Nuclear Chemistry

1. RADIOACTIVITY

Unstable elements emit radiation and convert into stable elements. The element radium is present in the digits and hands of radium watches with emits radiations. The nucleus of the atom participates in such conversions. Therefore, they are called nuclear reactions. The study of radioactive reactions is called radiochemistry.

2. Discovery of Radioactivity

Radioactivity was first discovered by Henry Becquerrel. Curie couple was awarded with Nobel prize for preparation of radium salt. Madam Curie got Nobel prize for the discovery of Ra and Po. Three types of radiations are emitted by radioactive elements, which are as follows.

3 α-Rays

(1) These are nuclei of He ($_2He^4$).
(2) Their kinetic energy is high, because their velocity is 14500 to 23000 Km per second.
(3) Their penetrating power is very due low velocity.
(4) They are capable of ionising the gases because they are charged particles.
(5) They do not deviate from their path under electric and magnetic fields, because their mass is high.
(6) Their mass is 1.6×10^{-24}g x 4 = 6.67×10^{-24} g or 4 amu.
(7) They are attracted towards negative charge in the electric field.

4. β-Rays

(1) These are negatively charged particles on which unit negative charge exists.
(2) These particles are similar to electrons whose mass is 9.1×10^{-28} g and velocity is 1,600000 Km per sec.
(3) Their kinetic energy is very low due to low mass.
(4) They are attracted towards positive charge.
(5) Thin metal sheet can stop them, but their penetrating power is very high as compared to particles because their velocity is higher than that of α-particles.
(6) They have capability of ionising gases, because they are charged particles.
(7) These are also called cathode rays.

5. γ-Rays

(1) They are electromagnetic waves, which are high energy rays like X-rays.
(2) Velocity of these rays is equal to that of light and calculation of their energy is done by the formula, $E = h\nu$.
(3) These rays are unaffected by electric field.
(4) Their penetrating power is very high. These rays can penetrate 20-25 cm thick lead sheet.
(5) Penetrating power of these rays is maximum due to their very high velocity.
(6) They cannot ionise gases, because they are neutral rays.

Comparison of properties of different radiations

	Property	α-Rays	β-Rays	γ-Rays
1.	Penetrating power	1	100	10000
2.	Velocity	14500-23000 Km sec.$^{-1}$	160000 Km. sec^{-1}	3 x 108 m.sec^{-1}
3.	Kinetic energy	High 4.9 Mev	0.5 - 2 Mev	E=hv Very high
4.	Effect in electric field	Attracted towards negative charge	Attracted towards	Unaffected positive charge
5.	Ionising power	10000	100	1
6.	Mass	4 amu	Negligible like electron	Zero
7.	Nature	Dipositive He ion	Negative electron	Electromagnetic waves

α, β and γ rays are emitted from an unstable nuclei of some atoms, the property known as radioactivity. Due to high energy of these rays, they are capable of breaking the bonds. This is the reason why these radiations break the bonds present in the compounds of blood and tissues of the body and destroy. them. Madam Curie suffered from cancer due to this reason. These radiations damage the genes also. They destroy the molecules of genes, thus babies are born abnormal.

6. Unit of Radioactivity

Unit of radioactivity is curie, Ci.

Radioactivity 1 curie = Emission of 3.7 x 10^{10} radiations per second.

millicurie = 10^{-3}Ci, microcurie = 10^{-8}Ci

Curie unit is replaced by Becquerrel unit 1975.

1 Bq. = 1 decomposition per second or emission of one radiation per second.

Rutherford = 10^6 decomposition/second

(3) a, b and γ rays are also called Bacquerrel rays.

7. Effect of Emission of α, β α ν δ γ Rays and Group Displacement Law

There is no effect of charge and mass on emission of γ rays, because charge of these rays is zero and mass is negligible. γ Rays are always emitted on emission of α and b particles

(1) One a particle has +2 charge and 4 mass. Therefore. charge and mass are decreased by 2 and 4, respectively on the emission of one a particle.

$_{92}U^{238} \rightarrow {}_2He^4 + {}_{90}Th^{234}$

$_XA^Y \rightarrow {}_{X-2}B^{Y-4} + {}_2He^4$

$_{8S}At^{218} \rightarrow {}_{83}Bi^{214} + {}_2He^4$

Therefore, place of the daughter nucleus in the periodic table gets shifted towards left, i.e., two places backwards, on emission of one α particle. .

$_{84}PO^{215} \rightarrow {}_{82}Pb^{211} + {}_2He^4$

Atomic number	84	82	2
Atomic weight	215	211	4
Group number	VIA	IV A	-
	16	14	

(2) When p particle is emitted, then charge number of the nucleus increases by one. p Particle is released from the nucleus by the following reaction, because b particle is an electron.

$_0n^1 \rightarrow {}_1P^1 + {}_{-1}e^0$

Therefore, one proton is increased in nucleus and one charge is increased but atomic weight remains same, because mass of proton and neutron is almost equal.

$_{90}Th^{233} \rightarrow {}_{91}Pa^{233} + {}_{-1}e^0$

$_{83}Bi^{213} \rightarrow {}_{84}Po^{213} + {}_{-1}e^0$

Therefore, the place of daughter nucleus shifts one group forwards in the periodic table.

8. Rate of Radioactive Decay

Number of atoms disintegrated in unit time is called rate of radioactive decay.

