Physics of Nuclear Medicine

(1) Radiation Physics:-

A- Properties of Nuclei:

Rutherford found that the nucleus is tens of thousands of times smaller in radius than the atom itself. Since Rutherford's initial experiments, many additional scattering experiments have been performed, using high-energy protons, electrons, and neutrons as well as alpha particles (helium-4 nuclei). These experiments show that we can model a nucleus as a sphere with a radius *R* that depends on the total number of nucleons (neutron and protons) in the nucleus. This number is called the NUCLEON NUMBER denoted by A. The radii of most nuclei are represent by the following equation;

$$R = R_o \, A^{\frac{1}{3}} \qquad (1)$$

Where

R is the radius of nucleus.

R_o is an experimentally determined constant $= 1.2$ Fermi

$= 1.2 \times 10^{-15}$m

A is also called the mass number.

The number of protons in a nucleus is the **atomic number** *Z*. The number of neutrons is the **neutron number** *N*. The nucleon number or mass number *A* is the; sum of the number of protons *Z* and the number of neutrons *N*:

$${}^{A}_{Z}X_{N} \qquad A=Z+N \qquad (2)$$

A single nuclear species having specific values of both *Z* and *N* is called a **nuclide**, Table (1) lists values of *A*, Z, and *N* for a few nuclides. The electron structure of an atom, which is responsible for its chemical properties, is determined by the charge *Ze* of the nucleus. The table shows some nuclides that have the same *Z* but different *N*. These nuclides are called **isotopes** of that element; they have different masses because they have different numbers of neutrons in their nuclei. A familiar example is chlorine ($C\ell$, Z=17).

About 76% of chlorine nuclei have $N=18$; the other 24% have $N=20$. Different isotopes of an element usually have slightly different physical properties such as melting and boiling temperatures and diffusion rates. The two common isotopes of uranium with $A=235$ and 238 are usually separated industrially by taking advantage of the different diffusion rates of gaseous uranium hexafluoride (UF_6) containing the two isotopes.

Table (1) also shows the usual notation for individual nuclides: the symbol of the element, with a pre-subscript equal to Z and a pre-superscript equal to the mass number *A*. The general format for an element $E\ell$ is ${}^{A}_{Z}E\ell$. The isotopes of chlorine mentioned above, with $A=35$ and 37, are written ${}^{35}_{17}C\ell$ and ${}^{37}_{17}C\ell$ and pronounced "chlorine-35" and "chlorine-37", respectively. This name of the element determines the atomic number Z, so the pre-subscript *Z* is sometimes omitted, as in ${}^{35}C\ell$.

Table (1) Compositions of Some Common Nuclides

Nucleons	Mass Number (Total Number of Nucleons), A	Atomic Number (Number of Protons), Z	Neutron Number $N = A - Z$
${}^{1}_{1}H$	1	1	0
${}^{2}_{1}D$	2	1	1
${}^{4}_{2}He$	4	2	2
${}^{6}_{3}Li$	6	3	3
${}^{7}_{3}Li$	7	3	4
${}^{9}_{4}Be$	9	4	5
${}^{10}_{5}B$	10	5	5
${}^{11}_{5}B$	11	5	6
${}^{12}_{6}C$	12	6	6
${}^{13}_{6}C$	13	6	7
${}^{14}_{7}N$	14	7	7
${}^{16}_{8}O$	16	8	8
${}^{23}_{11}Na$	23	11	12
${}^{65}_{29}Cu$	65	29	36
${}^{200}_{80}Hg$	200	80	120
${}^{235}_{92}U$	235	92	143
${}^{238}_{92}U$	238	92	146

BOLS, UNITS, CONSTANTS

Radius of electronic orbit = 10^{-10} m.

Radius of nucleus = 10^{-15} m.

charge of electron ($\bar{e}$) = 1.602×10^{-19} C.

charge of proton ($+e$) = 1.602×10^{-19} C.

A = mass number.

Z = atomic number.

X = is the chemical symbol for the eleme

$^{A}_{Z}X$ = nuclide or nuclides

$^{Am}_{Z}X$ = (m metastable State) is an isomer of X [differ in their nuclear energy States.

a.m.u = is defined as 1/12 of the mass of a $^{12}_{6}C$ atom.

1 a.m.u = 1.66×10^{-27} kg

N_A = Avogadro number = 6.0221×10^{23} (atoms/gm

= 6.0221×10^{23} ~~at~~ atomic weigh (atom/mole)

A_w = atomic weight

Number of atoms/g = $\frac{N_A}{A_w}$

Grams/atom = $\frac{A_w}{N_A}$

Number of electrons/g = $\frac{N_A \cdot Z}{A_w}$

mass of electron (m_e) = 0.000548 a.m.u.

mass of proton m_p = 1.00727 a.m.u.

mass of neutron m_n = 1.00866 a.m.u.

1 a.m.u = 931.5 MeV.

Mass defect and Binding Energy :-

If $Z =$ no. of p^s.
$N =$ no. of n^s.
$m_p =$ the mass of proton.
$m_n =$ the mass of neutron.

$Zm_p + Nm_n =$ the total mass of neucleons in the nucleus.

Experimentaly, the actual mass of nucleus is less than the total mass of nucleons.

$\Delta m =$ The mass difference between the sum of the masses of constituent neucleons and the actual mass.

$\Delta m =$ mass defect.

If $M =$ is the actual mass of the nucleus.

$$\therefore \boxed{\Delta m = Zm_p + Nm_n - M}$$

$$\Delta m = Zm_p + (A-Z)m_n - M$$

Δm may be regarded as mass which is converted into energy which goes to bind the nucleons into the nucleus.

the energy equivalent to the mass defect is Called Binding energy (B.E.) of the ~~neut~~ nucleus

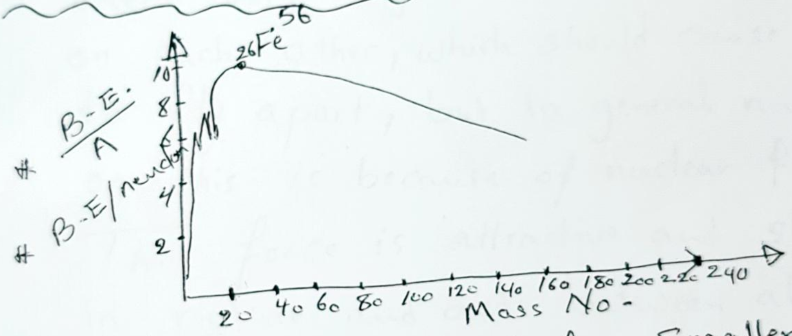
$$\therefore \quad B.E. = \Delta m\, C^2$$

$$= [Zm_p + (A-Z)m_n - M]\, c^2$$ (in Joule

C = is the speed of light.

$$B.E. = [Zm_p + (A-Z)m_n - M] \times 931.5$$ (Me

Binding Energy Curve :-



(i) B-E/nucleon is small for Smaller nuclei
Ex. $_1H^2$ the B.E./nucleon = 1.11 MeV

(ii) B-E./nucleon increase rapidly for nuclei up to A = 20, peaks indicate that these nuclei are more stable than their neighbous.

(iii) After 20 the Curve rises gradually and reaches maximum at A = 56 for $_{26}Fe^{56}$ which is 8.79 MeV.
Between 40 and 120 the Curve is flat the average is 8.5 MeV

intermediate mass (A = 40 → A = 100) are the most stable, (Large amônt of energy must be required to liberate each of their nucleons.

(IV) After A = 120, the B-E/A start decreasing and drops to 7.6 MeV for ^{235}U

Nuclear Stability :

p^s are (+) charged
n^s are (0) charged.

p^s exert very Large electrostatic repulsive force on each other, which should cause the nucleus to fly apart, but in general nucleus is stable one this is because of nuclear force.

This force is attractive and short range. in nature and acts between all nuclear particles.

p^s attract each other due to nuclear force
p^s repel each other due to Coulomb's force.

nuclear force is quite Large in magnitude as compared to the Coulomb's force.

The attractive force also acts between pairs of n^s and between p and n.

260 stable nuclei, hundreds of other nuclei have been observed but these are unstable

- * even no. of p^s and even no. of n^s preferred by nature for stable nuclides

- * odd no. of p^s and odd no. of n^s combination of stable nuclides is found only in the Light elements. Less stable nuclei

- * even - odd combination un-stable

- * A high n/p ratio give rise to β^- decay and α
A Low n/p ratio can result in electron capture and β^+

Ex. Calculate the binding energy of ${}_{26}Fe^{56}$ if its mass is 55.975 a.m.u. Also Calculate binding energy per nucleon.

Mass of ${}^{56}_{26}Fe$ is $M = 55.975$ a.m.u

$M_p = 1.007825$ "

$m_n = 1.008665$ "

$Z = 26$

$A = 56$

$$\Delta m = Zm_p + (A-Z)m_n - M$$

$$= 26 \times 1.007825 + (56-26) \times 1.008665 - 55.975$$

$$= 26.20345 + 30.25995 - 55.975$$

$$\Delta m = 0.4884 \text{ a.m.u}$$

$$B.E = 0.4884 \times 931.5 = 454.7004 \text{ MeV}$$

$$B.E/A = 454.7004/56 = 8.12 \text{ MeV/nucleon}$$

Ex. Find the radius of ^{206}Pb

$$R = R_o A^{1/3}$$

$R_o = 1.2 \times 10^{-15} m = 1.2 fm$

$A = 206$

$$R = 1.2 \times 10^{-15} \times (206)^{1/3}$$
$$= 1.2 \times 10^{-15} \times 5.9059$$
$$= 7.08708 \times 10^{-15}$$
$$= 7.08708 \text{ fm}.$$

Isotopes, isobars and isotones

- **Isotopes**, atomic nuclei with the same atomic number Z, but different neutron numbers N.

$${}^{A}_{Z}X_{N} \text{ and } {}^{A+1}_{Z}X_{N+1}$$

Example: the carbon isotopes 12C, 13C and 14C.

- **isotopes** are chemically equivalent. Only processes that depend on mass exhibit a slightly different behavior for different isotopes (differences in the physical chemical equilibria, differences in diffusion velocity, isotopic shifts in atomic spectra, resonance frequencies in molecules, critical temperature of superconductors). These phenomena are called **isotope effects.**

➢**Isobars**, atomic nuclei with equal mass number A, but different proton numbers Z. Isobars belong to different chemical elements.

$$ {}^{A}_{Z}X_{N} \text{ and } {}^{A}_{Z+1}Y_{N-1} $$

Example: 14C and 14N.

➢**Isotones**, atomic nuclei with equal neutron number N, but different atomic numbers Z.
Isotones belong to different chemical elements

$$ {}^{A}_{Z}X_{N} \text{ and } {}^{A+1}_{Z+1}Y_{N} $$

Example : 14C6 and 16O8

Mirror nuclei

- Mirror nuclei :are isobars (same A) with opposite numbers of protons and neutrons. For example,14C (Z=6, N=8) and 14O (Z=8, N=6) are mirror nuclei.

