RADIOACTIVITY

1. RADIOACTIVITY

"*Radioactivity is a process* in which nuclei of certain elements undergo spontaneous disintegration without excitation by any external means."

Henry Becquerel (1891) observed the spontaneous emission of invisible, penetrating rays from potassium uranyl sulphate $K_2UO_2(SO_4)_2$, which influenced photographic plate in dark and were able to produce luminosity in substances like ZnS.

Later on, **Madam Marie Curie and her husband P. Curie** named this phenomenon of spontaneous emission of penetrating rays as, **Radioactivity.** They also pointed out that radioactivity is a characteristic property of an unstable or excited nucleus, i.e., a nuclear property is **independent** of all the external conditions such as pressure, temperature, nature of other atoms associated with unstable atom but **depends** upon the amount of unstable atom.

Curies also discovered a new radioactive element Radium from pitchblende (an ore of U i.e.U_3O_8) which is about 3 million times more radioactive than uranium. Now a days about 42 radioactive elements are known.

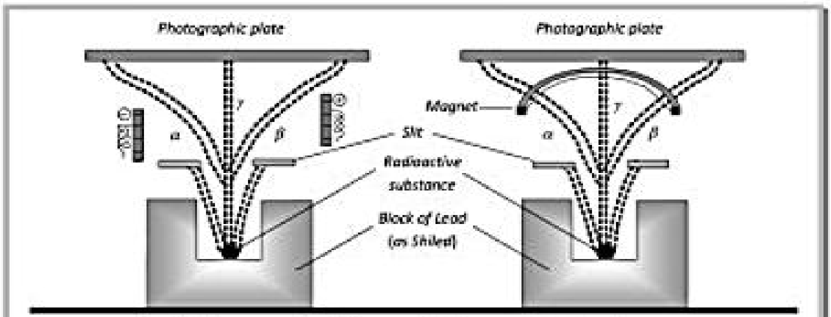
The elements whose atoms disintegrate and emit radiations are called radioactive elements.

Radioactivity can be detected and measured by a number of devices like ionisation chamber, **Geiger Muller** counter, proportional counter, flow counter, end window counter, scintillation counter, Wilson cloud chamber, electroscope, etc. The proper device depends upon the nature of the radioactive substance and the type of radiation emitted. Geiger Muller counter and proportional counter are suitable for solids and liquids, ionisation chamber is most suitable for gases.

Lightest radioactive isotope is tritium ($_1H^3$); other lighter radioactive nuclides are ^{14}C, ^{40}K and ^{99}Tc.

2. NATURE OF RADIOACTIVE EMISSIONS

The nature of the radiations emitted from a radioactive substance was investigated by **Rutherford (1904)** by applying electric and magnetic fields to the radiation as shown in figure.



Study of the nature of radiations emitted form a radioactive substance

It is observed that on applying the field, the rays emitted from the radioactive substances are separated into three types, called α, β, and γ-rays. The α-rays are deflected in a direction which shows that they carry positive charge; the β-rays are deflected in the opposite direction showing that they carry negative charge and the γ-rays are not deflected at all showing that they carry no charge.

3. CHARACTERISTICS OF RADIOACTIVE RAYS

Radioactive rays are characterised by the following properties:
(i) They blacken photographic plates.
(ii) They pass through thin metal foils.
(iii) They produce ionization in gases through which they passes.
(iv) They produce luminescence in zinc sulphide, barium platinocyanide, calcium tungstate, etc.

Radioactive radiations are composed of three important rays, namely α, β and γ–rays which differ very much in their nature and properties, e.g. penetrating power, ionising power and effect on photographic plates. Remember that γ-rays are not produced simultaneously with α and β-rays but are produced subsequently.

3.1 Properties of α, β-particles and γ-rays.

S.No	Property	α-Particles	β-Particles	γ-rays
1.	Nature and value of charge	Positive and double of the charge of the proton	Negative and equal to the charge of electron 1.6×10^{-19} C	Uncharged (Neutral)
2.	Nature of particle	Doubly ionized helium atom (2 protons and 2 neutrons)	Electron (or) positron	Electromagnetic waves
3.	Mass	Four times the mass of the proton $(4\times1.67\times10^{-27}kg)$	Equal to the mass of electron $9.1\times10^{-31}kg$	Mass less
4.	Specific charge $\frac{q}{m}$	$\frac{3.2\times10^{-19}}{4\times1.67\times10^{-27}} = 4.79\times10^{7}$	$1.7\times10^{11}Ckg^{-1}$	Uncharged and mass less
5.	Explained by	Tunnel effect	Neutrino hypothesis	Transitions of nuclei into the ground energy level after α and β decay
6.	Effect of electric and magnetic fields	Deflected by electric and magnetic fields	Deflected by electric and magnetic fields	Unaffected
7.	Penetrating power	1	100	10000
8.	Ionizing power	100000	100	1
9.	Velocity	Less than the velocity of light $(1.4\times10^{7}m/s\ to\ 2.2\times10^{7}ms^{-1})$	Approximately equal to the velocity of light	$3\times10^{8}m/s$
10.	Mutual interaction with matter	Produce heat	Produce heat	Produce the phenomenon of Photoelectric

4. SOME BASIC TERMS

4.1 Isotopes, Isobars and Isotones :

S.No	Isotopes	Isobars	Isotones
1.	The atoms of the same elements whose charge number (Z) is same but mass number is different are known as isotopes.	The atoms with mass number same and charge number different are known as isobars.	The atoms with same neutron number but A and Z are different are known as isotones
2.	Chemical properties are same	Chemical properties are different	Chemical properties are different
3.	Number of electrons is same	Number of electrons is different	Number of electrons is different
4.	Occupy same place in periodic table	Occupy different places in periodic table	Occupy different places in periodic table.
5.	Example ${}_8O^{16}, {}_8O^{17}, {}_8O^{18}$ ${}_1H^1, {}_1H^2, {}_1H^3$ ${}_{10}Ne^{20}, {}_{10}Ne^{21}, {}_{10}Ne^{22}$	${}_1H^3$ and ${}_2He^3$ ${}_6C^{14}$ and ${}_7N^{14}$ ${}_8O^{17}$ and ${}_9F^{17}$	${}_3Li^7$ and ${}_4Be^8$ ${}_1H^2$ and ${}_2He^3$ ${}_1H^3$ and ${}_2He^4$

4.2 Isodiaphers :

Atoms having same isotopic number are called isodiaphers.

Mathematically, isotopic number (isotopic excess) = (N - Z) or (A - 2Z)

Where, N = Number of neutrons; Z = Number of protons

Examples :

(i) ${}_{92}Np^{235}$ and ${}_{90}Th^{231}$ (ii) ${}_{19}K^{39}$ and ${}_9F^{19}$ (iii) ${}_{29}Cu^{65}$ and ${}_{24}Cr^{55}$

4.3 Isoelectronic species :

Species (atoms, molecules or ions) having same number of electrons are called isoelectronic.

Examples :

(i) N^{3-}, O^{2-}, F^-, Ne, Na^+, Mg^{2+}, Al^{3+}, CH_4, NH_3, H_2O and HF have 10 electrons each.

(ii) P^{3-}, S^{2-}, Cl^-, Ar, K^+ and Ca^{2+} have 18 electrons each.

(iii) H^-, He, Li^+ and Be^{2+} have 2 electrons each.

(iv) CO, CN^- and N_2 have 14 electrons each.

(v) N_2O, CO_2 and CNO^- have 22 electrons each.

4.4 Isosters :

Molecules having same number of total atoms and also same number of electrons are called isosters.

