B.Sc-I (Sub), Paper-1, Group-B (Inorganic chemistry)

Unit: 4 Isotopes (By Dr. Birendra Kumar, Maharaja College)

⟹ Isotopes?

Atoms of an elements having same atomic number/numbers of electrons or protons but different atomic masses/mass numbers are called isotopes.

Isotopes differ in numbers of neutrons. Their chemical properties are similar but physical properties are different. For example, hydrogen has three isotopes: Protium ($_1H^1$ or H), Deuterium ($_1H^2$ or D) & Tritium ($_1H^3$ or T). They differ in atomic masses (1, 2, 3 resp.) & number of neutrons (0, 1, 2 resp.)

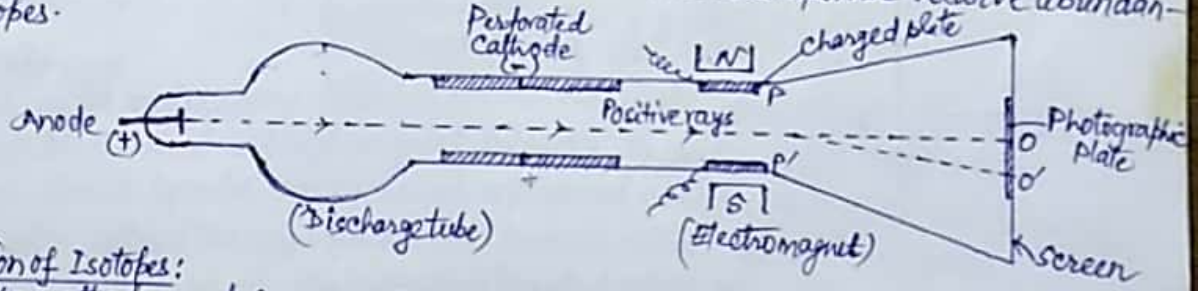
Radioactive isotopes are formed by successive emission of one α & 2 β particles from a nucleus.

e.g. $_{92}U^{238} \xrightarrow{-\alpha} {}_{90}Th^{234} \xrightarrow{-\beta} {}_{91}Pa^{234} \xrightarrow{-\beta} {}_{92}U^{234}$. Here $_{92}U^{238}$ & $_{92}U^{234}$ are isotopes.

⟹ Identification/Detection of Isotopes:

Isotopes are presently identified mainly by mass spectrograph. It separates different isotopes of an element into a line spectrum on a photographic plate according to their masses.

The discharge tube is filled with the gaseous element and the positive rays as they emerge from the perforated cathode pass through two slits to get a narrow beam. The latter is then passed through electric and magnetic fields. By suitably adjusting the two fields, all particles having the same mass are brought to a focus on a photographic plate so as to produce a fine line rather than a parabola. The developed plate is known as mass spectrum. Since the positions of the lines depend upon the mass and the intensities upon the relative abundance of isotopes.



⟹ Separation of Isotopes:

The methods used for separation of isotopes are followings:

1. Gaseous diffusion method: Since the rate of diffusion of a gas is inversely proportional to the square root of its molecular weight, hence lighter isotope of an element will diffuse more readily through porous barrier than the heavier isotope and thus a partial seperation of isotopes can be done. In the separation of U^{235} & U^{238}, the lighter one being more important. When uranium hexafluoride vapour passed through a series of porous barriers then the vapour passing through each barrier is richer in U^{235} than that left behind. The extent of isotopic enrichment per stage is very-very small. Moreover, by using several thousand diffusion stages in a cascade, over 90% U^{235} can be obtained from the natural Uranium having only 0.72%.
2. Electromagnetic separation method: Ions of different isotopes of an elements are deflected to different extent by electric and magnetic field and hence they can be collected seperately. This is the only method which produces 100% pure isotope.
3. Fractional distillation method: This method has been used for the separation of isotopes of Hg, Cl, Zn & K. The basic principle of separation of isotopes by means of this method is that lighter fraction of isotopic mixture distills out first leaving behind a residue which is rich in heavier fraction.

