Lecture Two / Instruments for Radiation Detection and Measurement

Certain natural elements (primarily the very heavy ones) have unstable nuclei that disintegrate to emit various rays :

1- Alpha particles: positively charged, which stops in a few centimeters of air, are the nuclei of helium atoms.
2- Beta particles: negatively charged, are more penetrating but can be stopped in a few millimetres of tissue, they are high speed electrons.
3- Gamma rays: are very penetrating and are physically identical to x-rays, they usually much higher energies than the x-rays.

For the comparison between them Each element has a specific No. of protons in the nucleus; for example, Carbon has six protons, Nitrogen has seven protons and Oxygen has eight protons. However, for each element, the No. of neutrons can vary.

Isotopes : Nuclei of a given element with different numbers neutrons. There are two types:

a- **Stable isotopes** : if they are not radioactive.
b- **Radioisotones** : if they are radioactive.

Example:

Carbon has two stable isotopes and several radioisotopes (Isotopes referring to a single element).

Radionuclides : is appropriate when several radioactive elements are involved.

Radioactivity

All elements can be either stable or not stable depending on the building of the atom and their nucleus. Each atom is composed of nucleus (which contain a number of neutrons and protons) and surrounded by electrons.

Stable elements have normal ratio of $n/p \geq 1$.

Its $n/p = 1$ for low atomic No. $Z = 1$ to 20.

And its $n/p > 1$ for elements of $Z > 20$

For none stable elements (radioactive) this ratio either above or below normal.

1- If elements have n/p > normal ratio

then they have neutrons more than normal number. Thus will decay (transform) by:

a- Neutron emission

This occur when the No. of neutrons is very high than normal. (n >>> normal). The type of radiation is Neutron particles.

b- Neutron disintegration: this occur by transform the Neutron into proton and this will companied by Beta particles.(This happen when n > normal)

$$n \longrightarrow p + \beta$$

Type of radiation:-

1. Electron which called Beta particles (β) because it's from the nucleus.
2. Gamma (γ) ray when the proton goes to stable or lower energy state.

2- For elements which have n/p < normal

The elements decay by either proton emission

a. Proton emission

This occur when the No. of protons is very high than normal.(when p >>> normal). The type of radiation is Protons particles.

b. Electron capture: (when p > normal)

The proton transform into neutron by capturing electron from the K-shell of the atom.

$$p + e \longrightarrow n$$

In this process of transformation (decay) the following radiation is given:

1. X- rays: The vacancy in the K-Shell will be filled from other shells (L, M, N…).

2. Positron (e+) particles instead of the electron captured by the proton. The positron is electron except it has +ve charge.

3. γ- rays: when the neutron goes to stable state.

Decay (transformation process):

Each radioactive atom try to reach the stable state in the following probability:-

dN/dt α No. of total radioactive atoms.

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

$$\Longrightarrow \quad N = N_o e^{-\lambda t} \qquad (1)$$

N is No. of radioactive atoms after (t) time.

N_o is No. of radioactive atoms at t = 0 (originally present).

λ is decay constant. (Units sec^{-1}, min^{-1}, …)

e is Natural logarithm.

From equation (1) we can gate:

$$\frac{dN}{dt} = \frac{dN_o}{dt} e^{-\lambda t}$$

dN/dt = A (activity of atoms after t time)

dNo/dt = Ao (activity of atoms at t = 0 time original activity)

$$\Longrightarrow \quad A = A_o e^{-\lambda t} \qquad (2)$$

When N = 1/2 N_o or, A = 1/2 A_o Then the time of transformation called physical half-life ($T_{½}$).

Physical half-life : is the time needed for either half of the No. of radioactive atoms or the activity to reduce to half its original activity.

$$T_{1/2} = \frac{0.693}{\lambda} \quad (3)$$

This means for every radioactive atoms:

$$T_{1/2}\,\lambda = constant = 0.693 \quad (4)$$

Note: In equations 1, 2, 3 and 4 the time and decay constant must take the same units of time (time (sec), λ (sec^{-1}); time (min), λ (min^{-1}); etc…..).

Average life or (mean life):

$$T_a = \frac{1}{\lambda} \quad or \quad T_a = 1.44\,T_{1/2} \quad (5)$$

to calculate the No. of radioactive atoms and the activity of the sample. In each atomic weight of any element there is a constant No. of atoms which is called Avogadro No. (6.02 x 1023 atoms/Aw).

Units of Radioactivity:

1- Curie (Ci): The No. originally represented the radioactivity of 1g of radium. This is equal to 3.7 x 1010 disintegration per second, but this unit has been changed by another unit which is independent of the disintegration ratio of radium and small unit.

2- Becquerel (Bq): The SI unit for radioactivity which is equal to 1 disintegration per second. This can be used for any radioactivity.

So, 1Bq = 1 disintegration/sec. and 1Ci = 3.7 x 10^{10} Bq.

Basic characteristic of radioactivity:

1- When an element decays (parent) its daughter which is also radioactive formed.
2- There are over 1000 known radionuclides, most man-made

3- Heavy elements tend to have many more radioisotopes than light elements.

4- Characteristic that helps identify the radionuclides are the type and energy of Its radiation.

5- Some man-made radionuclides emit types of radiation not emitted by natural radioactive which are positron emitters (β+) such as 18F.

6- Metastable elements are radioactive elements atoms that emit only γ-rays and changed to stable state of the same elements.

$$^{99m}\text{Tc} \longrightarrow \gamma + {}^{99}\text{Tc stable}$$

7- According to the characteristics of radionuclides (energy and type of radiation) they are divided into three groups:

I- Research: The radionuclides which are used for this purpose have:

a- very penetrating

b- low energies

3H give β, and 14C give β

II- Diagnosis: The radionuclides which are used for this purpose have: a- long penetrating depth b- short physical half-life. Such as 99*m*Tc and 32P are mostly γ-emitters that have enough penetrating depth to detect out of the body and enough physical half-life.

III- Therapy: The radionuclides which are used for this purpose have: a- short penetrating depth b- long physical half-life. Such as charge particles α, β, protons ,neutrons and ions.