Examples :

(i) N_2 and CO (ii) HCl and F_2 (iii) CaO and MgS

Exercise

Match the following :

1.	Isotopes	A. ${}_8O^{16}$ and ${}_8O^{17}$
2.	Isobars	B. Na^+, Mg^{2+}, F^-
3.	Isosters	C. ${}_1H^2$ and ${}_2He^3$
4.	Isotones	D. CO_2 and N_2O
5.	Isoelectronic	E. ${}_AX^Z$, ${}_{A-2}X^{Z-A}$
6.	Isodiaphers	F. ${}_{20}Ca^{40}$ and ${}_{19}K^{40}$

Ans. 1–A, 2–F, 3–D, 4–C, 5–B, 6–E

5. RATE OF RADIOACTIVE DECAY

"According to the law of radioactive decay, the quantity of a radioelement which disappears in unit time (rate of disintegration) is directly proportional to the amount present."
The law of radioactive decay may also be expressed mathematically.
Suppose the number of atoms of the radioactive element present at the commencement of observation, i.e. when $t = 0$ is N_0, and after time t, the number of atoms remaining unchanged is N_t, then the rate of decay of atoms is $-\frac{dN_t}{dt}$ (the word 'd' indicates a very-very small fraction; the negative sign shows that the number of atoms N_t decreases as time t increases)

Now since the change in number of atoms is proportional to the total number of atoms N_t, the relation becomes $-\frac{dN_t}{dt} = \lambda N_t$, where λ is a radioactive constant or decay constant.
Rate of decay of nuclide is **independent** of temperature, so its energy of activation is zero.
Since the rate of decay is directly proportional to the amount of the radioactive nuclide present and as the number of undecomposed atom decreases with increase in time, the rate of decay also decreases with the increase in time. Various forms of equation for radioactive decay are

$$N_t = N_0 e^{-\lambda t};$$

$$\log \frac{N_0}{N_t} = \frac{\lambda t}{2.303}$$

$$\lambda = \frac{2.303}{t} \log \frac{N_0}{N_t}$$

where N_0 = Initial number of atoms of the given nuclide, i.e. at time 0
N_t = Number of atoms of that nuclide present after time t.
λ = Decay constant

Note : This equation is similar to that of first order reaction, hence we can say that radioactive disintegration are examples of first order reactions. However, unlike first order rate constant (K), the decay constant (λ) is independent of temperature.

5.1 Characteristics of decay constant (λ) :

It is characteristic of a nuclide (not for an element).
Its units are time^{-1} .
Its value is always less than one.

5.2 **Half-life Period ($t_{1/2}$) :** Rutherford in 1904 introduced a constant known as half-life period of the radio-element for evaluating its radioactivity or for comparing its radioactivity with the activities of other radio-elements. The half-life period of a radio-element is defined as the time required by a given amount of the element of decay to one-half of its initial value.

Mathematically, $t_{1/2} = \frac{0.693}{\lambda}$

5.3 Average Life Period (T) : Since total decay period of any element is infinity, it is meaningless to use the term total decay period (total life period) for radio elements. Thus the term average life is used which is determined by the following relation.

$$\text{Average life (T)} = \frac{\text{Sum of lives of the nuclie}}{\text{Total number of nuclei}}$$

5.4 Relation between average life and half-life : Average life (T) of an element is the inverse of its decay constant i.e., $T = \frac{1}{\lambda}$

Substituting the value of λ in the above equation , $T = \frac{t_{1/2}}{0.693} = 1.44 t_{1/2}$

Thus, Average life (T) = 1.44 × Half-life ($t_{1/2}$) = $\sqrt{2} \times t_{1/2} = 1.414\ t_{1/2}$

Thus the average life period of a radioisotope is approximately under-root two times of its half life period.

5.5 Specific activity : It is the measure of radioactivity of a radioactive substance. It is defined as 'the number of radioactive nuclei which decay per second per gram of radioactive isotope'. Mathematically, if 'm' is the mass of radioactive isotope, then

$$\text{Specific activity} = \frac{\text{Rate of decay}}{\text{m}} = \frac{\lambda N}{\text{m}} = \lambda \times \frac{\text{Avogadro number}}{\text{Atomic mass in g}}$$

Where N is the number of radioactive nuclei, which undergoes disintegration.

5.6 Activity (A) :

(a) The number of atoms of any material decaying per second is defined as the activity of that material.

(b) Its value depends on the quantity and nature of that material.

(c) Formulae of activity

(i) $A = -\frac{dN}{dt}$ (ii) $A = \lambda N$

(iii) $A_0 = \lambda N_0$ (iv) $A = A_0 e^{-\lambda t}$

where A_0 = maximum initial activity; A= activity after time t, λ =decay constant,

N_A = Avogadro number , m = mass of material

5.7 Units of Radioactivity –

S.I unit – disintegrations per second i.e., Bq

1 Bq = 1 disintegration/s

Practical units: curie and rutherford.

1 curie = 3.7×10^{10} disintegration/second:

1 Rutherford = 10^6 disintegrations/second.

Illustration :

1. The half life period of ${}_{53}I^{125}$ is 60 day. What % of radioactivity would be present after 180 day ?

Sol. $t_{1/2} = 60$ day, $T = 180$ day

$$\therefore \quad n = \frac{T}{t_{1/2}} = \frac{180}{60} = 3$$

$$\therefore \quad \text{\% of radioactivity left after 3 halves} = \frac{N_0}{2^3} = \frac{100}{2^3} = \mathbf{12.5\%}$$

2. What mass of ^{14}C isotope will have an activity equal to one curie? $t_{1/2}$ of ^{14}C is 5730 years.

Sol. $-\frac{dN}{dt} = 1 \text{ curie} = 3.7 \times 10^{10}$ disintegrations per second

$$\lambda = \frac{0.693}{5730 \times 365 \times 24 \times 3600}$$

$$-\frac{dN}{dt} = \lambda N \text{ or } 3.7 \times 10^{10} = \frac{0.693}{5730 \times 365 \times 24 \times 3600} \times N$$

Or $N = 9.65 \times 10^{21}$ atoms

$$\text{Or amount of } {}^{14}C = \frac{14}{6.023 \times 10^{23}} \times 9.65 \times 10^{21} = 0.2244 \text{ g}$$

Exercise

1. The half-life period of a radio active element is 100 seconds. Calculate the disintegration constant and average life period. How much time will it take for 90% decay?

Ans. $0.00693\ s^{-1}$, 144.3 s, 332.3 s

6. THEORY OF RADIOACTIVE DISINTEGRATION

Rutherford and **Soddy**, in 1903, postulated that radioactivity is a nuclear phenomenon and all the radioactive changes are taking place in the nucleus of the atom. They presented an interpretation of the radioactive processes and the origin of radiations in the form of a theory known as **theory of radioactive disintegration**. The main points of this theory are as follows :

The atomic nuclei of the radioactive elements are unstable and liable to disintegrate any moment.

The disintegration is spontaneous, i.e., constantly breaking. The rate of breaking is not affected by external factors like temperature, pressure, chemical combination etc.

During disintegration, atoms of new elements called daughter elements having different physical and chemical properties than the parent elements come into existence.

During disintegration, either alpha or beta particles are emitted from the nucleus.

The disintegration process may proceed in one of the following two ways :

6.1 **α-particle emission :** When an α-particle ($_2He^4$) is emitted from the nucleus of an atom of the parent element, the nucleus of the new element, called daughter element possesses atomic mass or atomic mass number less by four units and nuclear charge or atomic number less by 2 units because α-particle has mass of 4 units and nuclear charge of two units.

$$\underset{\substack{\text{Mass number : A}\\ \text{Atomic number : Z}}}{\textbf{Parent element}} \xrightarrow{-\alpha} \underset{\substack{A-4\\ Z-2}}{\textbf{Daughter element}}$$

Examples are:

$$\underset{\text{(Radium)}}{_{88}Ra^{226}} \longrightarrow \underset{\text{(Radon)}}{_{86}Rn^{222}} + {_2He^4};$$

$$\underset{\text{(Uranium)}}{_{92}U^{238}} \longrightarrow \underset{\text{(Thorium)}}{_{90}Th^{234}} + {_2He^4}$$

$$\underset{\text{(Bismuth)}}{_{83}Bi^{213}} \longrightarrow \underset{\text{(Thallium)}}{_{81}Tl^{209}} + {_2He^4};$$

$$\underset{\text{(Polonium)}}{_{84}Po^{215}} \longrightarrow \underset{\text{(Lead)}}{_{82}Pb^{211}} + {_2He^4}$$

6.2 **β-particle emission :** β-particle is merely an electron which has negligible mass. Whenever a beta particle is emitted from the nucleus of a radioactive atom, the nucleus of the new element formed possesses the same atomic mass but nuclear charge or atomic number is increased by 1 unit than the parent element. Beta particle emission is due to the result of decay of neutron into proton and electron.

$$_0n^1 \rightarrow {_1p^1} + {_{-1}e^0}$$

The electron produced escapes as a beta-particle-leaving proton in the nucleus.

