EMT 515 :- RADIONUCLIDES IN THE ENVIRONMENT (2 units)

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SYNOPSIS

Natural radioactivity, fusion, fission, decay processes, acidity, nuclear models, energetic of nuclear reactions. Principles and measurement of radioactivity. Application of radioactivity. Radiation hazards. Applications of radioisotopes. Nuclear structure and Nuclear reactions, Decay reactions kinetics of decay reaction. Bombardment reactions and the growth of radio activity, Analytical use of radionuclide. Chemical path way studies, radio- isotope dilution methods, radio immunoassay, radio activation analysis.

LECTURE CONTENT

FUNDAMENTAL PARTICLES

All of the simple particles which exist in nature have been found to undergo reactions in which they are converted into or obtained from other particles or radiations. There are, then no particles which are immutable and which can be said to be truly fundamental. There are however, seven simplest known particles. These particles can be considered to serve as the building units for more complicated forms of matter.

1. Electron: first to be recognized having been discovered by J.J. Thomson in 1897.
2. Proton: the nucleus of the ordinary hydrogen atom was observed as positively charged rays in a discharged tube in 1886. However, the existence of protons as independent particles in a tube containing ionized hydrogen at how pressure were by J.J. Thompson in 1906
3. Positron: found by Prof. Carl Anderscon in 1932. The positions were found among the particles produced by the interaction of cosmic rays with matter. They seem to be identical with electrons except that their charge is positive instead of negative. Their life span as free particle is very short, usually less than a us ($1x10^{-6}$sec).
4. Neutron : discovered by J. Chadwick in 1932. Neutrons are particles with mass only slightly larger than that of the proton and with zero electric charge. Because they have no electrical charge, neutron interact with other forms of matter only very weakly.

5. On passage through solid substance they deflects only when they undergo direct collision with nuclei. Because neutrons and nuclei are so small, the chance of collision is very small and neutron s are accordingly able to penetrate thro great thickness of heavy elements.

6. Mesons: discovered in 1936 by Carl Anderson and seth Neddermeyer. They are produced by the interaction of cosmic rays with matter. They are either positive or negative in charge, and have mass approx. 1/1oth of that of a proton. Mesons have very short lives, they probably undergo decomposition into positions or electrons and neutrinos .
7. Neutrino: is a particle with mass about equal to that of the electron, but with no electric charge. Its existence was surmised (guessed) about 1925, in order to account for some experimental results on the emission of beta particles by radioactive substances which seemed to contradict the law of conservation of energy. Since then a number of further experiment have been carried out in an effort to verify the existence of neutrino .
8. Photon : or light quantum may also be described as one of the fundamental particles. In 1905, Einstein assumed that light (visible light, UV, X-rays etc) has some of the properties of particles. He called these particles of light, light quanta and the name photons has since been introduced. The amount of light constituting a light quantum is determined by the frequency of light, $\nu = c/\lambda$

NUCLEAR STRUCTURE

Particles in the nucleus are protons and neutrons; these are known collectively as nucleons. They are packed together in a tiny volume compared with that of the atom. The electrostatic forces of repulsion within the nucleus are extremely high and yet most nuclei do not split apart. They are held together by an even more powerful attractive force between the nucleons called the nuclear binding force which depend on the fourth power of the distance between nucleons.

Repulsive force $\propto 1/d2$ attractive force $\propto 1/d4$

The nuclear binding force increases as the distance between nucleons decreases and vice verse when the nucleon distance increases**.**

RADIOACTIVITY

Natural Radioactivity

In 1896 Becquerel, whilst investigating the property of fluorescence, discovered that a crystal of uramium salt spontaneously emitted radiation which could penetrate matter

opaque to light and affect a photographic plate. In 1898 marie and pierre curie discovered new radioactive elements – radium and polonium .

The nuclei of isotopes of atoms that spontaneously emit energy or subatomic particles without requiring an input energy are said to be naturally radioactive. Naturally radioactive substances have been shown to emit three kind of rays or particles.

1. Alpha rays (∝-rays): is composed of two neutrons (2n) and two protons (2p). It is identical to the positively charged nuclei of a helium atom (He^{2+}). Because of their relatively large mass (2p + 2n), alpha particles do not travel very far and are not very penetrating. Thus ∝-rays can be stopped by a layer of human skin, a thin sheet of Al foil or several sheets of paper. They do, however have a very powerful ionizing effect upon any gas through which they pass.
2. Beta particles (β- particles): are fast moving electron (e-) that may travel up to 90% of the speed of light. Because of their smaller mass and higher speed they are about 100more times penetrating than alpha particles but they are much less effective in ionizing gases. They can be stopped by an Al plate 0.3cm thick.
3. Gamma rays (ɣ - rays): are not particles but a form of high energy electromagnetic radiation and consequently they travel with the speed of light. They resemble X – rays but have an even shorter wavelength. They possess very great power of penetration hence can only be stopped by thick layers of lead or concrete.

Name + symbol	Identity	Charge	Magnetic field	Relative mass (amu)	Vel.	Penetration
Alpha (∝, $^4_2He^{2+}$ $^4_2$∝)	Helium nucleus	+2	Deflected one way	4.0026	5-10% of the speed of light	Low
Beta (β, -i^0 β, -i^0e)	Electron	-1	Strongly deflected the opposite way.	0.000549	Up to 90% of the speed of light	Moderate
Gamma (ϒ, $^0_0$ ϒ)	Radiant energy similar to x –	0	Not deflected	0	Speed of light $3x10^{10}$ cm/sec	High

	ray					

DETECTI0N OF RADIATION

The radiation emitted from a radioactive isotope can be detected in a number of ways namely;

1. Photographic emulsions – radioactivity was discovered by Becquerel who left a radioactive substance on a photographic plate. The radiation affects photographic film in a similar way to light. This method is used today in works and factories where there is any radioactive hazard. Everyone entering the premise carries a portion of special film in a small container, this is developed on leaving or after a certain period of time, and shows whether the wearer has been exposed to radiation and also of which type.
2. Scintillation screens and counters : some substances interact with radioactive radiation by giving out light. Example include Zin sulphide and Caesium iodide which give flashes of light every time radiation hits them/ the flashes can be counted using a photocell.
3. Cloud and bubble chambers : a cloud chamber in a very small container of super saturated vapour. As radiation passes thro' the vapour, it produces ions along its path. The ionization increases some of the inter particle forces so that a small droplet of liquid form along the pathway of radiation. A track of tiny droplet shows the presence of radioactive radiation. A bubble chamber is a small container of superheated liquid. Radiation causes bubbles of vapour to form along its pathway.
4. Ionization chambers and Geiger- Muller tubes: an ionization chamber contains a small volume of gas at low pressure between a pair of electrodes. Radiation entering the chamber causes ionization. These ions them move to the electrodes to constitute a small electric current.