Nuclear physics
3rd Class.
Medical physics

"Radioactivity"

Radioactivity was discovered by Henri Becquerel in 1886.

Radioactivity: is the spontaneous emission of energetic radiations having high penetrating power by a substance.

This activity is shown by many elements having atomic number in between 83 to 102.

○ Radioactive elements emit radiations composed of three distinct kinds of rays, which is α, β and γ radiation.

α is positively charged particles. [$({}^4_2He)$, ++]

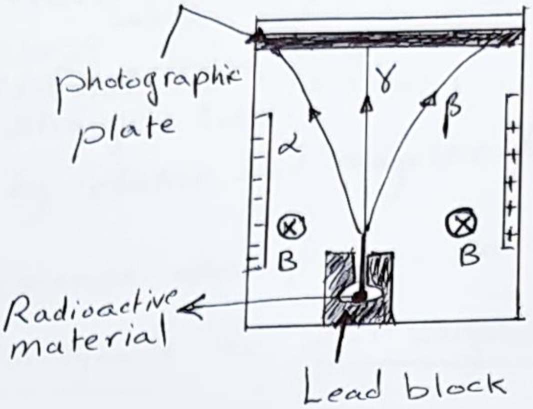
β is negatively charged particles. [−]

γ is electromagnetic radiation.

○ The radioactivity is spontaneous phenomenon, unaffected by any external agent Like ①high temperature, ②high pressure, [3]Large electric field and [4]high magnetic field, etc, it is a statistical phenomenon (we cannot predict which atom of the substance will decay or how many atoms will decay.

The existence of three types of radiations are demonstrated by the Simple Experiment:-

small quantity of radioactive material is placed at the bottom of hole drilled in a Lead block



- The Lead block is placed in an evacuated chamber to avoid absorption of the rays
- The photographic plate is kept at a short distance in the chamber
- After Long exposure, the photographic plate is developed, three different lines are observed on the photographic plate.
- α particles are deflected towards the left.
- β particles are deflected towards the right (more deflected than α)
- γ - rays are not deflected.
- α and β are charged with opposite charges and magnitude of charge on α - particle is more as compared to the β - particle.
- If electric field is applied by two parallel plates α - particles are deflected towards negetive plate. β - Particles are deflected towards positive plate. γ - is not deflected.

Properties of Alpha - particles :

1- is a helium nucleus consisting of 2 protons and 2 neutrons and has 2 units of positive charge.

2 - α- particles travel with high velocity [illegible] $(1.4 \times 10^7$ to 1.7×10^7 m/s$)$ they move along straight line.

3- They are deflected by electric and magnetic fields

4- They produce fluorescence when fall on the surface Like barium platinocyanide or Zinc Sulphate.

5- They are Scattered by nuclei of heavy atoms.

6- They Can ionise the gas. Their ionisation power is very Large Compared to β- particles and γ-rays

Properties of β - particles :-

1- is a negative charge and mass equal to that of an electron.

2- travel with very high velocity nearly equal 1/10th of velocity of Light.

3- These particles are deflected by electric and magnetic fields.

4- Their ioniZation power is small as compared to α-particles, have Long range.

5- affect the photographic plates.

6- They produce fluorescence in barium platinocyanide

7- Their penetration power is more than α- particles and can penetrate through thin metal foils.

Properties of Gamma-rays :

1- electromagnetic waves, having very small wavelength (0.005 A° → 0.5 A°)

2- electrically neutral

3- They produce fluorescence and affect the photographic plates.

4- not deflected by electric and magnetic fields.

5- Their penetration power is very high as compared to β-particles.

6- Their ionization power is very small.

LAW OF RADIOACTIVITY

○ The rate of a particular radioactive material disintegrates is independent of physical and chemical conditions, it depend upon the number of radioactive atoms presents in the substance at that instant.

The Law states "the rate of disintegration of the radioactive substance at any instant is directly proportional to the actual number of atoms of the radioactive element present at that instant."

Let N_0 = the number of radioactive atoms of the substance at time $t = 0$

N = the number of radioactive atoms present in the substance at "t" time.

rate of disintegration $= \frac{dN}{dt}$

$$-\frac{dN}{dt} \propto N$$

$$\frac{dN}{dt} = -\lambda N \quad \text{....} (1)$$

λ = is proportionality Constant

= is decay constant.

= disintegration Constant.

λ depends upon the nature of the radioactive material and is entirely independent of external physical conditions.

λ is different for different substances.

λ is defined as "the ratio of the amount of substance which disintegrates in unit time to the amount of substance present at that instant

$$\boxed{\lambda = \frac{dN/dt}{N}}$$

From equation (1) :-

$$\frac{dN}{N} = -\lambda dt \quad \text{....} (2)$$

integrating eq. (2), we get:.

$$\ln N = -\lambda t + C$$

where C is constant of integration, the value Can be obtained by using $t=0$,

At $t=0 \Rightarrow N = N_0$

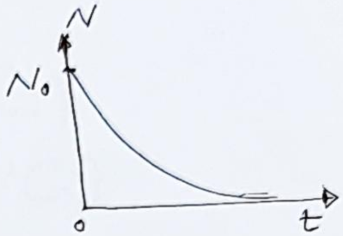
$$\therefore C = \ln N_0$$

$$\ln N = -\lambda t + \ln N_0$$

$$\ln N - \ln N_0 = -\lambda t$$

$$\ln\left(\frac{N}{N_0}\right) = -\lambda t$$

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



ACTIVITY A

activity is the decay rate of substance.

$$\therefore A = \left|\frac{dN}{dt}\right| = \lambda N$$

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

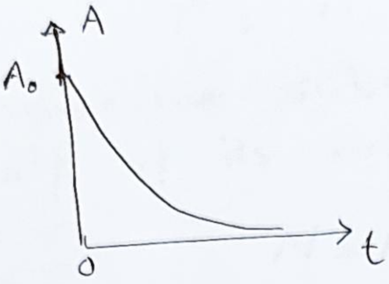
We have $N = N_0 e^{-\lambda t}$

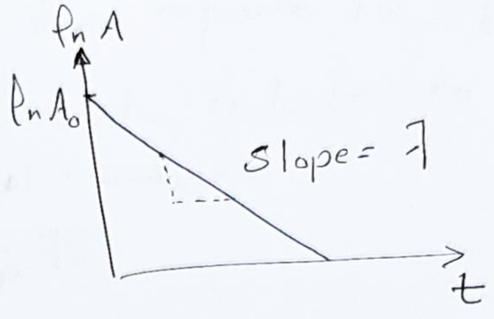
$$N\lambda = \lambda N_0 e^{-\lambda t}$$

$$\boxed{A = A_0 e^{-\lambda t}}$$

A_0 : is the activity of substance at $t=0$

∴ (N) and (A) is decrease exponentially with time





Activity of radioactive substance is measured in Curie (Ci)

in milli-Curie (m Ci)

in micro-Curie (μCi)

* Curie is defined as the activity of one gramme of radium in which 3.7×10^{10} atoms disintegrate in one Second.

$$1 \text{ Curie} = 3.7 \times 10^{10} \text{ disintegration/sec}$$
$$1 \text{ mCi} = 10^{-3} \text{ Ci}$$
$$1 \text{ μCi} = 10^{-6} \text{ Ci}.$$

* Rutherford : 1 Rutherford is that amount of radioactive substance which gives 10^6 disintegrati per Second.

HALF LIFE (T)

T : is the time required for a given radioactive substance to reduce to half of its original number.

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

At $t = T$

$$N = \frac{1}{2} N_0$$

$$\frac{1}{2} N_0 = N_0 e^{-\lambda T}$$

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

$$\ln \frac{1}{2} = -\lambda T$$

$$\ln 1 - \ln 2 = -\lambda T$$

$$-\ln 2 = -\lambda T$$

$$\boxed{\therefore T = \frac{0.693}{\lambda}}$$

MEAN LIFE (τ):

$$\tau = \frac{\text{Total life time of all atoms}}{\text{Total number of atoms}}$$

The mean life time of a radioactive atom is defined as the ratio of the total time of all the radioactive atoms to the total number of radioactive atoms present in the Substance.

Total Life of time of all No atoms $= \int_{t=0}^{t=\infty} t\,dN$

$$\tau = \frac{\text{Total Life time}}{\text{Total number of atoms}}$$

$$\tau = \frac{\int_{t=0}^{t=\infty} t\,dN}{N_o}$$

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

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

$$\therefore dN = \lambda N\,dt = \lambda N_o e^{-\lambda t}\,dt$$

using equ. above :-

$$\tau = \frac{\int_0^{\infty} t \lambda N_o e^{-\lambda t}\,dt}{N_o}$$

$$\therefore \tau = \lambda \int_0^{\infty} t\, e^{-\lambda t}\,dt$$

$$\tau = \lambda \left[\frac{t e^{-\lambda t}}{-\lambda} - \int \frac{dt}{dt} \left(\int e^{-\lambda t}\,dt \right) dt \right]_0^{\infty}$$

$$= \lambda \left[\frac{t e^{-\lambda t}}{-\lambda} - \frac{e^{-\lambda t}}{-\lambda^2} \right]_0^{\infty}$$

$$= \lambda \left(\frac{1}{\lambda^2} \right)$$

$$\boxed{\tau = \frac{1}{\lambda}}$$

$\therefore$ The mean life (τ) of a radioactive substance is the reciprocal of the decay Constant (λ).

$$T = \frac{0.693}{\lambda}$$

$$\therefore \quad T = 0.693\,\tau$$

○ or $\tau = 1.44\,T$

we know that: $N = N_0 e^{-\lambda t}$

multiplying both side by λ, we get

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

$$\frac{\lambda N}{\lambda N_0} = e^{-\lambda t} \Rightarrow \frac{\text{Activity at } t}{\text{activity at } t=0} = e^{-\lambda t}$$

At $t = \tau$:-

$$\frac{\text{Activity at } t}{\text{activity at } t=0} = e^{-\lambda\tau} = e^{-\lambda\frac{1}{\lambda}} = e^{-1}$$

$$= 0.368$$

Thus, the mean life time is the time required for the activity to fall to 0.368 or 36.8% of any initial value.

SPECIFIC ACTIVITY :

A_s : is the specific activity of a substance

: is defined as the activity of one gram of a radioactive substance.

$$A_s = \frac{\text{Activity}}{M \text{ in gram}}$$

$$A_s = \frac{A}{M} = \frac{\lambda N}{M}$$

The number of atoms in one gram of a Substance $= \dfrac{N_A}{At.wt}$.

$N_A =$ Avogadro's number.