$$\underset{\substack{\text{Mass number : A}\\ \text{Atomic number : Z}}}{\textbf{Parent element}} \xrightarrow{-\beta} \underset{\substack{A\\ Z+1}}{\textbf{Daughter element}}$$

Examples are:

$$\underset{\text{(Lead)}}{_{82}Pb^{214}} \longrightarrow \underset{\text{(Bimuth)}}{_{83}Bi^{214}} + {_{-1}e^0};$$

$$\underset{\text{(protoactinium)}}{_{90}Th^{234}} \longrightarrow + {_{91}Pa^{234}} + {_{-1}e^0}$$

$$_{83}Bi^{213} \longrightarrow \underset{\text{(Polonium)}}{_{84}Po^{213}} + {_{-1}e^0}$$

Special case : If in a radioactive transformation 1 alpha and 2 beta-particles are emitted, the resulting nucleus possesses the same atomic number but atomic mass is less by 4 units. A radioactive transformation of this type always produces an isotope of the parent element.

$$_ZA^A \xrightarrow{-\alpha} {_{Z-2}B^{A-4}} \xrightarrow{-\beta} {_{Z-1}C^{A-4}} \xrightarrow{-\beta} {_ZD^{A-4}}$$

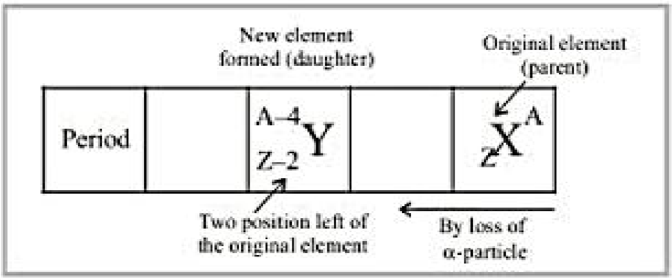
A and D are isotopes.

6.3 **γ-rays emission :** γ-rays are emitted due to secondary effects. The excess of energy is released in the form of γ-rays. Thus γ-rays arise from energy re-arrangements in the nucleus. As γ-rays are short wavelength electromagnetic radiations with no charge and no mass, their emission from a radioactive element does not produce new element.

7. GROUP DISPLACEMENT LAW

Soddy, Fajans and **Russell (1911-1913)** observed that when an α-particle is lost, a new element with atomic number less by 2 and mass number less by 4 is formed. Similarly, when β-particle is lost, new element with atomic number greater by 1 is obtained. The element emitting then α or β-particle is called parent element and the new element formed is called daughter element. The above results have been summarized as **Group displacement laws** as follows :

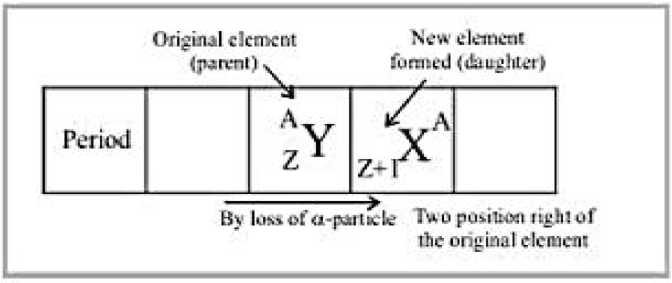
(1) When an α-particle is emitted, the new element formed is displaced two positions to the **left** in the periodic table than that of the parent element (because the atomic number decreases by 2).



For example, when

$$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$$

(2) When a β-particle is emitted, the new element formed is displaced one position to the right in the periodic table than that of the parent element (because atomic number increased by 1).



For example,

$$_{90}Th^{234} \longrightarrow {}_{91}Pa^{234} + {}_{-1}e^{0};$$
$$_{6}C^{14} \longrightarrow {}_{7}N^{14} + {}_{-1}e^{0}$$

7.1 To calculate no of α-particles and β-particle emitted

$$_{Z}X^{A} \longrightarrow {}_{Z^1}Y^{A^1} + x\alpha + y\beta$$

x: no of α-particles emitted y: no of β-particles emitted

$$_{Z}X^{A} \longrightarrow {}_{Z^1}Y^{A^1} + x\,{}_{2}He^{4} + y\,{}_{-1}e^{0}$$

$$A = A^1 + 4x \qquad x = \frac{A - A^1}{4}$$

$$Z = Z^1 + 2x - y \qquad y = Z^1 - Z + 2x \qquad y = \left(\frac{A - A^1}{2}\right) - \left(Z - Z^1\right)$$

eg : $\quad {}_{92}U^{238} \longrightarrow {}_{82}Pb^{206} + x\,{}_{2}He^{4} + y\,{}_{-1}e^{0}$

$$x = \frac{A - A^1}{4} = \frac{238 - 206}{4} = 8$$

no. of α-particles = 8

$$y = \left(\frac{A - A^1}{2}\right) - (Z - Z^1) = \left(\frac{238 - 206}{2}\right) - (92 - 82) = 16 - 10 = 6,$$

no. of β-particles = 6

Illustration :

1. Th_{90}^{234} disintegrates to give Pb_{82}^{206} as the final product. α and β particles emitted during the process are

(A) 7 and 6 (B) 6 and 7 (C) 2 and 4 (D) 4 and 2

Ans. (A)

Sol. Suppose the number of α particles emitted are 'x' and β particles emitted are 'y'. Then,

$$Th_{90}^{234} \rightarrow Pb_{82}^{206} + x\,{}_{+2}^{4}\alpha + y\,{}_{-1}^{0}\beta$$

On equating mass number on both sides, we obtain

$234 = 206 + 4x + 0y$

Or $x = 7$

On equating atomic number on both sides,

$90 = 82 + 2x - y = 82 + 2.7 - y$

Or $y = 6$

So, 7α and 6β particles are emitted.

Exercise :

The mass number of Th is 232 and its atomic number is 90. In terms of its radioactive disintegration six α and four β-particles are emitted. What is mass no. and at. no. of products ?

Ans. **208, 82**

8. THEORIES REGARDING NUCLEAR STABILITY

8.1 Even odd theory of nuclear stability

The number of stable nuclides is maximum when both p and n are even number.

p	n	No. of stable nucleus
even	even	165
even	odd	55
odd	even	50
odd	odd	5

8.2 Magic numbers and nuclear stability

Nuclei with 2, 8, 20, 28, 50, 82 or 126 protons or neutrons are exceptionally stable and have a larger number of stable isotopes than neighboring nuclei in the periodic table. These numbers are called magic numbers. They are supposed to represent completely filled nuclear shells of energy levels.

e.g. ${}_{50}Sn$ having 10 stable isotopes while ${}_{51}Sb$ has only two stable isotopes.

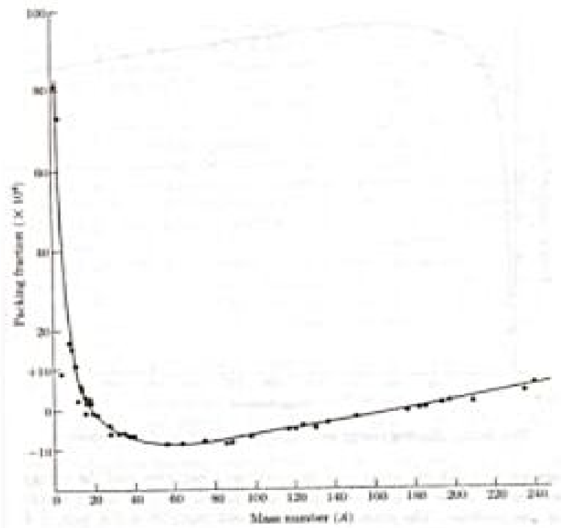
Nuclei with magic number of protons as well as neutrons have notably high stabilities. [eg. $^{4}_{2}He$, $^{16}_{8}O$, $^{40}_{20}Ca$ and $^{208}_{82}Pb$]. 165 such stable nuclei are known.

8.3 Packing Fraction

'Aston' expressed relation between isotopic mass & mass number in terms of packing fraction.

$$\textbf{Packing Fraction} = \frac{\text{Atomic mass} - \text{Mass number}}{\text{Mass number}} \times 10^4$$

Packing fraction of C–12 is exactly zero. packing fraction may be positive or negative. Negative packing fraction implies that nuclei is stable. Positive packing fraction implies that nuclei is unstable. Some lighter nuclei have positive packing fraction although nucleus is stable. Mo, Ru, Rh, Pd have lowest packing fraction



8.4 Binding Energy

Binding Energy : It is defined energy required to break the nucleus into its component protons & neutrons. Binding energy per nucleon gives a quantitative measure of nuclear stability.

