Activity of population, radioactive equilibrium and Units of radioactivity.

(1) **Activity of population or 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

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

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

(2) **Radioactive equilibrium:** Suppose a radioactive element A disintegrates to form another radioactive element B which in turn disintegrates to still another element C.

$$A \longrightarrow B \longrightarrow C$$

In the starting, the amount of A (in term of atoms) is large while that of B is very small. Hence the rate of disintegration of A into B is high while that of B into C is low. With the passage of time, A go on disintegrating while more and more of B is formed. As a result, the rate of disintegration of A to B goes on decreasing while that of B to C goes on increasing. Ultimately, a stage is reached when the rate of disintegration of A to B is equal to that of B to C with the result the amount of B remains constant. Under these conditions B is said to be in equilibrium with A. For a radioactive equilibrium to be established half-life of the parent must be much more than half-life of the daughter.

It is important to note that the term equilibrium is used for reversible reactions but the radioactive reactions are irreversible, hence it is preferred to say that B is in a steady state rather than in equilibrium state.

At a steady state,

$$\boxed{\frac{N_A}{N_B} = \frac{\lambda_B}{\lambda_A} = \frac{T_A}{T_B}\left(\because T = \frac{1}{\lambda}\right)},$$ Where λ_A and λ_B are the radioactive constants for the processes $A \rightarrow B$ and $B \rightarrow C$ respectively. Where T_A and T_B are the average life periods of A and B respectively.

In terms of half-life periods, $\boxed{\frac{N_A}{N_B} = \frac{(t_{1/2})_A}{(t_{1/2})_B}}$

Thus at a steady state (at radioactive equilibrium), the amounts (number of atoms) of the different radioelements present in the reaction series are inversely proportional to their radioactive constants or directly proportional to their half-life and also average life periods.

It is important to note that the radioactive equilibrium differs from ordinary chemical equilibrium because in the former the amounts of the different substances involved are not constant and the changes are not reversible.

(3) **Units of radioactivity :** The standard unit in radioactivity is curie (c) which is defined as that amount of any radioactive material which gives 3.7×10^{10} disintegration's per second (dps), i.e.,

1c = Activity of 1g of $Ra^{226} = 3.7 \times 10^{10}\, dps$

The millicurie (mc) and microcurie (μc) are equal to 10^{-3} and 10^{-6} curies i.e. 3.7×10^{7} and 3.7×10^{4} dps respectively.

$$1c = 10^{3}\, mc = 10^{6}\, \mu c;\ \ 1c = 3.7 \times 10^{10}\, dps;\ 1mc = 3.7 \times 10^{7}\, dps;\ \ 1\mu c = 3.7 \times 10^{4}\, dps$$

But now a day, the unit curie is replaced by Rutherford (rd) which is defined as the amount of a radioactive substance which undergoes $10^{6}\, dps$. i.e., $1\, rd = 10^{6}\, dps$. The **millicurie** and **microcurie** correspondingly Rutherford units are **millirutherford** (mrd) and **microrutherford** (μrd) respectively.

$$1\, c = 3.7 \times 10^{10}\, dps = 37 \times 10^{3}\, rd; \qquad 1\, mc = 3.7 \times 10^{7}\, dps = 37\, rd;$$

$$1\, \mu c = 3.7 \times 10^{4}\, dps = 37\, mrd$$

However, is SI system the unit of radioactivity is **Becquerel** (Bq)

1 Bq = 1 disintegration per second = 1 dps = 1μrd

$$10^{6}\, Bq = 1\, rd$$

$$3.7 \times 10^{10}\, Bq = 1\, c$$

(4) **The Geiger-Nuttal relationship:** It gives the relationship between decay constant of an α-radioactive substance and the range of the α-particle emitted.

$$\boxed{\log \lambda = A + B \log R}$$

Where R is the range or the distance which an α-particle travels from source before it ceases to have ionizing power. A is a constant which varies from one series to another and B is a constant for all series. It is obvious that the greater the value of λ the greater the range of the α-particle.