   A Geiger-miller tube is a special application of the idea of an ionization chamber. It is a cyclindrical tube with a central electrode. Radiation enters the tube thro' a mica window at one end.

Ions produced by the radiations are accelerated towards the central electrode producing a tiny flow of charge which can be amplified and measured in counts per minutes (c.p.m)

RADIOACTIVE DECAY

The change which occurs when an atom loses particles from the nucleus is known as radioactive decay. Unlike chemical changes, the rate of decay in affected by temperature, pressure, or chemical action.

Some radioactive materials decay into other substances which are themselves radioactive. This process continues until an element is produced which is not radioactive and has a stable nucleus. Such a chain of reaction is known as a decay series. Loss of beta particles is known as beta decay and the emission of alpha particle is alpha decay.

$\propto$ – decay – usually emitted by heavy nuclei. The nucleus reduces both its mass and its atomic number by expelling a helium nucleus (2p and 2n).

$$\frac{238}{92}U \Rightarrow \frac{234}{90}Th + \frac{4}{2}He$$

X – decay result in (i) reduction in mass no by 4

(ii) reduction in atomic no by 2

β - decay – Three forms of β -decay are known. All of these involve an interaction between neutrons and protons.

1. β^- decay – a neutron becomes a proton and an electron inside the nucleus, the electron is expelled e.g

$$\frac{210}{8B}\beta i \Rightarrow \frac{210}{84}\text{Po} + {}^{0}\text{e}$$

β^- decay results in (i) no change in mass no.

(ii) increase in atomic no by 1.

2. β^+ dacay – a proton becomes a neutron and a positron inside the nucleus the positron (a particle with the sample properties as an electron except that it is positively charged) is expelled e.g
$\frac{30}{15}$P ==➔ $\frac{30}{14}$Bi + ^{0}e

β^+ decay results in (i) no change in mass no

(ii) decrease in atomic no by 1.

3. K-capture :- an inner shell (K –shell) electron is captured by the nucleus. It converts a proton to a neutron e.g ${}^{40}_{19}$K + ${}^{0}_{-1}$e =➔ ${}^{40}_{18}$R K- capture remets in
   (i) No change in mass no
   (ii) Decrease in atomic no by 1

Of these three types, β^- decay in the most common.

ɣ- decay – after emitting ∝- and β- rays a nucleus is often left in a high energy state. The nucleus can reduce its energy by giving out high – energy radiation inform of ɣ-rays which have ɣ- decay results in similar properties to X – rays.

(i) No change in mass no.
(ii) No change in atomic no.

E.g $\frac{80}{35}$ Br^+ ===➔ $\frac{80}{35}$ Br + $\frac{0}{0}$ ɣ

Where $\frac{80}{35}$ Br+ is an 'excited' bromine nucleus.

DISLACEMENT LAWS AND DECAY SERIES

The term displacement law is sometimes used to summarize the change that occur to a nucleus when it undergoes ∝- or β- decay.

A change of minus two in group number in the displacement law for ∝- decay.

A group VII atom becomes a group V atom

'' '' '' '' '' VII atom.

Hence ∝- decay always results in the decrease of the atomic number of a nucleus by 2.

A change of plus one in group number in the displacement law for β- decay. E.g

A group VII atom becomes a group VII atom

'' ''VII '' '' '' '' '' I atom

Thus β- decay always result in the increase of the atomic member of a nucleus by 1.

Some of the naturally occurring unstable isotopes decay to give product isotopes which are themselves unstable. Such a product isotope, called a daughter isotope, may itself generate another radioactive isotope which decays to a third isotope. A whole series of product can result from decay of a single isotope. A single series of this sort is known as a decay series e.g uranium decay series.

$\frac{235}{92}U$ ==➔ $\frac{231}{90}Th$ ===➔ $\frac{231}{91}Pa$ ==➔ $\frac{227}{89}Ac$ ==➔ $\frac{227}{90}Th$

$\frac{211}{83}Bi$ ←=== $\frac{211}{82}Pb$ ←=== $\frac{215}{84}Po$ ←==== $\frac{219}{86}Rn$ ←=== $\frac{223}{88}Ra$

$\frac{207}{81}Tl$ ===➔ $\frac{207}{81}Pb$ (stable).

ARTIFICIAL RADIOACTIVITY

Stable atoms can be converted into radioactive atoms by the collision of particles travelling at high speed. Such particles include neutron ($^{1}_{0}n$), proton ($^{1}_{1}p$),beta particles ($^{0}_{-1}e$) or alpha particles ($^{4}_{2}$ He). The first artificialy produced isotope , $^{13}_{7}N$, was made by bombarding $^{10}_{5}B$ with $\propto$ – particle.

$^{10}_{5}B + {}^{4}_{2}$ He ===➔ $^{13}_{7}N + {}^{1}_{0}n$.

Using this technique, hundred of radioactive isotopes that do not occur naturally have been made, including all of the artificially produced elements with atomic numbers greater than 92.

Other examples.

1. $^{14}_{7}N + {}^{4}_{2}$ He ==➔ $^{17}_{8}O + {}^{1}_{1}H$
2. $^{249}_{98}Cf + {}^{15}_{7}$ N ==➔ $^{260}_{105}X + 4{}^{1}_{0}n$

PROTON, NEUTRON HYPOTHESIS OF NUCLEAR COMPOSITION

The number of protons is represented by atomic number Z. The total number of protons and neutrons is represented by mass number A. The protons and neutrons are referred to as nucleons . the neuron number N = A-Z/ $\propto$- particle is written as $_{2}He^{4}$

:- A= 4, Z = 2

:- N = A-z = 4 – 2 = 2.

ISOTOPES – these are nuclear species with the same A and Z values.

ISOBARS – these have same mass number A but different atomic number, Z e.g

$_{32}Ge^{76} + {}_{34}Se^{76}$, $_{52}Te^{130} + {}_{54}Xe^{130} + {}_{56}Ba^{130}$, $_{80}Hg^{204} + {}_{82}Pb^{204}$

ISOTONES – these are species with the same number of neutrons ie the same N values but different mass numbers e.g $_{14}Si^{20}$, $_{15}P^{31}$, $_{16}S^{32}$.

NUCLEAR ISOMERS : these have same A &Z value but different radioactive properties. Nuclear isomer at different energy state of the same nuclear each having a different measurable lifetime e.g Antimony, Sb^{124}

Sb^{124} – sb^{124} , Sb^{124mi} , Sb^{124m2}

60days 1.5mins 21mins.

M= meta stable ie in an excited state.