Mass defect (Δm) = mass of neutron + mass of proton – mass of nucleus

Binding energy of nucleus = $\Delta m c^2$

The binding energy for a nucleus containing Z protons and N neutrons can be calculated as

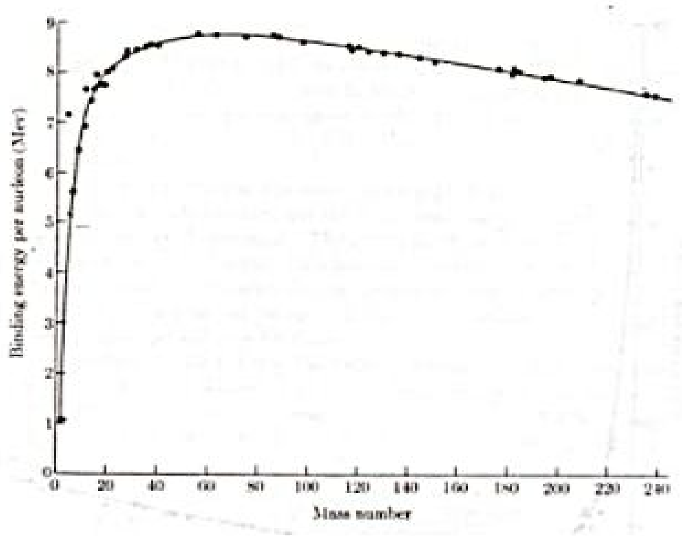
$$\text{Binding energy} = (ZM_H + Nm_n - {}^{A}_{Z}M)c^2$$

Note that above equation does not include Zm_p, the mass of Z protons. Rather, it contains ZM_H, the mass of Z protons and Z electrons combined as Z neutral $^{1}_{1}H$ atoms, to balance the Z electrons included in $^{A}_{Z}M$, the mass of the neutral atom.

If Δm = 1 a.m.u then B.E. = 931.5 MeV

$$\text{B.E. per nucleon} = \frac{\text{B.E.}}{\text{No. of nucleons}}$$

* A very heavy nucleus, say A = 240, has lower binding energy per nucleon compared to that of a nucleus with A = 120. Thus if a nucleus A = 240 breaks into two A = 120 nuclei, energy would be released in the process. This implies nucleons get more tightly bound. It has very important applications for energy production through fission.



* Consider two very light nuclei ($A \leq 10$) joining to form a heavier nucleus. The binding energy per nucleon of the heavier nuclei is more than the binding energy per nucleon of the lighter nuclei, again energy would be released in such a process of fusion. Nuclear binding energy is maximum for mass number 50 – 60. Fe, Co, Ni very high nuclear binding energy.

Illustration :

1. The atomic mass of $_8O^{16} = 15.9949$ amu. Calculate the BE/nucleon for this atom. Mass of 1n and 1p is 2.016490 amu. and $m_e = 0.00055$ amu.

Sol. Mass of 1n + 1p = 2.016490 amu.

$\therefore$ Mass of 8n + 8p = 8 × (2.016490) amu.

$\therefore$ Total mass of O^{16} atom = m (p + n) + m (electron)   (m = mass)

$$= 8 \times (2.016490) + 0.00055 \times 8 = 16.13632 \text{ amu}$$

$\therefore$ Mass defect = 16.1363 – 15.9949 = 0.1414 amu

$\therefore$ BE = Mass defect × 931.478 MeV

$= 0.1414 \times 931.487 = 131.71$ MeV

$$\therefore \quad \text{BE/nucleon} = \frac{\text{Total BE}}{\text{No. of nucleons}} = \frac{131.71}{16} = \mathbf{8.232\ MeV}$$

2. Calculate the mass defect and binding energy per nucleon for an alpha particle whose mass is 4.0028 amu. $m_p = 1.0073$ and $m_n = 1.0087$ amu.

Sol. α-particle has 2p and 2n

$\therefore$ Mass of 2p + 2n in α-particle = (2 × 1.0073) + (2 × 1.0087) = 4.032 amu

Actual mass of a-particle (given) = 4.0028 amu

$\therefore$ Mass defect = 4.032 – 4.0028 = **0.0292 amu.**

Now BE = Mass defect × 931 = 0.0292 × 931 = 27.1852 MeV

$$\therefore \text{BE/Nucleon} = \frac{27.1852}{4} = \mathbf{6.7963\ MeV}$$

Exercise :

1. Calculate the binding energy for $_1H^2$ atom. The mass of $_1H^2$ atom is 2.014102 amu, where ln and 1p have their weights 2.016490 amu. Neglect mass of electron.

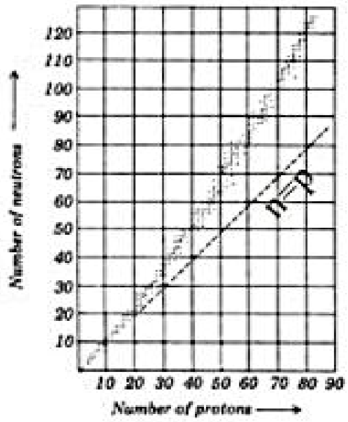
Ans. **2.2232 MeV**

8.5 Neutron / proton ratio and stability belt

For atomic number < 20, most stable nuclei have n: p ratio nearly 1 : 1 (except H & Ar).

For n/p ratio > 1.52, nucleus is unstable. Largest stable nucleus is $^{209}_{83}Bi$ for which n/p ratio is 1.52.

For atomic number > 83, there are no stable nuclei.



9. EXPECTED EMISSIONS FROM UNSTABLE NUCLEUS

9.1 n/p ratio above stability belt : Those nucleus which have high value of n/p ratio (lie above the stability belt) undergoes $^{0}_{-1}\beta$ decay.

$$n \longrightarrow p + ^{0}_{-1}\beta$$

$$^{32}_{15}P \longrightarrow ^{32}_{16}S + ^{0}_{-1}\beta$$

Beta decay is possible whenever the mass of the original neutral atom is greater than the final atom. The difference between the rest mass energy of the initial constituents and that of the final products is called the Q-value of the process. Thus, if U_i is the rest mass energy of the initial constituents and U_f is that of the final products,

$$Q = U_i - U_f$$

Q value is positive i.e. isolated neutron may decay into proton. The energy of $_{-1}{}^{0}\beta$ particle can be any thing between zero & Q. Such transformation takes place because of weak forces operating within the nucleus.

9.2 n/p ratio below stability belt :

(a) α-decay

$$^{212}_{83}Bi \longrightarrow ^{208}_{81}Tl + ^{4}_{2}He$$

Observed in nuclei with A > 210

Mass number & the atomic number of the daughter nucleus decreases by 4 & 2 respectively compared to parent nucleus. Alpha decay may take place spontaneously or it can be initiated. Alpha decay is possible whenever the mass of the original neutral atom is greater than the sum of the masses of the final neutral atom and the neutral helium-4 atom. All the alpha particles coming from a particular decay reaction have the same kinetic energy.

(b) $\left(^{0}_{+1}\beta\right)$ **Positron decay**

$$_1^1p \longrightarrow _0^1n + ^{0}_{+1}\beta$$

Those nucleus which have low value of n/p ratio (lie below the stability belt) undergoes $^{0}_{+1}\beta$ decay.

Q value is negative i.e. isolated proton will not decay into neutron.
Positron decay is possible whenever the mass of the original neutral atom is greater than at least two electron masses larger than the final atom.

(c) **K electron capture -** Electron is captured from Ist shell and one neutron is formed by the combination of captured e^- and a proton of the nucleus.

$$^{A}_{Z}X + ^{0}_{-1}e \longrightarrow ^{A}_{Z-1}Y$$

$$^{106}_{47}Ag + ^{0}_{-1}e \longrightarrow ^{106}_{46}Pd$$

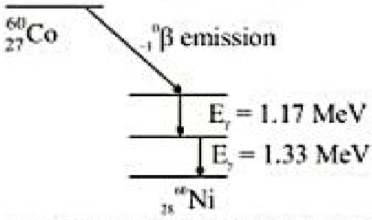
$$^{1}_{1}p + ^{0}_{-1}e \longrightarrow ^{1}_{0}n$$

* Electron capture can occur when ever the mass of original neutral atom is larger than that of final atom.
* Those nucleus having low n/p ratio can capture K shell electron.
* X-rays are emitted during the process.