$= 6.023 \times 10^{23}$ atoms.

$$\because \; {}_{Z}X^{At.wt}$$

The number of atoms in M gram substance is : $N = \dfrac{N_A}{At.wt} \times M$

At.wt : is the atomic of the substance.

$$\frac{N}{M} = \frac{N_A}{At.wt} = \frac{6.023 \times 10^{23}}{At.wt}$$

The Specific activity A_s is given by :-

$$A_s = \lambda \frac{N}{M}$$

$$\Rightarrow \quad A_s = \lambda \frac{N_A}{At.wt} = \lambda \frac{6.023 \times 10^{23}}{At.wt}.$$

$$= \frac{0.693}{T} \times \frac{6.023 \times 10^{23}}{At.wt}$$

$$A_s = \frac{4.174 \times 10^{23}}{T \times At.wt}$$

$T =$ is the half life of the substance.

Ex : Find the mass of the substance Corresponding to 1 Ci ?

Sol. Let M be the mass of the substance at T its half-life.

N : the number of atoms.

$$\Rightarrow N = \frac{N_A}{At.wt} \times M$$

$$= \frac{6.023 \times 10^{23} \times M}{At.wt}$$

the activity of the substance is :

$$A = \lambda N$$

$$A = \lambda \times \frac{6.023 \times 10^{23} \times M}{At.wt}$$

$$= \frac{0.693}{T} \times \frac{6.023 \times 10^{23}}{At.wt} \times M$$

Let the activity $A = 1$ Ci

$A = 3.7 \times 10^{10}$ disintegration/sec/gm

$$\therefore 3.7 \times 10^{10} = \frac{0.693}{T} \times \frac{6.023 \times 10^{23}}{At.wt} \times M$$

$$\boxed{\therefore M = 8.864 \times 10^{-14} \times At.wt \cdot T}$$

T : in Second.

For example the mass of 1 Ci source of ^{238}U having half life 4.5×10^{9} years

$$\therefore \; M = 8.864 \times 10^{-14} \times 238 \times 4.5 \overset{10^{9}}{\times} 365 \times 24 \times 60 \times 60$$

$$\boxed{\Rightarrow M = 3000 \text{ kg}}.$$

∴ 3000 kg of uranium will have activity equal to one Curie.

PARTIAL RADIOACTIVE DECAY

when a single nuclide can decay by more than one process [α-particle and β-particle]. The total probability of decay is increased.

○ mode of decay :- it is the decay by α-particle or by β-particle at a particular stage in integration.

Two modes of decay are independent, probabilities and decay constant for individual decay modes are additive.

If $\frac{dN_\alpha}{dt}$, $\frac{dN_\beta}{dt}$ are the rates of decrease in number of radioactive atoms for the two modes separately the total decrease in number of atoms in time dt is given by :

$$-dN = dN_\alpha + dN_\beta$$

$$\frac{dN_\alpha}{dt} = \lambda_\alpha N \quad \text{and} \quad \frac{dN_\beta}{dt} = \lambda_\beta N$$

$$\therefore \quad -dN = \lambda_\alpha N dt + \lambda_\beta N dt$$

or $$-dN = (\lambda_\alpha + \lambda_\beta) N dt$$

Where : N = is the number of radioactive atoms at an instant t.

λ_α = constant decay of α- decay

λ_β = constant decay of β- decay

Integration of above equation, we get:

$$N = N_0 e^{-(\lambda_\alpha + \lambda_\beta)t}$$

or $$N = N_0 e^{-(\lambda_{total})t}$$

where N_0 = is the number of radioactive atoms at $t=0$

$$\frac{\lambda_\alpha}{\lambda_{total}} \quad \text{or} \quad \frac{\lambda_\alpha}{\lambda_\alpha + \lambda_\beta}$$ = is called branching ratio of α-decay.

$$\frac{\lambda_\beta}{\lambda_{total}} \quad \text{or} \quad \frac{\lambda_\beta}{\lambda_\alpha + \lambda_\beta}$$ = is called branching ratio of β-decay.

We have :

$$\frac{dN_\alpha}{dt} = \lambda_\alpha N = \lambda_\alpha N_0 e^{-(\lambda_\alpha + \lambda_\beta)t}$$

and

$$\frac{dN_\beta}{dt} = \lambda_\beta N = \lambda_\beta N_0 e^{-(\lambda_\alpha + \lambda_\beta)t}$$

If there are number of decay modes of substance:-

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \cdots$$

$$\therefore \frac{0.693}{T} = \frac{0.693}{T_1} + \frac{0.693}{T_2} + \frac{0.693}{T_3} + \cdots$$

or

$$\frac{1}{T} = \frac{1}{T_1} + \frac{1}{T_2} + \frac{1}{T_3} + \cdots$$

where $T_1, T_2, T_3 \ldots$ are partial half lives of different decay modes.

SUCCESSIVE DISINTEGRATION:.

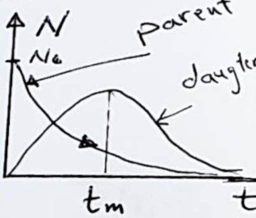
parent : is the original radioactive atom.

daughter : is transformed from the parent into new atom by disintegration.

when the daughter atom is radioactive and disintegrates into new daughter atom.

The successive transformation leads to a Long Chain of different radioactive atoms ending in a non-radioactive stable element. (these different stages of disintegration naturally constitute a series; this is called Law of Successive disintegration:

$$A \longrightarrow B \longrightarrow C \rightarrow \cdots\cdots (X) \text{ stable.}$$



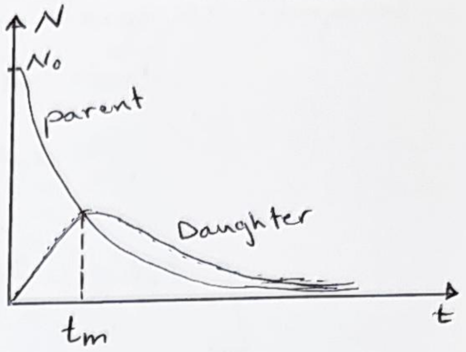
$$N_1 \xrightarrow{\lambda_1} N_2 \xrightarrow{\lambda_2} N_3 \xrightarrow{\lambda_3} \cdots$$

$$\left[N_1 = N_0 e^{-\lambda_1 t} \right]$$

$$N_2 = \frac{\lambda_1 N_0}{\lambda_2 - \lambda_1} \left[e^{-\lambda_1 t} - e^{-\lambda_2 t} \right]$$

t_m = is the time at which the activity of parent is equal to the activity of daughter. this type of equilibrium is called ideal equilibrium.

Radioactive Equilibrium :-



At this point it is highly illuminating to discuss about the cases of equilibrium between the parent and the daughter;- these are

(i) Ideal equilibrium
(ii) secular equilibrium.
(iii) transient equilibrium.

(i) Ideal equilibrium :-

At $t = t_m$ tha activity of parent is equal to the daughter $\Rightarrow \lambda_1 N_1 = \lambda_2 N_2$

we know $\Rightarrow N_1 = N_0 e^{-\lambda_1 t}$

at $t = t_m \Rightarrow$ the activity of parent A is :-

$$N_1 \lambda_1 = \lambda_1 N_0 e^{-\lambda_1 t_m}$$

The value of t_m is :-

$$t_m = \frac{1}{\lambda_2 - \lambda_1} \ln\left(\frac{\lambda_2}{\lambda_1}\right)$$

$$\Rightarrow N_1 \lambda_1 = \lambda_1 N_0 e^{\ln(\lambda_2/\lambda_1)^{\lambda_1/\lambda_1 - \lambda_2}}$$

$$\therefore N_1 \lambda_1 = \lambda_1 N_0 \left(\frac{\lambda_2}{\lambda_1}\right)^{\lambda_1/\lambda_1 - \lambda_2}$$

we have $T_1 = \frac{0.693}{\lambda_1}$ and $T_2 = \frac{0.693}{\lambda_2}$

$\therefore$ the activity of parent is:- $N_1 \lambda_1 = \lambda_1 N_0 \left(\frac{T_1}{T_2}\right)^{T_2/T_1 - T_2}$

(ii) Secular or Permanent Equilibrium :-

The case when parent is extemely Longer lived than daughter i.e. half life of parent is very Large as Compared with the half Life of daughter nuclei.

Since $T_1 >>> T_2$, then $\lambda_1 <<< \lambda_2$

we have

$$N_2 = \frac{\lambda_1 N_0}{\lambda_2 - \lambda_1}\left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right]$$

$$N_1 = N_0 e^{-\lambda_1 t}$$

$\because \lambda_2 >>>> \lambda_1$

λ_1 can be neglected in Comparison with λ_2

$\Rightarrow N_2 \lambda_2 = N_1 \lambda_1$ [shows that at equilibrium] the activity of parent is equal to the activity of the daughter.

* example of the permanent equilibrium:

$${}^{90}_{38}Sr \xrightarrow[\beta^-]{T_1 = 28yrs} {}^{90}_{39}Y \xrightarrow{T_2 = 64.8\ hrs} {}^{90}_{40}Zr \text{ (stable)}$$

(iii) Transient equilibrium:-

Consider the daughter shorter lived than parent $T_1 > T_2$

* example of transient equilibrium is:

$${}^{140}Ba \xrightarrow{T_1 = 300hrs} {}^{140}La \xrightarrow{T_2 = 40\ hrs} {}^{140}Ce \text{ (stable)}$$

Radioactive Series :-

Radioactive disintegration occurs with the emission of α and β particles, the original parent atom changes int a new atom called daughter atom. This daughter atom may be radioactive which also eject another particle. This process of parent-daughter formation Continues through the series of elements ending up finally with stable and non-radioactive element. These different stages of disintegration naturally form a series.

The first member of series is called parent,
The intermediate members are called daughters,
The final stable member is called the end product.

Naturally: there are Four Series:

(1) Uranium Series.
(2) Actinium Series.
(3) Thorium Series.
(4) Neptunium Series.

Table lists the names of four important radioactive Series

Mass number A	Series	Parent	half life	stable end product
4n	Thorium	$^{232}_{90}Th$	1.39×10^{10} yrs	$_{82}Pb^{208}$
4n+1	Neptunium	$_{93}Np^{237}$	2.25×10^{6} yrs	$_{83}Bi^{209}$
4n+2	Uranium	$_{92}U^{238}$	4.51×10^{9} yrs	$_{82}Pb^{206}$
4n+3	Actinium	$_{92}U^{235}$	7.07×10^{8} yrs	$_{82}Pb^{207}$

Artificially produced Radionuclides:

When the elements bombarded by a Light particle, an unstable nucleus was formed and this nucleus disintegrates spontaneously :

$${}^{10}_{5}B + {}^{4}_{2}He \longrightarrow {}^{13}_{7}N^{*} + {}^{1}_{0}n$$

${}^{13}_{7}N^{*}$ is unstable and decays by the following

$${}^{13}_{7}N^{*} \longrightarrow {}^{12}_{6}C + {}^{0}_{1}e$$

T = 10.1 mints.
(minutes)

$${}^{27}_{13}Al + {}^{4}_{2}He \longrightarrow {}^{31}_{15}P^{*} \longrightarrow {}^{30}_{15}P^{*} + {}^{1}_{0}n$$

${}^{30}_{15}P^{*}$ unstable and radioactive and decays by the following mode :.

$${}^{30}_{15}P^{*} \longrightarrow {}^{30}_{14}Si + {}^{0}_{1}e$$

T = 3 (min)

${}^{0}_{1}e$: + charge and mass equal to electron (positron)

Applications of Radioactivity:

1- In medicine Science :-

^{59}Fe (study the deficiency of red blood cells.