ISOTOPIC NUMBER = N-Z ie no of neutron – no of proton

Q. Obtain the isotopic number in term of A&Z.

A. Isotopic no = A -2Z

PARTICLES IN NUCLEAR REATIONS

The following particles are usually encountered in nuclear reactions

1. $^{1}_{1}H$ – a proton or hydrogen atom
2. $^{2}_{1}H$ – a deuteron or hydrogen atom
3. $^{1}_{0}n$ - neutron
4. $^{0}_{-1}e$ – electron
5. $^{0}_{1}e$ – positron
6. $^{0}_{0}\tilde{\nu}$ - neutrino
7. $^{0}_{0}\tilde{\nu}$ - antineutrino
8. $\propto$ - particle – 42He
9. Υ - radiations – similar to X – rays & have no mass. When there are Υ – radiations in a nuclear reaction, there is no change in the values of A & Z; the only change is in the energy of the nucleus.

NUCLEAR REACTION

A nuclear reaction is a process in which a nucleus reacts with another nucleus in an elementary particle ($\propto$- particle, electrons) or a photon to produce in a time of the order of 10^{-12} sec or less one or more nuclei.

M

Most of the nuclear reactions studied to date involves nucleus + proton + deuteron or triton or helium ion or electron or photon the products obtained are nuclei of different species and one or more light particles. The chief exception to this prescription are the

fission reactions and the more recently investigated reactions include by heavy atoms such as lithium, beryllium , boron , carbon.

Example of nuclear reactions:

1. Ruther ford of reaction : this is the disintegration of nitrogen by $\propto$ – particles. The product are an isotope of oxygen and a proton.

   $^{14}N \text{ ====} \rightarrow {}^{17}_{8}O + {}_{1}{}^{1}H$

2. Joliot & curie reaction : this is the boundardment of $_{13}Al^{27}$ by $\propto$ – particles to give an isotope of phosphorous and a neutron.

   $_{13}AL^{27} + {}^{4}_{2}He \text{ ===} \rightarrow {}^{30}_{15}P + {}^{1}_{0}n$

   Shorthand notation for these reactions for the Ruther ford reaction.

   $_{7}N^{14}$ ($\propto$, P) $_{8}O^{17}$

   For Joliot & curie

   13Al 27 ($\propto$, n) $^{30}_{15}P$

RULES FOR BALANCING NUCLEAR EQUATIONS

1. The sum of masses on the LHS must be equal to that on the RHS.
2. The sum of charges on the LHS must be equal to that on the RHS.

More example of nuclear reactions.

$^{226}_{86}Ra \text{ ===} \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He.$

$^{239}_{93}Ne \text{ ===} \rightarrow {}^{239}_{94}Pa + {}^{0}_{-1}e$

$\propto$- particles from radioactive particles may be used to bring about unclear reactions e.g

$^{9}_{4}Be + {}^{4}_{2}He \text{ ===} \rightarrow {}^{12}_{6}C + {}^{1}_{0}n.$

The neutron produced by such bombardment may be used to causes additional nuclear reaction e.g to bombard Li.

$^{6}_{3}Li + {}^{1}_{0}n ====➔ {}^{4}_{2}He + {}^{3}_{1}H.$

Protons can be used to causes nuclear reactions according to the following e.g.

$^{14}_{7}N + {}^{1}_{1}H ===➔ {}^{11}_{6}C + {}^{4}_{2}He.$

And electrons can be used to effect nuclear reactions.

$^{54}_{26}Fe + {}^{2}_{1}H ===➔ {}^{55}_{27}Co + {}^{1}_{0}n.$

If the product of a nuclear reaction is unstable, such a product disintegrates further e.g the Co in the preceding reaction disintegrates to give Fe and a position

$^{55}_{27}Co ===➔ {}^{55}_{26}Fe + {}^{0}_{1}e$

NUCLEAR ENERGY

In the nuclear equations given in the preceding example, it was shown that there is no change in the sum of the masses. However there is actually a small change in mass and this small deficiency in mass is known as the mass defect and its energy equivalent in known as the binding or nuclear energy . for example,

$2\ {}^{1}_{1}H + 2\ {}^{1}_{0}n ===➔ {}^{4}_{2}He.$

Let us compare the mass of the reaction and products.

$2\ {}^{1}_{1}H$: 2 x 1.007825 = 2.015650 amu

2 10n : 2 x1.008665 = 2.017330 amu

:- mass of reactants = 4.032980amu

Mass of the product = 4.002604 amu

Mass defect or difference = (4.032980 – 4 .002604) = 0.030376 amu

This mass lost is converted into energy during the reaction according to Einstein equation

$E = mc^2$

Where E = energy in ergs, m= mass in g, c= velocity of light ($3x10^{10}cm\ s^{-1}$)

Since c^2 is very large (9×10^{20}) a very small amount of mass multiplied by this number results in a large release of energy. The amount of energy released in the formation of ^4_2He can be calculated thus

$E = mc^2$

$= (+ 0.030376 \text{ amu}) (3 \times 10^{10} \text{ cm / sec})^2$

$= (+0.030376 \text{ amu}) (9 \times 10^{20} \text{ cm / sec})$

$= + 2.73384 \times 10^{19}$ ergs

This can be converted to calories, since

$1 \text{ cal} = 4.184 \times 10^7$ erg.

Thus $E = + 2.73384 \times 10^{17}$ ergs x 1 cal / 4.184×10^7 ergs

$E = +6.534 \times 10^{11}$Cal .x 4.184 = to convert to joules

Nature and Energetic of Nuclear Reactions:

Nuclear reactions like chemical reactions are accompanied by a release or absorption of energy. This is shown by adding Q to the R. H. S. of the equation in the Rutherford reaction

$^{14}_7Ne + ^4_2He \Longrightarrow ^{17}_8O + ^1_1H + Q$

In chemical reactions, Q is expressed per mole, for nuclear processes Q is expressed per nucleus. In the Rutherford reaction,

$Q = -1.19 \text{ meV} = 1.19 \times 1.60 \times 10^{-6}$ ergs

Calculate the value of Q when 1 g atom of $^{14}_7N$ is converted to $^{17}_8O$

$Q = - 6.02 \times 10^{23} \times 1.19 \times 1.60 \times 10^{-6}$ ergs

$= - 11.462 \times 10^{17}$ ergs.

When Q is negative the reaction is accompanied by absorption of energy and it is said to be an endoergic reaction. When Q is positive the reaction is accompanied by a release of energy and is said to be an exoergic reaction. If Q is known experimentally, it is sometimes possible to compute the unknown mass of one of the participating nuclei. In this way, the masses of a number of radioactive nuclei have been determined. It is offen possible to calculate Q if the masses of the nuclei are unknown provided that the product nucleus is radioactive and decay back to the initial nucleus with known energy.

