclear Reaction**.

Thus, a nuclear reaction must cause a transformation of at least one nuclide to another.

1. **HELIUM INDUCED REACTION**
   In this reaction Alpha particles obtained from radioactive nuclei are bombarded on nuclei
   **Example:**

$$N_7^{14} + He_2^4 \rightarrow O_8^{17} + H_1^1\ (Proton)$$

2. **PROTON INDUCED REACTION**
   In this reaction protons obtained from radioactive nuclei are bombarded on nuclei
   **Example:**

$$Li_3^7 + H_1^1 \rightarrow He_2^4 + He_2^4$$

3. **DEUTERON INDUCED REACTION**
   In this reaction deuteron nuclei are bombarded on nuclei
   **Example:**

$$Li_3^7 + H_1^2 \rightarrow He_2^4 + He_2^4$$

4. **GAMMA INDUCED REACTION**
   High energy gamma radiation are found to induce nuclear reactions
   **Example:**

$$Al_{13}^{27} + H_1^2 + \gamma(50MeV) \rightarrow Na_{11}^{25} + 2H_1^1$$

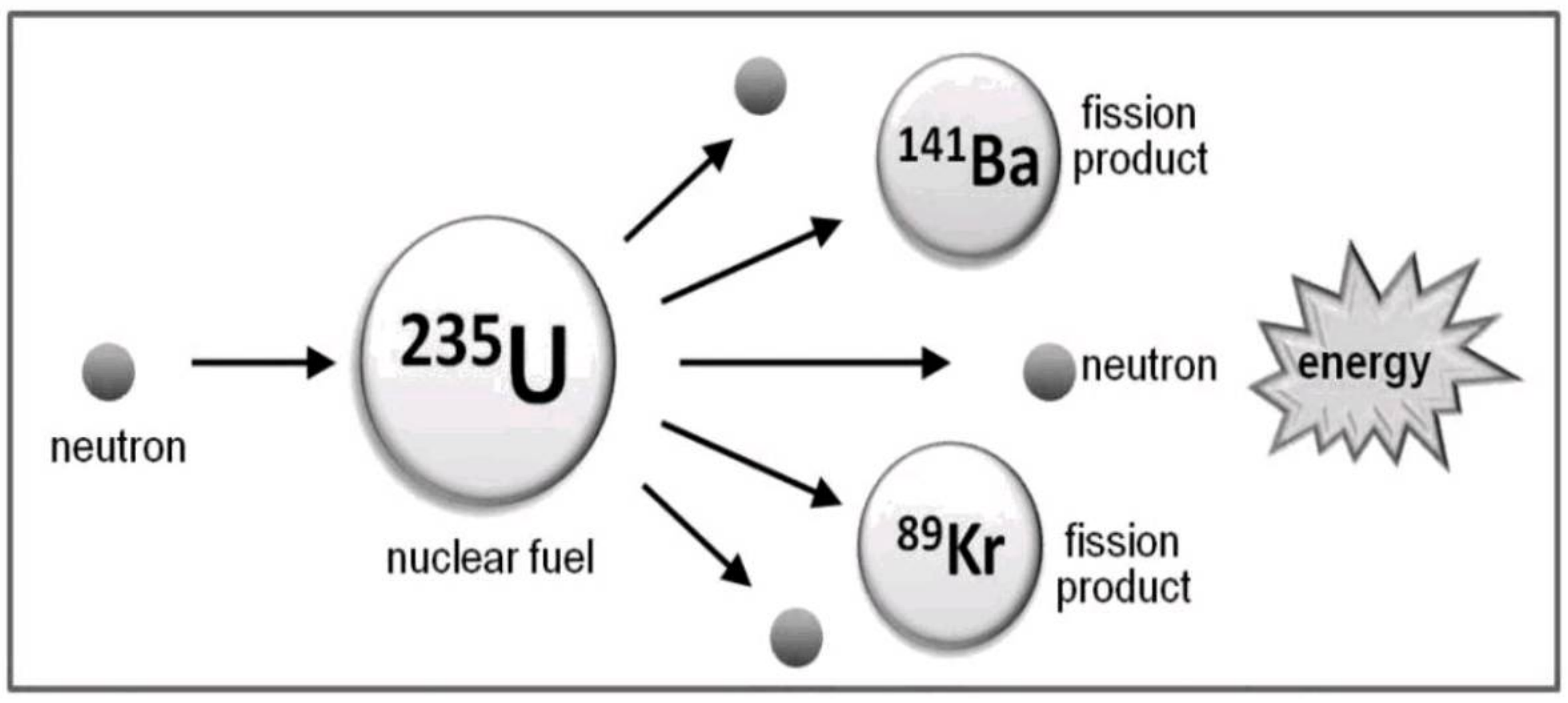
 