If dN atoms disintegrate in dt time, then

$$-\frac{dN}{dt} \propto N$$

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

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

Here λ is called disintegration constant. After manipulation of the equation.

$$N = N_0e^{-\lambda t}$$

9. Process of Radioactive Disintegration is a First Order Reaction

$$\lambda = \frac{2.303}{t}\log\frac{N_0}{N} \text{ or } \frac{2.303}{t}\log\frac{a}{(a-x)} \qquad \text{if } x = 9/2 \qquad t_{1/2}\ \frac{0.693}{\lambda}$$

Unit = Second^{-1}

Radioactive disintegration occurs infinitely, as in a first order reaction.

Half-life of disintegration is the time in which 50% of the substance disintegrates.

Example - If half-life of a radioactive substance is 20 days, tben its disintegration will Occur as follows.

$$1g \xrightarrow{20\,\text{days}} 0.5\text{ g} \xrightarrow{20\,\text{days}} 0.25\text{g} \xrightarrow{20\,\text{days}} 0.125\text{ g}$$

$$t_{1/2} = \frac{0.693}{\lambda}$$

λ = Disintegration constant

$\frac{1}{\lambda}$ = Average life or "Tau"

$$T = \frac{1}{\lambda} = \frac{t_{1/2}}{0.693} = 1.44\ t_{1/2}$$

9.1. Reactivity of Substance

We know that

$$\frac{dN}{dt} = \lambda N$$

Where N is the number of nuclei in m gram mass of a substance of mass number, A.

$$N = \frac{6.023\times10^{23}\times m}{A}$$

After each half-life, amount of substance remains half of its initial value. Therefore, reactivity also becomes half. If numbers of half-life are x, then reactivity becomes $(1/2)^x$

10. Nuclear Structure and Nuclear Property

Nucleus of an atom is made up of particles like proton neutron, meson, pion, etc. Proton and neutron are called nucleons. How are the protons having similar charge are arranged in the nucleus and some nuclei are stable and the other are unstable. To explain this, scientists put forward some theories, wllich are as follows.

(1) Liquid-Drop Theory

Nucleus is regarded as behaving similar to a drop of liquid. The nucleons move in the nucleus in the same way as the molecules of the liquid move in the drop of that liquid. The forces of repulsion between positively charged protons in the nucleus try to break the drop, but surface tension of the liquid does not allow it to do so.

Due to increase in the number of protons, repulsive forces of the protons become more effective than the surface tension of the liquid. When repulsive forces get more effective than the surface tension, then round drop-like nucleus becomes distorted. Beyond proton number 83, distortion becomes so high that drop breaks. Many radiations are emitted on breaking of this drop and the nucleus shows radioactivity.

(2) Even-Even Nucleon Theory

The nucleus in which protons and neutrons are present in even numbers, are stable. For example.

$$_6C^{12},\ _8O^{16},\ _{20}Ca^{40}$$

This theory is not applicable, because there are many stable nuclei known in wllich number of nucleons is odd. For example,

$_3Li^6$, $_1H^2$, $_5B^{10}$

(3) Quantum Theory of Closed Shell

The protons and neutrons are filled in the nucleus in accordance with Pauli's principle and spins of nucleons are –1/2 and -lh. On the basis of several calculations. the nucleus in which the number of nucleons is 2, 8, 20, 50, 82, 126. are found to be very stable. These numbers of nucleons are called magic number. The nucleus in which magic number is not present is unstable. Such a nucleus emits radiation to convert into a stable nucleus.

(4) Pion Exchange Theory

Positively charged protons are present in the nucleus. How do these protons live together in such a small nucleus? This is explained by a Japanese scientist, Yukawa on the basis of pion exchange theory. Nucleons are regarded to undergo interconversion. Thus, protons and neutrons present in the nucleus keep on exchanging pions.

$$_1P^1 + {}_{-1}p^0 \rightarrow {}_0n^1$$

$$_1P^1 \rightarrow {}_0n^1 + {}_{+1}\pi^0$$

Pions are positively as well as negatively charged particles. Therefore, due to charge-transfer, they are highly attracted towards the nucleons and are strongly bound in the nucleus. P Particles obtained from disintegration of unstable nucleus are negative pions and are generated by change of neutrons to protons.

(5) Nuclear Binding Energy Theory.

Mass decreases due to arrangement of nucleons in a very small space of nucleus. This difference of mass is converted into energy according to Einstein equation ($E = mc^2$) and this energy binds the nucleons. Therefore, thii energy is called binding energy. Binding energy can be understood by following equation.

Binding energy of $_2He^4$

(1) Mass of two protons = 2 x 1.007 amu
= 2.014 amu

(2) Mass of two neutrons = 2 x 1.008 amu
= 2.016 amu

Therefore, mass of $_2He^4$ = 2.014 + 2.016 = 4.030 amu

Therefore, decrease in mass = 4.030 - 4.00
= 0.030 amu

Δm = 0.030 gram / mole
= 3×10^{-2} gram / mole
= 3×10^{-5} Kg / mole

'This deficiency in mass is converted into energy according to Einstein equation.

$\Delta E = mc^2$
$= 3 \times 10^{-5} \times (3 \times 10^8)^2$
$= 27 \times 10^{11}$ Kg $m^2 s^{-2}$ $mole^{-1}$
$= 2.7 \times 10^{12}$ Joule I mole

Value of ΔE per atom

Atoms in 1 mole = 6×10^{23}

$$\Delta E = \frac{2.7 \times 10^{12}}{6 \times 10^{23}}$$

$= 4.5 \times 10^{-12}$ Joule / atom

1eV = 1.6×10^{-19} Joule, 1MeV = 1.6×10^{-13} Joule

Binding energy per atom = $\frac{4.5 \times 10^{-12}}{1.6 \times 10^{-13}}$

= 28.4 MeV

Binding energy of an atom, can be found out by the following formula.