^{24}Na (Pumping action heart

^{131}I (Functioning of kidney, liver under normal and diseased, treatment of thyroid glands

^{60}Co, ^{198}Ag treatment of cancer.

^{32}P curing skin diseases.

2- In agriculture.

3- In industry.

4- In nuclear research.

5- In Food preservation.

6- In radioactive dating: ^{14}C

Example :- 1 gm of a radioactive substance disintegrates at the rate of 3.7×10^{10} dis/s. The atomic weight of substance is 226. Calculate its mean life.

Sol :-

$$A = N \lambda$$

$$N = \frac{N_o}{W} . m$$

$$= \frac{6.023 \times 10^{23} \times 1}{226}$$

$$\Rightarrow \quad 3.7 \times 10^{10} = \frac{6.023 \times 10^{23}}{226} \times \lambda$$

$$\lambda = \frac{3.7 \times 10^{10} \times 226}{6.023 \times 10^{23}}$$

$$= 1.389 \times 10^{-11} \text{ per sec.}$$

$$\tau = \frac{1}{\lambda}$$

$$= \frac{1}{1.389 \times 10^{-11}} = 7.1 \times 10^{10} \text{ sec.}$$

$$= \frac{7.1 \times 10^{10}}{365 \times 24 \times 60 \times 60} = 2251 \text{ years.}$$

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UNIT - 3 -

[MODES OF RADIOACTIVE DECAY]

1- α - particle decay:-

Radioactive nuclides with very high atomic Numbers (greater than 82) decay most frequently with the emission of an α-particle, it appears that the no. of p^s in the nucleus increases beyond 82, the Coulomb forces of repulsion between the p^s become Large enough to over come the nuclear forces that bind the nucleons together.

The unstable nucleus emits α - particle composed of $2p^s$ and $2n^s$.

As a result of α - decay, the atomic No. of the nucleus reduced by 2, and the mass No. is reduced by 4. (which is in fact a helium nucleus)

The general reaction for α- decay can be written as:

$$_{Z}^{A}X \longrightarrow {}_{Z-2}^{A-4}Y + {}_{2}^{4}He + Q$$

Q: is the total energy released in the process.

Q: is Called the disintegration energy.

$$_{88}^{226}Ra \longrightarrow {}_{86}^{222}Rn + {}_{2}^{4}He + 4.8\,MeV$$

Since the momentum of α- particle must be equal to the recoil momentum of the radon nucleus, and Since the radon nucleus is much heavier than α- particle The disintegration energy appears almost entirely as the Kinetic energy of the α-particle (4.78 MeV), they are emitted with discrete energies.

2- β- particle decay :-

The ejection of a positive or a negative electron from the nucleus, is called the β-decay.-

$\bar{\beta} \equiv \bar{e}$ (The negative electron or negatron)

$\beta^{+} \equiv \overset{+}{e}$ (The positive electron or positron).

The basic tranformations may be written as:

$$^{1}_{0}n \longrightarrow {}^{1}_{1}P + {}^{0}_{-1}\beta + \bar{\nu} \qquad (\bar{\beta}\ \text{decay})$$

$$^{1}_{1}P \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta + \nu \qquad (\beta^{+}\ \text{decay})$$

$^{1}_{0}n$: neutron

$^{1}_{1}P$: proton

ν : neutrino] identical particles, with opposite spins, no charge and practically no mass.

$\bar{\nu}$: antineutrino

2-1- Negatron Emission :-

:- The radionuclides with an excessive number of $^{1}_{0}n^{s}$ or high (n/p) ratio lie above the region of stability these nuclei tend to reduce the n/p ratio to achieve stability.

This accomplished by emitting a negative electron.

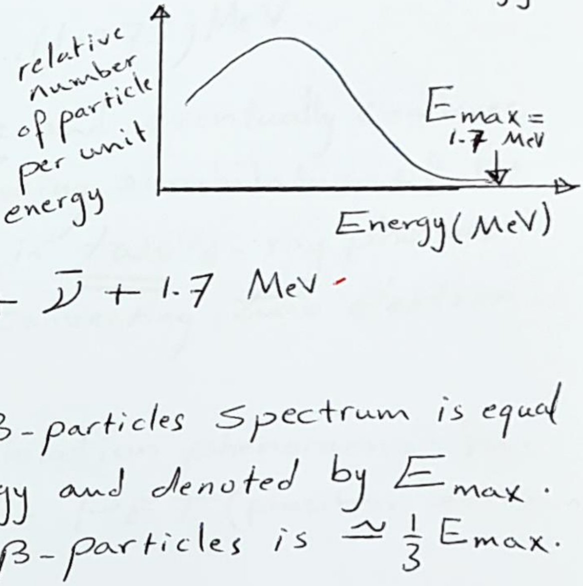
The general equation for the negatron or β^- decay is written as:

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \bar{\nu} + Q$$

Q: is the disintegration energy, this energy is provided by the difference in masses between the initial nucleus ${}^{A}_{Z}X$ and the Sum of masses of the product nucleus ${}^{A}_{Z+1}Y$ and the particles emitted.

The spectrum in β decay is continuous. experimental data show that the β- particles are emitted with all energies from Zero to the maximum energy

This figure shows the distribution of energy among the β particles. for ${}^{32}P$



$${}^{32}_{15}P \longrightarrow {}^{32}_{16}S + {}^{0}_{-1}\beta + \bar{\nu} + 1.7\ \text{MeV}$$

The endpoint energy of β-particles spectrum is equal to the disintegration energy and denoted by E_{max}.
The average energy of β-particles is $\simeq \frac{1}{3} E_{max}$.

2-2- Positron emission:

Positron-emitting nuclides have a deficit of ${}^{1}_{0}n$s, and n/p ratios are Lower than those of the stable nuclei of the Same atomic number or neutron number,
The overall decay reaction is as follows:

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta + \nu + Q $$

Q : is shared by the ${}^{0}_{+1}\beta$, ν and any γ-rays emitted by the daughter nucleus.

A specific example of positron emission is the decay of ${}^{22}_{11}Na$:

$$ {}^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + {}^{0}_{+1}\beta + \nu + 1.82\ MeV $$

1.82 MeV (released energy) is the sum of the maximum kinetic energy of the positron (0.545 MeV) and the energy of γ-rays, (1.275) MeV.

✓ The positron is unstable and eventually combines with another electron, producing annihilation of the particles. This event results in two γ-ray photons each of 0.511 MeV, thus converting two electron masses into energy.

✓ Positron-electron annihilation phenomenon has a practicl use in Radiology - PET (positron emission Tomography).

3- ELECTRON CAPTURE :-

electron capture is a phenomenon in which one of the orbital electrons is captured by the nucleus, thus transforming a proton into a neutron :-

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

[the general equation of nuclear decay]

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

the electron Capture is an alternative process to the positron decay.

The unstable nuclei with neutron deficiency may increase their n/p ratio to gain stability by electron Capture,

The electron Capture process involves mostly the K-shell electron, because of its closeness to the nucleus, the process is then referred to as K-capture. L or M capture processes are also possible in Some cases.

The decay by electron Capture creates an empty hole in the involved shell that is then filled with another outer orbit electron, thus giving rise to the characteristic X-rays.

There is also the emission of Auger electrons, which are monoenergetic electrons produced by the absorption of characteristic X-rays by the atom and reemission of the energy in the form of orbital electrons ejected from the atom.

Another name for characteristic X-rays produced by the interaction of photons with the atom is fluorescent X-rays; The excess energy released by the atom through electron transition from an outer orbit to an inner orbit appears as photons (fluorescent X-rays) or Auger electrons.

The probability of fluorescent X-ray emission VS Auger electrons depends on the atomic number of the atom involved.

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UNIT II

NUCLEAR REACT

4- Internal Conversion :-

In this process, the excess nuclear energy is passed on to one of the orbital electrons which is then ejected from the atom. The kinetic energy of the internal conversion electron is equal to the energy released by the nucleus minus the binding energy of the orbital electron involved.

5- **Isomeric Transition** :- involves an excited nucleus in the metastable state decaying to the ground state :-

Exmple :- ^{99m}Tc decaying to ^{99}Tc with a half-life of 6 hours and $E_{\gamma} = 140$ keV.

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UNIT-4-

NUCLEAR REACTIONS

1- The α, p reaction :

Rutherford in 1919 in an experiment in which he bombarded nitrogen gas with α- particles from a radioactive Source:

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H + Q$$

Q is generally represents the energy released or absorbed during the nuclear reaction.

If Q is positive, energy has been released and the reaction is Called <u>exoergic</u>.

If Q is negative, energyhas been absorbed and the reaction is <u>endoergic</u>.

Q is equal to the difference in masses of the initial and final particles.

<u>Example</u>: Calculate the Q - value of the following reaction

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H + Q$$

Mass of Initial particles a.m.u		Mass of final particles a.m.u.
$^{14}_{7}N$ = 14.003074		$^{17}_{8}O$ = 16-999133
$^{4}_{2}He$ = 4.002603		$^{1}_{1}H$ = 1.007825
18.005677	$<$	18.006958

Δm = 0.001281 a.m.u.

1 a.m.u = 931.5 MeV

$Q = -0.001281 \times 931.5 = -1.19$ MeV

α, p reaction : A reaction in which an α-particle interacts with a nucleus to form a compound nucleus which in turn, disintegrates immediatly into a new nucleus by the ejection of a proton. is called α, p reaction.

α : bombarding particle.
p : ejected particle.

The general reaction of this type is written as

$$ {}^{A}_{Z}X + {}^{4}_{2}He \longrightarrow {}^{A+3}_{Z+1}Y + {}^{1}_{1}H + Q . $$

$$ {}^{A}X(\alpha, p)^{A+3}Y $$

2- The α, n Reaction:-

The bombardment of a nucleus by α particles with the subsequent emission of neutrons is designated as an α, n reaction.

${}^{9}Be(\alpha, n)^{12}C$ [This is the first reaction used for producing small neutron sources]

A material containing a mixture of radium and beryllium has been commonly used as a neutron source.

3- Proton bombardment :-

proton being captured by the nucleus with the emission of γ-ray : ${}^{9}Li(P, \gamma)^{8}Be$

${}^{12}C(P, \gamma)^{13}N$

other possible reactions produced by proton :
(P, n), (P, d) and (p, α) ; $d \equiv {}^{2}_{1}H$

4- Deutron bombardment :-

deutron particle is a combination of a proton and a neutron (^2_1H). Deutron bombardments with the result that the compound nucleus emits either a ^1_0n or a ^1_1p -

Two types of reactions can be written as :-

$$^A_ZX\,(d,n)\,^{A+1}_{Z+1}Y$$

$$^A_ZX\,(d,P)\,^{A+1}_{Z}X$$

Source of high-energy neutrons is produced by the bombardment of beryllium by deuterons :

$$^2_1H + ^9_4Be \longrightarrow ^{10}_5B + ^1_0n$$

The process is known as <u>stripping</u> ; In this process the deutron ^2_1H is not captured by the nucleus but pass close to it. The ^1_1p is stripped off from the deuteron and the ^1_0n continues to travel with high speed.