The following example illustrates this.

Obtain the energy absorbed in the nuclear reaction $^{106}{}_{46}$ Pd (n, p) $^{106}{}_{45}$Rh $t^1/_2$ = 30s.

mass of neutron = 1.008665 amu mass of proton = 1.007825 amu

In the reaction $^{106}{}_{45}$Rh (β,ϒ) $^{106}{}_{46}$Pd, 3.54 Mev of energy is released.

One atomic mass unit = 931.5 Mev.

Writing the equation in full:

(i) $_{46}$ Pd ^{106} + $_{O}n^{1}$ ===➔ $_{45}Rh^{106}$ + $^{1}{}_{1}H$ + Q

(ii) $_{45}Rh^{106}$ ===➔ $_{46}Pd^{106}$ + β + ϒ + 3.54

On adding equations (i) & (ii)

$_{O}n^{1}$ ===➔ $_{1}H^{1}$ + β +ϒ + Q + 3.54

For energy balance, the masses and energies on both side of the equation must be equal, for β – particle emission, and electron capture processes, the masses of e^- never have to be included in calculations when atomic mass are use.

$M_n = M_p + Q + 3.54$

Q = Mn – Mp – 3.54

Q= 931 (1.008665 – 1.007825) – 3.54

Q= 2.7mev.

1. Compute the Q values for the following reaction from the given masses.

(a) Mg^{24} (d, p) Mg^{25} (Ans Q= 5.11meV)

(b) B^{10} (n &) Li (Ans Q= 3.16meV)

(c) The rxn S^{33} (n, p) p^{33} is exoergic by 0.53 mev. What is the mass of p^{33} Ans. (p^{33} =32.9717amu)

(d) ${}^{3}_{1}H + {}^{2}_{1}H \dashrightarrow {}^{4}_{2}He + {}^{1}_{0}n$ give ans in cal (4.08×10^{11})

Mg^{24} = 23.985045, n = 1.0086654, ^{25}Mg = 24.985840 $\propto$= 4.0026036, d = 2.0141022 ,

Li =7.016005, p = 1.0078252, B^{10} = 10.013535, S^{33} =32.971460, t=3.0170

(a) Mg^{24} (d, p) Mg^{25}

$^{24}Mg + {}^{2}_{1}H ===> {}^{25}Mg + {}^{1}_{1}H + Q.$

23.985045 + 2.0141022===>24.985840 +1.0078252 +Q

Q = (23.985045 +2.0141022) – (24.985840 + 1.0078252) (931.5MeV

= (25.9991472 – 25.9936652) 931.5 MeV

=0.005482 x 931.5 mev

Q=5.106483 mev

2. Write the balanced equation for the following reactions

(a) ${}^{23}_{10}Ne$ (p, ${}^{o}_{-1}e$)

(b) ${}^{41}_{18}Ar$ ($\propto$, ${}^{o}_{1e}$)

(c) ${}^{38}_{19}K$ (d, ${}^{o}_{1}e$)

(d) ${}^{84}_{37}$ Rb ($\propto \beta$)

(e) ${}^{9}_{4}Be$ (p,d)

(f) ${}^{16}_{8}O$ (d , $\propto$)

(g) ${}^{27}_{13}Al$ (n, $\propto$)

(h) ${}^{40}_{18}Ar$ (n, Υ)

DIFFERENCES BETWEEN CHEMICAL AND NUCLEAR REACTIONS

	Chemical Reaction	NUCLEAR Reaction
1	No new element are produced	New elements are produced
2	Only electrons in outer energy levels outside the nucleus are involved	Particles inside the nucleus are involved

3	The reaction absorbs or release relatively small amounts of energy	The reaction may produce large amount of energy
4	The rate of reaction is a affected by temp concentration, catalyst and other external factors	The rate of reaction is independent of external factors

RADIOACTIVE DECAY AND GROWTH

The decay of a radioactive substance follows an exponential law given by

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

Where N_o = no of atoms at time t = 0

N = no of undecayed atoms at time t

λ= constant characteristic of the particular radioactive species and is referred to as the decay constant.

This radioactive decay can be represented thus

A ==========> Prod

(parent) (daughter)

t = 0 N_o -

t = t N x

The rate of this decay can be followed as

(i) Rate of appearance of product, dx/dt

(ii) Rate of disappearance of the parent atom/ rate = rate of appearance of product/ and rate of disappearance of the parent = - dN/dt

Since both expressions are the same

$dx/dt = - dN/dt = \lambda N$

$-dN/dt = \lambda N$

$-dN/N = \lambda dt$

Integrate $\int -dN/N = \lambda \int dt$

$\ln N = \lambda t + c$ where c is the integration constant

Evaluate c, At $t = 0$ $\ln No = \lambda(o) + c$, $C = - \ln No$

Subs for c in eqn (1)

$-\ln N = \lambda t - \ln No$ or $\ln No/N = \lambda t$

$\ln No - \ln N = \lambda t$ $No/N = e\lambda t$

$\ln N - \ln No = - \lambda t$ $No = Ne\lambda t.$

$\ln N/No = - \lambda t$

$N/No = e^{-\lambda t}$

$N = N_o e^{-\lambda t}$ The unit of λ is t^{-1}

The characteristic rate of decay is conveniently given in terms of half – life, $t^1/_2$ which is the time required for an initial no of atoms to be reduced to half by transformation

Therefore When $t = t½$ $N = No/2$ Recall, $\ln N/No = -\lambda t$ Sub for $t = t½$ and $N = No/2$

$\ln No/2 \times 1/No = -\lambda t½$ $\ln ½ = -\lambda ½$ $\ln 2 = \lambda t½$ $t½ = \ln 2\lambda y = 0.693/\lambda$

The half- life or rate of decay of a radioisotope is independent of temperature and all other factors. In practical work N is not directly evaluated and dN/dt is not usually measured. The usual procedure is to determine a quantity proportional to λN. This quantity is referred is as the ACTIVITY, A (cpm).

$A \propto \lambda N$ $A = C\lambda N$

Where C = detection coefficient and is dependent on the nature of the detection instrument such as Geiger. Muller counter.

The decay equation using activities is given by

$A = A_o e^{-\lambda t}$

The usual procedure for determining the decay constant is to obtain the values of activity at successive time t.