(d) **γ-decay**
When an α or β decay takes place, the daughter nucleus generally formed is in excited state & comes to ground state by a single or successive transitions by emitting electromagnetic radiations i.e. γ rays.

$$^{60}_{27}Co \longrightarrow ^{60m}_{28}Ni + ^{0}_{-1}\beta$$

$$^{60m}_{28}Ni \longrightarrow ^{60}_{28}Ni + ^{0}_{0}\gamma$$



No. of neutron and proton is unchanged while quantum state of nucleon changes.

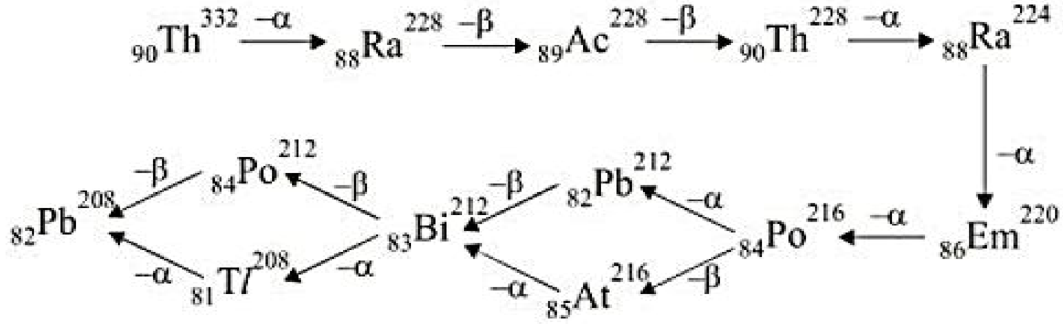
10. RADIOACTIVE DISINTEGRATION SERIES

Many radioactive nucleus (Z > 82) are obtained in nature as a member of natural decay series. The series of nuclear reaction is known as radioactive disintegration series.

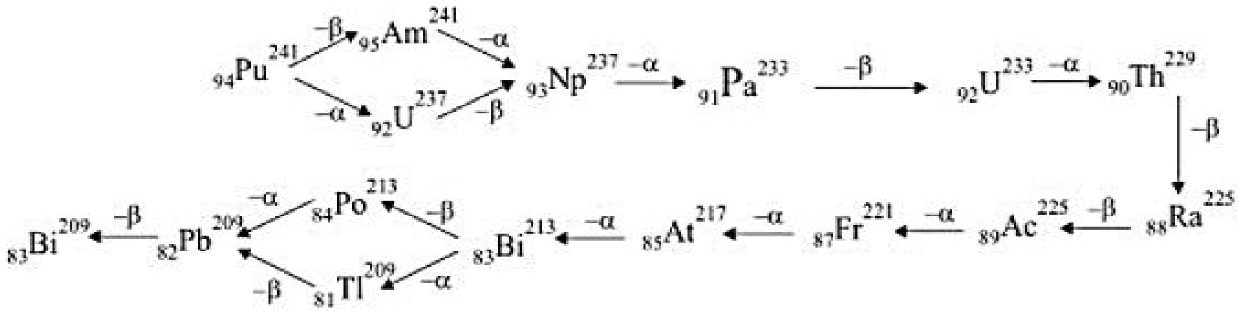
Series	Parent Nucleus	Last Nucleus	No. of α	No. of β
4n or Thorium series	Th^{232}	Pb^{208}	6	4
(4n+1) or Neptutinum series	Pu^{241}	Bi^{209}	8	5
4n+2 or Uranium series	U^{238}	Pb^{206}	8	6
4n+3 or Actinium series	U^{235}	Pb^{207}	7	4

4n, 4n + 3 and 4n + 3 series are natural while (4n +1) is artificial.

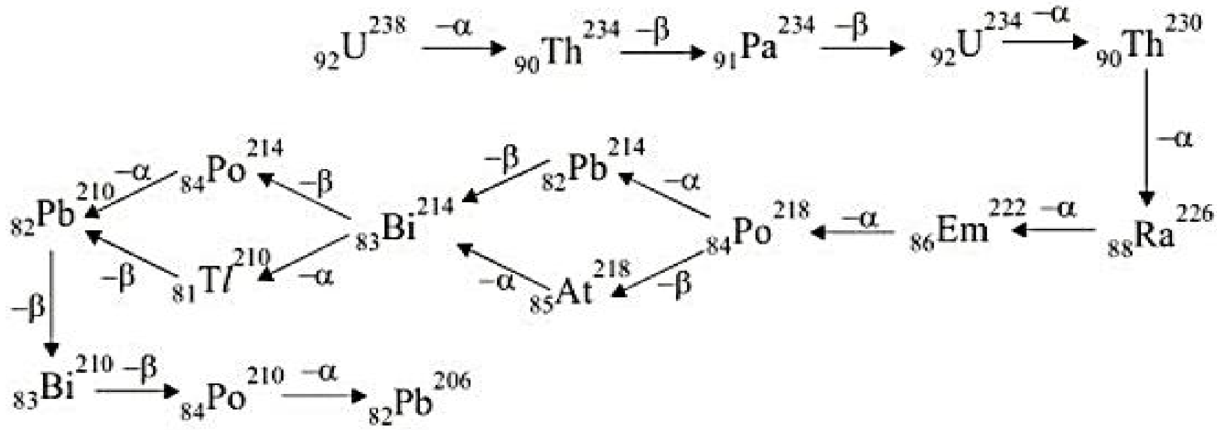
THE THORIUM SERIES :



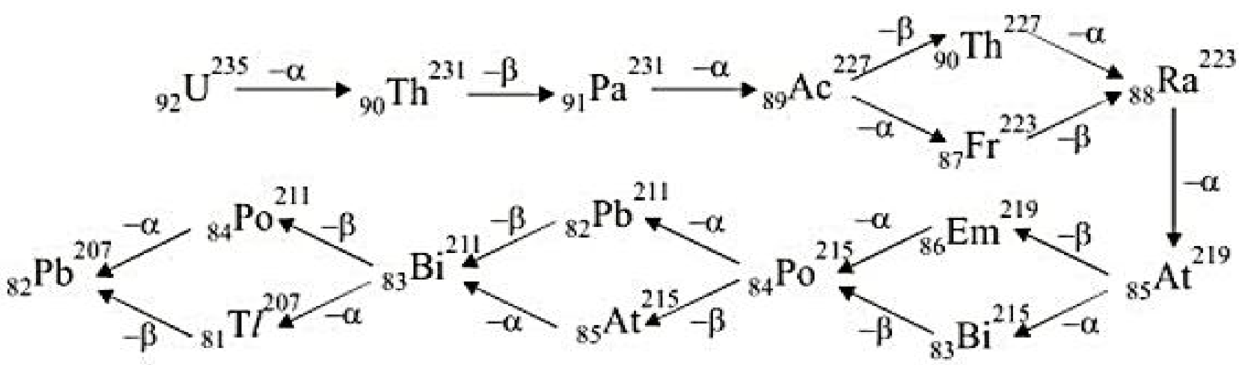
THE NEPTUNIUM SERIES :



THE URANIUM SERIES :



THE ACTINIUM SERIES :



11. APPLICATION OF RADIOACTIVITY

Radioisotopes find numerous applications in a variety of areas such as medicine, agriculture, biology, chemistry, archeology, engineering and industry. Some of the are given below :

11.1 Age determination (carbon dating) : Radioactive decay follows a very exact law, and is virtually unaffected by heat, pressure, or the state of chemical combination of the decaying nuclei, it can be used as a very precise clock for dating past events. For instance, the age of earth has been determined by uranium dating technique as follows. Samples of uranium ores are found to contain Pb^{206} as a result of long series of α- and β-decays. Now if it is assumed that the ore sample contained no lead at the moment of its formation, and if none of the lead formed from U^{238} decay has been lost then the measurement of the Pb^{206}/U^{238} ratio will give the value of time t of the mineral.

$$\frac{\text{No. of atoms of } Pb^{206}}{\text{No. of atoms of } U^{238} \text{ left}} = e^{-\lambda t-1},$$ where λ is the decay constant of uranium-238

Alternatively, $$t = \frac{2.303}{\lambda} \log \frac{\text{Initial amount of } U^{238}}{\text{Amount of } U^{238} \text{ in the mineral present till date}}$$

Similarly, the less abundant isotope of uranium, U^{235} eventually decays to Pb^{207}; Th^{232} decays to Pb^{208} and thus the ratios of Pb^{207}/U^{235} and Pb^{208}/Th^{232} can be used to determine the age of rocks and minerals. Many ages have been determined by this way to give result from hundreds to thousands of million of years,.

