NATIONAL OPEN UNIVERSITY OF NIGERIA

COURSE CODE: CHM 406

COURSE TITLE: NUCLEAR AND RADIOCHEMISTRY

CHM 406: NUCLEAR AND RADIOCHEMISTRY

MODULE 1 FUNDAMENTAL CONCEPT OF RADIOACTIVITY

Unit 1: Natural Radioactivity

1.0 Introduction.

Radioactivity is a phenomenon in which some elements emit small particles called radiation ns to form another element. This is in contrast to the accepted Dalton postulate of indestructibility of an atom. However, only elements with unstable nuclei known as radioactive are capable of undergoing natural radioactivity while stable nuclei do not. All elements having atomic number greater than 83 are radioactive and they undergo nuclear transmutation (Nuclear reaction) which differ significantly from ordinary chemical reactions.

The knowledge of radioactivity has contributed immensely to medicine, archeology, scientific research, industry, engineering and agriculture.

2.0 Objectives.

By the end of this unit, you should be able to:

(a) Define radioactivity and some other terms

(b) Know types of radioactivity

(c) Know types of electromagnetic radiations that are emitted

(d) Differentiate between ordinary chemical reactions and nuclear reactions.

3.0 Radioactive: Natural and Artificial

With exception of hydrogen ($^1H_1$), every atomic element has a nucleus which consists of neutrons and protons, with electrons occupying important empty space around the nucleus. Nucleus is a minute fraction of total volume of atom, yet nearly all the mass of an atom resides in the nucleus. Thus, nuclei are extremely dense. It has been shown experimentally that nuclei of all elements have approximately the same density of 2.4 x 10^{14} g/cm^3.Table 1.0 shows the general properties of basic components of an element

Table 1.0 : Basic constituents of an atomic element

Particle	**Mass**	**Charge**
Electron (e^-)	0.00054858 amu	-1
Proton (P)	1.0073 amu	+1
Neutron (n)	1.0087 amu	None

The number of Neutron to proton to any nucleus confirms the stability of the nucleus as thereby influence nuclear reaction is called neutron – proton ratio.

The neutron – proton ratio of an element dictates which it (element) will naturally undergoes radioactivity or not.

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3.1 Neutron - proton ratio and nuclear stability

The principal factors that determine stability of nucleus is stable is the neutron – proton ration (n/p). About 275 different nuclei have no evidence of radioactive decay, hence they are very stable. 157 nuclides out of it have even number of proton and even number of Neutron (even – even nuclei), 52 nuclides have even number of proton and odd number Neutron. 50 nuclides have odd number of protons and even number of neutron while only four nuclides have odd number of both proton and neutrons. These are presented in Table 2.0

Table 2.0: Abundance of naturally occurring nuclides

Number of particles	Even/ Odd	Even/ Odd	Even/ Odd	Even/ Odd
Number of protons	Even	Even	Odd	Odd
Number of neutrons	Even	Odd	Even	Odd
Number of such nuclides	157	50	52	4

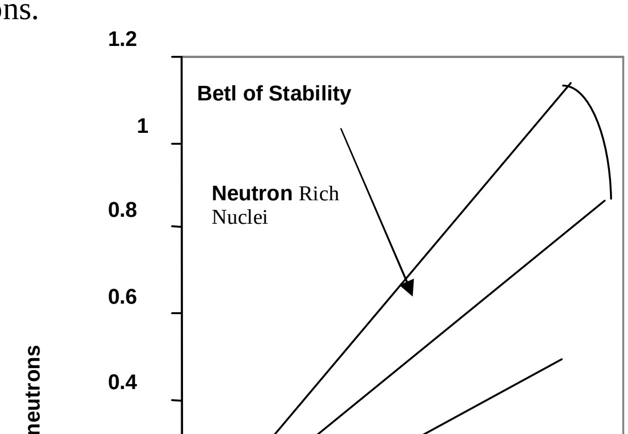
The following are lists of rules that guide the prediction of nuclear stability

(i) Nuclides with “Magic number” (2, 8, 20, 28, 50, 126) of protons or a number of neutrons or a sum of the two have unusual stability

(ii) Nuclei with even number of both protons and neutrons are generally more stable than those with odd numbers of these particles (Table 2.0).

(iii) All isotopes of the elements with atomic numbers higher than 83 are radioactive.

Figure 1.0 is a plot of the number of neutrons (*N*) versus number of protons (*Z*) for the stable nuclides (**the band of stability**). For low atomic numbers, the most stable nuclides have equal numbers of protons and neutrons (*N* _ *Z*). Above atomic number 20, the most stable nuclides have more neutrons than protons. Careful examination reveals an approximately stepwise shape to the plot due to the stability of nuclides with even numbers of nucleons.



Nuclei whose neutron – to-proton rations lie outside the stable region undergoes spontaneous radioactive decay by emitting one or more particles or electromagnetic rays or both. Depending on whether the nucleus is above, below or to the right of the band of stability (Fig 1.0), it emits various types of particles summarized on Table 1.0 in a nuclear reaction. Note that in a nuclear reaction, changes of one particle to another occur in a pattern that shows that nuclear reaction differs from ordinary chemical reaction as summarized in Table 3.0.

Table 3.0: Comparison of Chemical Reactions and Nuclear Reactions

	Chemical Reactions	**Nuclear Reactions**
1	Atoms are rearranged by the breaking and forming of chemical bonds.	Elements (or isotopes of the same elements) are converted from one to another.
2	Only electrons in atomic or molecular orbital are involved in the breaking and forming of bonds.	Protons, neutrons, electrons, and other elementary particles may be involved.
3	Reactions are accompanied by absorption or release of relatively small amounts of energy.	Reactions are accompanied by absorption or release of tremendous amounts of energy.
4	Rates of reaction are influenced	Rates of reaction normally are not

by temperature, pressure, concentration, and catalysts.	affected by temperature, pressure, and catalysts.

Both reactions are depicted by a complete chemical equation. However two major rules guide writing chemical equation of nuclear reaction.

(i) The sum of the mass numbers of the reactants must be equal the sum of mass number of the products

(ii) The sum of atomic number of the reactions must be equal to the atomic number of the products, this maintain charge balance.

3.2 Particles emission and position of stable region.

Some nuclei are unstable, hence they emit sub atomic particles or electromagnetic radiation in a phenomenon called radioactivity. Radioactivity can be of two types namely natural and artificial radioactivity.

(i) **Natural Radioactivity**: This is a type of radioactivity that occurs spontaneously, emitting electromagnetic radiations and particles which include beta, position and alpha particle. This type of decay or emission occurs, depending on the position of nuclei whether above, below or sides of the **stability / belt region**. Most radioactive nuclei lie outside this belt.

3.2.1 Above the band of stability: Neutron–rich region.

The nuclei in this region have too high ratio of neutron to protons then those within the belt to reduce this ration and more down toward the belt of stability, the undergo a nuclear reaction called Beta particle emission. A beta particle is an electron ejected from the nucleus when a neutron is converted into a proton

$$ {}^{1}_{o}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta $$

Beta particle emission leads to an increase in the number of proton in the nucleus and a simultaneous decrease in the number of neutrons .

Classical examples:

i $\quad {}^{228}_{38}Ra \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}\beta$

ii $\quad {}^{97}_{40}Zr \rightarrow {}^{97}_{41}Nb + {}^{0}_{-1}\beta$

iii $\quad {}^{40}_{19}K \rightarrow {}^{40}_{20}Ca + {}^{0}_{-1}\beta$

3.2.2. Below the band of stability: Neutron–poor region

The nuclei here have lower neutron – to – proton ratios that those within the belt therefore to increase this ratio and thereafter move up toward the belt of stability, the nuclei undergo possible two type of nuclear reaction; position emission or electron capture (K capture).

(a) Position emission is most commonly encounters with artificially radioactive nuclei of the higher element.

Classical example

i $\quad {}^{i}_{i}P \rightarrow {}^{1}_{0}n + {}^{0}_{+}\beta$

ii $\quad {}^{38}_{19}K \rightarrow {}^{38}_{18}Ar + {}^{0}_{+1}\beta$

(b) **Electron captures (K capture):** Is a capture of an electron usually a 1s electron by the nucleus. The captured electron combines with a proton to form a neutron so that the atomic number decreases by one while the mass number remain the same, hence the same net effect as position emission.