$A = A_o e^{-\lambda t}$

$\ln A = \ln A_o - \lambda t$

$\log A = \log A_o - \lambda t/2.303$

A plot of log A against t would give a slope of $\lambda/2.303$ and an intercept of $\log A_o$

However, a plot of activity of any given radioisotope remaining after a specific time yields a decay curve as shown

Sometimes a different shape of decay curve is given by a radioactive sample. This can only happen when one of the decay products is also radioactive. This is in fact a common situation. For example U^{238} is an $\propto$-emitter with a $t_{½} = 4.51 \times 10^9$ yrs. The daughter is Thorium ($_{90}Th^{234}$) which is a β emitter with a $t_{½} = 2.41$ days. The parent uranium can be separated from the daughter atoms by precipitation of the daughter with excess ammonium carbonate

Problem

1. 0.200g of polonium ($^{210}_{84}Po$) half –life 138.4 days is kept in a vessel. How much of it will remain after 21.0days. (Ans = 0.184g)
2. How much time must pass for 0.90g of a sample of actinium ($_{89}^{227}Ac$) to disintegrate $t_{½} = 21.6$yrs (Ans = 3.28yr)
3. What is the $t_{½}$ of an isotope if a sample of it gives 10,000 cpm and 3.50 hrs later it gives 8335 cpm. (Ans = 13.3hrs)
4. How much of a 1.00g sample of $^{238}_{92}U$ will disintegrate in a period of 10yrs. $t_{½} = 4.51 \times 10^9$ yrs (Ans $=1.54 \times 10^{-9}$g)

1. $t_{½} = \ln 2/\lambda = 0.693/\lambda \qquad 138.4 = 0.693/\lambda, \qquad \lambda = 0.693/138.4$

   $N = Noe^{-\lambda t} \qquad \ln N = \ln No - \lambda t \qquad \ln N/No = -\lambda t$

   $\log N/No = -\lambda t/2.303 = -0.693 \times 21 / 138.4 / 2.303$

   $N = 0.184$

UNITS OF RADIOACTIVITY

The familiar unit is the curie. This is the quantity of any radioactive nuclei in which the number of disintegration per second in 3.7×10^{10} mc.

Calculate the mass in gram of 1.00mc of ^{14}C from its t½ of 5720 yrs.

(1mc = $1.x\ 10^{-3}$ Ci, Ci = 3.7×10^{7} disintegrations/s)

t½ = In2/λ λ = In/t½ = 0.6930/5720yr = 0.693/5720 x365x24x3600 = 3.84×10^{-12} Sec^{-1}

dN/dt= λN

N = 3.7×10^{7}/ 3.8418×10^{-12} = 0.9631×10^{19} atoms

6.02×10^{23} = 14g of ^{14}C

0.96309 x19 = 14 x 0.96309 x 10^{19}/ 6.02 $x10^{23}$ = 2.24 $x10^{-4}$g

TYPE OF EQUILIBRUM IN RADIOACTIVE GROWTH

Suppose we have a parent giving rise to a daughter which is also radioactive giving rise to another daughter,

Parent ==➔ daughter ====>daughter

N_1 N_2

At any time t, the rate of change of the number of N_2 atoms is rep. By

$dN_2/dt = \lambda_1 N_1 - \lambda_2 N_2$

Bringing all the terms to the L.H.S.

$dN_2/dt + \lambda 2\ N2 - \lambda, N_1 = 0$

Substitute $N_1 = N_1^0 e^{-\lambda t} = 0$

:- $dN_2/dt + \lambda_2 N_2 - \lambda_1 N_1^0 e^{-\lambda t} = 0$

Solving the equation gives

$N_2 = \lambda_1/\lambda_2 - \lambda_1 N_1^0 (e^{-\lambda it} - e^{-\lambda 2t}) + N_2^0 e^{-\lambda 2t}$

Where N_2^O is the value of N_2 at time t = 0

The 1st term in the bracket ($e^{-\lambda it} - e^{-\lambda 2t}$) represents the growth of daughter from the parent and the decay of the daughter atoms. The last term $N_2^0 e - \lambda_2 t$ represents the contribution at any time from daughter atoms present initially.

There are three solutions to the equation above in each of which we take $N_2^0 = 0$. (or Three equilibrium can be obtained from the equation above

1. **Transient equilibrium**

A_T= Total activity of both parent and daughter

a = total activity of an initially pure parent fraction

b =activity due to parent above (i.e not taking into consideration activity due to daughter)

c = decay of freshly isolated daughter fraction

d = daughter activity growing in a freshly purified parent fraction

e = Total daughter activity in parent + daughter fraction

Transient equilibrium occur when $\lambda_1 < \lambda_2$ i.e the daughter has a shorter t½ and the parent is longer lived. When this system of parent daughter mixture is left for sometime, a radioactive equilibrium is reached and what happen is that $e^{-\lambda 2t}$ approaches 0. Also $N^0{}_2 e\text{-}\lambda_2 t$ ===>0, so that the equation $N_2=\lambda_1/\lambda_2\ N_1^0\ (e^{-\lambda 1t} - e^{-\lambda 2t}) + N_2^0 e^{-\lambda 2t}$ becomes $N_2 = \lambda_1/\lambda_2 - \lambda_1 \times N_1^0 e^{-\lambda 1t}$

$= \lambda_1/\lambda_2 - \lambda_1 \times N_1$

:- $N_1/N_2 = \lambda_2 - \lambda_1/\lambda_1$

The ratio N_1/N_2 is now made up of constant values λ_1, & λ_2 and it therefore becomes constant. If this calculation is made in terms of activity then $A_1/A_2= C_2(\lambda_2 - \lambda_1)/C_1\lambda_1$

Where C_1, C_2 are detection co-efficient of the instrument being used to detect the activity

2. **Secular Equilibrium**

= total activity of an initially pure parent fraction

(a) = activity due to parent. This is also the total daughter activity in parent + daughter fractions

(b) Decay of freshly isolated daughter

(c) Daughter activity growing in a freshly purified parent fraction

Secular equilibrium is obtained in the system where $\lambda_1 << \lambda_2$. In this case the parent activity does not decrease measurably during many daughter half life when such a system is left for some time. This is because $e^{-\lambda t} \rightarrow 0$ also $N_2^0 \, e^{-\lambda 2t}$ ===>O, because $\lambda_1 << \lambda_2$

Then $\lambda_2 - \lambda_1 \approx \lambda_2$

:-$N_2 = \lambda_1/\lambda_2 \, N_1^0 e^{-\lambda 1t} = \lambda_1/\lambda_2 \, N_1$

:- $N_1/N_2 = \lambda_2/\lambda_1$ or $\lambda_1 N_1 = \lambda_2 N_2$

Since N_1/N_2 now depend on constant values ie. $\lambda_1 \propto \lambda_2$ then the situation is referred to as equilibrium

3. No equilibrium state

N_1/N_2 is never a constant throughout the life time of the system. This situation is obtained when $\lambda_1 > \lambda_2$ ie. When the parent has a shorter life than the daughter.

