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PAPER- II

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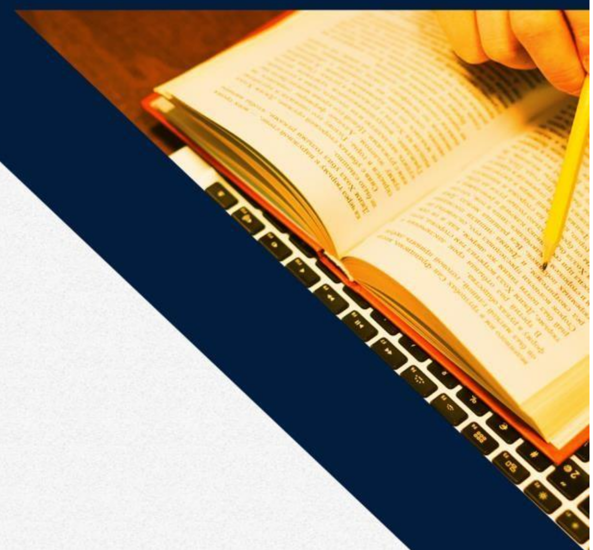
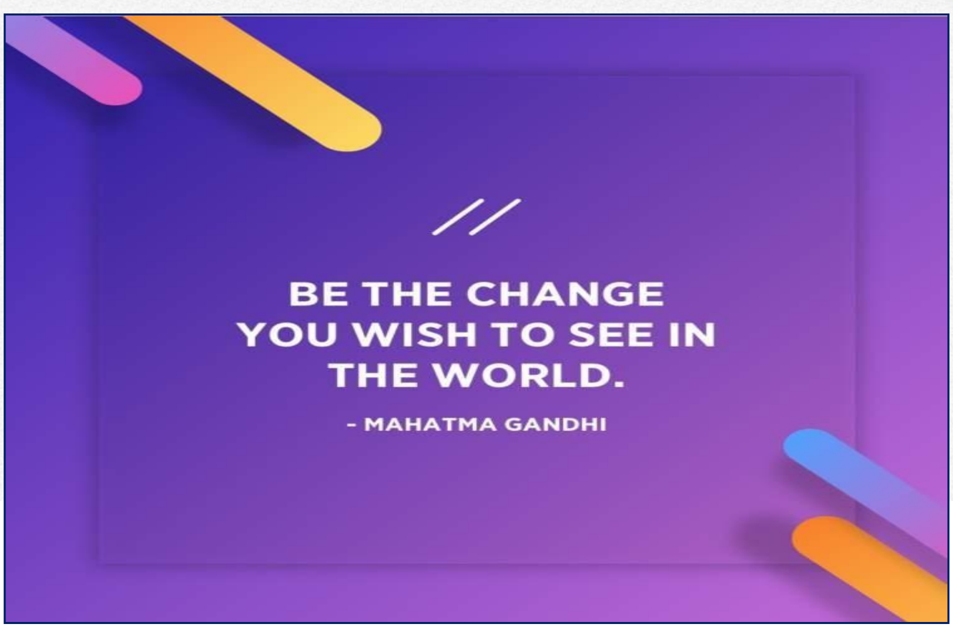




1.12. Nuclear Chemistry

Key Words:

Basic key Statements: discovery of radioactivity (1.12.1), definition (1.12.2), active radiation (1.12.3), radioactive substance (1.12.4), condition for radioactivity (1.12.5), characteristics of Alpha ray(1.12.6), characteristics of Beta ray(1.12.7.), characteristics of Gamma ray (1.12.8.), unit of radioactivity (1.12.9), alpha, beta gamma particle emission (1.12.11,12,13), half-life period (1.12.17), average life period (1.12.19), types of radioactive decay (1.12 22), isotopes (1.12.35), mono isotopes (1.12.36), actual atomic mass calculation (1.12.37), isobars (1.12.39), isotones (1.12.40), capture reaction (1.12.41), nuclear reaction (1.12.43), fission reaction (1.12.44), fusion reaction (1.12.45), nuclear reaction vs chemical reaction(1.12.47), nuclear density (1.12.48), nuclear stability (1.12.49), nuclear binding energy (1.12.56), mass defect (1.12.59), packing fraction (1.12.67), magic number (1.12.68), radiocarbon dating (1.12 71), uses of radioisotopes (1.12.72), fissile nuclides (1.12.77), fertile nuclides (1.12.78), Stellar energy (1.12.79), coldfusion (1.12.80), spontaneous fusion k1.12.81), unit of cross section (1.12.84), reaction cross section (1.12.83),

Standard key Statements: decay law(1.12.14), relationship between half life and average life (1.12.20), transient equilibrium (1.12.24), secular equilibrium (1.12.25), branching decay (1.12.27), group displacement law (1.12.28), separation of isotopes (1.12.38), particle particle reactions (1.12.42), Segre chart (1.12 51), Harkins rule(1.12.69), Meson theory (1.12.75), nuclear model (1.12.76), threshold energy (1.12.82),1/v law (1.12.86), temperature dependent reaction (1.12.96).

Advanced key Statements: radioactive disintegration (1.12.10), exponential law (1.12.16), radioactive equilibrium (1.12.23), radioactive series (1.12.29), similarities between radioactive series (1.12.34), spallation reactions (1.12.46), relative biological effectiveness (1.12.73), radiation hazards (1.12 74), cumulative chain fission yield (1 3.91), relation between fission energy and fission barrier (1.12.92), resonance (1.12.93).

Key Facts:

1.12.1. Discovery of radioactivity: After the discovery of X-Ray radioactivity was discovered by Henri Becquerel in 1986. The term radioactivity was first used by Marie Curie.

1.12.2. Radioactivity: Radioactivity is a nuclear phenomenon and is a drastic process of spontaneous disintegration of certain nuclei to form new elements with the emission of active radiation.

1.12.3. Active radiation: Active radiation is really consisting of α-particle ($_2He^4$), β-particle ($_{-1}e^0$) andγ-ray (a very short wavelength electromagnetic radiation). They are called active as they affect photographic plate and interact with electric and magnetic fields.

1.12.4. Radioactive substance: The substance which emit these radioactive rays are called radioactive substance.

1.12.5. Condition for radioactivity: The substance which have $\frac{n}{p} > 1.5$ are mainly radioactive. It will be further explained on binding energy curve.

1.12.6. Characteristic of α-ray:

a. Charge: +2e
b. Mass: 4 times of hydrogen.
c. Speed: $2 \times 10^7 m/s$
d. Penetrating power: weak, 0.1mm of Al.

1.12.7. Characteristics of β-ray:

e. Charge: -e

f. Mass: Mass of hydrogen.

g. Speed:$2 \times 10^8\ m/s$

h. Penetrating power: medium, 0.1mm of Al

1.12.8. Characteristic of γ-ray:

i. Charge:0

j. Mass:0

k. Speed:$3 \times 10^8\ m/s$

l. Penetrating power: high, 25 cm of steel and 5 cm of Pb

1.12.9. Unit of radioactivity:

- SI unit = Becquerel (Bq)
  1Bq = one disintegration per second (dps)
- The common unit is Curie (Ci)
  1 Ci=$3.6 \times 10^{10}\ dps$
- Other two submultiple units maybe used are millicurie and microcurie.
- Another unit is Rutherford (Rd)
- 1 Rd=$10^6\ dps$

1.12.10. Radioactive disintegration: Atoms of heavy element like is Uranium, thorium and radium etc. are constantly breaking up into fresh radioactive atom with the emission of α, β and γ-rays from there nuclei. In this process the parent atom disappears and give rise to new atom. This new atom is also radioactive and hence spontaneously break up until an inactive element is reached. This process is known as radioactive disintegration.