Besides the above long-lived radioactive substances viz. U^{238}, U^{235} and Th^{232} (which have been present on earth since the elements were formed), several short-lived radioactive species have been used to determine the age of wood or animal fossils. One of the most interesting substances is $_6C^{14}$ (half-life 5760 years) which was used by **Willard Libby** (Nobel lauret) in determining the age of carbon-bearing materials (e.g. wood, animal fossils, etc.) Carbon-14 is produced by the bombardment of nitrogen atoms present in the upper atmosphere with neutrons (from cosmic rays).

$$_7N^{14} + {_0n^1} \rightarrow {_6C^{14}} + {_1H^1}$$

Thus carbon-14 is oxidised to CO_2 and eventually ingested by plants and animals. The death of plants or animals puts an end to the intake of C^{14} from the atmosphere. After this the amount of C^{14} in the dead tissues starts decreasing due to its disintegration.

$$_6C^{14} \rightarrow {_7N^{14}} + {_{-1}e^0}$$

It has been observed that on an average, one gram of radioactive carbon emits about 12 β-particles per minute. Thus by knowing either the amount of C-14 or the number of β-particles emitted per minute per gram of carbon at the initial and final (present) stages, the age of carbon material can be determined by using the following formulae.

$$\lambda = \frac{2.303}{t} \log \frac{N_0}{N_t} \text{ or } t = \frac{2.303}{\lambda} \log \frac{N_0}{N_t}$$

where t = Age of the fossil, λ = Decay constant, N_0 = Initial radioactivity (in the fresh wood), N_t = Radioactivity in the fossil

The above formula can be modified as

$$t = \frac{2.303}{\lambda} \log \frac{\text{Initial of } C^{14}/C^{12} \text{(in fresh wood)}}{C^{14}/C^{12} \text{ ratio in the old wood}}$$

$$= \frac{2.303}{\lambda} \log \frac{\text{Initial amount of } C^{14}/C^{12} \text{ (in fresh wood)}}{\text{Amount of } C^{14} \text{ in the old wood}}$$

$$= \frac{2.303}{\lambda} \log \frac{\text{Radioactivity in fresh wood due to } C^{14}}{\text{Radioactivity in old wood due to } C^{14}}$$

$$= \frac{2.303 \times t_{1/2} \text{ of } C^{14}}{0.693} \log \frac{\text{counts min}^{-1} g^{-1} \text{ of } C^{14} \text{ in fresh wood}}{\text{counts min}^{-1} g^{-1} \text{of } C^{14} \text{ in old wood}}$$

Similarly, tritium $_1H^3$ has been used for dating purposes.

Illustration :

1. An old piece of wood has 25.6% as much C^{14} as ordinary wood today has $t_{1/2}$ of ^{14}C is 5760 years. Calculate the age of the wood ?

Sol. 'a' = amount of ^{14}C present originally in wood

Amount of ^{14}C now present in old wood = $(a - x) = \frac{25.6}{100} a = 0.256a$

$\therefore$ time 't' in which 'a' has changed to 0.256 a is

$$t = \frac{2.303}{\lambda} \log \frac{a}{0.256\,a}$$

Now, $\lambda = 0.693/5760 = 1.203 \times 10^{-4}\ y^{-1}$

$$t = \frac{2.303}{1.203 \times 10^{-4}} \log \frac{1}{0.256} \Rightarrow t = 11329 \text{ years}$$

Exercise :

1. The $_6C^{14}$ and $_6C^{12}$ ratio in a piece of wood is 1/16 part that of atmosphere . Calculate the age of wood. ($t_{1/2}$ of C_{14} is 5577 year).

Ans. 22308 year

11.2 Radioactive tracers (use of radio-isotopes) : A radioactive isotope can be easily identified by its radioactivity. Because of similar physical and chemical properties of radioisotopes and non-radioisotopes of an element, if a small quantity of the former is mixed with normal isotope, then chemical reactions can be studied by determining the radioactivity of the radioisotope. The radioactivity can, therefore act as a tag or label that allows studying the behaviour of the element or compounding which contains this isotope. An isotope added for this purpose is known as isotopic tracer. The radioactive tracer is also known as an isotopic tracer. The radioactive tracer is also known as an indicator because it indicates the reaction. Radioisotopes of moderate half-life periods are used for tracer work. The activity of radioisotopes can be detected by means of electroscope, the electrometer or the Geiger-Muller counter. Tracers have been used in the following fields :

(i) In medicine : Radioisotopes are used to diagnose many diseases. For example, Arsenic - 74 tracer is used to detect the presence of tumours, Sodium -24 tracer is used to detect the presence of blood clots and Iodine -131 tracer is used to study the activity of the thyroid gland. It should be noted that the radioactive isotopes used in medicine have very short half-life periods.

(ii) In agriculture : The use of radioactive phosphorus ^{32}P in fertilizers has revealed how phosphorus is absorbed by plants. This study has led to an improvement in the preparation of fertilizers. ^{14}C is used to study the kinetics of photo synthesis.

(iii) In industry : Radioisotopes are used in industry to detect the leakage in underground oil pipelines, gas pipelines and water pipes. Radioactive isotopes are used to measure the thickness of materials, to test the wear and tear inside a car engine and the effectiveness of various lubricants. Radioactive carbon has been used as a tracer in studying mechanisms involved in many reactions of industrial importance such as alkylation, polymerization, catalytic synthesis etc.

(iv) Analytical Studies : Several analytical procedures can be used employing radioisotopes as tracers.
(a) Adsorption and occlusion studies : A small amount of radioactive isotope is mixed with the inactive substance and the activity is studied before and after adsorption. Fall in activity gives the amount of substance adsorbed.

(b) Solubility of sparingly soluble salt : The solubility of lead sulphate in water may be estimated by mixing a known amount of radioactive lead with ordinary lead. This is dissolved in nitric acid and precipitate as lead sulphate by adding sulphuric acid. Insoluble lead sulphate is filtered and the activity of the water is measured. From this, the amount of $PbSO_4$ still present in water can be estimated.

(c) Ion-exchange technique : Ion exchange process of separation is readily followed by measuring activity of successive fractions eluted from the column.

(d) Reaction mechanism : By labelling oxygen of the water, mechanism of ester hydrolysis has been studied.

$$R-C\begin{matrix}\nearrow O \\ \searrow OR\end{matrix} + H\overset{*}{O}H \longrightarrow R-C\begin{matrix}\nearrow O \\ \searrow \overset{*}{O}H\end{matrix} + R'OH$$

(e) Study of efficiency of analytical separations : The efficiency of analytical procedures may be measured by adding a known amount of radio-isotopes to the sample before analysis begins. After the completion, the activity is again determined. The comparison of activity tells about the efficiency of separation.

11.3 **Use of γ–rays :** γ–rays are used for disinfecting food grains and for preserving food stuffs. Onions, potatoes, fruits and fish etc., when irradiated with γ–rays, can be preserved for long periods. High yielding disease resistant varieties of wheat, rice, groundnut, jute etc., can be developed by the application of nuclear radiations. The γ–rays radiations are used in the treatment of cancer. The radiations emitted by cobalt -60 can burn cancerous cells. The γ–radiations are used to sterilize medical instruments like syringes, blood transfusion sets. etc. These radiations make the rubber and plastics objects heat resistant.