Binding energy = DM (amu) x 931 MeV / amu

Binding energy per nucleon = $\frac{\text{Binding energy}}{\text{Number of nucleon}}$

If the value of binding energy per nucleon is higher, then the atom will be more stable. Average binding energy for stable nucleus is approximately 8 MeV.

11. Packing Factor

Packing factor = $\frac{\text{Mass defect}}{\text{Mass number}}$

Value of the packing factor is very low (of the order of 10^{-4}). Therefore, it is multiplied by 10^4.

Packing fraction = $\frac{\text{Expected mass} - \text{Actual mass}}{\text{Mass number}} \times 10^4$

Higher the value of packing fraction, less stable will be the nucleus.

11.1 Stability of Nucleus and Neutron-Proton Ratio

If the ratio of n/p is 1.0 then the nucleus is more stable. Nucleus of elements are unstable because n/p ratio are more than or less than 1.0 and they emit different radiations till the ratio of n/p comes near 1.0 and they get stability. This is the reason why radioactivity is found in heavy elements, which balance the ratio of n/p by emitting radiations.

Value of n/p decreases on emission of b particles or electrons by the nucleus, because the number of neutrons decreases and number of protons increases in this.

${}_0n^1 \rightarrow {}_1p^1 + {}_1e^0$

n/p Ratio increases on emission of a particles and they emit radiations till n/p ratio comes between 1.0 and 1.6

12. Nuclear Reactions

As we know that old bonds break in a chenlical reaction and new bonds are formed. For example, an ionic bond is formed by transfer of electron between Na and Cl and energy is released. Only electrons participate in this reaction and not the nucleus. Therefore, numbers of protons and neutrons are not affected.

In nuclear reactions, numbers of protons and neutrons are changed and mass is lost. Thus, energy equal to that mass ($\Delta E = mc^2$) is released. This is called nuclear energy.

${}_{92}UZ^{38} \rightarrow {}_{90}Th^{234} + {}_2He^4$

${}_{90}Th^{234} \rightarrow {}_{91}Pa^{234} + {}_{-1}e^0$

Nuclear reactions are also balanced, like chemical reactions. These are balanced by atomic number and mass number.

13. Nuclear Fission

Nucleus is less stable due to less per nucleon binding energy of heavy nucleus and they on getting energy, divide into two segments of medium masses.

When low velocity neutrons are showered on U^{235}, then heavy nucleus of U^{235} captures the neutron and forms a compound nucleus. This compound being unstable divides into to almost equal segments and emits high amount of energy. This is called nuclear fission and the energy released is called nuclear energy.

${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{36}Kr^{92} + {}_{56}Ba^{141} + 3({}_0n^{141})$ + Energy

In the products (except isotopes of Ba and Kr) of the above reaction, many other isotopes having mass number between 72 to 162. atomic number between 36. to 58 and I to 4 neutrons per U^{235} are released.

$$_{92}U^{235} + {}_0n^1 \longrightarrow \begin{cases} \rightarrow {}_{92}U^{236} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 \\ \rightarrow {}_{54}Xe^{144} + {}_{38}Sr^{90} + 2{}_0n^1 \\ \rightarrow {}_{55}Cs^{144} + {}_{37}Rb^{90} + 2{}_0n^1 \end{cases}$$

*[The nuclei, which can undergo fission, are U^{235}, U^{233}, Th^{232}, Pu^{239} etc. They are called Nuclear Fuels]

14. Atom Bomb

Atom bomb was first prepared in the year 1945. There is an uncontrolled fission process occuring in this. Low velocity neutrons are showered on $_{92}U^{235}$ and three high velocity neutrons are set free after the reaction, by which the rate of the reaction becomes so much uncontrolled that energy is released with terrific explosion.

15 Nuclear Reactor

In a nuclear reactor, a very large amount of energy of atom bomb is used in constructive works.

A nuclear reactor is a special type of furnace in which controlled fission of U^{235} is carried out and energy released in fission is kept under control. There are in total eight nuclear reactors in our country. Four of them are in Bhaba atomic research centre for research purposes and remaining four are power production reactors which are in Kota (Rajasthan), Narora (Uttar Pradesh), Kalapakkam (Tamil Nadu) and Tarapore (Maharashtra).

In this graphite and heavy water are used, which reduce the velocity of neutrons released from $_{92}U^{235}$, Therefore, they are called **moderators**. Velocity of neutrons decreases because they transfer their energy to the moderator on colliding with it. Low velocity neutrons react with new nuclei of fission substance and carry on the fission process. Cadmium rods are used as **neutron absorbers.**

Nuclear reactor is a block of graphite in which uranium and cadmium rods are embedded at definite positions. There is facility to move cadmium rods inside and outside the block. Thus, the rate of fission process is controlled. In the controlled fission, energy is released mainly in the form of heat. To remove this heat, ,cold water (or air) is passed in the reactor to form steam. Electricity is produced by this steam. Now-a-days. plutonium (PU^{239}) is normally used in place of $_{92}U^{235}$.