Classical example:

$$^{37}_{18}Ar \quad \rightarrow \quad ^{0}_{-1}e \quad + \quad ^{37}_{17}Cl$$

$$^{106}_{47}Ar \quad \rightarrow \quad ^{0}_{-1}e \quad + \quad ^{106}_{26}Pd$$

It is important to note that some of the neutron – poor nuclei, particularly the heavier ones, increase their neutron-to-proton ratios by undergoing alpha emission

3.2.3 Nuclei with Atomic Number greater than 83

All element with atomic number higher than 83 are radioactive in nature. They undergo a nuclear reaction by emitting alpha particles ($\propto$)

Classical example

$$^{226}_{88}Ra \quad \rightarrow \quad ^{222}_{84}e \quad + \quad ^{4}_{2}\propto$$

$$^{210}_{84}Po \quad \rightarrow \quad ^{201}_{84}Pb \quad + \quad ^{4}_{2}\propto$$

3.2.4 **Gamma ray emission**

Gamma rays are high energy radiation, emitted when an unstable nucleus undergoes a rearrangement of its constituent particle to give more stable, lower energy nucleus. Gamma rays are often emitted along with other type of subatomic particles.

$$^{99}_{43}Tc \quad \rightarrow \quad ^{99}_{43}Tc \quad + \quad ^{0}_{0}\gamma$$

Note that pure gamma emitter are rare, but rather , the radiation gamma accompany either alpha or beta radiation.

(ii) **Artificial radioactivity:** It is a non-spontaneous form of radioactivity which requires effect of bombardment of the nuclei with sub atomic particles. It is otherwise known as anthropogenic or induced radioactivity.

Juliot and his wife, Irrene Curie discovered artificial radioactivity in 1934 in which aluminum nuclei is bombarded with He nuclei to form new element with emission of electromagnetic ray or particles

$$^{4}_{2}He \quad + \quad ^{27}Al \quad \rightarrow \quad ^{30}P \ +^{1}_{1} n$$

4.0 Conclusion

Radioactivity is indeed a phenomenon in which electromagnetic radiation or sub atomic particles are emitted by a nuclear reaction so as to achieve or enter stability belt. Radioactivity is of importance to medicine, agriculture and industries.

Self Assessment Exercise

(i) What do you understand by the term radioactivity

(ii) Explain the concept of neutron –to-proton ration

(iii) What are subatomic particles that are emitted in nuclear reaction

(iv) Differentiation between natural and induced radioactivity.

5.0 Summary

In this unit we must have learnt

(i) What radioactivity means

(ii) About differences between nuclear and ordinary chemical reaction

(iii) About how to the balance nuclear reaction

(iv) About to rules that guide in predicting stability of a nucleus

(v) About various forms of emission nuclei can undergoes during nuclear reaction

(vi) Differences between natural and artificial radioativity

6.0 Tutor marked assignment

i. Differentiate between nuclear and ordinary chemical reaction

ii. Naturally occurring iodine is iodine – 127. Medically radioactive isotope of iodine – 125 and iodine 130 are used. Write atomic symbol for each isotope.

iii. Identify the symbol X in each of the following:

(a) ${}^{0}_{-1}X$ (b) ${}^{4}_{2}X$ (c) ${}^{1}_{0}X$ [d] ${}^{1}_{1}X$ (e) ${}^{0}_{+1}X$

(iv) Write short notes on various sub atomic particle that can be emitted by nuclei in the following condition so as to enter stability belt

(a) Above the stability region

(b) Below the stability region

7.0 Further reading and Other Resources

1. K. Timberlake and W. Timberlaka (2008). Basic Chemistry. Pearson Educational Inc. Boston. Pp 524 – 538

2. G. R. Choppin, J. Liljenzen and J. Rydbers (2002). Radiochemistry and Nuclear Chemistry. Butterworth- Heinemann, Woburn. Pp 1 – 10.

3. J. May (1989). The Greepeace Book of Nuclear age. Victor Golanoz Ltd. London.

MODULE 1 FUNDAMENTAL CONCEPT OF RADIOACTIVITY

Unit 2: Radioactive decay processes and nature of radioactivity

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1.0 Introduction.

Radioactive decay is the process by which an atomic nucleus of an unstable atom loses energy by emitting ionizing particles or electromagnetic radiation. The emission is spontaneous, in that the atom decays without any physical interaction with another particle from outside the atom. Usually, radioactive decay happens due to a process confined to the nucleus of the unstable atom. Many nuclei are radioactive. This means they are unstable, and will eventually decay by emitting a particle, transforming the nucleus into another nucleus, or into a lower energy state. A chain of decays takes place until a stable nucleus is reached.

2.0 Objectives

By the end of this unit, we should be able to

i. understand the meaning of radioactive decay.

ii describe what decay mode and energy are

iii tell what is meant by fission and fusion

iv calculate the half life of any disintegration

3.0 Radioactive decay.

Radioactive decay can simply be defined as a spontaneous nuclear transmutation or transformation of unstable nuclei that exist outside in the formation of stable isotope. The decay process is unaffected by pressure temperature, chemical forms. The decay, or loss of energy, results when an atom with one type of nucleus, called the *parent radionuclide*, transforms to an atom with a nucleus in a different state, or an entirely different nucleus, either of which is named the *daughter nuclide*. Often the parent and daughter are of different chemical elements. An example of this, a carbon-14 atom (the "parent") emits radiation (a beta particle and a gamma ray) and transforms to a nitrogen-14 atom (the "daughter").The daughter nuclide of a decay event may also be unstable (radioactive). In this case, it will also decay, producing radiation. The resulting second daughter nuclide may also be radioactive. This can lead to a sequence of several decay event , phenomenon known as *decay chain* . During radioactive decay, principles of conservation apply. Some of these laws are as follow:

- Conservation of energy
- Conservation of momentum (linear and angular)
- Conservation of charge
- Conservation of nucleon number

The type of decay that occurs depend on the position of the nuclei and consequently the type of radiation that follow. Hence, the decay process is characterizes by the decay period, mode and the energy without regards to either physical or chemical conditions

3.1 Kinetics of radioactive decay

The particles emitted are of different kinetics or kinetic energies. All radioactive decays obey first – order kinetics therefore rate of decay at time (t) = λ N

Where λ is the first order rate constant

N is the number of nuclei

NB: N at time zero I s (No) as at time t is Nt

Rate of decay = K(N) as

$$(In \left(\frac{No}{N}\right) = a \;\lambda\; t$$

NB: Each atom decay independently of the other, therefore stochiometrically a = 1

Therefore, $$In \left(\frac{No}{N}\right) = a\,\lambda\, t$$

In Nuclear chemistry, decay rate is of usually expresses in terms of half live tipe of the process. That is, the amount of time required for half of the original sample to react.

For first order process

$$Tik = \frac{In^2}{k} = \frac{0.693}{k}$$

Classical Example

A cobalt to decays with the emission of beta particle gamma rays with half life of 5.27 years

$$^{60}_{27}Co \rightarrow {}^{60}_{28}N_i + {}^{0}_{-1}\beta + {}^{0}_{0}\propto$$

How much of a 3.42 ag sample remain 30.0 years solution

$$Ts_2 = \frac{0.693}{K}, \qquad K = \frac{0.693}{t_1 l_2} = \frac{0.693}{5.27} = 0.131 \text{ yd}$$

$$\text{In } \frac{A_o}{A_1} = K_t = 0.131 \quad (30.0) = 3.93$$

Consider the inverse of two sides

$$\frac{A_o}{A} = 51$$

$$A = \frac{A_o}{51} = \frac{3.42}{51} = 0.067 \text{ of Co} - 60 = 0.067 \text{ eg.}$$

3.2 Decay mode and energy

Radioactive decay involves a transition from a definite quatum state of original nuclide to a definite quantum state of product nuclide. The energy difference between the two quanta levels involved in the transition correspond to what is known as decay energy. As for types of radioactive radiation, it was found that an electric or magnetic field could split such emissions into three types of beams or sub atomic particles. They are alpha , beta, and gamma. While alpha decay was seen only in heavier elements (atomic number 52, tellurium, and greater), the other two types of decay were seen in all of the elements. In analyzing the nature of the decay products, it was obvious from the direction of electromagnetic forces produced upon the radiations by external magnetic and electric fields that alpha rays carried a positive charge, beta rays carried a negative charge, and gamma rays were neutral. From the magnitude of deflection, it was shown that alpha particles were much more massive than beta particles. Passing alpha particles through a very thin glass window and trapping them in a discharge tube allowed researchers to study the emission spectrum of the resulting gas, and ultimately prove that alpha particles are helium nuclei. Other experiments showed the similarity between classical beta radiation and cathode rays: They are both streams of electrons. Likewise gamma radiation and X-rays were found to be similar high-energy electromagnetic radiation. Although alpha, beta, and gamma were found most commonly, there are other types of decay that were eventually discovered. Shortly after the discovery of the positron in cosmic ray products, it was realized that the same process that operates in classical beta decay can also produce positrons (positron emission). In an analogous process, instead of emitting positrons and neutrinos, some proton-rich nuclides were found to capture their own atomic electrons (electron capture), and emit only a neutrino (and usually also a gamma ray). Each of these types of decay involves the capture or emission of nuclear electrons or positrons, and acts to move a nucleus toward the ratio of neutrons to protons that have the least energy for a given total number of nucleons (neutrons plus protons).