12. NUCLEAR REACTIONS

The reactions in which nuclei of atoms interact with other nuclei or elementary particles such as α-particle, proton, neutron, deutron, etc, resulting in the formation of new nuclei with or without liberation of one or more elementary particles, are called nuclear reactions. The particles resulting nuclear reactions are also called projectiles. In all the nuclear reactions, the total number of protons and neutrons are conserved. Nuclear reactions may be expressed as similar as chemical reactions, like

$$_7N^{14} + {}_2He^4 \longrightarrow {}_8O^{17} + {}_1H^1$$

Here, the nucleus of nitrogen atom is converted in to the nucleus of oxygen atom by a-particle and proton is also produced as a by-product. These reactions may be expressed by short hand notation, in which the projectile and the liberating particle are expressed by their symbols, in a small bracket in between the parent and the product nucleus. For example, the above reaction may also be expressed as:

$$_7N^{14}\ (\alpha\ ,\ p)\ {}_8O^{17}$$

12.1 Some differences between nuclear and chemical reactions

No.	Chemical reaction	Nuclear reaction
1.	No new element is formed	New element is formed
2.	Valence electrons of atoms participates	Only the nucleus of atoms participates
3.	Balanced by the conservation of atoms	Balanced by the conservation of nuclear charge and mass number (total number of neutrons and protons)
4.	Mass conservation is obeyed	Disobey mass conservation
5.	May be exothermic or endothermic, liberating or absorbing relatively small amount of energy	May be exothermic or endothermic, liberating or absorbing relatively very high amount of energy
6.	May be reversible	Irreversible
7.	May obey kinetics of any order	Obeys only first order kinetics
8.	Rate depends on external factors like temperature and the catalytic conditions	Rate is independent from any external condition

12.2 Types of Nuclear Reactions :

(i) Projectile Capture Reactions:

$$_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} + \gamma$$

$$_{13}Al^{27} + {}_0n^1 \rightarrow {}_{13}Al^{28} + \gamma$$

(ii) Particle - particle reactions:

$$_{11}Na^{23} + {}_1H^1 \rightarrow {}_{12}Mg^{23} + {}_0n^1$$

$$_{11}Na^{23} + {}_1H^2 \rightarrow {}_{11}Na^{24} + {}_1H^1$$

(iii) Spallation reactions: High speed projectiles with 400Mev bombarded on high nucleus giving smaller nucleus.

$$_{29}Cu^{63} + {}_2He^4 \rightarrow {}_{17}Cl^{37} + 14\,{}_1H^1 + 16\,{}_0n^1$$

(iv) Fission reactions: It is the nuclear reaction in which a heavy nucleus is broken down by a slow or thermal neutron (energy about 0.04 eV) into two relatively smaller nuclei with the emission of two or more neutrons and large amount of energy. For example,

the **reaction of atom bomb:** ${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\ {}_{0}n^{1} + 200\ MeV$

It is also found that the products of nuclear fission reactions are not unique. Some more products are formed. The most probable mass numbers of the two nuclides formed are around 95 and 140 and an average of 2.5 neutrons is emitted out per fission.

$${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{54}Xe^{139} + {}_{38}Sr^{95} + 2\ {}_{0}n^{1}$$

$$\rightarrow {}_{53}I^{137} + {}_{39}Y^{97} + 2\ {}_{0}n^{1}, \text{ etc}$$

The destructive action of atom bomb is due to the following reasons:

(a) As some neutrons are produced in each fission, they may collide efficiently with the other U^{235} nuclei to produce more neutrons and thus the reaction occurs in chain like fashion. It results the emission of a large amount of energy in very small time.

(b) Each product of fission is radioactive and hence increases the intensity of radiation in that region, resulting the problems due to radiations.

(v) Fusion reactions: It is the nuclear reaction in which two or more light nuclei fused together to form heavier nuclei, with the evolution of tremendous amount of energy. In such reactions, relatively more stable nucleus having higher binding energy per nucleon is formed. Such reaction is difficult to occur because when the nuclei of different atoms come closer, they repel each other strongly. This is why, very high temperature of the order 10^6K is needed for the occurrence of such reactions. However, the overall reaction is highly exothermic due to large mass defect. Some examples of nuclear fusion reactions are:

Probable reaction occurring at the surface of sun: $4\ {}_{1}H^{1} \rightarrow {}_{2}He^{4} + 2\ {}_{+1}e^{0} + 24.7\ MeV$

Illustration :

Write equations for the following transformations :

(a) ${}_{7}N^{14}$ (n, p) (b) ${}_{19}K^{39}$ (p, α) (c) β^{+}–decay by ${}_{11}Na^{22}$

Sol. (a) ${}_{7}N^{14}$ (n, p) indicates that N^{14} on bombardment with neutrons gives proton.

$\therefore \quad {}_{7}N^{14} + {}_{0}n^{1} \longrightarrow {}_{Z}X^{m} + {}_{1}p^{1}$

on equating at. no. and mass no. on both sides, we get

${}_{7}N^{14} + {}_{0}n^{1} \longrightarrow {}_{6}C^{14} + {}_{1}p^{1}$

(b) ${}_{19}K^{39}$ (p, α) indicates that K^{39} on bombarment with proton gives α-particle.

There, ${}_{19}K^{39} + {}_{1}H^{1} \longrightarrow {}_{18}Ar^{36} + {}_{2}He^{4}$

(c) ${}_{11}Na^{22} \longrightarrow {}_{10}Ne^{22} + {}_{+1}e^{0}$ (β^{+} or positron)

Exercise :

Complete the following :

(1) ${}_{7}N^{14} + {}_{2}He^{4} \longrightarrow {}_{8}O^{17} + ...$ (2) ${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{55}A^{142} + {}_{37}B^{92} + ...$

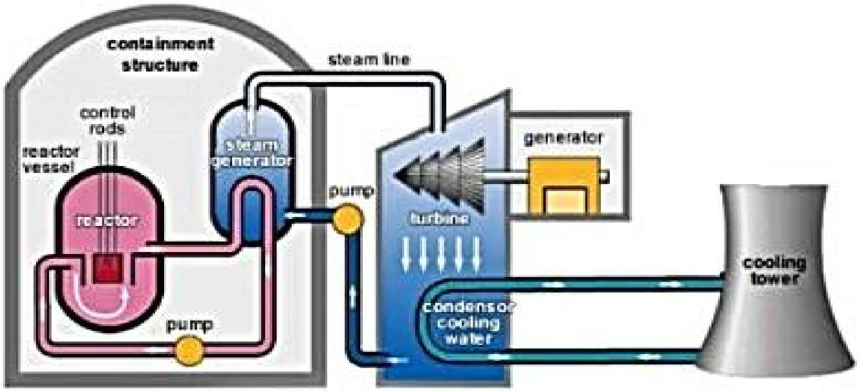
(3) ${}_{29}Cu^{53} \longrightarrow {}_{28}Ni^{53} + ...$

Ans. (1) ${}_{7}N^{14} + {}_{2}He^{4} \longrightarrow {}_{8}O^{17} + {}_{1}H^{1}$ (2) ${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{55}A^{142} + {}_{37}B^{92} + 2\ {}_{0}n^{1}$

(3) ${}_{29}Cu^{53} \longrightarrow {}_{28}Ni^{53} + {}_{+1}e^{0}$

13. NUCLEAR REACTOR

A nuclear reactor is the furnace, place where nuclear fission reaction is performed to get energy. The essentials of a nuclear reactor are:



(i) **Fuel** : Nuclear fuels are of two types:

(a) **Fissile materials** : These are the nuclides which directly results chain reaction on bombardment with slow neutrons. Such nuclides are U^{235}, Pu^{239}, U^{233}, etc.

(b) **Fertile material** : These are the nuclides which are non-fissile, but they may be converted in to a fissile material by the action of neutrons. Such nuclides are U^{238} and Th^{232}.

$$_{92}U^{238} + {}_0n^1 \longrightarrow {}_{92}U^{239*} \xrightarrow{-\beta} {}_{93}Np^{239} \xrightarrow{-\beta} {}_{94}Pu^{239}$$

$$_{90}Th^{232} + {}_0n^1 \longrightarrow {}_{90}Th^{233*} \xrightarrow{-\beta} {}_{91}Pa^{233} \xrightarrow{-\beta} {}_{92}U^{233}$$

Such conversions are performed in a special type of nuclear reactor called Breeder Reactor.

(ii) **Moderator**: It is used to slow down the fast neutrons without absorbing them. Example: water, graphite, helium, D_2O etc.

(iii) **Control rods**: These are the rods of material which can absorb neutrons and hence control the fission reaction. Example: Cadmium, boron, etc.