1.12.11. α particle emission: When an Alpha ($_2He^4$) particle is emitted from the nucleus of an atom, the nucleus of the new element possesses atomic weight less by 4 units and atomic number less by 2 units.

$$_{88}Ra^{226} \xrightarrow{-\alpha} {}_{86}Rn^{222}$$

1.12.12. β particle emission: When a beta particle (-1e0) is emitted from the nucleus of an element, the nucleus of the new element possesses atomic weight less by 4 units and atomic number less by 2 units.

$$_{82}Pb^{210} \xrightarrow{-\beta} {}_{83}Bi^{210} + {}_{-1}e^{0} + \gamma\text{-ray.}$$

1.12.13. γ-ray emission: Gamma rays are short wave electromagnetic radiations with no charge and no mass. Thus, the emission of gamma rays from a radioactive element will not produce a new element.

1.12.14 . Disintegration law or Decay law: the rate of disintegration of a radioactive element is directly proportional to the number of radioactive elements present at the instant.

Mathematically: $-dN/dt \propto N$

- The rate gradually decreases with increasing time. So that negative sign is justified.

1.12.15. $t = \frac{2.303}{\lambda} log(No/N)$

t is time.

No is initial amount of the element.

N is the final amount of the element.

λ is decay constant.

Radioactive decay obeys 1^{st} order kinetics.

1.12.16. **Exponential law:** $N = N_o e^{-\lambda t}$.

1.12.17. **Half life period**($t_{1/2}$): The time required to disintegrate half of the original amount is called its half-life.

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

1.12.18. Half life period independent with the initial amount, but this is a characteristic of a radioactive element.

1.12.19. **Average life period (t_{av}):** the rate of disintegration always decreases with increasing time. All the elements never disintegrate at the same time. They have a different life period.

$t_{av}=1/\lambda$

1.12.20. Relationship between half life period and average life period:

- $t_{1/2}=0.693t_{av}$
- $t_{av}=1.44t_{1/2}$
- $t_{av}>t_{1/2}$

1.12.21. Infinite time is required for complete disintegration of a radioactive element

i.e. $t = \infty$

1.12.22. Types of radioactive decay:

- **Alpha decay**: in Alpha decay two protons and two neutrons are emitted from the nucleus together as an Alpha particle.

$_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + \alpha({}_{2}He^{4}) + Q$ (Q is energy)

- **Beta decay:** In beta decay a negative electron is emitted by the nucleus and the atomic number is increased by 1 unit.

$_{6}C^{14} \rightarrow {}_{7}N^{14} + \beta + \bar{\nu} + Q$ ($\bar{\nu}$ stands for antineutrino)

- **Positron emission** also beta decay process results in a decrease by 1 unit in atomic number.

$_{11}Na^{22} \rightarrow {}_{10}Ne^{22} + \beta^{+} + \nu + Q$ (ν represent neutrino)

- **Electron capture** is a third type of beta decay in which the atomic number is decreased by 1 unit as in positron emission.
- In all types of beta decay processes since the atomic mass decreases very slightly the mass number remain unchanged.
- Another decay mode is known as **spontaneous fission** in which some heavy nuclei break up into to intermediate mass fragments and several neutrons.

1.12.23. Radioactive equilibrium: Radioactive phenomena is an irreversible process. So, there is no true equilibrium, only a steady state is appeared when two successive disintegration is formed.