## Nuclear Fission:

The process in which a heavy nucleus breaks up into two lighter nuclei of nearly equal masses after bombardment by a slow neutron is known as nuclear fission.

## Explanation

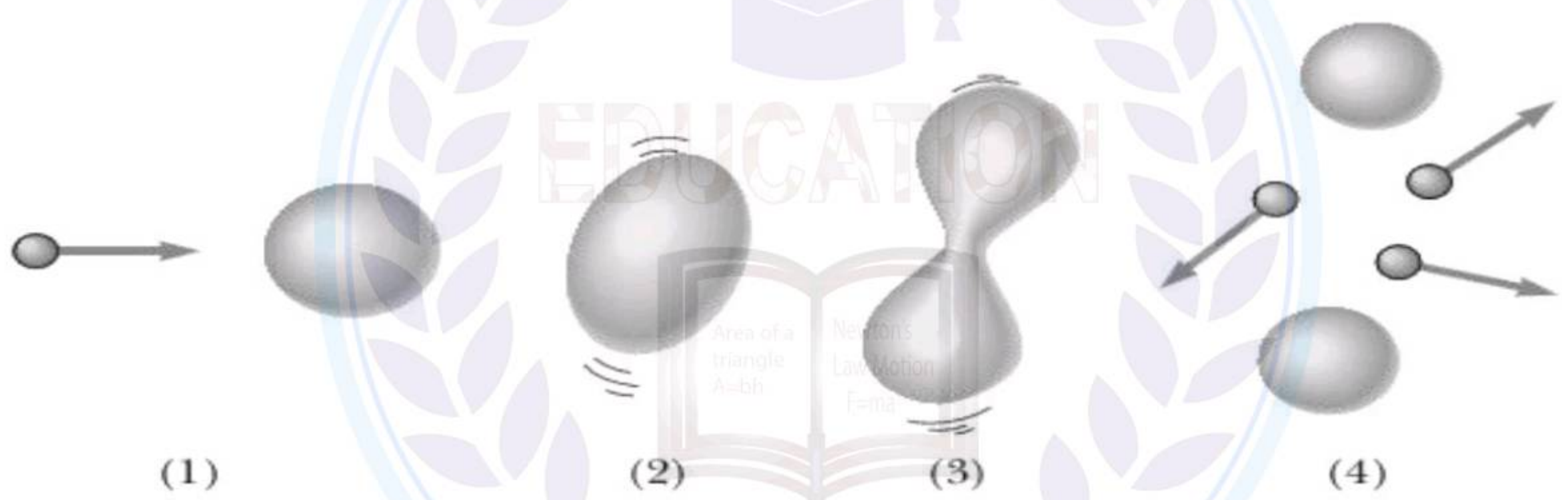
When an isotope of uranium of $U_{92}^{235}$ is bombarded with slow moving neutrons, then fission reactions takes place. During this process two new elements three neutrons and a large amount of energy is released. The two nuclei of new elements produced are Barium and Krypton.




$$U_{92}^{235} + n_0^1 \rightarrow Ba + Kr + 3n_0^1 + Energy\ released$$

Barium and Krypton are known as Fission pigments, which are radioactive. A large amount of heat energy is also liberated, which may be produced.

## Liquid Drop Model:




## Chain Reaction

Fission reaction is a chain reaction that has been classified into the following two types.