The mode of decay is dependent upon the particular type of nuclear involved in the reaction (position of unstable nuclei) It is important to remind here that in radioactive decay, there are numbers of conservation laws(3.0) that must be valid for a true decay to occur.

Consider the reaction

$$X_1 + X_2 \longrightarrow X^3 + X^4 \qquad \text{----------}\ y$$

Where X represent nucleus or elementary particles. X_1 and X_2 may be unstable nucleus and bombarding particles while X_3 and X_4 are products formed. So for this general reaction (y) the following number of conservation law holds.

a) The total energy of the system must be constant

$$E_1 + E_2 \longrightarrow E^3 + E^4$$

Where E include all forms of energy (kinetic and electrostatic energy)

b) The linear momentum must be constant

$$P = MV$$

$$P_1 + P_2 = P_3 + P_4$$

Note that $E_{kin} = P^2 / z\, m$

Where E_{kin} is kinetic energy

c) **The total charge** (proton + election) of the system must be constant

$$Z_1 + Z_2 = Z_3 + Z_4$$

d) The mass number of the system must be constant

$$A_1 + A_2 = A_3 + A_4$$

$$M_A = \quad z\, m\, M_H + NMn \quad = 2.016\ u$$

e) **The angular momentum** P_I of the system must be conserved

$$(PI)_1 + (PI)_2 = (PI)_3 + (PI)_4$$

3.2.1 (a) Alpha decay (α): An unstable nucleus undergoes alpha decay by emitting an alpha particles.

Example:

$$^{238}_{92}U \quad \rightarrow \quad ^{34}_{90}Th_i \quad + \quad ^{4}_{2}He$$

Alpha particle cause extensive ionization of matter. Alpha particles interact with matter which may also cause molecular excitation thereby resulting in fluorescence.

Alpha decay is observed for element heavier than lead (Pb) and for a few nuclear that is as light as Lanthanide (Ln). The decay energy can be calculated from known atomic mass since binding energy correspond to a

$$E = - 931.5\ \Delta M$$

Where $\Delta M = (M_{z\text{-}2} + M_{He} - M_{z})$

3.2.2 Beta decay: Is a spontaneous disintegration during which beta particles emitted or electron is captured.

Example:

$$^{14}_{6}Co \rightarrow {}^{14}_{7}N + {}^{0}_{+}e$$

Energetic elections cause ionizaton and molecular excitation in matter, although the effect is weaker and more difficult to detect than that alpha particle. Hence there is need to amplify the effect for counting of individual beta particles. Radioactive beta decay is depicted as β decay when include election emission β^{-} or ${}^{0}_{-}e$, position β^{+} or ${}^{0}_{+1}e$ and election capture (EC).

Example

$$^{137}Cs \longrightarrow {}^{137m}Ba + \beta^{-}$$

Electron capture (EC)

The EC decay process is written as ${}^{A}_{Z}X \xrightarrow{Ec} {}^{A}_{Z+}X + \nu.$

The captured election comes from one of the inner orbital of the atom. Depending on the election shall from which the evection originate, the process is sometimes referred to as K-capture or L- capture electron. The probability of capture of election in higher order shell decreases with quantum number of shell. Therefore the probability capture of e- from K-shell is far greater than capture of e- from L shell

The calculation of decay energy in election capture

$$Q_{EC} = -\ 931.5\ (M_{Z-1} - M_z)$$

3.2.3 Position Decay: In position emission a proton is an unstable nucleus is converted to a neutron and a position. The neutron remain in the nucleus has position is emitted.

Example:

$${}^{24}_{13}Al \rightarrow {}^{24}_{12}Mg + {}^{0}_{+1}e$$

3.2.4 Gamma decay: The emission of gamma is always is company of emission of other particles. It is the emission which occur where transition between energy levels of same nucleus take place.

Example:

$${}^{99m}_{43}Tc \rightarrow {}^{99}_{43}Tc + {}^{0}_{0}\lambda$$

Note that, because TC is an unstable from it quickly decay, emit γ ray as becomes stable. “^{m}Tc is metastable form of Tc.

3.2.5 GAMMA RAY EMISSION (${}^{0}_{0}\gamma$)

Gamma rays are high energy radiation, emitted when an unstable nucleus undergoes a rearrangement of as constituent particles is give more stable, lower energy nucleus Gamma rays are often emitted along with other type of particles.

Examples $${}^{99m}_{43}Tc \quad + \quad {}^{99}_{43}Tc \quad \rightarrow \quad {}^{99}_{43}Tc \quad + \quad {}^{0}_{0}\gamma$$

Note that pure gamma emitters are rare, but rather, the radiation accompanies either on alpha or beta radiation.

3.3 Nuclear Fission

Isotopes of unstable nuclei with atomic number greater than 80 are capable undergoing a nuclear reaction called nuclear fission, in where they split into nuclei of intermediate masses and emit one or more neutrons. The energy generated is called atomic energy. Some fission reaction are spontaneous while some are not spontaneous, hence, the non spontaneous require activation energy from bombardment. A given nucleus is splitted in many ways liberating enormous energy a typical examples.

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow \begin{cases} {}^{160}_{62}Sm + {}^{72}_{30}Zn + 4\,{}^{1}_{0}n + energy \\ {}^{146}_{57}La + {}^{37}_{50}Gr + 3\,{}^{1}_{0}n + energy \\ {}^{144}_{55}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n + energy \\ {}^{144}_{55}Cs + {}^{90}_{37}Rb + 2\,{}^{1}_{0}n + energy \\ {}^{144}_{54}Xe + {}^{90}_{38}Cr + 2\,{}^{1}_{0}n + energy \end{cases}$$

The ^{236}U is an intermediate nucleon and is short lived producing fragment as shown above. Particles that can supply the required activation energy include neutrons protons, alpha particles and fast electrons.

Experiment shows that when comparing the mass of original or starting materials with that of product. There is a little reduction. This missing mass has been converted into energy and is derived through Einstein equation $E = Mc^2$.

Where E is the energy released, m is the loss mass and c is the speed of light.

3.3.1 Chain Reaction

This is a continuous process of splitting of molecules to generate daughter nucleus and neutron. The neutron emitted have high energies with which, it bombard more nucleus. The second generations products are capable of splitting further in the presence of neutron, and this continue until a stable daughter nuclei is formed or it is controlled. So much heat energy is built up and atomic explosion can occur.

3.3.2 Nuclear Fusion Reactor

In a fusion reaction, fission reactor is controlled by injecting materials that absorb some neutrons so as to prevent explosion. Hence the energy produced can be productively converted into heat source in a power plant.

There are various type of nuclear reactors, these include

i Light water reactor

ii Breeder reactor.

3.4 Nuclear Fusion

This is coming together of small nuclei to form heavy nucleus. However, the fusion reaction require a temperature of about 1, 000,000,000 ^{o}C to overcome the repulsion of Hydrogen nucleus, after which they are forced to undergo fusion. Spectroscopic evidence shows that sun is a tremendous fusing reactor consisting of 73% H, 26% He and 1% other element. It is a major reactor that involves fusing of deuteron, ${}^{2}_{1}H$ and triton ${}^{3}_{1}$H at high temperature.

$$ {}^{2}_{1}H \quad {}^{3}_{1}H \quad \rightarrow \quad {}_{2}He \; + \; {}^{n}_{0}n \; + \; energy $$

3.5 Nature of Radiation

Although various electro may metric rays and sub atomic particles involves in radioactivity have been mentioned in earlier part of the modules, it necessary to reveal more about the nature of these radiations. Table 4.0 reveals some properties of three radiations.

The penetrating capacities of particles and rays are proportional to their energies before particles as position are about 100 times more penetrating than the heavier as shoner-moving alpha particles. Beta particles can be stopped by a $\frac{1}{3}$ inch trek (0.3cm) aluminum sheet. Beta particles can pierce a skin but can not touch internal organ.

Alpha particles have low penetrating ability as can not damage or penetrate skin. However they can damage internal tissue if inhaled. The high energy gamine rays have great penetrating power as severely damage both skin as internal organ. They travel at a tie speed of high and can only be stopped by timer layers of concrete or lead.

TABLE 4.0: Radio active emission and their properties

Type	Identify	Mass (amu)	change	Velocity	Penetration
Beta ($\beta, _{1}^{0}\mu\, ^{0}e$)	Election	0.00055	1-	≤ 90% speed light	Low to moderate depending in energy
Position ($_{+1}^{0}\beta,\ +_{1}^{0}e$)	Positively change election	0.00055	1+	≤ 90% speed of light	Low to moderate depending in energy
Alpha ($\alpha,\ _{2}^{4}\alpha,\ _{2}^{4}He$)	Helium nucleus	4.0021	2+	≤ 10% speed of light	Low
Proton ($_{1}^{1}\beta,\ _{1}^{1}H$)	Proton, hydrogen nucleus	1.0073	1+	≤ 10% speed of light	Low to moderate
Neutron ($_{0}^{1}n$)	Neutron	1.0087	0	≤ 10% speed of light	Very high
Gamma ($_{0}^{0}\gamma$) ray	High energy electromagnetic radiation such as X- rays.	0	0	Speeds of high	high

4.0 Conclusion

Radioactive decay is therefore a process of transformation of unstable nuclei to stable form through emission of subatomic particles depending on the position of the nucleus on the belt of stability. Fission and fusion are nuclear reaction that involved splitting of heavy nucleus to form light nuclei and coming together of small light nuclei to form heavy nucleus respectively. There are of importance particularly in generating heat energy which can be converted electrical energy.