At equilibrium state $N_1/N_2 = (t_{½})_1/(t_{½})_2 = \gamma_2/\gamma_1$

1.12.24. **Transient equilibrium**: The radio nuclei where the daughter has a first decay constant then the parent the relative amount of daughter i.e. N_B/N_A remains unchanged with time but the total activity slowly decreases. This process is known as transient equilibrium.

$$\frac{N_B}{N_A} = \frac{\lambda_A}{\lambda_B - \lambda_A}$$

$$^{234}\text{Th} \xrightarrow{\beta^-} {}^{234}\text{Pa} \xrightarrow{\beta^-} \ldots\ldots\ldots\ldots$$

1.12.25. **Secular equilibrium**: It is also known as permanent equilibrium. It is attained when the decay a constant of the parent is negligibly small in comparison to the decay constant of the daughter i.e. $\lambda_A << \lambda_B$.

$$\frac{N_B}{N_A} = \frac{\lambda_A}{\lambda_B} = \frac{(t_{1/2})_B}{(t_{1/2})_A}$$

$$^{238}\text{U} \xrightarrow{\alpha} {}^{234}\text{Th} \xrightarrow{\alpha} \ldots\ldots\ldots\ldots$$

1.12.26. If the parent is shorter-lived than the daughter ($\lambda_1 > \lambda_2$) **no equilibrium** is attained at any time.

1.12.27 . **Branching decay:** The case of branching decay occurs when a radioactive element can decay more than one mode.

1.12.28 . Group displacement law: To find a relation between daughter and parent elements in the disintegration process Soddy, Fajanand Russell established a simple rule known as Soddy-Fajan group displacement theory. It Suggest that

- In all known radio active transformation either an Alpha or a beta particle is emitted by a radioactive element.
- When an Alpha particle is emitted the atom of a new element is formed whose mass number is less by 4 units and atomic number is less by two units than those of the parent atoms and the daughter is shifted to two group left to the parent element in the periodic table.

  $_{84}Po^{215}$(gr.16)-α ❼ $_{82}Pb^{211}$ (gr.14).
- When a beta particle emits the daughter form having the same mass number but atomic number increases by 1 unit. Thus, the parent element and the daughter element are shifted to one group write to the parent atom in the periodic table.

  $_{82}Pb^{211}$(gr.14) ❼ $_{83}Bi^{211}$ ❼ $_{84}Po^{211}$ (gr.16)

1.12.29. Radioactive series : All the naturally occurring radioactive elements belong to one of the following three series.

- Uranium series {(4n+2) series}
- Thorium series {4n series}
- Actinium series {(4n+3)}

  These are also known as natural radioactive series.

1.12.30. Uranium series: This series is also called (4n+2) cease as the mass number of the elements of this series are given by this expression in which n is an integer whose value decreases by unity when we go from one radioactive element to the next one below it.

${}_{92}U^{238}$ ❼ ${}_{82}Pb^{206}$

1.12.31. Thorium series: This series is known as 4n series because mass numbers of this series are divisible by 4.

${}_{90}Th^{232}$ ❼ ${}_{82}Pb^{208}$

1.12.32. Actinium series: This is known as (4n+3) series because the mass number of the members of the series give a reminder of 3 e when divided by 4.

${}_{92}U^{235}$ ❼ ${}_{82}Pb^{207}$

1.12.33. Neptunium series {(4n+1)}: This series has been obtained from an artificial produced radioactive material.

${}_{93}Np^{237}$ ❼ ${}_{83}Bi^{209}$

- All the members of this series are either unknown or extremely rare in nature.

1.12.34. Similarities between radioactive series:

- In all series, a product is formed which disintegrates in a branching process by emitting either Alpha or beta particle. The two substance thus produced are then transformed in such a way as to give a common product.

- In all series there is an element of atomic number 86 which has the properties of an inert gas is called **emanation.**

The table in product in all the three series having an atomic number 82 is an isotope of lead i.e. Pb^{206}, Pb^{207}, Pb^{208}.

1.12.35. Isotopes: Different kinds of atoms of the same element which have same atomic number but different mass number are called isotopes of that element.

1.12.36. Mono isotopes: some elements like beryllium and fluorine are found in nature as a single isotope. 7 elements are called monoisotopic.

Only about 20 elements have been found to be monoisotopic.