- Controlled Fission Chain Reaction.
- Uncontrolled Fission Chain Reaction.

## Controlled Fission Chain Reaction

In a fission reaction for one atom of uranium, three neutrons are produced, which may give rise to fission reaction in other uranium atoms. If two neutrons out of three are stopped then chain reaction takes place at uniform rate and a fixed amount of energy is obtained. This is done by usually Cadmium or graphite rods. In a nuclear reactor-controlled chain reaction takes place.

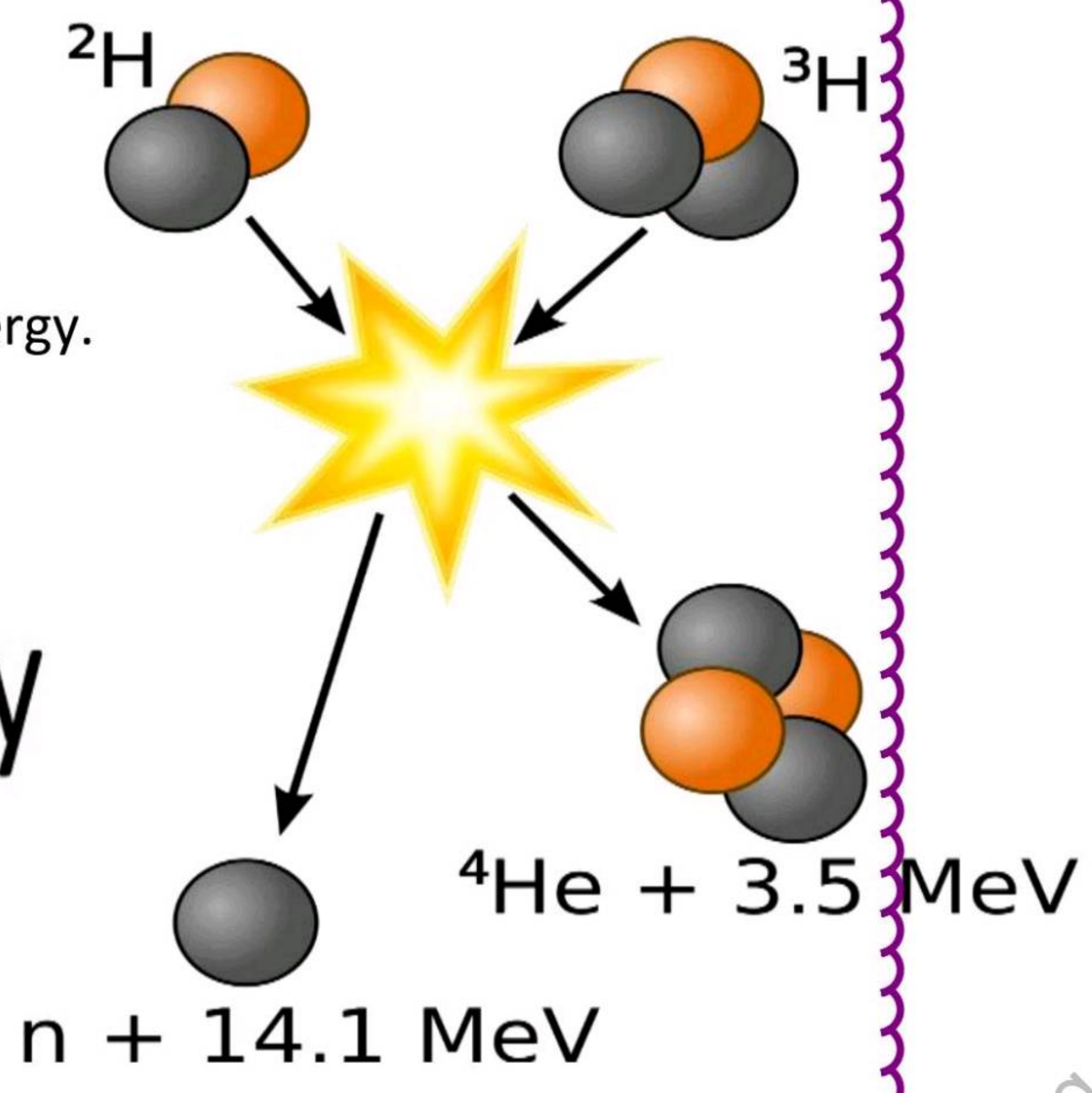
## Uncontrolled Fission Chain Reaction

If in a fission reaction, the number of neutrons is not controlled, then the reaction will build up at a very fast rate and in only few seconds, an explosion occurs. In an atom bomb, uncontrolled fission chain reaction takes place.



## NUCLEAR FUSION:

A process in which two light nuclei combine (or fuse together) to form a heavy nucleus and energy is released is called Nuclear Fusion. The energy released is called Thermo-Nucleus Fusion Energy.




$$ {}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + Energy $$

## Explanation

For example, when light nuclei of hydrogen are combined to form a heavier nucleus of helium energy is liberated.

The final mass is smaller than the initial mass and the deficit of mass is comparatively greater than in fission.

For this reason, the energy liberated in the process of fission.

It is very difficult to produce fusion reaction due to the fact that when two positively charged nuclei are bought closer and closer and then fused together. Work has to be done against the electrostatic force of repulsion. This requires a great deal of energy.

Fusion reaction can produce great amount of energy. The raw material 1 the reaction is deuteron, which is found in abundance in world oceans as heavy water.

The fusion reaction is possible in sun and stars because of very high temperature. The fusion reactions are also the basic source of energy in stars including the sun.