NUCLEAR FISSION AND FUSION

Nuclear fission

This occur when the unclean of a very heavy isotope such as ^{235}U,^{233}U or plutonium 239 splits to form one or more smaller, more stable nuclei by a particle such as neutron with the release of a large quantity of energy. The source of energy is the conversion of a tiny amount of mass into energy. This energy changes are tremendous many million times greater than the energy produced by chemical reactions e.g.

$^{235}_{92}U + {}^{1}_{0}n$ ====> $^{89}_{36}Kr + {}^{144}_{56}Ba + 3{}^{1}_{0}n$.

During this process there is a slight loss in mass i.e the total mass of the product is slightly less than the total mass of the reactants. The lost mass is converted into energy. The extra neutron given out during the fission of uranium atom might cause further fissions in neighbouring atoms, with the production of still more neutrons, all capable of causing fission. If this process were to continue, the fission process would accelerate rapidly and a self- sustaining or chain reaction would result which releases enormous amount of energy. A chain reaction cannot occur in natural uranium because very few of the neutron which are given our can cause further fission.

Nuclear fusion

Nuclear fusion involves using extremely high temperature(10million – 100million ^{0}C) to join or fuse two nuclei of light atoms (such as hydrogen) into a heavier nucleus (such as helium Li) with the release of enormous amount of energy. Because of the high temperature needed, fusion is more difficult to initiate than fission. Fusion is the source of energy for the sun and other stars.

At present the two most attractive fusion reactions for a nuclear fusion reaction are:

1. The deuterium – deuterium or D – D reaction, in which two deuterium (H – 2) nuclei fuse to form a helium 3 nucleus.

   $^{2}_{1}H + {}^{2}_{1}H =====> {}^{3}_{2}He + {}^{1}_{0}n$ + energy.

2. The deuterium – tritium or D – T reaction, in which a deuterium (^{2}H) nucleus and a tritium (^{3}H) nucleus fuse to form a ^{4}He.

   $^{2}_{1}H + {}^{3}_{1}H ====> {}^{4}_{2}He + {}^{1}_{0}n$ + energy.

Nuclear Reactors

Principle: a more constructive use of nuclear fission in the nuclear reactor which uses nuclear energy to produce electricity. One of the earliest type of reactors consists of huge cyclinder of graphite into which were inserted fuel rods of natural uranium and control rods of boron steel.

The graphite acts as a moderator i.e it cuts down the speed of the neutron escaping after the fission of a $^{235}_{92}U$ nucleus to such an extent that most of them are able to produce fission in other $^{235}_{92}U$ nuclei. The boron steel rods are used to control the reaction and prevent it getting out of hand. Boron is able to absorb neutrons and so prevent them producing further fissions. The rods moved in or out of the reactor until a balance is obtained in which each fission produces, on average, just one neutron capable of causing a further fission, and thus a controlled chain reaction takes place.

The energy is released inside the reactor in the form of heat, and this is removed by a coolant such as carbon dioxide gas, which is forced through ducts in the pile. The hot gas changes water into steam in a heat exchange at some distance from the pile, and this steam is used to drive electricity generators as in a conventional power station.

Types of nuclear reactions

1. Advance gas cooled reactor (AGR): this is similar to the first nuclear power station used in Britain (magnox station) but the fuel is enriched and encased in

stainless steel tubes. The enriched fuel contain a greater proportion of $^{235}_{92}U$ than occurs in natural uranium. These reactor operate at higher temperature and have increased power output than magnox stations.

2. Breeder reactors (or fast reactor): developed to overcome the potential shortage of uranium fuel for non conventional nuclear fission reactor. Breeder reactors use a mixture of abundant, non fissionable ^{238}U and fissionable plutonium -239 (^{239}Pu) that has been extracted and purified from conventional reactor wastes. Under bombardment with fast neurons, ^{239}Pu undergoes fission and ^{238}U is converted to fissionable plutonium -239, thus breeding additional fissionable fuel in the reactor. The net result is a hundred –fold multiplication of usable uranium reserve since the presently useless ^{238}U would be converted to a fissionable isotope.

   Step 1: $^{238}_{92}U + ^{1}_{0}n ====> ^{239}_{92}U$

   Step2: $^{239}_{92}U ====> ^{0}_{-1}\beta + ^{239}_{93}Np$

   Step3: $^{239}_{93}Np =====> ^{0}_{-1}\beta + ^{239}_{94}Pu$

   The fast reactors produces excess plutonium because the core is surrounded by a blanket of uranium, which is mostly the $^{238}_{92}U$ nuclide. This acts as a kind of moderator in that it absorbs neutrons and in to doing $^{238}_{92}U$ is converted into plutonium at a rate faster than the fuel is consumed. The fast quantities of heat produced in these reactors is removed by liquid sodium (which is pumped around the core) and then transferred to steam generators in the usual way.

   In summary all the various reactors in current use have essentially the same parts: the fuel, some form of moderator, control rods and a coolant. They may also have a neutron reflector (graphite casing) and the whole system in enclosed in a thick protective shield of concrete and lead or steel.

APPLICATION OF RADIOISOTOPES.

Radioactive clocks or dating

Soon after the discovery of radioactivity it was realized that radioactive decay constitute a clock by nature. Until this discovery geologists had no reliable absolute time scale for the geologic ages. The new knowledge about radioactive decay, the naturally occurring decay series and the identity of $\propto$- particles resulted in the first objective methods of geological dating.

Rutherford was the first that to suggest that $\propto$-decay must lead to the build up of the helium in uranium minerals and that the helium content of an uranium mineral could be

used to determine the time elapsed since its solidification. He applied this method to the study of some minerals ages. Shortly afterwards, the realization that Pb was the end product of U decay lead to a study of the Pb content of U minerals.

Discussed below are the various method for radioactive dating and as would be see none of these methods is free from difficulty and the greatest reliance can therefore be placed on those ages that are determined by two or more independent techniques.

1. Ratio of U to the content – once an atom of U^{238} disintegrates, the chain of successive decays produce 8 ∝- particles. Because the range of these particles are very short in dense matter most of the resulting helium atoms can be trapped in the interior of the rocks. Actually ∝-particles are helium ions but they readily acquire electrons by oxidising almost any substance and get converted into helium atoms. In cases when the rocks are impervious and where the helium content is low, the helium gas produced during decay is retained through the geological ages and now serve as an indicator of the fraction of U transformed since the formation of the ore. Although this method was the first dating one based on radioactive decay, its application as a reliable technique is limited because of the possibility of helium leakage during geological times. In general the U – He ages can be considered as lower limits only. Also this method is not applicable to extra terrestrial bodies.