16. Breeder Reactor

Amount of U^{235} in uranium found in nature is only 0.7%. Therefore, Breeder reactor was invented for supply of fissionable nuclei. In Breeder reactor, highly fissionable nuclei are prepared from less fissionable nuclei. U^{238} is converted into highly fissionable nuclei of Pu^{239} as given below.

$$_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} \rightarrow {}_{93}Np^{239} + {}_{-1}e^0$$

$$\downarrow$$

$$_{3}0n^1 + \text{Fission product} \xleftarrow{{}_0n^1} {}_{94}Pu^{239} + 2({}_{-1}e^0)$$

Similarly, highly fissionable U^{237} can be prepared from Th^{232}

Half-life of Pu is 24000 years and energy released by 1 gram of Pu is equal to energy released by 30 tons of TNT.

17 Nuclear fusion

Binding energy per nucleon of light nuclei is low, i.e., they are less stable. Therefore, nuclear reaction in which two lighter nuclei join with each other to form a heavy nucleus is called **nuclear fusion.**

In this, mass defect is very large. Therefore, many times more energy than nuclear fission is required. Fusion reaction is perfomled at very high temperatures, because positive nuclei repel each other. These high temperatures are produced by nuclear fission. Therefore, it is called thermonuclear reaction. Initially, energy has to be provided to these reactions. The energy obtained from fusion carries on the reaction further.

(1) By fusion of two nucleus of deuterium, nucleus of helium - 3 is formed. To start this process, about crore degree temperature is required.

$$_1H^2 + {}_1H^2 \xrightarrow[\text{temperature}]{\text{Very high}} {}_2He^3 + {}_0n^1 + \text{energy (3.3 MeV)}$$

(2) Helium-4 nucleus is fonned by fusion of deuterium and helium-3 nuclei and high amount of energy is released.

$$_1H^2 + _2He^3 \rightarrow _2He^4 + _1H^1 + \text{Energy (18.3 Mev)}$$

(3) By the fusion of tritium and deuterium nuclei. helium-4 nucleus is formed and high amount of energy is released.

$$_1H^3 + _1He^2 \rightarrow _2He^4 + _0n^1 + \text{Energy (17.8 Mev)}$$

(4) Tritium nucleus is formed by the fusion of two deuterium nuclei and high amount of energy is released.

$$_1H^2 + _1H^2 \rightarrow _1H^3 + _1H^1 + \text{Energy (4.0 Mev)}$$

18. Hydrogen Bomb

Hydrogen bomb is based on fusion reaction. In this, deuterium and tritium nuclei are fused and high amount of energy is released. To initiate the process, first high temperature is generated by exploding an atom bomb. After a few moments, temperature of lakhs of degrees is generated by fusion reaction.

This is a very fast process and terrific explosion occurs, which is extremely destructive.

$_1H^1 + _1H^2 \rightarrow _1H^2 + _1H^1 + 19 + 109$ calorie

$_1H^2 + _1H^2 \rightarrow _2He^3 + _0n^1 + 76 + 10^9$ calorie

$_1H^3 + _1H^2 \rightarrow _2He^4 + _0n^1 + 404 + 10^9$ calorie

19 Solar Energy

Temperature of the sun is approximately two crore degree. Sun continuously emits radiation in the form of heat and light, and this temperature never comes down. Therefore, it is believed that the source of this enormous energy is nuclear fusion. Unchangeable energy is produced by fusion, which maintains the temperature of the sun.

$$_1H^1 + _1H^1 \rightarrow _1H^2 + + _1e^0 + \text{Energy}$$

$$_1H^2 + _1H^1 \rightarrow _2He^3 + \text{Energy}$$

$$_2He^3 + _2He^3 \rightarrow _2He^4 + 2(_1H^1) + \text{Energy}$$

Complete reaction

$$4(_1H^1) \rightarrow _2He^4 + 2_{+1}e^0 + \text{Energy (27MeV)}$$

In three steps, He4 nucleus is fonned by the fusion of four protons at the temperature of sun (1.5 x 10^7 K), Thus, high amount of energy is released in the complete reaction, which maintains the temperature of the sun.

20. Radioactive Disintegration Series

Unstable radioactive element fonns stable nucleus by disintegrating itself and disintegration process goes on till completely stable nucleus is fonned. There are more than one steps in this process. Therefore, the disintegration steps, which occur in the formation of last stable element from an unstable element, all together make a disintegration series. There are following four disintegration series of heavy radioactive elements.