Self assessment exercises

1. Differentiate between K-capture and L capture
2. What do you understand by the terms fission and fusion
3. Write briefly on types of decay process known
4. Complete the following reaction

$$ {}_{0}^{1}n + {}_{92}^{235}U \rightarrow {}_{50}^{131}Sn + > + 2{}_{0}^{1}n + energy $$

5.0 Summary

In this unit we must have learnt

1. About the meaning of radioactive decay
2. About kinetics of decay processes
3. About various types of particles involved a decay process
4. About what nuclear fission and fusion are as well as their importance
5. About the nature and penetrating capacity of various particles.

6.0 Tutor marked assignment

1 What is a chain reactions and why are nuclear fission possess considers- chain reaction

2 The half life of $^{19}_{8}0$ is 30min what fraction of isotope originally present would be left after 12 mins

3 The half life of $^{11}_{6}$ is 203 mins. (i). How long will take for 95% of the sample to decay. (ii) How long will rate 99.5% of the sample to decay.

4 Compare as contrast the verifying properties of the electro magnetic rays as sub atomic known.

7.0 Further reading and Other Resources

1 K. Timberlake and W. Timberlaka (2008). Basic Chemistry. Pearson Educational Inc. Boston. Pp 524 – 538

2. G. R. Choppin, J. Liljenzen and J. Rydbers (2002). Radiochemistry and Nuclear Chemistry. Butterworth- Heinemann, Woburn. Pp 1 – 10.

3. J. May (1989). The Greenpeace Book of Nuclear age. Victor Golanoz Ltd. London.

MODULE 2: NUCLEAR MODELS AND ENERGETIC OF NUCLEAR REACTION

Unit 1: Nuclear Models

1.0 Introduction

Models are ways of explanation; scientists often offer to convey trends in observed behaviors of a particular object or concept. Observed phenomenona are used to develop model that is then tested through experiments. It can then afterwards be used to predict the future behavior of such object.

2.0 Objectives

In this unit we should be able to

i. Understand general concept nuclear model

ii. Describe the principle upon which the models are built

iii. Explain the single particle sheet model

iv. Explain collective nuclei model

v. Describe the unified model for defining model

3.0 Nuclear Model: General requirement.

In the same way quantized mode for the atom became the foundation for explaining chemical properties of element and justifying their order in the periodic system; patterns of nuclear stability, result of nuclear reaction at spectroscopy of radiation emitted by nuclei have yield information for the nucleus. In **nucleus,** there are two types of particles: proton and neutron packed closely together under the influence of two major forces;

i. Electrostatic force

ii. Nuclear force

It is worth to note that there are many suggestions or proposes on models but no singular nuclear model has been able to explain all about the nuclear phenomena.

3.1.1 Some general nuclear properties:

It is observed that the binding energy per nucleon is almost constant for the stable nuclei and that, the radius is proportional to the cube of the mass number. This explain or justify that there is fairly uniform distribution of charge and mass through out the volume of the nucleus, just as it supports the assumption of existence of a strong short range nuclear force.

There is an indication too, that central mass number with Z or N-values 2,8, 20, 28, 50 and 82 appear more stable. The other uniqueness of these numbers is that if the capturing of neutron or the energy required to release neutron is plotted for different client, it will be observed that maxima occurs at these same neutron number just as maxima occur for electronic ionization energy of the element He, Ne, Ar, Kr, (electron number 2,8,16,32). It shows that some kind of regular substructures exist in the nucleus

3.1.2 Quantitative energy level:

The constituents' substructure of neutron and proton with each type of nuclear pairs 'off as far as possible. The γ – emission from any particle nucleus involves discrete value. It can then be concluded that decay, radioactive nuclei, whether$\propto$,β, or γ involves a transition between discrete quantities energy level.

3.1.3 The nuclear potential well

Imagine a situation when a neutron of low kinetic energy approaches a nucleus. Since the neutron is uncharged, it is not affected by the coulomb field of the nucleus, hence more are with no interaction until it is close enough to empower the strong nuclear free. At this point neutron experience strong attraction to the nucleus and is absorbed. When the neutron is absorbed, energy is released and emitted in the form of a gamma- quantum. The energy of gamma γ can be calculated from the known masses of reactants and products nuclides E_{γ} = -931.5 (M_{A+1}-M_A –Mn) The energy released is the (neutron) budding energy of the nucleus. The total energy of the nucleus has thus decreased. This decrease is called potential well. He exact shape of the well is uncertain (parabolic or square) and depend on the mathematical form assumed for the interaction between the incoming molecule and the nucleus

3.1.4 Other requirements (properties)

There are other properties was as the difference for proper understanding of models. Presently, this include rotational energy and angular momentum which as better defined by principal quantum number (n) which is related to the total energy of the system and azimuthal quantum number (l) which is related to the rotational movement of the nucleus. Coupling of spin and orbital angular momentary are also important to the understanding of nucleus model. Various model have been proposed, these include.

3.2 The single-particle shell model:

It is known that nucleus moves around freely is a nuclear potential well which is spherically symmetric and that the energy of the nuclear varies between potential and kinetic like harmonic oscillation. For these condition, the solution of the schrodinger equation says € (nucleon) = $(2U_0/Mi^2)^6[2(n-1) + l]$

Where U_0 = potential at radius of 20, and m = mass of the nucleus. The following rules as valid in the potential well which form the basis to the model.

a. L can have all positive interger value beginning with O; independent of n
b. The energy of the l stage increases n
c. The nucleus enter the level with the lowest total energy independent of whether n or l is the lager
d. There are independent sets of levels for proton and for neutron
e. The Pauli's principle is valid (i.e) the system can not contain two particles with all quantum numbers by the same
f. The spin quantum number must be taken into account.

3.3The collective nuclear model:

The single particle model assumes that the mass and the charge of the nucleus are spherical. This is true only for nuclei that have distorted shapes. The most common assumption about the description the nucleus shape is ellipsoidal i.e. cross section of the nucleus is an ellipse Bohr ad Mottelson suggested that the nucleus be regarded as a highly compressed liquid undergoing rotation and vibration. Four discrete collective motions can be visualized

- can imagine nucleus rotates around the y-axis as well as the x-axis
- the nucleus may oscillate between prolate to oblate form (irrotation) as well as vibrate

Each model of such collective nucleus movement has its own quantized energy. In addition the movement may be coupled. The model allows calculation of rotational and vibration levels.

For example if ^{238}U excite above its ground state through interaction with high energy heavy ion (coulomb excitation). Three possible types of excitation are known.

a. Nucleus excitation in which quantum number (J) is charged to raise the nucleus to a higher energy level.
b. Vibrational excitation in which case j is unchanged by the nucleus is raised to a higher vibrational level characterized by a particular vibrational quantum number

c. Rotational excitation, also characterized by a particular rotational quantum number. It shows experimentally that rational levels are more closely nuclei spaces and thus transition between rotational level involves lower energies than de-excitation from excised nuclear or vibrational state.

In the case of even-even nuclei, the rotational energy can be often calculated for the simple expression

$€ rot= (€^2/2Irot[n_2(n_r-1)$

Where I_{rot} is the moment of the inertia as n_r to rational quantum number.

The validity of this quantum depends on whatever the different modes of motion can be treated independently or not which they can for strongly deformed nuclei level ^{238}U.

3.4The unified model for deforming nuclei:

The collective model gives good description of even-even nuclei, but can not account for discrepancy between observed spin and the spin value expected from simple particles shell model. This unified model concept has developed on assumption that a nucleon shell freely in a symmetrical. Potential well, a situation which is valid only for nuclei near closed shells. To angular movement of a odd – odd defined nucleus is due to both the rotational angular momentum of the deformed core and to the angular momentum of the odd nucleon. Consequently, the energy levels for such a nucleus are different, from those of the symmetric shell models.

Sir S.G. Nilsson calculated odd nuclei: as a function of the nuclear deformationβ. Each shell model level of angular momentum J split into J +1/2 levels (Nilsson).

The nelson level are quite different in all characteristics from the shell model state and their prediction of energy, angular momentum, quantum number and other properties agreed better with experimental data for the deformed nuclei than those of any other model.

4.0 Conclusion:

Various models suggested are attempts to capture the application of the trend in observation of nucleus and its substructure constituents in relation to linear, rotational and vibration motion and their equivalent energy level.