5- Neuton bombardment :-

Neutron, because the posses no electric charge, are very effective in penetrating the nuclei and producing nuclear reactions.

Slow neutrons or thermal neutrons [(0.025 eV) at room temperature] have been found to be extremely effective in producing nuclear transformations:

$$^{10}_5B + ^1_0n \longrightarrow ^7_3Li + ^4_2He$$

$$^{10}B\,(n,\alpha)\,^7Li$$

^1_0n slow neutrons.

The reaction $^{10}B(n,\alpha)^{7}Li$ form the basis of neutron detection; an ionization chamber is filled with boron gas such as BF_3. The α particle released by the (n,α) reaction with boron produces the ionization detected by the chamber.

(n,γ) reaction is the most common process of neutron capture; in this case the compound nucleus is raised to one of its excited states and then immediately returs to its normale state with the emission of a γ-ray photon -

γ-rays called capture γ-rays

the reaction can be written as follows:-

$$^{1}_{1}H + \underset{\uparrow}{^{1}_{0}n} \longrightarrow {}^{2}_{1}H + \gamma$$

Slow or thermal neutron

Products of the (n,γ) reaction, in most cases, have been found to be radioactive, emitting β particles

Ex: $$^{59}_{27}Co + {}^{1}_{0}n \longrightarrow {}^{60}_{27}Co + \gamma$$

Followed by:- $$\hookrightarrow {}^{60}_{28}Ni + {}^{0}_{-1}\beta + \gamma_1 + \gamma_2$$

$$^{197}_{79}Au + {}^{1}_{0}n \longrightarrow {}^{198}_{79}Au + \gamma$$

$$\hookrightarrow {}^{198}_{80}Hg + {}^{0}_{-1}\beta$$

(n,p) reaction:

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

$$\hookrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$$

Ex; of a fast neutron (n,P) reaction is the producti

of ^{32}P : $^{32}_{16}S + ^{1}_{0}n \longrightarrow ^{32}_{15}P + ^{1}_{1}H$

$$\hookrightarrow ^{32}_{16}S + ^{0}_{-1}\beta$$

6- Photodisintegration:-

An interaction of high-energy photon with an atomic nucleus can lead to a nuclear reaction and to the emission of one or more neucleons.

In most cases this process of photodisintegration results in the emission of $^{1}_{0}n^{s}$ by the nuclei :-

$$^{63}_{29}Cu + \gamma \longrightarrow ^{62}_{29}Cu + ^{1}_{0}n$$

In addition to (γ, n) reaction :- γ, P

γ, d

$\gamma, t \Rightarrow$ (t is triton $= ^{3}_{1}H$)

γ, α

7- Fission:-

This type of reaction is produced by bombarding certain high atomic No. nuclei by $^{1}_{0}n^{s}$. The nucleus after absorbing the $^{1}_{0}n^{s}$, splits into nuclei of lower atomic No. as well as additional $^{1}_{0}n^{s}$.

$$^{235}_{92}U + \underset{\substack{\uparrow \\ \text{thermal} \\ \text{neutron}}}{^{1}_{0}n} \longrightarrow ^{236}_{92}U^{*} \longrightarrow \underbrace{^{141}_{56}Ba + ^{92}_{36}Kr}_{\text{Fragments}} + 3\,^{1}_{0}n + \underset{\substack{\uparrow \\ 200\text{MeV}}}{Q}$$

Q : energy released, can be calculated by the mass difference between the original and final particles

- Fusion :-

Nuclear fusion may be considered the reverse of nuclear fission :- Low - mass nuclei are combined to produce one nucleus.

A typical reaction is :

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + \underset{\underset{17\text{-}6\ \text{MeV}}{\downarrow}}{Q} $$

the fusion reaction to occur, the nuclei must be brought sufficiently close together so that repulsive coulomb forces are overcome and the short-range forces can initiate the fusion reaction.

This is accomplised by heating Low Z nuclei to very high temperatures ($>$ than 10^{7} K) which is Comparable with the inner Core temperature of the Sun.

Activation nuclides

Elements can be made radioactive by various nuclear reactions,

The yield of nuclear reaction depend on the number of bombarding particles, the number of target nuclei, and the probability of the occurrence of the nuclear reaction. The probability is propotional to the quantity called cross - Section (unit of barns) : 1 barn = 10^{-24} cm^{2}

The cross section of nuclear reaction depend on; the target material, the type of the bombarding particles and their energy.

Slow ${}^{1}_{0}n^{s}$ (thermal) are very effective in activating nuclides, high flux of slow ${}^{1}_{0}n^{'s}$ ($10^{10} \rightarrow 10^{14}$ $n/cm^{2}/s$) are available in a nuclear reactor where neutrons are produced by fission reactions.

medical physics UNIT - 5 -
Nuclear physics
3rd class

Interaction of Ionizing Radiation

when an X-ray or γ-ray beam passes through a medium interaction between photons and matter can take place with the result that energy is transferred to the medium. The initial step in the energy transfer involves the ejection of electrons from the atoms of the absorbing medium. These high-speed electrons transfer their energy by producing ionization and excitation of the atom along their paths. IF the absorbing medium consists of body tissues, sufficient energy may be deposited within the Cells, destroying their reproductive Capacity. Most off the absorbed energy is converted into heat.

1- Ionization :- is the process by which a neutral atom acquires a positive or negative charge.

Ionizing radiation can strip electrons from atoms as they travel through media.

positive ion :- An atom from which electron has been removed.

negative ion :- In some Cases, the stripped electron may combine with a neutral atom to form a negative ion.

- ion pair : is the Combination of a possitively Charged ion and negatively charged ion.
- directly ionizing radiation :- Charged particles such as electrons protons, and α- particles.
- indirectly ionizing radiation :- Uncharged particles such as neutrons and photons.

hoton beam description :-

γ- ray emitted from a radioactive source consist of a Large number of photons, usually with a variety of energies.

A beam of photon can be described by many terms :-

1 - The fluence Φ of photon is the quotient (dN) by (da)

where (dN) is the number of photons that enter an imaginary sphere of cross-section area (da).

$$\Phi = \frac{dN}{da}$$

2 - Fluence rate or flux density ϕ is the fluence per unit time.

$$\phi = \frac{d\Phi}{dt}$$

where dt is the time interval.

3 - Energy fluence Ψ is the quotient of (dE_{fl}) by (da).

where dE_{fl} is the sum of the energies of all photons that enter a sphere of cross - sectional area (da);

$$\psi = \frac{dE_{fl}}{da}$$

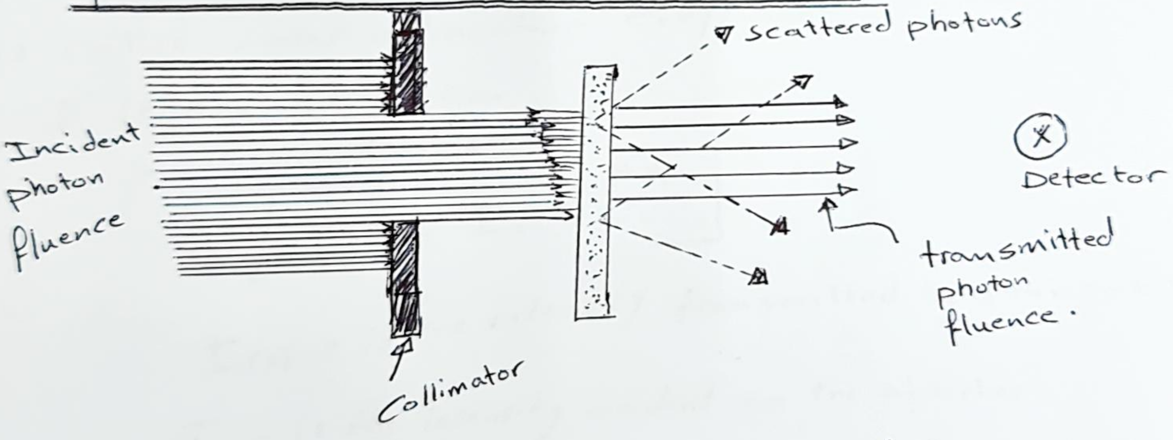
For monoenergetic beam dE_{fl} is just the number of photons dN times energy $h\nu$ carried by each photon ;

$$dE_{fl} = dN \, . \, h\nu$$

4- Energy fluence rate, energy flux density or intensity (ψ) is the energy fluence per unit time :-

$$\psi = \frac{d\psi}{dt}$$

3- Photon beam attenuation :-



An experimental arrangement designed to measure the attenuation of a photon beam.

Detector is placed at a fixed distance from the Source.

A narrow beam of monoenergetic photons is incident on an absorber of variable thickness.

dN : the reduction in number of photons

N : number of incident photon

dx : the thickness of the absorber.

$$\therefore \; dN \propto N dx$$

$$dN = -\mu N dx$$

where μ is the constant of proportionality called the attenuation coefficient.

(−) sign indicates that the number of photons decreases as the absorber thickness increases.

The above equation can also written in terms of intensity (I):

$$dI = -\mu I dx$$

$$\frac{dI}{I} = -\mu dx$$

(x) the thickness is expressed as a length, then μ is called Linear attenuation coefficient.

If (x) measured in cm.

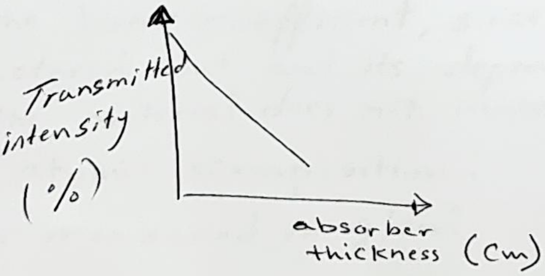
μ is in cm^{-1}.

$$\left[I(x) = I_o e^{-\mu x} \right]$$

$I(x)$ = is the intensity transmitted by a thickness X.

I_o = is the intensity incident on the absorber.

If I(x) is plotted as a function of x for a narrow monoenergetic beam, a straight line will be obtained on Semilogarithmic paper



HVL : half - value Layer

HVL : is defined as the thickness of an absorber required to attenuate the intensity of the beam to half its original value.

That means that when $X = HVL$, $I/I_0 = 1/2$

$$\therefore \quad HVL = \frac{\ln 2}{\mu} = \frac{0.693}{\mu}$$

The first HVL is defined as that thickness of material which reduces the incident beam intensity by 50%

The Second HVL reduces the beam to 50% of its intensity after it has been transmitted through the first HVL.