(I) Thorium series or 4n series

(2) Neptunium series or (4n + 1) series

(3) Uranium series or (4n + 2) series

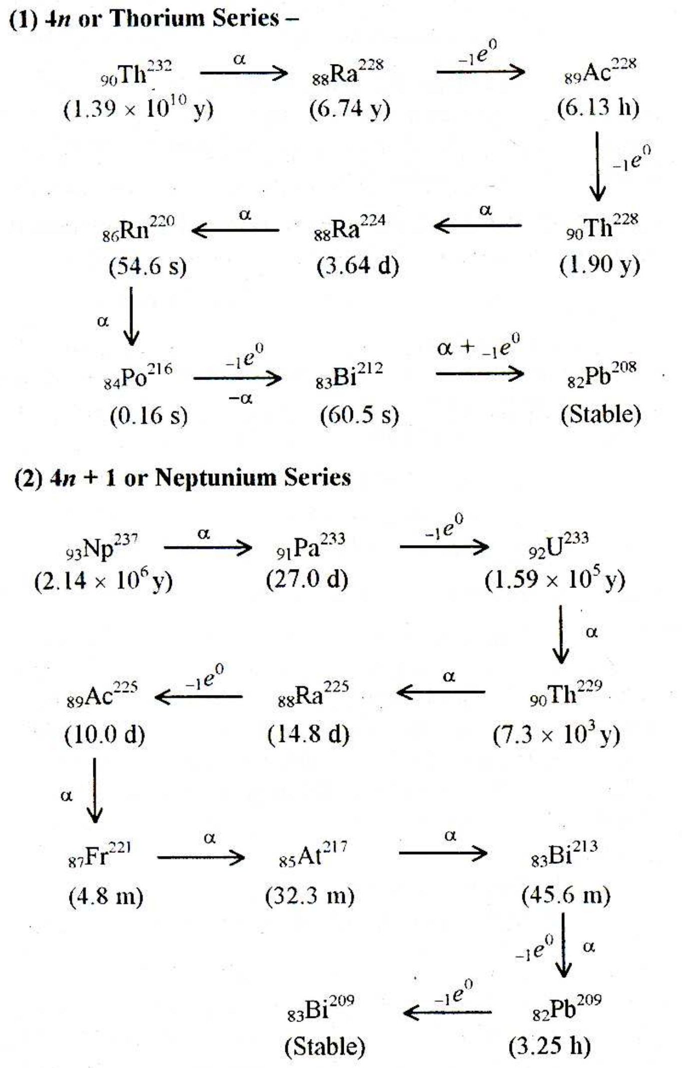
(4) Actinium series or (4n + 3) series

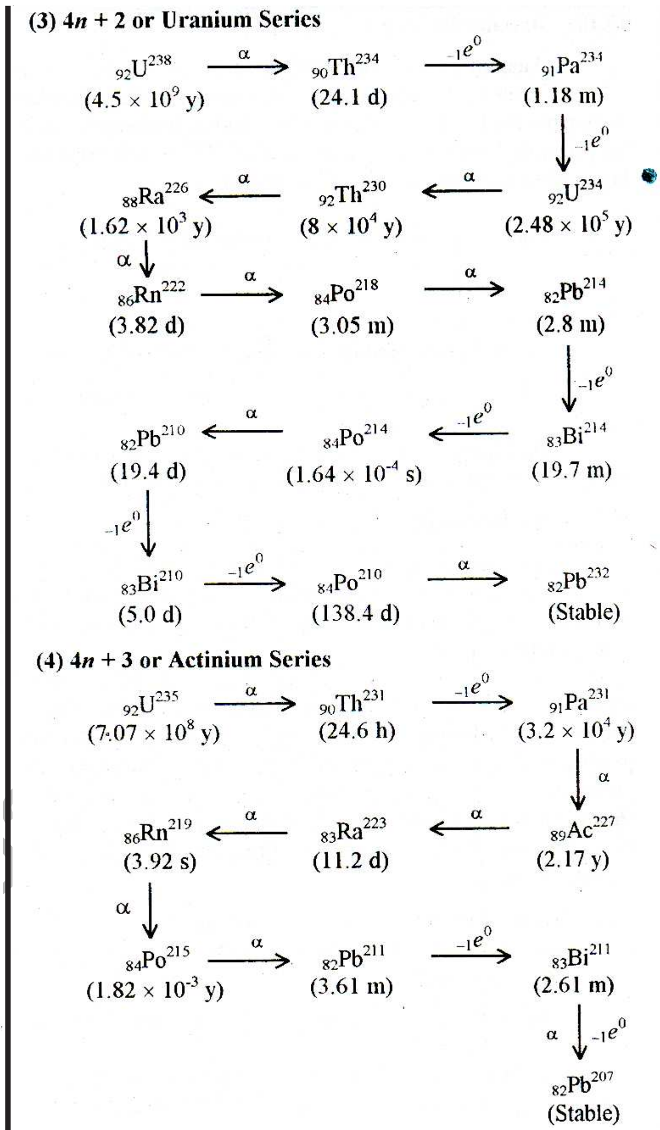
Mass number of all the members of 4n series are completely divisible by 4, whereas, on dividing mass number of (4n + 1), (4n + 2) and (4n + 3) series, remainders are 1, 2 and 3. respectively.

Main Characteristics of Disintegration Series

Series	Parent element	Half life of parent element (in years)	Stable end product	Emitted Radiations	
				α	β
4n (Th)	$_{90}Th^{232}$	1.4×10^{10}	$_{82}Pb^{208}$	6	4
4n + 1 (Np)	$_{93}Np^{237}$	2.25×10^6	$_{83}Bi^{209}$	7	4
4n + 2 (U)	$_{92}U^{238}$	4.51×10^9	$_{82}Pb^{206}$	8	6
4n + 3 (Ac)	$_{92}U^{235}$	7.07×10^8	$_{82}Pb^{207}$	7	4

20.1. Disintegration Series





21. Artificial Radioactivity

Bombardment of stable elements by particles like ex, $_1H^1$, $_1H^2$, $_1H^3$, $_2He^4$, $_0n^1$, can be used to make them radioactive. Artificially prepared stable radioactive elements are called artificial radioactive elements.

For example, aluminium on bombardment with exparticles, gives radioactive phosphorus, with emission of neutrons and positrons. Emission of neutrons ceases on stopping bombardment, whereas emission of positron continues, but rate of emission goes on decreasing.