Self assessment exercise

i. What do you understand as shell states force and nucleon force

ii. Describe any two named models known.

iii. Explain the meaning of the term

a. Principal quantum number

b. Azimuthal quantum number

5.0 Summary

In this unit , we must have leant about :

i. The general concept nuclear model

ii The principle upon which the models are built

iii The single particle sheet model

iv The collective nuclei model

v The unified model for defining model

6.0 Tutor marked assignment

i The observed quadrupole moment of ^{59}Co is 0.4 barn (a) What is the deformation value β (b) What spin value is expected from Nilsson diagram.

ii Explain the meaning of the terms

c. Principal quantum number

d. Azimuthal quantum number

iii Compare and contrast collective nuclear model and the unified model for deforming nuclei

7.0 Further reading and Other Resources

1 K. Timberlake and W. Timberlaka (2008). Basic Chemistry. Pearson Educational Inc. Boston. Pp 524 – 538

2. G. R. Choppin, J. Liljenzen and J. Rydbers (2002). Radiochemistry and Nuclear Chemistry. Butterworth- Heinemann, Woburn. Pp 1 – 10.

3. J. May (1989). The Greenpeace Book of Nuclear age. Victor Golanoz Ltd. London.

MODULE 2: NUCLEAR MODELS AND ENERGETIC OF NUCLEAR REACTION

Unit 2: Energetic of nuclear radiation

1.0 Introduction

During a nuclear reaction between atomic nucleus and another atomic particle three different processes are possible these are

(a) Nuclear transmutation (in which new nucleus – are formed

(b) Inelastic scattering (in which original nucleus are exerted to a higher energy state

(c) Elastic scattering (in which the nucleus remain uncharged. The mass and energy relationship projectiles interact with a nucleus are brought to fore.

2.0 Objectives

In this unit, we shall be able to

(i) Describe the mass-energy relationship when particles and nucleus interact

(ii) Understand various conservation laws as they affect the nuclear reactions.

(iii) Describe the forms of energy in the three main stages of nuclear reaction

3.0 Conservation laws in nuclear interaction

All conservation laws are applicable in nuclear reaction - These laws are:

(a) The conservation of total energy $\Delta E = 0$

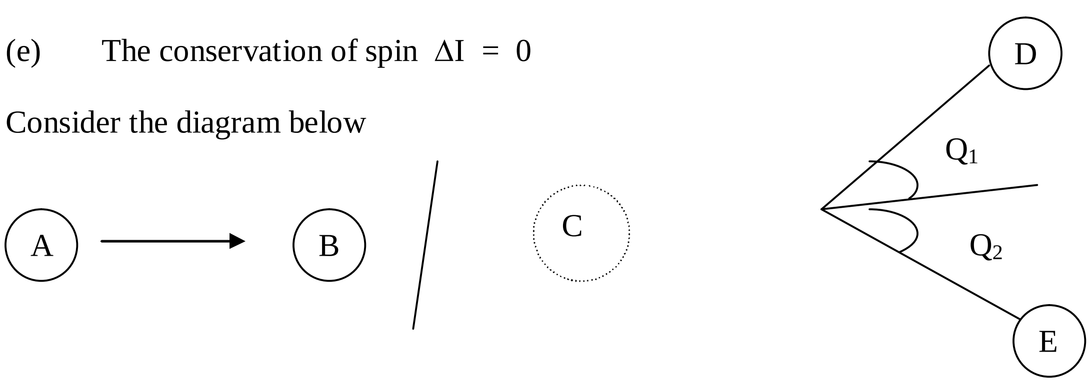
(b) The conservation of the linear momentum $\Delta P = 0$

(c) The conservation of total change $\Delta z = 0$

(d) The conservation of mass number $\Delta A = 0$

(e) The conservation of spin $\Delta I = 0$

Consider the diagram below



M1	M2	Mi	M4	M3
V1	V2=0	Vi	V4	V3

This illustrates a projectile in which substance A collide with target atom B, forming intermediate system C. The C system split into product D and E. – This is nuclear reaction V_1 is > 0 but V_2 is made to be zero.

3.1 Conservation of used energy

$\Delta E = \Delta$ product - Δ reactant = 0

Since the linear momentum is a vector quantity

$$P_1 + 0 = P_3 \cos\theta - P_4 \cos\theta_4$$

$$P_3 \sin\theta = P_4 \sin\theta_4$$

Note that some of these laws (d) and (e) are not always obeyed in high energy reaction in which new elementary particles may be found. Assuming that mass of the particle was independent of its velocity the kinetic energy equation as deduced by Newton

$$E_{kin} = \tfrac{1}{2} Mv^2$$

3.2 The Mass Energy

For radioactive decay, the energy numeration is given by its Q value.

$$Q \text{ (MeV)} = -961.5\ Am^o$$

Where $Am^o - M^o{}_3 + Mo_4 – Mi^o – M_2{}^o$

If mass disappears in the reaction ($\Delta Mo < 0$) energy is released, then the reaction is said to be **exoergic** and Q is positive.

For Q < 0 the reaction is **endoergic** as $\Delta Mo > 0$

$E_{kin} = (m – m^o)c^2$ can be separated to five terms if we define

E^o mass = $Mo\ c^2$ and

$E_{Kaf} = Mc^2$

Then $E_{tot} = E_{kin} + E^o{}_{mass}$

Note also that $E_{tot} = E_{kin} + E_{pot}$

Hence that $E_{tot} = E_{kin} + E^{o}_{mass} = E_{kin} + E_{pot}$

Therefore $E_{mass} = E_{pot}$

Where E_{kin} is translational, rotational, vibrational energy and E_{pot} = mass energy, gravitational, electrostatic energy, surface energy, chemical binding energy etc.

To have a E_{tot} that include atomic masses in their grounds state E^{o} mass, the excitation energy of the nucleus above its ground state E_{exc}, the absorption/emission of protons in the reaction E_v and c reaction between charged particles, the electrostatic potential (Coulomb) energy Ecol, the columb energy must be zero or positive (repulsive). The incoming projective must possess enough kinetic energy to overcome any repulsion. In the process of reaction of repulsion of charged particles, product results in greater kinetic energy.

$$E_{tot} = 6_{rm} + 6_{cone} \_ E^{o}_{MeG} + E_{xec} + E_r$$

3.3. Elastic scattering

The elastic scattering energy is exchanged between the projectile and the target nucleus but the value of Q is zero. An important elastic scattering reaction is nuclear reactors involves the slowing down of neutrons from kinetic energies, which they possess when emitted in nuclear fission. The neutrons are slowed down to energies comparable to those of a neutron of gas at the temperature of the material in which they are moving, hence they are known as thermal neutrons.

$$E_{kin} = KT$$

The process of slowing down of energetic neutron to low kinetic energies is called moderation.

3.4 Inelastic scattering

In this group of nuclear reaction called inelastic scattering, part of the kinetic energy of the projectile is transferred to the target nucleus as excitation energy without changing the values of A or Z of either target or projectile . If the projectile is a heavy ion, it may also become excited. However, the collision of the projectile and target nucleus forming the product does result in a value of Q greater than zero

$$X_1 + X_2 \quad a \quad - \quad X_1 + X_2 + \gamma$$

$$ \quad b \quad - \quad X_1 + X_2^*$$

The reaction path (a) indicates that the energy Q is emitted as a γ ray. In the reaction path (b), the Q is retained as excitation energy of the target include.

In example of an inelastic scattering reaction of the formation of an isomer of Ag by the irradiation of ^{107}Ag with neutrons.

$$^{107}Ag\ (n, n') ;\quad ^{107}m\ Ag \longrightarrow {}^{107}\ Ag + \gamma$$

As an example of nuclear transmutation consider the following

$$^{14}_{7}N \quad x \quad ^{4}_{2}He \rightarrow \left(^{18}_{9}F\right)^{*} \rightarrow {}^{17}_{18}0 + {}^{1}H$$

$$\Delta M^{o} = (m_3^{\ o} + m_4^{\ o} - m_1^{\ o} - m_2^{\ o}$$

$$\Delta m^{o}\ (16.999131 + 1007325 - 14.003074 - 4.002603)$$

$$\Delta m^{o} = 0.001279(u)$$

3.5 The Compound Nucleus model

If $E^{o}{}_{kn} > E_{cb}$, the attractive nuclear force dominate and the particles is absorbed by the target nucleus. Assuming $Q > 0$, the $E^{o}{}_{mass}$ deceases. This means that, E_{exe} increases and the system is transformed into excited compound nucleus.