**CHAPTER-19** **NUMERICALS from Past Papers** 

**1994**

**Q.8. (c)** Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton = 1.0078U, mass of a neutron = 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

**2001**

**Q.8. (d)** Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton is 1.0078U, mass of a neutron is 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

**2006**

**Q.8. (d)** The half-period of $_{104}Po^{210}$ is 140 days. By what percent does its activity decrease per week? **(3.465 % per week)**

**2007**

**Q.7. (d)** Calculate the binding energy of hydrogen atom.

Given that: $m = 9.1 \times 10^{-31}$Kg $e = 1.6 \times 10^{-19}$Coul

$\epsilon_o = 8.854 \times 10^{-12}$Coul²/Nm² $h = 6.63 \times 0^{-34}$J s **(–13.6 eV)**

**2009**

**Q.8. (d)** If the number of atoms per gram of $_{88}Ra^{236}$ is $2.666 \times 10^{21}$ and it decays with a half-life of 1622 years, find the decay constant and the activity of the sample.

**($1.35 \times 10^{-11}$ sec$^{-1}$, $3.61 \times 10^{11}$ disintegration/sec)**

**2010**

**Q.2. (xiii)** A deuteron ($3.3431 \times 10^{-27}$ kg) is formed when a proton ($1.6724 \times 10^{-27}$ kg) and a neutron ($1.6748 \times 10^{-27}$) combine; calculate the mass defect and binding energy (in MeV). **($4.1 \times 10^{-30}$ kg, 2.3MeV)**

**2012**

Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton is 1.0078U, mass of a neutron is 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

**2013**

The number of atoms per gram of $_{88}Ra^{226}$is $2.666 \times 10^{21}$ and it decays with a half-life of 1622 years. Find the activity and decay constant of the sample.

**($1.35 \times 10^{-11}$ sec$^{-1}$, $3.61 \times 10^{11}$ disintegration/sec)**

**2014**

**Q2 (v)**Find the binding energy of $_{52}Te^{126}$ in MeV if the mass of a proton is 1.0078U, mass of a neutron is 1.0086U, mass of a Te atoms = 125.9033U. **(1061 MeV)**

**2015**

**Q2 (v)** Find the binding energy and packing fraction (B.E per nucleon) of $_{52}Te^{126}$.

Given that: $m_p$=1.0078U $m_n$=1.0086U $m_{Te}$=125.9033U 1U=931.5MeV