4. Mass spectrometry: The principle of this method is essentially that of the mass spectrograph in which each isotope present in a stream of ions is bent through a different path by a suitable arrangement of electric and magnetic fields. If instead of photographic plate for detecting the rays, a number of small receivers are placed in the proper positions, the separate isotopes can be collected.

⟹ Radiocarbon dating

The age of piece of wood or animal fossil can be ascertained by using radiocarbon dating. Will and Libby was awarded Noble prize for this brilliant discovery/method. The determination of the age of a wood sample (i.e. the time which elapsed after the death of the living plant) consists of determining the ratio of the amount of C^{14}/C^{12} in both the living and dead pieces of the wood. We know that atmospheric CO_2 is a mixture of $C^{14}O_2$ & $C^{12}O_2$ having a definite ratio of the two. Plant absorbs CO_2 from atmosphere and prepares wood (cellulose). During its lifetime, the said ratio is the same as that present in the atmosphere but when the plant is cut or dead, the said ratio begins to decrease continuously. As C^{14} starts decaying: $C^{14} \longrightarrow N^{14} + \beta^0_{-1}$ (β-particle) ($t_{1/2} = 5760$ years)

Now from disintegration law, $N = N_0 e^{-\lambda t}$ we have, t (age of the wood) $= \frac{2.303 t_{1/2}}{0.693} \log \frac{N_0}{N}$

Here $N_0 = C^{14}/C^{12}$ ratio in the living plant, $N = C^{14}/C^{12}$ ratio in the dead plant, $t_{1/2}$ = half life of $C^{14} = 5760$ years. Now if the amount of C^{14} in the living and dead wood/plant is known then

t (age of the wood) $= \frac{2.303}{0.693} t_{1/2} \log \frac{\text{Amount of } C^{14} \text{ in living wood}}{\text{Amount of } C^{14} \text{ in dead wood}}$.

⟹ Tracer technique

Tracers are the radioactive isotopes which are used in understanding the mechanism of chemical, biochemical and physiological processes. As such if we want to trace the course of an atomic species in a chemical or physical change, we mix a small quantity of the radioactive isotope (tracer) with non-radioactive isotope, the presence of which is later on determined in the products. This is called tracer technique or radioactive labelling.

The followings are important uses of tracers/tracer technique:

1. Mechanism of photosynthesis: The process of photosynthesis is represented by the equation:

$$6CO_2 + 6H_2O \xrightarrow{\text{UV-light}} 6O_2 + 6C_6H_{12}O_6$$

Now, a very important question arises whether evolved oxygen comes from CO_2 or H_2O or both. In order to answer this question, H_2O is made to react with CO_2 containing O^{18} (CO_2^*) and it is found that the evolved oxygen does not contain O^{18}, i.e. O^{18} present in CO_2^* goes to sugar and water. Therefore, the evolved oxygen comes from H_2O and not from CO_2, and consequently in views of above observations, the process of photosynthesis can be treated as:

$$6CO_2^* + 12H_2O \longrightarrow C_6H_{12}O_6^* + 6H_2O^* + 6O_2$$

2. Mechanism of hydrolysis of ester: When an ester is hydrolysed by water containing O^{18} (as H_2O^*) alcohol thus formed does not have any O^{18}, while the acid has whole of it. This means C–O but not the O–R′ bond of ester breaks during the hydrolysis.

$$R-\overset{O}{\overset{\|}{C}}-OR' + H-O^{18}-H \rightleftharpoons R-\overset{O}{\overset{\|}{C}}-O^{18}-H + R'-OH.$$

3. Circulation of blood: A small quantity of NaCl solution containing radiosodium (Na^{24}) is injected into the vein of patient's forearm. If blood circulation is normal the presence of radio activity soon detected in the foot. It increases rapidly and becomes maximum within an hour. However, if blood circulation is impair, radioactivity will increases slowly showing that blood has some difficulty in reaching the foot. Thus, the point of restriction can be detected.