Hence the excitation of the compound nucleus is

$$E_{exe} = Q + E^{o}{}_{Kin}$$

4.0 Conclusion

It is demonstrated enough that conservation laws are all applicable in nuclear reactions.The total amount of energy remains the same, but keep changing in the three main stages of nuclear reaction

Self assessment exercise

i. What is the Q value for the reaction (a) "B (d, ∝) 9 BC
ii. What is meaning of moderation
iii. List all conservation laws that are applicable to nuclear reaction

5.0 Summary

In this unit we have learnt that

i. about the conservation laws and how they are applicable to nuclear reaction
ii. about to three phases that make up the nuclear reaction
iii. about the elastic scattering
iv. about Inelastic scattering

6.0 Tutor marked assignment

i. Calculate the mass of an electron accelerates through a potential of 2 x 10^8V
ii. ^{12}C atoms are used to irradiate ^{239}PU to produce an isotope of berkelinm. What is the coulomb barrier height.
iii. Briefly explain the following concept
    a. Nuclear transmutation
    b. Inelastic scattering
    c. Elastic scattering
    d. Thermal neutron

7.0 Further reading and Other Resources.

1. K.S. Krane (1988). Introductory nuclear Physics. John Wiley and Son, London.

2. K. Timberlake and W. Timberlaka (2008). Basic Chemistry. Pearson Educational Inc. Boston. Pp 524 – 538

3. G. R. Choppin, J. Liljenzen and J. Rydbers (2002). Radiochemistry and Nuclear Chemistry. Butterworth- Heinemann, Woburn. Pp 1 – 10.

4. J. May (1989). The Greenpeace Book of Nuclear age. Victor Golanoz Ltd. London

MODULE 3 MEASUREMENT OF RADIOACTIVITY

Unit 1: Principle and measurement of radioactivity

1.0 Introduction

There is need to device a mechanism that can accurately qualifying (detect) and quantifying the radioactivity and its effects. This will play role in both application of the radioactivity and monitoring its hazards on man and environment. Various types of equipment are employed in the measurement of radioactivity that make use of different principles, each has its limitation which account for preference for others

2.0 Objective of the unit

By the end of this unit, you should be able to

(i) explain the principle underlying the measurement of radiation

(ii) know various methods and instrument used in measuring radioactivity

(iii) know limitation of those methods used in measuring radioactivity

3.0 Measurement of radiation

There are so many techniques used for qualitative (detection) and quantitative measurement of individual nuclear properties. This unit discusses these along with the problems associated with the proper sample preparation so as to achieve precision and accuracy.

3.1 Sample Preparation

So many factors come into counting efficiency; like sample must be prepared with care and effort must be ensured it is reproducible if several samples case to be compared.

Samples can be either prepared in either liquid form or solid form

3.1.1 Liquid sample: In this form of samples, the emitters are included in the detection system as it ensures high efficiency and reproducibility .Counting of alpha particle and beta emitters are best achieved in liquid sample system.

3.1.2 Solid sample: This sample techniques can be achieved in variety of ways such as precipitation, evaporation, and electrolysis. The advantage of using solid sample for counting is that, the sample can be made very robust and small, allowing the use of either very simple counting system (e.g. Gieger muller counter) or the use of commercial counting system. However , care must be taken to ensure uniform thickness solid media.

3.2 Qualitative and Quantitative measurement

Various techniques and instruments are in vogue when it comes to doing both qualitative (detection) and quantitative measurement.

The detection and counting device are linked together, hence it is worthy to mention that the qualitative and quantitative measurement go on simultaneously.

3.2.1 General Properties of detector

When a nuclear particle enters detector, it produces excitation and ionization, both of which can be used for detection. The excitation, if followed by fluorescent de-excitation leads to emission of light which can be registered by light sensitive devices such as photomultiplier type (PMT) which transform light into an elective current (i).

$$i \quad \frac{\Delta Q}{\Delta t} \quad \frac{Electric \quad change}{Time}$$

If the current passes through a resistor R, it will produce a voltage pulse.

$$\Delta V = R\frac{\Delta Q}{\Delta t}$$

The pulse is otherwise called signal which can then be quantified.

The following are the techniques and instruments which are commonly used to the measurement of radioactivity.

3.3 Track Measurement

Tracks are formed by nuclear particles in cloud chambers, in solids and in photographic emulsions. The track reveals individual nuclear reaction and radioactive decay processes.

The tracks formed can be directly observed by naked eye in cloud and bubble chambers. However, be cause of short life span of tracks, it is important to have a permanent record through photography.

Tracks measurements are in various form.

3.3.1 Cloud and bubble chambers

This was discovered in 1911. A chamber contains air saturates with vapour. Particles emitted from radioactive substances ionize in air chamber. On cooling to droplet of liquid, these ions condense, leading to production of frog-like tracks which may be photographed.

3.3.2: Solid state nuclear track detector (SSNTD).

The main type of SSNTD is photographs emulsion, crystals, glasses and plastic. Because of high density, nuclear plastic make easy identification of particle. Nuclear emulsion are similar to optical photographic emulsion. It is used commonly for α particle measurement.

3. 4 Gas Counter

The principle of all gas filled counters in ion chambers. The ionization produced in ion chamber is too low to be detected except for alpha particles. However the ion pair are multiplied greatly. Common forms of gas ionization counter include :

3.4.1 Geiger – Muller Counter

Radiation enters the tube through a thin window. Geiger muller counter can detect only β and γ radiations. Note that it is note suitable for α particles because α particles cannot penetrate the wall of window.

3.4.2 Ion Chamber:

The ion chamber is a gas – filled space between two electrodes. Electrodes are two parallel plates or has found in another design, cathode act as hollow cylinder and anode acts as a thin wire if its center. The chamber is designed for recording radiation reaching it from outside. It is used to measure β particle

3.4.3 Proportional Counter

It is similar to ionization chamber. The gas multiplication is a function which varies with the applied voltage, and the voltage which must be constant. The sector pulse output is directly proportional to the primary ionization. Hence proportional counter helps to distinguish α and β particles and between identical particles of different energies.

This technique is also used to detect also neutron.

3.5 Scintillation Detector

Scintillating counting technique was developed in 1908 by Rutherford and Gelger as a reliable method of counting α particles by observing visually the fleshes of luminescence produced in a thin layer on ZnS by the α particle. Scintillation optical consist of scintillator or phosphor optically couples to a photomultiplier tube which produces a pulse of electric current when light is transmitted to the tune from the scintillator.

Common forms of scintillator include:

3.5.1 Gas Scintillator

Several high purity gases are useful scintillator notable N_2, He, Ar, Kr and Xe. Except for N_2, much of the emitted light is in UV range. Therefore photomultiplier tube that is sensitive to uv must be used or a wave – height shifting ages like N_2 is added.

3.5.2 - Liquid Scintillator - This has a wide use for routine measurement of β emitter. The sample is dissolved directly in liquid scintillator solution and a light output measured by photomultiplier tube. Liquid scintillating counting offers several advantages when measuring low energy β emitters compare to other detector with problems like attenuation by detector window, self absorption and backscattering are avoided. However introduction of sample into scintillator medium often reduces the light output greatly, a phenomenon known as quenching. The technique also measure α emitter.

3.5.3 - Solid Scintillator

Various solid media are used in solid scintillating techniques. This offer a great advantage in measuring almost all the emitters. ZnS (Ag) is a traditional phosphor for α detection, while anthrancene and stilbene can be used for β particles detector. NaI with small amount of Tl (NaI(Tl)) is a most common phosphor used in measuring γ rays.

4.0 Conclusion

Measuring radiations with accuracy and precision is of high importance. Various known techniques and instruments with condition of use are highlighted above. Techniques are selective in terms of the emitters they detect and quantify

Self Assessment Exercise

(i) What do you understand as qualitative and quantitative measurement of radiations

(ii) Define the terms "Accuracy" and Precision

5.0 Summary

In this unit we must have learnt

(i) About Qualitative and quantitative measurement

(ii) About the general properties of Detector

(iii) Various techniques and instrument used in measuring sub atomic particles

(iv) Principle and condition underlying the use of various counting system employed in measuring radioactivity.

6.0 Tutor Marked Assignment

(i) Explain in detail the general conditions and properties of detector used in measuring radioactivity

(ii) What is quenching

(iii) Write short note on scintillating techniques

(iv) Gieger Muller tube remains a very good instrument technique in serving of radioactivity measurement. Discuss.

(v) Explain what is Track Measurement?

7.0 Further reading and Other Resource

1. K.S. Krane (1988). Introductory nuclear Physics. John Wiley and Son, London.
2. K. Timberlake and W. Timberlaka (2008). Basic Chemistry. Pearson Educational Inc. Boston. Pp 524 – 538
3. G. R. Choppin, J. Liljenzen and J. Rydbers (2002). Radiochemistry and Nuclear Chemistry. Butterworth- Heinemann, Woburn. Pp 1 – 10.
4. J. May (1989). The Greenpeace Book of Nuclear age. Victor Golanoz Ltd. London

MODULE 3 MEASUREMENT OF RADIOACTIVITY

Unit 2: Application of radioactivity

1.0 Introduction:

The modern world has come to witness application of radiation of sub atomic particles and electromagnetic rays in various sphere of humman life. This has contributed immensely to the improvement of quality of life. This include application in archeological research, Agricultural proactive, diagnosis treatment of various discuss conditioner and nuclear power reactor etc.