It is known from the study of these reactions that aluminium is converted to P–30 on bombardment by alpha particles. P-30 is unstable nucleus. Therefore, it goes on disintegrating and emitting positrons continuously. Unstable nucleus of P-30. converts to stable nucleus of Si-30 after disintegration.

$$_{13}Al^{27} + _2He^4 \rightarrow _{15}P^{30} + _0n^1$$

$$_{15}P^{30} \rightarrow _{14}Si^{30} + _1\beta^0$$

- Positron

Silicon (Stable)

Thus. radioactive isotopes of many stable elements can be prepared by artificial methods.

(i) Carbon from Boron

$_{5}B^{10} + {}_{2}He^{4} \rightarrow {}_{7}N^{13} + {}_{0}n^{1}$

$_{7}N^{13} \rightarrow {}_{6}C^{13} + {}_{1}\beta^{0}$

(ii) Carbon from Nitrogen

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

(iii) Manganese from Cobalt

$_{27}Co^{59} + {}_{0}n^{1} \rightarrow {}_{25}Mn^{56} + {}_{2}He^{4}$

22 Radio Carbon Dating

By this method, age of any piece of wood or fossil of an animal or plant can be easily determined. Carbon present in protoplasm is a mixture of stable isotopes (C^{12} and C^{l3}) and radioactive isotopes (C^{14}).

Neutron particles generated from cosmic rays of sunreact with atmospheric nitrogen to form radioactive carbon.

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

$_{6}C^{14}$ reacts with the atmospheric oxygen to form CO_2. This CO_2 diffuses into the atmosphere and a definite proportion of this. CO_2 is present in the atmospheric CO_2. In the process photosynthesis, CO_2 is also absorbed by plants along with atmospheric CO_2. Radioactive carbon reaches the animal body from these plants taken in as food. In this manner. radioactive carbon and normal carbon are present in definite proportions in the plant and animal bodies. When plants and animals are dead, tlten the ratio of radioactive carbon and ordinary carbon starts changing, because the radioactive carbon disintegrates as follows.

$_{6}C^{14} \rightarrow {}_{7}N^{14} + {}_{1}e^{0}$ $t_{1/2}$ = 5770 years

Fresh plants have a definite $\frac{*C}{C}$ ratio. By calculating the half-life from the lowered $\frac{*C}{C}$ ratio after death of plants, age of plants and animals can be calculated.

23. Isotopes

The atoms, which have same atomic number but different atomic weights, are called isotopes. e.g., three isotopes of oxygen are $_{8}O^{16}$, $_{8}O^{17}$ and $_{8}O^{18}$

Thus, isotopes are formed due to different numbers of neutrons in the nuclei of the atoms.

$_{92}U^{238}$ and $_{92}U^{234}$ $_{90}Th^{230}$ and $_{90}Th^{234}$

$_{82}Pb^{218}$ and $_{82}Pb^{210}$

Isotopes of many elements are unstable and therefore, they exhibit radioactivity. They can be obtained by artificial transfonnation. These are called radio isotol)es.

24. Isobars

Atoms of different elements whose atomic weights are same, they are called isobars. Therefore, number of protons and neutrons are different in isobars. But the total of protons and neutrons is same. e.g.

$_{19}K^{40}$, $_{20}Ca^{40}$, $_{18}Ar^{40}$

25. Isotones

The atoms in which number of neutrons is same are called isotones, e.g.,

(1) $_{6}C^{14}$, $_{7}N^{15}$ and $_{8}O^{16}$ (2) $_{2}He^{4}$ and $_{1}T^{3}$

26. Apldications of Radio Isotopes

(1) As Tracers

Radioactive isotopes are used as tracers for determining the pathway of chemical conversions,.

(a) To identify the mechanism - It had been a belief for many years that H^+ ion from a carboxylic acid and OH^- ion' from C_2H_5OH react with each other and get removed in the fonn of a water molecule during the process of esterification.

$CH_3–COO–H+H–O–C_2H_5 \rightarrow CH_3COOC_2H_5 + H_2O$

But on using radioactive oxygen, it was found that released water molecule is formed by joining up of H^+ from C_2H_5OH and OH^- from CH_3COOH.

$CH_3–CO–OH+H–O–C_2H_5 \rightarrow CH_3COOC_2H_5 + H_2O$

(b) In Biochemical Science - Tracer elements are used for knowing the mechanisms of biochemical reactions occuring in plants and animals. CO_2 containing radioactive C^{14} was used for knowing the mechanism of photosynthesis.

(2) As Catalysts

Many radioisotopes are used in the form of catalysts, e.g., $_{27}Co^{60}$ is used as a catalyst in the manufacture of polythene from ethene.

(3) In Radio Therapy

Curing of diseases with the help of radiations is called radio therapy. For example,

(a) $_{53}I^{131}$ is used to control throat cancer.

(b) $_{15}P^{32}$ is used in the therapy of blood cancer.

(c) Radiations emitted by $_{15}P^{32}$. $_{27}Co^{60}$ and $_{86}Rb^{222}$ give relief when they are showered on cancer-affected parts.

(4) In Agriculture

High quality crop is obtained when the seeds are treated with α particles.

(5) As Energy Source

Energy obtained from radio isotopes is used in nuclear reactors as source of energy used for peaceful purposes.

(6) To Determine Age of Earth

On the basis of radioactive property of uranium, age of the earth and rocks is calculated.

(7) In Estimation of Age of Fossils

Age of fossils is determined by the help of radioactive carbon.