A problem to illustrate the application of this method is as follows:

A 0.500g sample of Radium ($^{226}_{88}Ra$) in sealed into a very thin walled tube so that the ∝-particles emitted from the Ra and its decay product can penetrate and be collected in an evacuated volume of 25.0ml. what helium pressure at 20.0^0C would be built up in 100yrs $t_{1/2}$ of $_{226}{}^{88}Ra = 1.60 \times 10^3$yrs.

5 ∝-particles are produced as Ra disintegration to a stable isotope of Pb.

$_{88}Ra^{226}$ =====>$5^4_2He + {}^{206}_{78}Pb.$, $t_{½}$ of $_{88}Ra^{226} = 1.60 \times 10^3$yr $t_{½} = 0.693/\lambda$

- $\lambda = 0.693/t_{1/2} = 0.693/1.60 \times 10^3 = 4.331 \times 10^{-4}\ yr^{-1}$

We know that, $N = Noe^{-\lambda t}$ No = 0.5g, t = 100yrs. $N= 0.5\ e^{-4.331} \times 10^{-4} \times 100yrs = 0.5 \times 0.9576$ 0.4788g.

Change in number of atom ; $N = N_0 – N = 0.5 – 04788$ =0.0212g.

From the equation of rxn, 1mole Ra ≈ 5mole He. 0.0212/226 mole Ra = 5/1 x 0.0212/225 mole He

= 4.68×10^{-4} mole He At stp 1mole of any gas occupies $22.4dm^3$

:- 4.69×10^{-4} mole He will occupy $22.4/1 \times 4.69 \times 10^{-4} dm^3$ = $0.00105056\ dm^3$ = $10.51cm^3$.

Using $P_1V_1/T_1 = P_2V_2/T_2$ P_2 = pressure at stp = 760mmHg V_2 = vol. at stp = $10.51cm^3$.

T_2 = temperature at stp = 273k. P_1 = pressure of the built up at 20^0C

$V_1 = 25cm^3$, $T_1 = 20^0C = 288k$.

$P_1 = P_2V_2T_1/V_1T_2 = 760 \times 10.51 \times 298/23 \times 273 = 348.43mmHg$

Or PV = n RT when R= 0.0821 lit. Atm. Mol^{-1} V = 25×10^{-3} lit T = 298k n = 4.69×10^{-4} mol

P = nRT/V = $4.69 \times 10^{-4} \times 0.0821 \times 298/25 \times 10^{-3}$ = o.458978atms or x760 =348.82mmHg

Thus when determing age by this method, the helium gas trapped in the rock is collected and the pressure, volume, temperature values are obtained. From these can be obtained the volume at STP and from which the mass of the radioactive sample possibly uranium can be obtained. From the mass of helium trapped in the rock, the mass of U decayed can be calculated.

Radiocarbon dating

This method use radioactive carbon -14 to determine the age of plants, wood , teeth, bone fossils and other carbon containing substances from plants or animals. The method utilizes two major assumptions:

(i) ^{14}C has been formed and continues to be formed at a constant rate in the upper atmosphere due to cosmic-ray bombardment of nitrogen.

(ii) The ^{14}C is absorbed into all organic matter in the form of $^{14}CO_2$. The rate of absorption is a constant while the organism is alive, but drops to zero when it dies.

Carbon -14 is produced in the atmosphere when cosmic ray neutrons strike nitrogen nuclei

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

The $^{14}_{6}C$ is the converted chemically by reaction with oxygen to $^{14}_{6}CO_2$, which is then incorporated into plants and animals through the processes of photosynthesis and respiration in the carbon cycle. As long as a plant or animal is alive its ^{14}C constant should reach and maintain a relatively constant steady state level. But after death the ^{14}C uptake stops, and the ^{14}C originally incorporated in the organism decays and decreases.

The half-life of ^{14}C is 5730yrs; after that length of time the original ^{14}C content has decreased by one-half. Thus, measuring the remaining ^{14}C content provides an estimate of the age of an object.

$\ln [No/Nt] = \lambda t$ where Nt = remaining carbon content

No = initial carbon content

$\lambda = \ln 2/t_{1/2} = 0.693/t_{1/2}$. t = age of the object

The method in limited to objects less than approx. 50,000yrs old because it is difficult to measure the very small amount of ^{14}C present in items older than this (i.e limited by the lower limit of detectable ^{14}C activity).

A problem to illustrate this method of dating is given below:

Libby & colleagues have found that a very small amount of the CO_2 in the air is radioactive. This is as a result of continuous bombardment of N_2 in the upper atom by neutrons of cosmic origin. This radioactive ^{14}C is uniformly distributed among all forms of C that are in equilibrium with the atmosphere and it is found to show 15.3 cpm per g of C. When plant dies, they no longer remain in equilibrium with the air and the C slowly lose its activity. Cyprus wood from an ancient Egyptian tomb has an activity of 6.88cpm per g of C. Estimate the age of this wood and presumably the age of the tomb $t_{1/2}$ of $^{14}_{6}C = 5.73 \times 10^3$yrs .

Solution

$\log No/N = \lambda t/2.303$

$t = 2.303/\lambda \log No/N$

No = 15.3cpm N = 6.88cpm.

$\log No/N = \log 15.3/6.88 = 0.3471$

$\lambda = 0.693/t_{1/2} = 0.693/5.73 \times 10^3\ yr^{-1}$

$= 1.2094 \times 10^{-4}\ yr^{-1}$.

:- $t = 2.303 \times 0.3471 / 1.2094 \times 10^{-4}$ yr

$= 6609.65$yr or 6.60×10^3yrs

U-Pb, Th – Pb method:- the lead isotope: ^{206}Pb and ^{208}Pb are the stable end product of ^{238}U and ^{232}Th decay respectively.

Provided there is no other source of Pb in an U or Th mineral the amount of these Pb isotope present may be used as quantitative indicator for the amount of U and Th decays that has taken place. Since Pb is not likely to escape like helium, this method might be expected to show greater reliability than the He method. However the pb – U or Pb – Th ratio may be changed by leaching or other processes. The distinction between ^{206}Pb and ^{208}Pb is made satisfactory by mass spectrographic analysis. Age determination ranging up to 3×10^9yrs have been found by these methods. The presence of any non-radiogenic Pb i.e ^{204}Pb is corrected for.

^{206}Pb – ^{207}Pb ratio method –

^{206}Pb is uranium - lead and ^{207}Pb is actinium –lead. This method is used for very old rocks containing uranium. This method is less sensitive to chemical or mechanical loss of either U or Pb than the proceeding method (ie 3rd method). However the Ra species produced in each decay chain have very different half-lives and thus the results obtained are affected by Ra leakage

$^{238}U \Longrightarrow {}^{206}Pb$

$^{235}Ac \Longrightarrow {}^{207}Pb.$

Presence of Ra introduces an error in the results. It is essential that the rocks or minerals are freed of appreciable amount of non-radiogenic Pb.