4- Coefficients :-

A. Attenuation coefficient :- μ is depends on the energy of photons and the nature of the material

μ produced by a thickness x depends on the number of electrons presented in that thickness.

μ depends on the density of the material.

μ/ρ is the mass attenuation coefficient

ρ :- is the density of the material.

μ/ρ :- will be independent of density.

μ/ρ : This is more fundamental coefficient than the Linear coefficient, since the density has been Factored out and its dependence on the nature of the material does not involve density but rather the atomic composition.

IF ρ : is measured in g/cm^3

μ/ρ : has units of cm^2/g.

when using μ/ρ in equ. below

$$I_{(x)} = I_o \, e^{-\mu/\rho \cdot \rho X}$$

the thickness should be expressed as ρX

ρX : has units of g/cm^2

$$\mu x = (\mu/\rho) . \rho X$$

$$\rho X = g/cm^3 . cm$$

In addition to the cm and g/cm^2 units the absorber thickness can also expressed in units of electron$/cm^2$ and atoms$/cm^2$

${}_e\mu$: electronic attenuation coefficient

${}_a\mu$: atomic attenuation coefficient

$${}_e\mu = \mu/\rho \cdot \frac{1}{N_o} \quad cm^2/electron.$$

$${}_a\mu = \mu/\rho \cdot \frac{Z}{N_o} \quad cm^2/atom.$$

where Z is the atomic number.

N_o is the number of electron per gram

$$N_o = \frac{N_A \cdot Z}{A_w}$$

where N_A is Avogadro's number

A_w is the atomic weight.

3- Energy transfer coefficient :-

when a photon interacts with the electron in the material, a part or all of its energy is converted into kinetic energy of electrons -

photon beam traversing a material, the fraction of photon energy transferred into kinetic energy of charged particles per unit thickness of absorber is given by the μ_{tr} ;

μ_{tr} : energy transfer coefficient

$$\mu_{tr} = \frac{\bar{E}_{tr}}{h\nu} \cdot \mu$$

$\bar{E}_{tr}$: is the average energy transferred into kinetic energy of charged particles per interaction

μ_{tr}/ρ : the mass energy transfer coefficient.

C - Energy absorption Coefficient :-

Most electrons set in motion by the photons will lose their energy by inelastic collisions (ionization and excitation), with atomic electrons of the material.

μ_{en} : The energy absorption Coefficient.

μ_{en} : is defined as the product of energy transfer coefficient and $(1-g)$

g : is the fraction of the energy of secondary charged particles that is lost to bremsstrahlung in material.

$$\mu_{en} = \mu_{tr}(1-g)$$

μ_{en}/ρ : the mass energy absorption coefficient.

Most interactions involving soft tissues or other Low-Z material in which lose energy almost entirely by ionization collisions, $\mu_{en} = \mu_{tr}$, μ_{en} is important quantity in radiotherapy. (energy absorbed in tissue) bremsstrahlung (braking radiation) : is the result of radiative "collision" interaction between a high-speed electron and a nucleus. the $\bar{e}$ while passing near a nucleus may bedeflected from its path by the action of Coulomb forces of attraction and lose energy as bremsstrahlung.

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UNIT-6-

Interactions of photons with matter

Attenuation of a photon beam by an absorbing material is caused by Five major types of interactions

1- photodisintegration; this is the reaction between photon and nucleus, is only important at very high photon energies > 10 MeV.

2- Coherent Scattering
3- Photoelectric effect.
4- Compton effect.
5- pair production.

each of these processes can be represented by its own attenuation coefficient, which varies with the energy of the photon and with the atomic number of the absorbing material

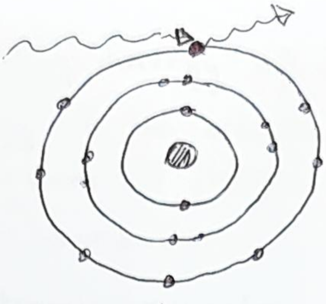
The total attenuation coefficient is the Sum of individual coefficients for these processes:

$$\mu/\rho = \sigma_{coh}/\rho + \tau/\rho + \sigma_c/\rho + \pi/\rho$$

σ_{coh} : attenuatin coefficient for coherent scattering
τ : 〃 〃 〃 photoelectric effect.
σ_c : 〃 〃 〃 Compton scattering.
π : 〃 〃 〃 Pair production.

Coherent Scattering:- [Known as Classical scattering or Rayleigh scattering]

an electromagnetic wave passing near the electron and setting it into oscillation, the oscillating electron reradiates the energy at the same wavelength as the incident beam.

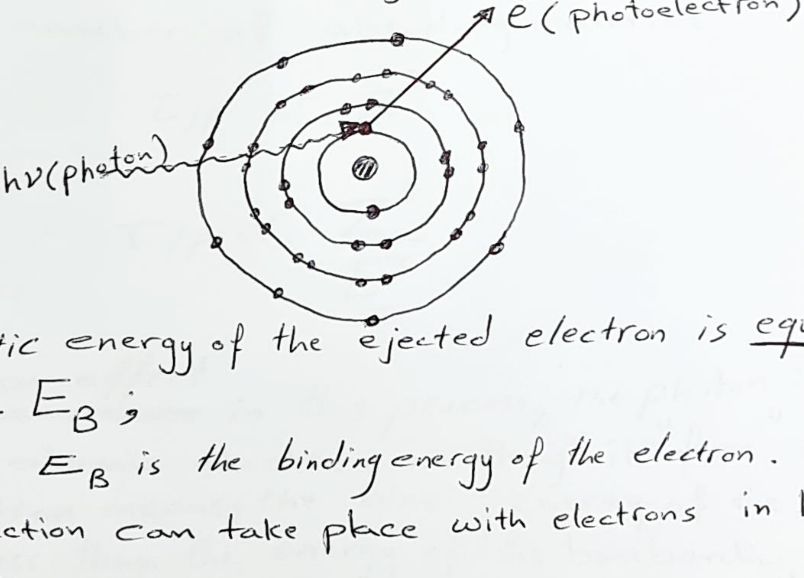


atom

[Coherent Scattering]

Thus, no energy is changed into electronic motion and no energy is absorbed in the medium.

Photoelectric effect:- is a phenomenon in which a photon is absorbed by an atom and as a result one of its orbital electrons is ejected



- The kinetic energy of the ejected electron is equal to $h\nu - E_B$;

where E_B is the binding energy of the electron.

This interaction can take place with electrons in K, L, M or N shells.

ejection of electron from the atom, leaving the atom in the excited state. The vacancy be filled by an outer orbital electron with the emission of a characteristic X-ray

There is also the possibility of emission of Auger electrons, which occurs when the enegy released as a result of the outer electron filling the vacancy is given to another electron in a higher shell.

The K-shell binding energy of soft tissues is only about 0.5 keV, the energy of the characteristic photons produced in biologic absorbers is very Low and can be considered to be Locally absorbed.

For higher atomic number materials, the characteristic photons are of higher energy and may deposit energy at large distances compared with the range of photoelectron.

- The probability of photoelectric absorption depends on the photon energy:

$$\tau/\rho \propto \frac{1}{E^3}$$

- The photoelectric attenuation depends strongly on the atomic number of absorbing material

$$\tau/\rho \propto Z^3$$

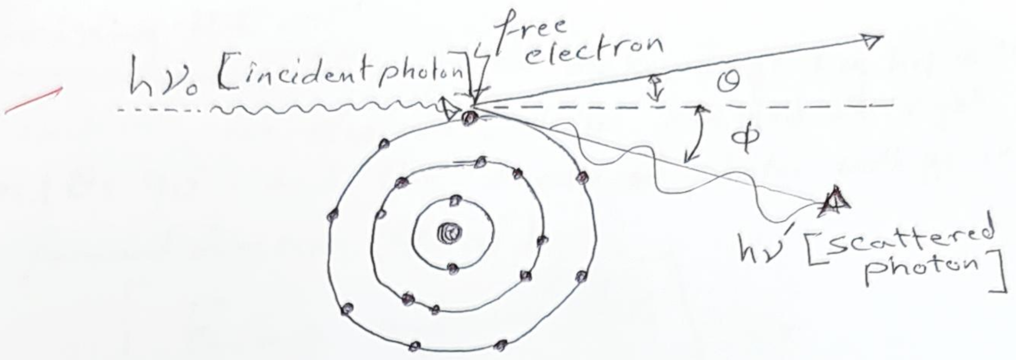
$$\therefore \quad \tau/\rho \propto \frac{Z^3}{E^3}$$

Compton effect in this process, the photon interact with an atomic electron as though it "free" electron "Free" electron means: the binding energy of the electron is much less than the energy of the bombarding photon.

In this interaction the electron recieves some energy from the photon and emitted at an angle θ, the photon is Scattered at an angle ϕ, with reduced energy.

By applying the Laws of Conservation of energy and momentum; we derive the following relationships:

- $$E = h\nu_0 \frac{\alpha(1-\cos\phi)}{1+\alpha(1-\cos\phi)}$$



$$\left[h\nu' = h\nu_0 \frac{1}{1+\alpha(1-\cos\phi)} \right]$$

$$\boxed{\cot\theta = (1+\alpha)\tan\phi/2}$$

where $h\nu_0$ = is the incident photon energy.
$h\nu'$ = is the scattered photon energy.
E = is the electron energy.
$\alpha = h\nu_0 / m_0c^2$
m_0c^2 = is the rest energy of the electron

$$\boxed{m_0c^2 = 0.511 \text{ MeV}}$$

If $h\nu_0$ is expressed in MeV, then $\alpha = \frac{h\nu_0}{0.511}$

Special cases of Compton Effect :-

1- Direct hit ; If a photon makes a direct hit with the electron, the electron will travel forward ($\theta = 0$ degrees) and the scattered photon will travel backward ($\phi = 180°$) in such a collision, the electron will receive maximum energy E_{max}, and the photon scattered with minimum energy $h\nu'_{min}$;

$$E_{max} = h\nu_0 \frac{2\alpha}{1+2\alpha}$$

$$h\nu'_{min} = h\nu_0 \frac{1}{1+2\alpha}$$

2- Grazing Hit If a photon makes a grazing hit with the electron, the electron will be emitted at right angles ($\theta = 90^\circ$) and the scattered photon will go in the forward direction ($\phi = 0^\circ$)

$$\left[E = 0 \quad \text{and} \quad h\nu' = h\nu_0 \right]$$

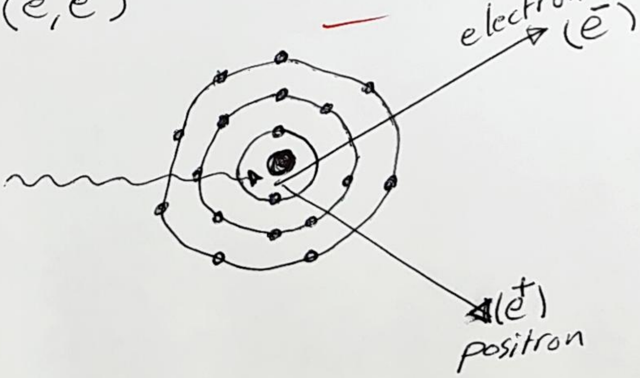
3- 90° photon Scatter: If Photon is scattered at right angles ($\phi = 90^\circ$) $\Rightarrow \cos\phi = 0$, The angle of the electron emission in this cas depend on α according to the following equation:

$$\left[\cot\theta = (1+\alpha)\tan\phi/2 \right]$$

4- Pair Production:- If the energy of photon is > 1.022 MeV, this Photon interact strongly with electromagnetic field of an atomic nucleus and gives up all its energy and Creating a pair of $\bar{e}$ and $\overset{+}{e}$.

$$\begin{aligned} 1.022\ \text{MeV} &= 2m_0c^2 \\ &= 2 \times 0.511\ \text{MeV} \\ &= 1.022\ \text{MeV} \end{aligned}$$

1.022 MeV is the minumum energy is required to Create the pair of electrons ($\bar{e}$, $\overset{+}{e}$)



UNIT -7-
medical physics
Nuclear physics
3rd class

Interactions of charged Particles

Charged particles [electrons, protons, α- particles and nuclei] interact principally by ionization and excitation Radiative collisions in which the charged particle interacts by the Bremsstrahlung process are possible but are much more likely for electrons than for heavier charged particles.