(8) In Discovery of New Elements and Compounds

New elements are discovered by nuclear reactions so that periodic table can be updated.

(9) In the Security of Nation

Ratio isotopes are used in atomic warheads for security of our country.

27. Man-made Elements

Earlier it was believed that a total of 92 elements are there in nature. Last element is uranium, U–92, which is unstable radioactive element. Presently, there are elements from atomic number 93 to 109, which are not found in nature, i.e. they are synthesised artificially. These elements are called transuranic elements, because they come after u-92. First transuranic element is neptunium (Np-93) which is obtained by bombardment on U^{238} with neutrons.

$$_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} \rightarrow {}_{93}Np^{239} + {}_{-1}e^0$$

$_{93}Np^{239}$ is a radioactive element which forms $_{94}Pu^{234}$ by emission of β-particles.

$_{93}Np^{239}$

$$_{93}Pp^{239} \rightarrow {}_{94}Pu^{239} + {}_1e^0$$

Thus, elements can be synthesised by nuclear reaction which are not found in nature.

Solved Example

Ex.1 If half-life of element A is 10 years, calculate the time required to reduce its reactivity to 1/8 of its original value.

Sol. $$\frac{1}{8} = \left(\frac{1}{2}\right)^x = \left(\frac{1}{2}\right)^3$$

Number of half-life = 3

Time = 3 x 10 = 30 years

Ex.2 Calculate the numbers of α and β particles emitted in the conversion of ${}_{92}U^{238}$ to ${}_{82}Pb^{206}$.

Sol. Suppose that the number of emitted a particles is x and number of b particles is y.

$${}_{92}U^{238} \rightarrow {}_{82}Pb^{206} + x({}_2He^4) + y(-e^0)$$

(i) On balancing mass number on both the sides.

$238 = 206 + 4x + 0y$

$238 = 206 + 4x$

$$x = \frac{238-206}{4} = 8$$

Number of emitted α particles = 8

(ii) On balancing charge number on both the sides

$92 = 82 + 2x + (-1)y$

$92 = 82 + 2 \times 8 + -y$

$y = 98 - 92 = 6$

Number of emitted β particles = 6

Ex.3 1.0 gram of a radioactive substance becomes 0.50 gram after 10 days, then calculate the decay constant and half-life.

Sol. $$\lambda = \frac{2.303}{t} \log \frac{No}{N}$$

$$= \frac{2.303}{t} \log \frac{1.0}{0.50}$$

$$= \frac{2.303}{10} \log^2$$

$$= \frac{2.303}{10} \times 0.3010 = 0.06393$$

$\lambda = 0.0693$

Half-life $t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{0.0693} = 10$ days

Ex.4 Reactivity of a wood sample is 10 $dm^{-1}g^{-1}$ and reactivity of freshly cut tree is 15 $dm^{-1}g^{-1}$, then what should be the age of the sample of wood, if half-life of ${}_6C^{14}$ is 5770 years (d = disintegration)

Sol. $$\lambda = \frac{0.693}{t^{1/2}} = \frac{0.693}{5770} y^{-1} = 1.3 \times 10^{-4} y^{-1}$$

$$t = \frac{2.303}{\lambda} \log \frac{N_0}{N}$$

$N_0 = 15\ dm^{-1}g^{-1}$ $\quad N = 10\ dm^{-1}\ g^{-1}$

$t = \frac{2.303}{1.3\times10^{-4}} \log \frac{15}{10}$ $\quad t = \frac{2.303}{1.3\times10^{-4}} (\log 3 - \log 2)$

$t = \frac{2.303}{1.3\times10^{-4}} (0.47 - 0.30)$ $\quad t = \frac{2.303\times0.17\times10^4}{1.3} = \frac{0.39\times10^4}{1.3} = 0.3 \times 10^4 = t = 3000$ yrs.

Ex.5 Rate of disingegration of a $CaCO_3$ sample of a preserved egg-shell is 500 d $hour^{-1}g^{-1}$. Calculate the age of the shell when half-life of C^{14} is 5770 years and rate of radiation of living animals is 15 $dm^{-1}g^{-1}$.

Sol. $\lambda = \frac{0.693}{t^{1/2}} = \frac{0.693}{5770} = 1.3 \times 10^{-4} y^{-1}$

$\frac{500d\ hours^{-1}}{60} = 8.3\ d\ min^{-1}$

$t = \frac{2.303}{\lambda} \log \frac{N_0}{N}$ $\quad t = \frac{2.303}{\lambda} \log \frac{15}{8.3}$

$t = \frac{2.303\times10^4}{1.3} \log \frac{15}{8.3}$ $\quad t = \frac{2.303\times10^4}{1.3} (\log 15 - \log 8.3)$

$t = \frac{2.303\times10^4}{1.3} (1.17 - 0.90) = 4.7 \times 10^3$ years

Ex.6 In a sample of uranium ore, 5.00 mg of U^{238} and 2.00 mg of Pb^{206} are present, then what should be the age of the rock. If half-life of U^{238} is 4.5×10^9 years.