Ages of about 2.6×10^9yrs have been found by this method for samples of uranite and monazites from several formations.

Once the ^{206}Pb – ^{207}Pb ratio is determined then the age of the sample can be read from the graph

Potassium – Argon dating –

Potassium in the form of ^{40}K is found in living organisms. After death it is converted to the stable isotope ^{40}Ar, which has a half-life of 1.3 billion years. This conversion process, known as K- capture, occurs when ^{40}K absorb one of its own inner electrons into its nucleus.

$$^{40}_{19}K + {}^{0}_{-1}e \Longrightarrow {}^{40}_{18}Ar.$$

The age of any potassium - containing mineral or other substance can then be determined by measuring the ratio of ^{40}Ar: ^{40}K.

This dating method extends the age determination range up to about 1 million yrs and is very useful in dating young to intermediate age samples.

RADIOACTIVE TRACERS OR ISOTOPE TRACERS

Radioisotope also have impt applications as tracers in medicine , pollute detection , agriculture, industry and for the study of impt. Chemical and biochemical reaction mechanism. If a small quantity of a radioactive element or compound is mixed with a nonradioactive form of the same substance then the movement or behaviour of the whole mass can be followed with some from of radiation detector e.g. Gerger counter or other types of radiations detector. Radioisotopes which are used for this purpose are called tracers. They can be detected in extremely small conceratation and they are indistinguishable but easily detected because of their radioactivity. A no of common examples are given below.

A definite limitation of the radioactive tracer method is the absence of known active isotope of suitable $t_{1/2}$ for a few elements especially O_2 and N_2.

^{14}O has a $t_{1/2}$ of 72secs.

^{15}O " " 118secs.

^{19}O " " 29secs.

^{16}N " " 9secs.

^{17}N " "4secs.

These isotopes are useless as tracers. However some use has been found for the 10min ^{13}N which shows β^+ activity Ne ,He, Li and B isotopes with $t_{1/2}$ > 1sec are available.

Deuterium has found many applications as aH tracer. The use of Tritium $^{3}_{1}H$ is not entirely equivalent as a tracer because its properties are much different from those hydrogen.

Application of Tracers

Physical applications:

Self- diffusion in metal e.g lead –

In this experiment radioactive Pb is diffusing into non – radioactive Pb. The set-up is as shown in the diagram. Radioactive Pb^{212} is pressed into contact with a thin foil of

inactive Pb. This foil of inactive Pb must be thick enough to stop all the ∝-particles (being given by the radioactive Pb).

A detection instrument placed as shown would not give any reading. However after sometime, some values are given on the detection instrument. This is because the radioactive Pb has diffused into the non-radioactive Pb and the thickness of the non-radioactive Pb is not enough to stop all the ∝-rays as diffusion progress. The ∝ activity is found to increase as recorded by the detection instrument.

Leakages in pipes –

Leak in hidden pipelines may be located by mixing a radio isotope with the material being transported and monitoring the surface for radioactivity .

Medicine –

Tracers are used in medicine for diagnosis and treatment. ^{24}Na, injected into the bloodstream as a salt solution can be monitored to trace the flow of blood and detect possible constrictons or obstructions in the circulatory system. Iodine -131 can be used to trace a number of bodily activities including liver activity, brain tumours and possible cancer or malfunction of thyroid gland. When the thyroid gland is functioning properly it rapidly removes iodine from the blood stream.

A malfunctioning thyroid can be detected by giving the patient a drink of water containing a known amount of iodine -131 and measuring the radioactivity just above the thyroid to see if the iodine in absorbed at the normal rate.

Biological processes –

The rate of uptake of radioactive materials in the organism is a measure of the rate of the actual process $^{32}_{15}P$ has been used in fertilizers and information about the respiration of plants has been obtained by using $^{14}_{6}CO_2$.

Chemical Applications -

The exchange reaction between isopropyl iodide and iodide ions -

$$C_3H_7I_B + I^-_A \longleftrightarrow C_3H_7I_A + I^-_B.$$

In order to ascertain if this exchange reaction actually occurs, it is possible to use radioactive tracers. Radioactive iodide ions are used i.e IA is made radioactive and then added unto isopropyl iodide. After a sufficient interval of time the isopropyl lodide is tested for radioactivity. If there is an appreciable amount of radioactive atoms in the isopropyl iodide then it means that the exchange reaction actually occurs. If there is an

extremely small amount of radioactivity in the isopropyl iodide, then the exchange does not occur.

Reaction mechanisms –

Radioactive tracers can be used to study the fate of a particular atom in a chemical reaction e.g Fumaric acid in the presence of acidified $KMnO_4$ would give two molecules each of CO_2 and formic acid respectively.

$$HOOC.\ CH:\ CHCOOH \xrightarrow[H^+]{KmnO_4} 2CO_2 + 2HCHOOH.$$

It is required to investigate if the formic acid is formed from any of the fumaric c atoms. In order to do this fumaric acid is synthesized using radioactive "C in the formation of carboxylic group .

$$HOO^{11}C.^{12}CH:\ ^{12}CH.^{11}COOA \Longrightarrow 2^{11}CO_2 + 2H^{12}CHOOH$$

The products CO_2 and HCHOOH are tested for radioactivity. It was found that the CO_2 was radioactive but the formic acid was not. This implies that the radioactive C is not involved in the formation of formic acid. i.e carboxylic carbon atoms.

Reaction pathways or mechanism –

The most obvious method by which tracers can be applied to reaction mechanism studies is by labelling one of the atoms in the reactant so that its fate may be determined in the products. There are two general types of application. Firstly , the movement of two differently bound atoms of the same element may be followed, as in the formation of an ester from an ^{18}O- labelled alcohol. Thus, when methyl benzoate is formed from $CH_3{}^{18}OH$ and benzoic acid of normal isotopic abundance, the resulting water does not contain any ^{18}O, thus showing that the $C_6H_5CO - OH$ bond of the acid is broken in the reaction rather than the $CH_3 - OH$ bond of the alcohol.

$$C_6H_5CO - OH + CH_3 - {}^{18}OH \Longrightarrow C_6H_5C \qquad + H - OH$$

Also when labelled water reacts with the ester ethyl ethamoate, it is found that the ethanoic acid is labelled and not the ethanol .

$$H - {}^{18}OH + COC_2H_5 \Longrightarrow H - O - C_2H_5 + CH_3 - C.$$