Study Notes on Radioactivity

https://byjusexamprep.com

Radioactivity

Kinetics of nuclear disintegration:

- Radioactive decay is a first order process. Hence,

  $$-\frac{dN}{dt} = \lambda N \text{ or } N = N_0 e^{-\lambda t}$$

  Here,

  N = number of radioactive nuclei at any time t;

  N_0 = number of radioactive nuclei at t = 0;

- Activity: Activity (A) = – dN/dt = λN

Radioactivity:

It is the phenomenon of spontaneous emission of particles, electromagnetic radiation, or both by unstable nuclei.

Properties of α, β-particles and γ- rays:

Properties	Alpha	Beta	Gamma
1. Nature nuclei	Fast moving He electrons	Fast moving radiations	High energy
2. Representation	$_2He_4$ or α	$_{-1}e^0$ or $_{-1}\beta^0$	γ or $^0_0\gamma$
3. Charge	2-unit (+ve)	1 unit (–ve)	No charge
4. Velocity	1/10 of light	33% to 90% of light	Same as light waves
5. Relative penetrating power	1 or (0.01 mm of Al foil)	100 or (0.01 cm of Al foil)	10000 or (8 cm lead or 25 cm steel)
6. Travel distance in air	2 – 4 cm	200 – 300cm	500 m
7. Kinetic energy	high	low	–
8. Effect on ZnS plate	Luminosity	Little effect	–
9. Mass g/particle	6.65×10^{-24}	9.11×10^{-28}	–
10. Relative ionizing power	10000	100	1

S.I. units:

Disintegration per second (symbol s^{-1} or dps).

1 dps = 1 Bq (Becquerel)

Other units are as follows:

1 Ci (Curie)	=	3.7×10^{10} dps.
1 Rd (Rutherford)	=	10^6 dps
Specific activity	=	dps/gm

Half-life ($t_{1/2}$): The time taken by half the nuclei (originally present) to decay:

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

Note: After n half-lives have passed, activity gets reduced to $\frac{1}{2^n}$ of its initial value.

Average life (t_{avg}) formula is:

$$t_{avg} = \frac{1}{\lambda} = \frac{t_{1/2}}{0.693} = 1.44\, t_{1/2}$$

Uses of Radioisotopes:

(i). **Oxygen-18:** It is used to study reaction mechanisms. In photosynthesis, O^{18} isotope is used in CO_2^{18}.

(ii). **Cobalt-60:** It is used to sterilize surgical instruments and to improve the safety and reliability of industrial fuel oil burners. Along with this, it is used in cancer treatment, food irradiation, gauges, and radiography.

(iii). **Iodine-131:** It is used to treat thyroid disorders, (Graves's disease).

(iv). **Cadmium-109:** It is used to analyze metal alloys for checking stock, scrap sorting.

(v). **Calcium-47:** It is an important aid in biomedical researchers to study the cellular functions and bone formation in mammals.

(vi). **Carbon-14:** It is a major research tool which helps in research to ensure that potential new drugs are metabolized without forming harmful by-products. It is used in biological research, agriculture, pollution control and archeology.

(vii). **Cesium-137:** It is used to treat cancerous tumors to measure correct patient doses of radioactive pharmaceuticals to measure and control the liquid flow in oil pipelines to tell researchers whether oil wells are plugged by sand and to ensure the right fill level for packages of food, drugs and other products. (The products in these packages do not become radioactive).

(viii). **Chromium-51:** It is used in research in red blood cell survival studies.

(ix). **Copper-67:** When injected with monoclonal antibodies into a cancer patient, it helps the antibodies bind to and destroy the tumor.

(x). **Iodine-123:** It is widely used to diagnose thyroid disorders and other metabolic disorders including brain function.

Application of radioisotopes:

(i). Determination of the age of the rock-by-rock dating method: Let us consider a rock containing U-238 isotope formed many years ago. The age of this rock can be determined by considering its radioactive disintegration which is governed by the relation:

$$N = N_0 e^{-\lambda t}$$

Here,

N_0 = Amount of U-238 isotope originally present in a small quantity of the rock or mineral at the time the rock was formed.

N = Amount of U-238 still left undecayed after the lapse of time, t which represents the age of the rock.

λ = disintegration constant of U-238.

$$\lambda t = 2.303 \log_{10}\left(1+\frac{Pb^{206}}{U^{238}}\right) \text{and } e^{\lambda t} = 1+\frac{Pb^{206}}{U^{238}}$$

(ii). Determination of the age of recent objects by radio-carbon dating method:

$${}_6C^{14} \rightarrow {}_7N^{14} + \beta\text{-particle}$$

$$t = \frac{2.303\, t_{1/2}}{0.693}\log_{10}\frac{N_0}{N} = \frac{2.303\, t_{1/2}}{0.693}\log\left[\frac{\text{Amount of } C^{14} \text{ in fresh wood}}{\text{Amount of } C^{14} \text{ in dead wood}}\right]$$

Expected emission from unstable nucleus:

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

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

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

Beta decay is possible whenever the mass of the original neutral atom is greater than the final atom.

2. n/p ratio below stability belt:

(a). α-decay:

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

It is observed in nuclei with A > 210.

Mass number & the atomic number of the daughter nucleus decreases by 4 & 2 respectively compared to the 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.

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

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

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

Q value is negative i.e., isolated protons will not decay into neutrons.

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.

K electron capture:

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

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

$$P + e \longrightarrow n$$

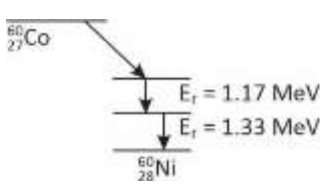
Electron capture takes place whenever the mass of the original neutral atom is larger than that of the final atom. Those nuclei having low n/p ratio can capture K shell electrons. X-rays are emitted during the process.

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 transition by emitting electromagnetic radiations i.e. γ rays.

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

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



Lifetime of the metastable nucleus thus forms is less than 10^{-9} sec.

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

Some difference 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 generally participate in reaction.	Only the nucleus of atoms participates in reaction.
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.	Disobeys mass conservation.
5.	May be exothermic or endothermic, liberating or absorbing relatively small amounts of energy.	May be exothermic or endothermic, liberating or absorbing relatively very high amounts of energy.
6.	May be reversible.	Only 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.