Sol. $\lambda = \frac{0.693}{t^{1/2}} = \frac{0.693}{4.5\times10^9} = 0.15 \times 10^9 = 1.5 \times 10^8$

Digintegration of uranium to lead

$U^{238} \rightarrow {}_{82}Pb^{206} + 8({}_2He^4) + 6({}_1e^0)$

$\therefore$ 206 gram of Pb is obtained from 238 gram of U

$\therefore$ 2×10^{-3} gram of Pb is botained from $\frac{238}{206} \times 2 \times 10^{-3}$ gram of U

$= \frac{436\times10^{-3}}{206} = 2.1 \times 10^{-3}$ gram of U

2×10^{-3} gram of Pb = 2.1×10^{-3} gram of U

2.0 gram of Pb = 2.1 gram of U

Therefore, initial amount of uranium

5.00 mg + 2.10 = 7.10 mg

$t = \frac{2.303}{\lambda} \log \frac{N_0}{N}$ $\quad t = \frac{2.303}{0.693} \times 4.5 \times 10^9 \log \frac{7.10}{5.00}$

$t = \frac{2.303}{0.693} \times 4.5 \times 10^9 \times 0.15$

$t = 2.2 \times 10^9$ years

Ex.7 The counting rate of a given sample is 40 and 20 α-particles per minute at the beginning and after 3 minutes respectively. Evaluate decay constant :

(1) 0.2303 min^{-1} (2) 0.50 min^{-1} (3) 0.40 min^{-1} (4) None

Sol. $\lambda = 2.303 / t \log N_0/N = 2.303 / 3 \times \log 40/20$

$= 2.303 / 3 \times 0.30 \quad = 2303\ min^{-1}$

Ex.8 A nuclear reactor produces radioactive phosphorus (P^{32}) with half life of 13.8 days. Initially the activity was 2.0 x 10^9 nuclei per second. After how much time from the begining of production the activity will reduce to 1 x 10^9 dps.

(1) 13.8 days (2) 27.6 days (3) 6.9 days (4) None

Sol. $l = 2.303/t \log N_0/Nt$

$0.69/13.8 = 2.303/t \log 2 \times 10^9/1 \times 10^9$

$0.69/13.8 = 2.303 \times 0.30 /t$

$t = 13.8$ days

Ex.9 Activity of radio active nuclide is 120 particles per minute. The activity after one third of its half life period (particles per minute)

(1) 96 ppm (2) 120 ppm (3) 240 ppm (4) None

Sol. $\lambda = 2.303/t_{0.5/3} \log N_0/N_t$

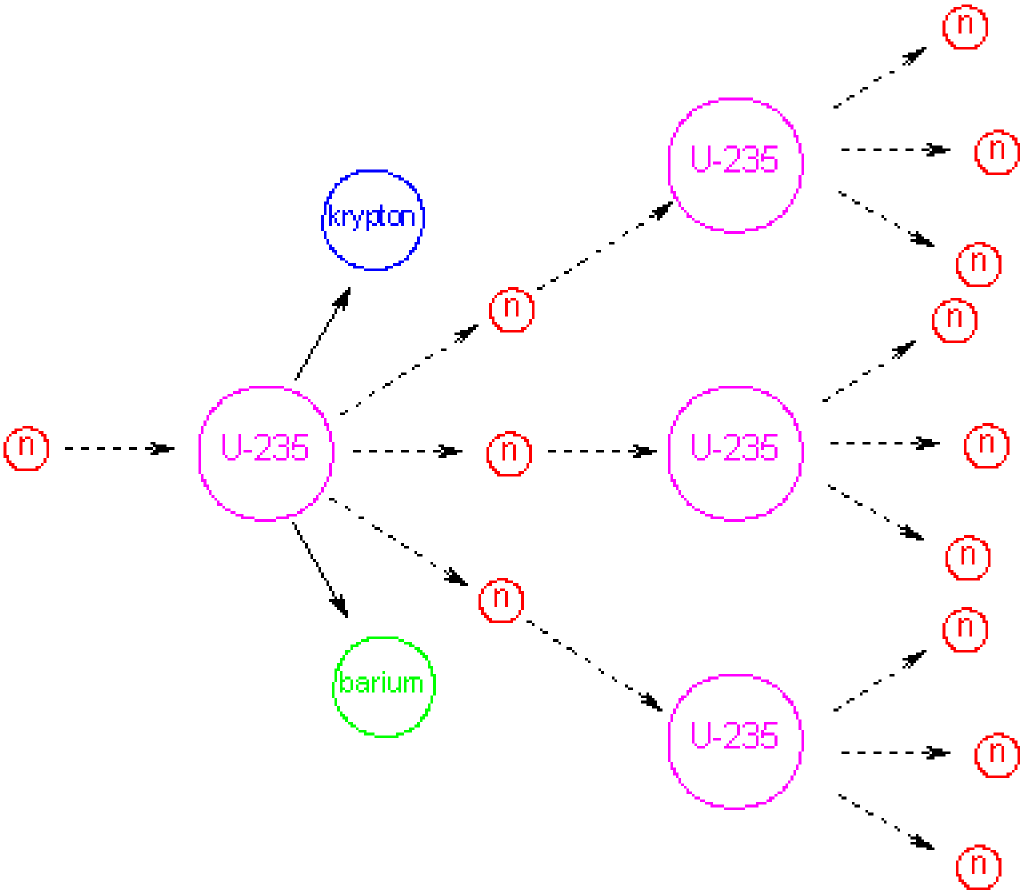
$0.693/t_{0.5} = 2.303/t_{0.5/3} \log 120/N_t$

$0.693/t_{0.5} = 6.9/t_{0.5} \log 120/N_t$

$0.1 = \log 120/N_t$

Antilog $0.1 = 120/N_t$

$1.25 = 120/N_t$, $N_t = 120/1.25 = 96$ ppm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