The charged particle interactions or collisions are mediated by Coulomb Force between the electric field of the traveling particle and electric fields of orbital electrons and nuclei of atoms of the material.

Collisions between the particle and the atomic electrons result in ionization and excitation of the atoms.

collisions between the particle and the nucleus result in radiative Loss of energy or bremsstrahlung.

Particles also suffer scattering without significant Loss of energy.

Because of much smaller mass, electrons suffer greater multiple scattering than do heavier particles.

In addition to the Coulomb interactions, heavy charged particle give rise to nuclear reactions, thereby producing radioactive nuclides.

For example : a proton beam passing through tissue produces short-lived radioisotopes, ^{11}C, ^{13}N and ^{15}O, which are positron emitters.

The rate of kinetic energy loss per unit path Length of the particle $\frac{dE}{dX}$ is known as;

Stopping Power [S].

[S/ρ] is called the mass stopping power.

ρ is the density of medium

[S/ρ] is expressed in MeV. cm²/g.

1- Heavy charged particles :-

charged particles may be classified as Light or heavy, depending upon their masses.

Electrons and positrons are called "Light" particles because of their very tiny mass [~ 1/1840 of mass of a proton].

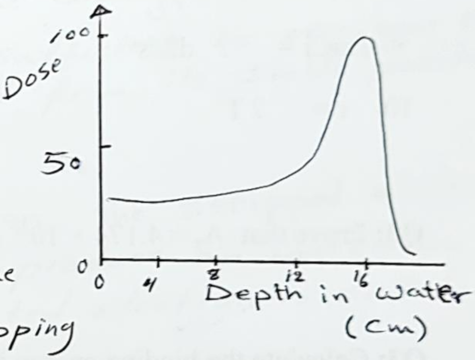
A charged particle is called "heavy" if the rest mass is large compared to the rest mass of an electron. Examples : protons, mesons, α-particles and atomic nuclei.

The rate of energy loss per unit path length or stopping power caused by ionization interactions for charged particles is proportional to the square of particle charge and inversely proportional to the square of its velocity

i.e. $$\left.\begin{array}{l} S \propto q^2 \\ S \propto \dfrac{1}{v^2} \end{array}\right]$$ where q is the charge
v is the velocity

Thus, as the particle slows down, its rate of energy loss increases and so does the ionization or absorbed dose to the medium.

Figure shows: the dose deposited in water increases at first very slowly with depth and then very sharply near the end of the range, before dropping to an almost zero value



This peaking of dose near the end of the particle range is called the Bragg peak.

Because of the Bragg peak effect and minimal scattering, protons and heavier charged particle beams provide a much sought after advantage in Radiotherapy - the ability to concentrate dose inside the target volume and minimize to surrounding tissues.

2 - Electrons :-

Interaction of electrons when passing through matter are quite similar to those of heavy particles.

Electrons have small mass, they suffer greater multiple scattering and changes in direction of motion. As a consequence, the Bragg peak is not observed for electrons.

In water or soft tissue, the electrons lose energy by ionization and excitation. This results in deposition of energy or absorbed dose in the medium.

Ionization process :- consists of stripping electrons from the atoms.

Excitation process :- If the energy transferred to the orbital electron is not sufficient to overcome the binding energy, it is displaced from its stable position and then returns to it.

In the process of ionization, the stripped electron receives sufficient energy to produce an ionization track of its own. This ejected electron is called a Secondary electron or δ-ray

Because of its small mass, an electron may interact with the electromagnetic field of a nucleus and slowing so rapidly that a part of its energy is lost as bremsstrahlung. The rate of bremsstrahlung increases with the increase in the energy of the electron and atomic number of the medium.

Interactions of Neutrons

Neutrons are indirectly ionizing.
X-rays and γ-rays are indirectly ionizing Radiation.

Neutrons interact basically by two processes:

1- recoiling protons from hydrogen and recoiling heavy nuclei from other elements.

2- nuclear disintegration. [emission of heavy charged particles, neutrons, and γ-rays]

In the (1) process; may be likened to billiard_ball collision in which the energy is redistributed after the Collission between the colliding particles.
The energy transfer is very efficient if the colliding particles have the same mass. (e.g. a neutron colliding with a hydrogen nucleus).
The neutron Loss very little energy when colliding with a heavier nucleus.
The most efficient absorbers of a neutro beam are the hydrogenous materials such as paraffin Wax or polyethylene.

Lead, which is a very good absorber for X-rays or γ-rays, is a poor shielding material against neutrons.
The dose absorbed in Fat exposed to a neutron beam is about 20% higher than in muscle.

~~medical physics~~
~~Nuclear~~ Nuclear physics
3rd class

UNIT-8

Radiation Dosimetry

Radiation dosimetry is the method used to convert the amount of ionizing radiation deposited in tissue to its effect in tissue, which is influenced by 'damage" potential" of the radiation type (e.g. energy, size, charge, half-life, etc.) the administered dose, and the dose rate.

Radiation dosimetry in the fields of health physics and radiation protection is the measurement, calculation and assessment of the ionizing radiation dose absorbed by an object, usually the human body. This applies both internally, due to ingested or inhaled radioactive substances, or externally due to irradiation by source of radiation.

In 1928, the International Commission on Radiation Units and Measurements [ICRU] adopted the roentgen as the unit of measuring X- and γ- radiation exposure. The unit is denoted by R. The quantity exposure measured in R Can be converted into a quantity called absorbed dose

The roentgen is a unit of exposure. The quantity exposure is a measure of ionization produced in air by photons.

The ICRU defines exposure [X] as the quotient of dQ by dm; where dQ is the absolute value of the charge of the ions of one sign produced in air when all the electrons (negatrons and positrons) Liberated by Photons in air of mass dm are completely stopped in air.

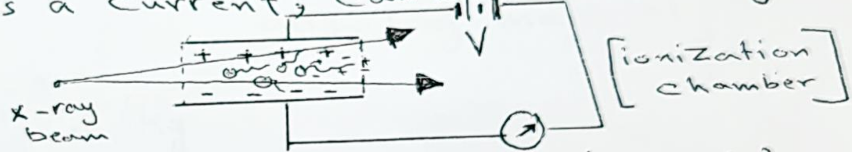
$$X = \frac{dQ}{dm}$$

The SI unit for exposure is coulomb per kilogram (C/Kg);

$$1\ R = 2.58 \times 10^{-4}\ C/Kg \quad \text{in } \underline{\underline{\text{air}}}$$

The definition of roentgen: is illustrated as follows when an X-ray or γ-ray beam in passing through air sets in motion electrons by photoelectric effect, Compton effect, or pair production.

These high-speed electrons produce ionization along their tracks. Because of the electric field produced by the voltage applied across the ion-collection plates, the positive charges move toward the negative plate and the negative charges move toward the positive plate. This constitutes a current, can be measured by an electrometer.



Roentgen was originally defined as $1 R = 1\ esu/cm^3$ (esu: is electrostatic unit) in air at standard temperature and pressure (STP).

The current definition of $1 R = 2.58 \times 10^{-4}\ C/kg$ air is equivalent to the original if the charge is expressed in coulombs ($1\ esu = 3.333 \times 10^{-10} C$) and the volume of air is changed to mass;

$$1\ cm^3 \text{ of air at STP weights} = 1.293 \times 10^{-6}\ kg$$

The exposure applies only to X- and γ radiation is a measure of ionization in air only and cannot be used for photon energy above about 3 MeV.

Definition of Absorbed Dose:

The quantity absorbed dose has been defined to describe the quantity of radiation for all types of ionizing radiation including charged and uncharged particles ; all materials and all energies .

Absorbed dose is a measure of the biologically significant effects produced by ionizing radiation.

Absorbed dose is the quotient $\frac{d\bar{E}}{dm}$ where $d\bar{E}$ is the mean energy imparted by ionizing radiation to material of mass dm .

The old unit of dose is rad (radiation absorbed dose)

$$1 \text{ rad} = 100 \text{ erg/g}$$ [absorption of 100 ergs of energy per gram of absorbing material]

$$1 \text{ rad} = 10^{-2} \text{ J/Kg}.$$

The SI unit for absorbed dose is gray (Gy)

$$1 \text{ Gy} = 1 \text{ J/Kg}$$

The relationship between gray, centigray (c Gy) and rad is :

$$1 \text{ Gy} = 100 \text{ rad}$$

$$1 \text{ Gy} = 100 \text{ c Gy}$$

or

$$\left[1 \text{ rad} = 10^{-2} \text{ Gy} = 1 \text{ c Gy}\right]$$

Definition of Kerma

The quantity kerma (K) [Kinetic energy released in the medium]

Kerma is defined as: "The quotient of dE_{tr} by dm; where dE_{tr} is the sum of the initial kinetic energies of all the charged ionizing particles ($\bar{e}$'s, $\overset{+}{e}$'s) liberated by uncharged particles (photons) in a material of mass dm

$$K = \frac{dE_{tr}}{dm}$$

The unit of kerma (K) is the same as for dose that is J/Kg
in SI unit is (Gy) gray.