2.0 Objectives

By the end of this unit, you should be able to:

(i) Know the application of radioactivity in archeological studies

(ii) Know the importance of radioactivity to(medical) diagnosis and treatment of diseases

(iii) Know the principle behind using knowledge of radiation to improve the agricultural practices.

(iv) Know how application of radiation of sub atomic particle helps the nuclear power reaction.

3.0 Use of Radionuclide in Archeology/Environmental studies

Radiological dating is a technique by environmentalist, archeologist, geologist and history to determine the age of artifact be it plants or animals, such as wood, fibres, natural pigment bone and cotton. This is done by measuring the amount of carbon - 14, a natural occurring radioactive form of carbon.

The radioactive carbon – It is produced continuously in the upper atmosphere as nitrogen atom captures cosmic ray neutrons.

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

The radioactive carbon dioxide ${}^{14}_{6}CO_2$ is produced from the reaction of ${}^{14}_{6}C$ with oxygen.

After death of the plant uptake of ${}^{14}_{6}CO_2$ stops.

Carbon-14 undergoes beta decay, the amount of radioactive carbonate in the plant material decrease steadily

$$^{14}_{6}C \quad \rightarrow \quad ^{14}_{7}N \quad + \quad ^{0}_{1}e$$

Researchers use half life of carbon – 14 (5730years) to calculate the length of time, an event (like death of plant take) place. The carbon – 14 techniques is useful only for dating objects less than 50,000years old. Older object can be analysed studied using K – Ar and U – Pb methods, which is capable of analyzing older object since K – 40, Ar – 40 has half life of 1.3 billion years. Through radiological dating, the age of rocks brought back from the moon by the Apollo mission was found to be about 4 x 10^a year calculate approximately the age calculates for earth.

Classical Example

A piece of wood taken from a cave in New Mexico is found to have a carbon-14 activity (per gram of carbon) only 0.636 times that of wood cut today. What is the age of the wood. The half life of carbon-14 is 5730 years.

Solution from 1st order rate constant for ^{14}C

$$T1_2 = \frac{0.693}{K}$$

$$K = \frac{0.693}{t^{d/2}} - \frac{0.693}{5730} = 1.21 \times 10^{-4} \text{years}$$

The present ^4c active N, is 0.6 36 time to original activity

$$N = 0.630N_o$$

We substitute into first* order decay equation

$$\text{In}\left(\frac{No}{N}\right) = Kt$$

$$\text{In}\left(\frac{No}{0.630No}\right) = (1.21 \times 10^{-4})t$$

Cancel No and solve it

$$\text{In}\left(\frac{1}{0.636}\right) = (1.21 \times 10^{-4} \times t$$

$$T = 3.74 \times 10^{3}$$

3.1 Uses of Radioactivity in Agricultural activities

The use of radiation of sub atomic particles to improve agricultural practices is a major landmark in human endeavor.. Absorption of gamma rays helps in eliminating dangerous stain of *Egoherichia coli* bacteria particularly in red meat. The use of pesticide DDT has been confirmed toxic, to human and animal that are repeatedly exposed to it. This has been effectively replaced by a radiological technique. This is used indirectly to sterilize the males' larva producing no offspring. The food item treated does not carry radioactive rays.

3.2 Industrial uses

There are many application of radioactivity in industry and engineering. It helps in industries when precision is of importance and required. The flow of liquid or gas through a pipeline can be monitored by injection of a sample containing a radioactive substance. Leaks in pipes can also be detected easily, thereby preserving life..

3.3 Medical uses

The use of nuclides as radioactive tracers in medicine has been globally acknowledged. A radiation detector can be used to follow the path of the element throughout the body system. Cobalt radiation treatment for cancerous tumor is well known. Solution of ^{2u}Na is injected into bloodstream to follow the flow of blood and locate obstruction to circulatory system.

Thallum – 201 to technetium -99 have been used to survey damage from heat disease. Iodine – 123 concentrate in the thyroid gland, liver and certain part of the brain. This radioactive type is used to monitor goiter and often thyroid problem.

3.4 Scientific Research

The pathway of clinical can be investigated using radioactive traces.

Using labeled radioactive campus like $^{14}CO_2$ helps identify intermediate molecules. Example is photosynthetic process. Labeled $^{14}CO_2$ helps tracing intermediate molecule.

Uranium - 235 is used in binding nuclear power plant includes help ration in nuclear research as well as generating energy to drive industries.

4.0 Concluison

Radioactivity indeed has come to many important roles in improving the quality of life. It also help in projecting quality future of well as uncovering the possible problem in terms of good research.

Self Assessment Test

(i) What is meant by radioactive tracers

(ii) Any hazard associated with the use of radioactivity in treatment of agricultural product

(iii) What are the radionuclide uses in medical diagnosis

5.0 Summary

In this unit we must have learnt about

(i) The general application of radioactive

(ii) How to use radiation of isotope preserve agricultural product

(iii) Low the knowledge of radioactivity help in medical diagnosis and treatment.

(iv) How to use radioactivity in industry

(v) The use of radioactivity in scientific research

(vi) How age of antiquity as determined by the use of radioisotopes.

6.0 Tutor Marked Assignment

(i) If the amount of radioactive phosphorus age in a sample decreases from 1.5mg to 0.25mg in 28 days. What is the half life of phosphorus – 32.

(a) The half life of radioactive decay of calcium -47 is 4.5 days. If a sample has an activity of 1.0 μ after 27 days. What was the initial activity of the sample?

(iii) Explain various application of radioactivity in the following:

(a) Medical practices

(b) Dating of Artifact

(c) Scientific research

(d) Industries

Agricultural practice

7.0 Further reading and Other Resource

1. K.S. Krane (1988). Introductory nuclear Physics. John Wiley and Son, London.
2. K. Timberlake and W. Timberlaka (2008). Basic Chemistry. Pearson Educational Inc. Boston. Pp 524 – 538
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4. J. May (1989). The Greenpeace Book of Nuclear age. Victor Golanoz Ltd. London

MODULE 3: MEASUREMENT OF RADIOACTIVITY

Unit 3: Radiation hazards.

1.0 Introduction.

Various application of radioactivity are indeed leading to quality improvement in life, as discussed in the preceding unit. However, this phenomenon has potential of destroying the same life, it tends to protect. Therefore hazards associated with radiation are discussed in this unit.

2.0 Objectives

In this unit ,we shall be able to

(i) Describe about various sources of radiation exposure

(ii) Know about the relationship before radiation and health condition

(iii) Know about management of hazardous nuclear waste

(iv) Understand the ways of protection from radiation exposure.

3.0 Exposure to radiation.

Human beings are in constant contact with at least low levels of radiation from natural occurring radioactive isotopes in our homes, office, food, water and air we breathe.

The following isotopes, for instance potassium- 40 is present in all potassium containing food .$^{14}_{1}$ C, radion-222, strontium-90 and iodine-181 are in various food and air around man.

Cosmic is another source of background radiation, people that travel often in air stands the chance of receiving greater amount of cosmic radiation because there are fewer molecules in atmosphere to absorb he radiation.

Medical source of radiation are additional source of radiation exposures. These include dental, X-ray, hip, spine and mammogram. Contact with radiation during research also constitutes a major source. By 1992, approximate 100 radiologists had died of a result of biological radiation damage. Table 6.0 shows average annual radiation receive in U.S.A

Table 6: Shows average annual radiation receives by a person in U.S.A

	Source	Dose (mrem)
	The ground	20
Natural	Air, water, food	30
	Cosmic rays	40
	Wood, concrete, break	50
	Chest – ray	20
	Dental- x ray	20
	Mammogram	40
Medical	Hip x – ray	60
	Lumbar some x-ray	70
	Upper gastrointestinal X-ray	200
	Television	20
Others	Air travel	10
	Radon	200
	* Varies wisely	

Mrem = milli radiation equivalent in man

3.1 Radiation and Health disorders

The biological effect of very large whole body doses leads to radiation sickness and early death while large organ doses lead to local cell destruction, and possibly organ death. Exposure to radiation greater than 100rem, person may suffer the symptoms of radiation sickness: Nausea, vomiting, fatigue and reduction in white blood cell count. At dosage greater that 300rem all white blood cell get destroyed, victim suffer diarrhea, hair loss and other infection while at 500rem, half of the population dies hence it is called L D_{50} (Lethal dose for one half the population). Table 70 shows function L D_{50} for various life form. Dosage above 600 leaves all humans fatal within a week.

Table 7.0: Lethal dose (LD_{50}) for different life form

Life form	D_{50} (rem)
Insect	100,000
Bacterium	50,000
Rat	800
Human	500
Dog	300

* Radiation equivalent in human

The earth we live is drenched in radiation from cosmic sources and mineral exploration from the ground. Therefore, the effects of the natural radiation background has become an important health issue particularly radon levels in houses. Also related closely to this is the effect of man-made sources of similar low levels, such as nuclear waste.