(iv) **Coolant:** These are the material which transforms the energy produced in the fission reaction in to heat energy. Example: Liquid alloy of sodium and potassium, heavy water, polyphenyls, etc

14. ARTIFICAL TRANSMUTATION

It is the method of conversion of atom of one element in to the atom of other element with the help of some particles like alpha particle, proton, deutron, neutron, etc (called projectiles). The first such transmutation was performed by Rutherford. When N^{14} atoms were bombarded by very fast moving α-particles, the nitrogen atom has changed in to oxygen atom and proton is produced simultaneously

$$_7N^{14} + {}_2He^4 \longrightarrow {}_8O^{17} + {}_1H^1$$

Later on, Rutherford and Chadwick shown that most of the nuclei may be transmuted by the suitable projectile. After the discovery of cyclotron, a particle accelerating machine, such transmutations become more easier.

15. ARTIFICAL RADIOACTIVITY

When Irene Curie and F. Juliot bombarded the atoms of Al^{27}, B^{10} or Mg^{24} by fast moving α-particles, protons, neutrons and positrons were produced. They observed that the emission of protons and neutrons stop on stopping the bombardment but the emission of positron continues. They also observed that the rate of emission of positron decreases exponentially in the manner similar to natural radioactivity. They named the isotope emitting positron as **artificial radioisotope** and the phenomenon as **artificial radioactivity**.

$${}_{13}Al^{27} + {}_{2}He^{4} \longrightarrow {}_{14}Si^{30} + {}_{1}H^{1}$$

$$\longrightarrow {}_{15}P^{30} + {}_{0}n^{1}$$

$$\downarrow$$

$${}_{14}Si^{30} + {}_{+1}e^{0}$$

SOLVED EXAMPLES

Q.1 The half-life of a radioisotope is 1.5 hours. If its initial mass is 32 g, the mass left undecayed after 6 hours is

(A) 32 g (B) 16 g (C) 4 g (D) 2 g

Ans. (D)

Sol. $N = \text{mass left} = \dfrac{N_0\,(\text{initial mass})}{2^{t/t_{1/2}}}$

$N = {}^{32}\!/_{2^4}\left(\text{since } t/_{t_{1/2}} = 6/_{1.5} = 4\right) = 2\text{ g}$

Q.2 After 24 hours, only 0.125 g out of an initial quantity of 1 g of a radioisotope remains behind. Its half-life period is

(A) 7.2 h (B) 7.99 h (C) 6.99 h (D) 10.0 h

Ans. (B)

Sol. In this problem, 'a' = 1.0 g and '$a-x$' = 0.125 g and 't' = 24 h. Therefore, the disintegration constant.

$$\lambda = \frac{2.303}{t}\log\frac{a}{a-x}$$

Or $\lambda = \dfrac{2.303}{24}\log\dfrac{1}{0.125} = 0.0866\ h^{-1}$ Or $t_{1/2} = \dfrac{0.693}{0.0866} = 7.99$ hours

Q.3 The half-life period of I_{53}^{125} is 60 days. What percent of the original radioactivity will be present after 180 days?

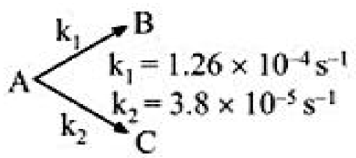
(A) 50% (B) 20.5% (C) 12.5% (D) 25%

Ans. (C)

Sol. $t_{1/2} = 60$ days and t = 180 days

Therefore, ${}^{t}\!/_{t_{1/2}} = \dfrac{180}{60} = 3.0$ Or $N = \dfrac{N_0}{2^{3.0}} = \dfrac{1}{8}N_0 = \dfrac{1}{8}\times 100$ percent of $N_0 = 12.5\%$

Q.4 A radioisotope undergoes decomposition which follows two parallel paths as shown below



The percentage distribution of 'B' and 'C' are

(A) 80% of 'B' and 20% of 'C' (B) 76.83% 'B' and 23.17% 'C'

(C) 90% 'B' and 10% 'C' (D) 60% 'B' and 40% 'C'

Ans. (B)

Sol. The percent distribution of

'B' is $\frac{k_1}{k_1+k_2} \times 100 = 76.83\%$, 'C' is $\frac{k_2}{k_1+k_2} \times 100 = 23.17\%$

Q.5 The activity of 1 g of radium is 0.5 curie. Calculate the half-life period of radium and the time required for the decay of radium from 2.0 g to 0.25 g.
(Atomic mass = 226)

Ans. 9492 yrs.

Sol. Number of atoms in 1.0 g of $^{226}Ra = \frac{6.023 \times 10^{23} \times 1.0}{226}$

Activity $-\frac{dN}{dt} = 0.5$ curie

$= 0.5 \times 3.7 \times 10^{10}$ disintegrations per second

$= 1.85 \times 10^{10}$ disintegrations per second

$-\frac{dN}{dt} = \lambda N$ or $1.85 \times 10^{10} = \lambda \times \frac{6.023 \times 10^{23}}{226}$

Or $\lambda = 6.945 \times 10^{-12}\ s^{-1}$ Or $t_{1/2} = \frac{0.693}{6.945 \times 10^{-12}} = 9.978 \times 10^{10}\ s$

$= \frac{9.978 \times 10^{10}}{3600 \times 24 \times 365}$ years = 3164 years

Time required for the decay of 2.0 g to 0.25 g = three half lives =
$3 \times 3164 = 9492$ years

Q.6 A certain radioisotope ${}^{A}_{Z}X$ ($t_{1/2}$ = 10 days) decays to give Y^{A-4}_{Z-2}. If 1.0 g atom of X^{A}_{Z} is kept in a sealed vessel, how much helium will collect in 20 days?

Ans. 16.8 L

Sol. Decay of ${}^{A}_{Z}X$ to ${}^{A-4}_{Z-2}Y$ produces one helium atom. Therefore, decay of 1.0 g atom of ${}^{A}_{Z}X$ will produce 1.0 g of atom of helium gas. Half-life of X = 10 days.

Therefore, the amount decayed in 20 days = $\frac{1}{2} + \frac{1}{4} = \frac{3}{4}g$ of atom

1.0 g atom of He = 22,400 cm^3 at 0°C and atm

3/4 g atom of He = $22,400 \times \frac{3}{4} = 16,800\ cm^3$

Q.7 A sample of $^{14}CO_2$ was to be mixed with ordinary CO_2 for a biological tracer experiment. In order that 10 cm^3 of diluted gas should have 10^4 dis/min, what activity (in μCi) of radioactive carbon is needed to prepare 60 L of diluted gas at STP. [1 Ci = 3.7×10^{10} dps]

(A) 270 μCi (B) 27 μCi (C) 2.7 μCi (D) 2700 μCi

Ans. (B)

Sol. $A = \lambda N$; activity (or rate of decay) of 10 ml gas $\Rightarrow \frac{10^4}{60}$ dps

rate of decay of 60 litre gas $= \left(\frac{10^4}{60}\right) \times \frac{60 \times 1000}{10} = 10^6$ sec

($\because$ 1 Ci = 3.7×10^{10} dps) $= \frac{10^6}{3.7 \times 10^{10}} = 27 \times 10^{-6}$ Ci $= 27$ μCi Ans.

Q.8 The analysis of a mineral of uranium reveals that ratio of mole of ^{206}Pb and ^{238}U in sample is 0.2. If effective decay constant of process $^{238}U \longrightarrow {}^{206}Pb$ is λ then age of rock is

(A) $\frac{1}{\lambda} \ln \frac{5}{4}$ (B) $\frac{1}{\lambda} \ln \left(\frac{5}{1}\right)$ (C) $\frac{1}{\lambda} \ln \frac{4}{1}$ (D) $\frac{1}{\lambda} \ln \left(\frac{6}{5}\right)$

Ans. (D)

Sol. $t = \frac{1}{\lambda} \ln \left[\frac{n_{Pb} + n_U}{n_U}\right]$ ...(i)

given $\frac{n_{Pb}}{n_U} = 0.2 = \frac{1}{5} \Rightarrow \left(\frac{n_{Pb} + n_U}{n_U}\right) = \frac{1}{5} + 1 = \left(\frac{6}{5}\right)$ ...(ii)

Substituting (ii) in (i)

$t = \frac{1}{\lambda} \ln \left(\frac{6}{5}\right)$

Saved /storage/emulated/0/Pictures/TouchShot/20170809_000117.jpg