For a photon beam traversing a medium, kerma at a point is directly proportional to the photon energy fluence Ψ :

$$K = \Psi \left(\frac{\bar{\mu}_{tr}}{\rho} \right)$$

where $(\bar{\mu}_{tr}/\rho)$ is the mass energy transfer coefficient for the medium averaged over the energy fluence spectrum of photons.

$$\frac{\bar{\mu}_{en}}{\rho} = \left(\frac{\bar{\mu}_{tr}}{\rho} \right) (1 - \bar{g})$$

where $\bar{\mu}_{en}/\rho$ is the averaged mass energy absorption coefficient and $(\bar{g})$ is the average fraction of an electron energy Lost to radiative processes:

$$\therefore \quad K = \Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)\Big/(1-\bar{g})$$

A major part of the initial kinetic energy of electrons in Low-atomic-number material (e.g., air, water, Soft tissue) is expended by inelastic collisions (ionization and excitation) with atomic electrons; Only a small part is expended in the radiative collisions with atomic nuclei (Bremsstrahlung)

Kerma can thus divided into two parts:

$$K = K^{col} + K^{rad}$$

K^{col} : collision Kerma.

K^{rad} : radiative Kerma.

$$K^{col} = \Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)$$

$$\left[K^{rad} = \Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)\cdot\left(\frac{\bar{g}}{1-\bar{g}}\right)\right]$$ prove that?

$\because \quad K = \Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)\Big/(1-\bar{g})$

$\because \quad K = K^{col} + K^{rad.}$

$\because \quad K^{rad}$ is small $\Rightarrow$ assume equal to Zero.

$\therefore \quad K = K^{col} \Rightarrow \cancel{\Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)/(1-\bar{g})} = K^{col} = \Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)$

$$\Rightarrow \quad K^{rad} = \Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)\Big/(1-\bar{g}) - \Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)$$

$$= \left[\frac{1}{(1-\bar{g})} - 1\right]\Psi\left(\frac{\bar{\mu}_{en}}{\rho}\right)$$

$$\therefore \quad K^{rad} = \left[\frac{\bar{g}}{1-\bar{g}}\right]\Psi\,\frac{\bar{\mu}_{en}}{\rho}$$

Exposure AND Kerma :

Exposure was defined as $\frac{dQ}{dm}$

where dQ : is the total charge of ions of one sign produced in air when all the electrons (negatrons and positrons) liberated by photons in (dry) air of mass (dm) are completely stopped in air.

Exposure is the ionization equivalent of collision Kerma in air.

It can be calculated from K^{col} by knowing the ionization charge produced per unit of energy deposited by photons.

$\bar{W}$: The mean energy required to produce an ion pair in dry air is almost constant for all electron energies.

$\bar{W} = 33.97$ eV/ion pair

If e is the electronic charge $= 1.602 \times 10^{-19}$ C.

$\Rightarrow \frac{\bar{W}}{e} =$ is the average energy required per unit charge of ionization produced.

$\because 1\,eV = 1.602 \times 10^{-19}$ J

$\therefore \frac{\bar{W}}{e} = 33.97$ J/C

Exposure (X) is given by :

$$X = (K^{col})_{air} \cdot \frac{e}{\bar{W}}$$

$\because K^{col} = \Psi \left(\frac{\overline{\mu_{en}}}{\rho} \right)$

$$\therefore X = \Psi_{air} \left(\frac{\overline{\mu_{en}}}{\rho} \right)_{air} \cdot \left(\frac{e}{\bar{W}} \right)_{air}$$

Absorbed dose To Air

Determination of absorbed dose from exposure;

$$D_{air} = (K^{col})_{air}$$

$$= X \cdot \overline{\frac{W}{e}}$$

$$D_{air}\,(J/kg) = X(R) \cdot (2.58 \times 10^{-4})\frac{C/kg}{R} \cdot (33.97)(J/C)$$

$$= 0.876 \times 10^{-2}\left(\frac{J/kg}{R}\right) \cdot X(R)$$

$$\because\ 1\,cGy = 10^{-2}\,J/kg$$

$$\therefore D_{air}\,(cGy) = 0.876\left(\frac{cGy}{R}\right) \cdot X(R)$$

[0.876] is the conversion factor from roentgen to cGy for air; under the conditions of electronic equilibrium.

Absorbed dose to Any Medium:-

The absorbed dose D to a medium can be calculated from the energy fluence Ψ and the weighted mean mass energy absorption coefficient $(\bar{\mu}_{en}/\rho)$:

$$D = \Psi \cdot \bar{\mu}_{en}/\rho$$

Suppose Ψ_{air} is the energy fluence at a point in air and Ψ_{med} is the energy fluence at the same point :

$$\frac{D_{med}}{D_{air}} = \frac{(\bar{\mu}_{en}/\rho)_{med}}{(\bar{\mu}_{en}/\rho)_{air}} \cdot \frac{\Psi_{med}}{\Psi_{air}}$$

$$\because D_{air} = X \, \frac{\overline{W}}{e}$$

$$D_{med} = X \cdot \frac{\overline{W}_{air}}{e} \cdot \frac{(\bar{\mu}_{en}/\rho)_{med}}{(\bar{\mu}_{en}/\rho)_{air}} \cdot \frac{\Psi_{med}}{\Psi_{air}}$$

If X is in (R)

and D_{med} is in (cGy)

$$\therefore D_{med} = 0.876 \frac{(\bar{\mu}_{en}/\rho)_{med}}{(\bar{\mu}_{en}/\rho)_{air}} \cdot X \cdot \frac{\Psi_{med}}{\Psi_{air}}$$

$$\boxed{D_{med} = f_{med} \cdot X \cdot \frac{\Psi_{med}}{\Psi_{air}}}$$

where $f_{med} = 0.876 \dfrac{(\bar{\mu}_{en}/\rho)_{med}}{(\bar{\mu}_{en}/\rho)_{air}}$.

f_{med} : is sometimes called roentgen-to-rad conversion factor.

Nuclear physics
3rd class

UNIT-9-

Radiation protection

1- External Radiation protection:-

2- Internal Radiation Protection:-

I- External Radiation Protection:-

Three basic methods used to reduce the the external radiation hazard are ; time, distance and shielding.

Ⓐ- Time :- The amount of radiation an ~~and~~ individual stays in the radiation field:-

$$\text{Dose (mrem)} = \text{Dose Rate (mrem/hr)} \times \text{Time(hr)}$$

Therefore, to limit a person's dose, one can restrict the time spend in the area.

Stay time :- How Long a person can stay in an area without exceeding a prescribed Limit.

Stay time is calculated from the simple relationship:

$$\text{stay Time} = \frac{\text{Limit(mrem)}}{\text{Dose Rate (mrem/hr)}}$$

Ⓑ Distance : The amount of radiation an individual receives will also depend on how close the person is to the source.

1. The Inverse Square Law - point sources of X- and γ- radiation follow the inverse square Law, which states that the intensity of the radiation (I) decreases in proportion to the inverse of the distance from the source (d) squared.

$$I \propto \frac{1}{d^2}$$

$$I = K \frac{1}{d^2}$$ where K is a constant of unknown value.

For an intensity I_1 at distance d_1, and another intensity I_2 at distance d_2 :

$$I_1 = K\frac{1}{d_1^2} \; ; \; I_2 = K\frac{1}{d_2^2}$$

$$\frac{I_1}{I_2} = \frac{K/d_1^2}{K/d_2^2}$$

$$\therefore \frac{I_1}{I_2} = \frac{d_2^2}{d_1^2} \quad OR \quad I_1 d_1^2 = I_2 d_2^2$$

2. Gamma Constants Γ

Gamma radiation levels Γ in R/hr for one Curie of many radionuclides at a distance of one meter have been measured. These gamma constants can be used to determine: (1) The expected exposure rate at a given distance (using the inverse square Law) for a known quantity of radionuclide.

(2) The activity of a radionuclide from a measured exposure rate.

$\boxed{1 \text{ Foot} = 30.48\text{cm}}$

3. Gamma Exposure Rate Formula:

The exposure rate from a gamma point source can be approximated from the following expression:

$$mR/hr = \frac{6CEf}{d^2}$$

where C: is the activity of the gamma emitter in mCi.

E: is the gamma ray energy in MeV

f: is the fraction of disintegration yielding the gamma of energy E.

$$\frac{6 \times Ci\left[\begin{matrix}\gamma_1 , \gamma_2 \\ ((\gamma_1 \times \%)+\gamma_2 \times \%)\end{matrix}\right]}{1^2} \leftarrow f$$

d: is the distance from the Source in feet

If more than one gamma ray is emitted by the radionuclide of interest, then the Contribution from each one must be calculated separately and Summed.

C. Shielding : When reducing the time or increasing the distance may be not possible, one can choose shielding material to reduce the external radiation hazard.
The proper material to use depend on the type of radiation and its energy.

1. Alpha and Beta Radiation

α- particles are easily shielded. A thin piece of paper or several cm of air is usually sufficient to stop them.

α- particles present no external radiation hazard.

β- particles are more penetrating than α- particles

β - shields are usually made of aluminum, brass, plastic, or other materials of Low atomic number, to reduce the production of Bremsstrahlung radiation.

2- X- and γ- Radiation:

Monoenergetic X- or γ rays collimated into a narrow beam are attenuated exponentially through a shield according to the following equation:-

$$I = I_o e^{-\mu x}$$

I = intensity outside of a shield of thickness X

I_o = unshilded intensity , μ = Linear attenuation coeff. of the shielding material.

Lead : is a common shielding material for X-ray and γ- radiation because : it has a high density, is inexpensive, and is relatively easy to work with.

When working with a radionuclide that emits multiple types of radiation such as β-particles and γ- radiation its is sometimes necessary to shield with several materials

Types of shielding and amount of shielding vary depending on photon energy.

D. External Exposure Personnel Monitoring:

External radiation exposure is measured by personnel monitoring devices. Four major types of monitoring devices is use today are;

1- The pocket dosimeter
2- film badge
3- thermoluminescent dosimeter TLD
4- optically stimulated Luminescent (OSL) dosimeter.

II - Internal Radiation Protection:

Internal radiation exposure results when the body is Contaminated internally with a radionuclide when radioactive materials enter into the body, they are metabolized and distributed to the tissues according to the chemical properties of the elements and Compounds in which they are Contained.

A: Radioactive Materials in the body

Radioactive substances, Like other toxic agents, may gain entry into the body by **four** processes:

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1- inhalation - breathing radioactive aerosols or dust
2- Ingestion - drinking contaminated water, or transferring radioactivity to the mouth.
3- Absorption - entry through intact skin.

ثقب

4- Injection - puncture of skin with an object bearing radioactive materials.

How Long a radioactive substance stays in the body?

is a combination of the radiological half-life of the radionuclide and the biological half-life of the substance

The biological half-Life is defined as the amount of time it takes for half of the substance to be eliminated from the body by biological means. It is completely independent from the radiological half-Life, as it depends entirely on bodily processes such as metabolism

The combination of the two half-~~tif~~ Lives is called effective half-Life (T_{eff}):

$$T_{eff} = \frac{T_R \times T_B}{T_R + T_B}$$

where T_R : the radiological half-life

T_B : the Biological half-Life.

T_{eff} is always shorter than either the radiological or biological half-Life

B- Internal Exposure Monitoring :-

Internally deposited radioactive material can be monitored by measuring the radiation emitted from the body or by measuring the amount of radioactive material contained in the Urine

Such monitoring techniques are called bioassays