Basically, when it comes to the effect of radiation on human cell, two type of cells come into mind: those that directly involve in functioning of the organ (e.g bone marrow, liver, or the nervous system) and those which are associated with reproductions. Radiation damages give rise in the former to somatic effect such as cancer induction and to later,a genetic effect.

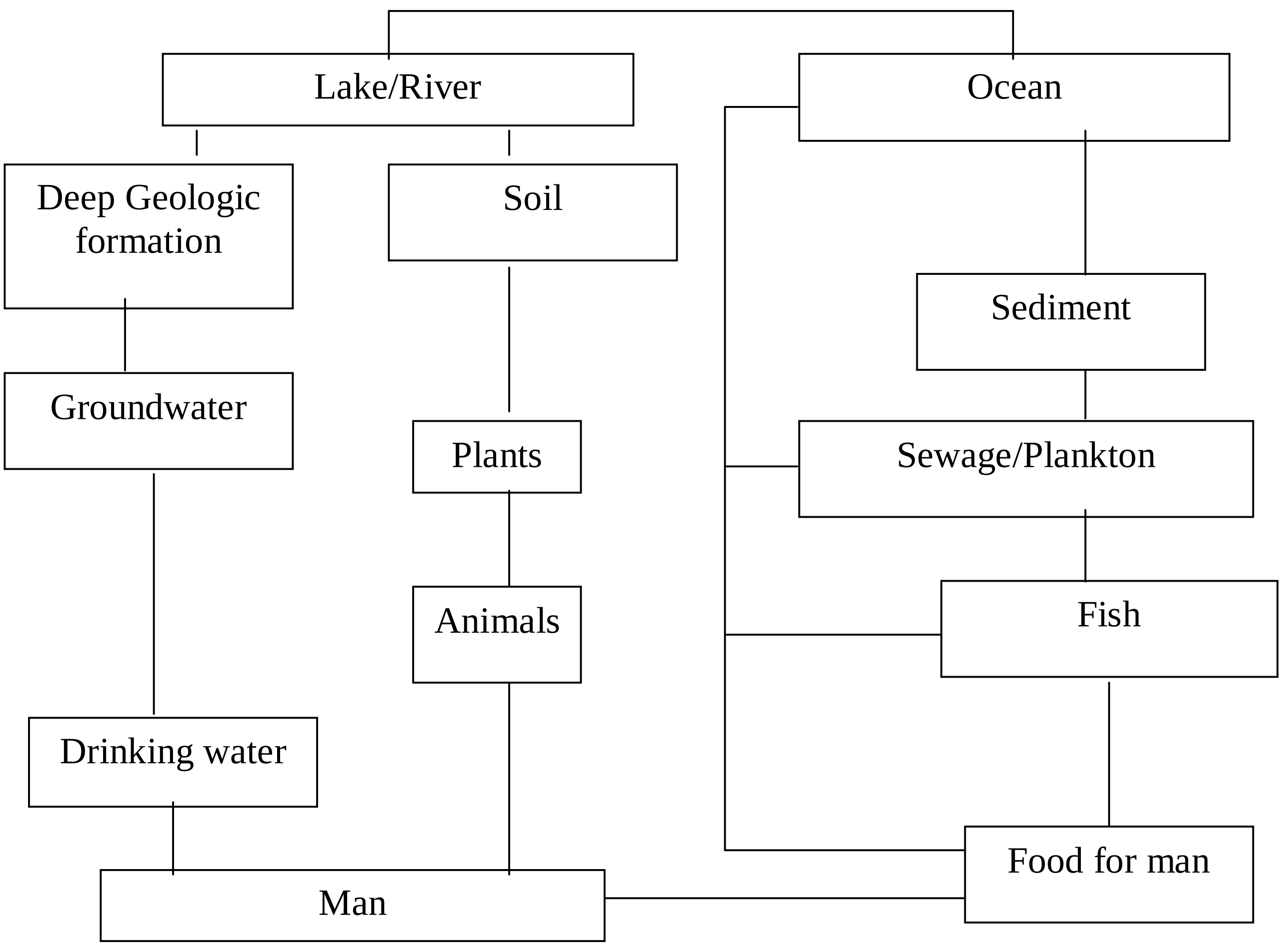
Exposure to large dose radiation can be of two types namely:

(i) Accidental exposure: e.g Japan, Chernobyl. This exposure is said to be stochastic because the harm caused is statistically distributed over the exposed population. The frequency of tumor induction is observed to increase linearly with the dose.

(ii) Delibrate Exposure : are deterministic because the damage is caused intentionally to a certain organ or population. Such irradiations are considered to have a threshold value, below which no effects occur.

3.2 Management of Radioactive waste

Handling of radiation waste is a major source of radiation in the community. Nuclear power system remains the cheapest, source of power to drive industries and electricity, however, the hazard it generates if the waste is not properly disposed is overwhelming. Countries that involves in nuclear power generation used to dispose the nuclear power waste through a large water bodies such as ocean and seas. However , the hazards effect from those waste only come back to man with time, as shown i in the figure 2.0.



Early 1990 the Environmental pollution agency gave its approval for the storage of radioactive hazardous waste in chambers 2150 ft underground. That was implemented in 1999 when waste isolation pilot plant (WIPP) marked repository site in New Mexico to receive plutonium waste from former U. S. Bomb factories.

However, despite the U.S authority assured the populace the safety of such scheme, the mean of transporting such waste to site has been another (problem) source of radiation, should the nuclear waste be transported through the rail or by a highway truck.

Another safer method of handling hazardous nuclear waste as proposed in the wake of various criticism over dumping nuclear waste in either deep sea or buried deep underground, include casting the nuclear waste into ceramics to eliminate the possibility of waste dissolving in ground water.

The encapsulated waste could then be deposited in underground salt drone. Salt drones are located in geographically stable areas that has held petroleum and compressed natural gas trapped for million of years. Another method involves storing long-lived radionuclide from spentt fuel underground in a heavy, shock – resistant container until they have decayed to the point they are no longer biologically harmful. Example strontium - 90 ($t1/2$ = 28years) and plutonium – 298 ($t \frac{1}{2}$ = 24000 years) must be stored for 280 years and 240,000 years respectively before they loose 99.9% activities. However the problem of corrosion of container is another point the critics argued for picking holes in the method.

3.3 Protection measure from radiation laboratory work.

Three basic principles are recommended for keeping radiations exposure to a minimum level These are:

(i) Shielding

(ii) Control

(iv) Distance

If a radiochemical laboratory is designed properly and the work is performed in such a manner that the general background contamination is sufficiently low so as to avoid low level tracer, then the health aspect of radiation control are satisfied. The general principles are:

1. Special room/location is used for radioactive work
2. The airborne contamination must be prevented in the laboratory
3. The air velocity in the hood should never be below $0.5m^{s-1}$
4. Limitation of radioactive work to a minimum area
5. The room should be equipped with alarm system to monitor hazards such as interrupted water system.
6. Entering and leaving the f laboratory should be through air locked and hand as well as feet must be sensored for radioactivity.
7. Shielded cells are used which helps to keep the pressure low than that for the working pressure

3.4 Control of radiation protection measure

In larger organization, protection of radiation measure follows three stages

(i) Prevention – This include the use of devices such as fume hoods, α boxes, radiation shielding, tongs etc.

(ii) Supervision stage involved the use of radiation instrument to monitor radiation level. For instance small TLD, film or pocket pen dosimeter are used for individual monitoring. For spills and contamination of hand and shoes, special contamination instrument (counters) are used which are more sensitive than the monitoring dose instrument.

(iii) The after control usually consists of checking personal dosimeter and a medical examination. This may be depending on the type, and level of work executed. The dosimeter may be checked, twice a week or a month, while examination may be once or several times a year.

4.0 Conclusion

The use of radioactive isotope can indeed be negatively consequential if adequate steps are not taken into cognizance. The methods of nuclear waste disposal still remain a great source of radiation. However, shielding oneself will still go a long way in curbing individual exposure to the radiation.

Self assessment Exercise

i. Discuss briefly what is meant by accidental exposure as deliberate exposure

ii. What is LD_{50}

5.0 Summary

In this unit, we must have learnt about

(i) Various sources man can be exposed to radiation

(ii) Various health disorder that exposure of hazard radiation can lead to

(iii) Types of exposure

(iv) How nuclear waste are being handled

(v) Methods of protecting radiation exposure

6. 0 Tutor marked assignment

(i) Briefly discuss the method involved in management of radioactive wasted

(ii) Explain what is involved in protecting man and environment from radiation exposure

(iii) Certain diseases are directly or indirect consequences of radiation exposure. Explain

(iv) Radiation dosages beyond LD50, man stand the risk of extinction. Discuss.

(v) Types what radiation protective measure is all about.

7.0 Further reading and Other Resources

1. K.S. Krane (1988). Introductory nuclear Physics. John Wiley and Son, London.
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