1.12.37. Actual atomic mass calculation: the atomic weight of an element is a statistical mean of the atomic masses of different isotopes of the elements. The value of atomic weight depends on the relative proportions of the various isotopes.

Example: ordinary chlorine consists of 75% ^{35}Cl isotope and it 25% off^{37}Cl isotope. Hence its atomic mass is $\frac{(75 \times 35) + (25 \times 37)}{(75 + 25)} = 35.5$

1.12.38. Separation of isotopes: Since all the isotopes of a given element have similar properties, it is almost impossible to separate them by chemical method. Some physical methods have been used for this purpose, such as

- **Gaseous diffusion method**: If a mixture consisting of two gaseous isotopes, the lighter isotope passes through the porous portion more rapidly than the heavier one.

- **Thermal diffusion method:** This method is based on the tendency of heavier molecules of a gas to concentrate in the cooler region of the vertical tube.
- **Fractional distillation and evaporation method**: Lighter isotope distilled off first why the heavier isotope distilled off last.
- **Electromagnetic method:** This method is based on the principle of Dempster's mass spectrograph. This method has been used for the separation of the three isotopes of neon.

1.12.39. **Isobars:** The atoms of different elements which have the same mass number but different atomic number are called isobars.

1.12.40. **Isotones**: The atoms of different elements which have the same number of neutrons but different atomic number are called isotones.

1.12.41. **Capture reaction:** In this reaction the bombarding particle is captured or absorbed by the target nucleus with the emission of gamma rays.

$${}_{6}C^{12} + {}_{1}H^{1} \rightarrow {}_{7}N^{13} + \gamma.$$

1.12.42. **Particle – particle reactions:** In these reactions the bombarding particle is absorbed by the target nucleus to form the compound nucleus which breaks down to give final product.

$${}_{11}Na^{24} + {}_{2}He^{4} \rightarrow {}_{13}Al^{28} \rightarrow {}_{13}Al^{26} + 2\,{}_{0}^{1}n$$

1.12.43. Nuclear reaction: This is a process in which a heavy nucleus (target) is bombarded by high energy particle (projectile) and produce more stable lighter nuclei is called nuclear reaction.

General representation: $\underbrace{A}_{Target} + \underbrace{B}_{Projectile} \rightarrow \underbrace{C}_{Product} + \underbrace{D}_{emitted\ particle}$

Mode of writing: **A(B,D)C**

1.12.44. Fission reaction: This is a nuclear reaction in which is heavier constable nucleus is broken down into it to light a stable nucleus with river basin of huge amount of energy is called Nuclear fission reaction.

- In this process it will require high energy nucleus producers about 2.5 free neutrons.
- Each fission produces 200MeV energy.
- Fission always occur in a symmetric fashion, it means number of nuclei undergoing unsymmetrical fission is maximum.

1.12.45. Fusion reaction: This is a nuclear reaction in which two lighter nuclei combined together to produce more stable heavier nucleus with liberation of higher amount of energy called as nuclear fusion reaction.

- This reaction occurs at a very high temperature 20x10^6 degree Celsius to overcome the repulsive forces arise between the two nuclei.
- This is also known as the thermonuclear reaction.
- Generally, it occurs in the Stellar region.

1.12.46. Spallation reactions: This is a special type of nuclear fission reaction where is medium nucleus is broken down in presence of very high energy charged particle (400MeV) to produce a new nucleus with liberation of large number of particles is called Spallation reaction.

1.12.47. Nuclear reaction vs chemical reaction:

- In chemical reactions rearrangement of outermost electrons of the atom takes place while the nuclei remain unaffected. So, no new atomic species are formed in chemical reaction. But in the nuclear reaction there is a change in nucleus so new atomic species are formed.
- The amount of energy released in nuclear reactions is millions of times greater than that produced in chemical reactions.

1.12.48. Nuclear density: Nuclear mass/nuclear volume.

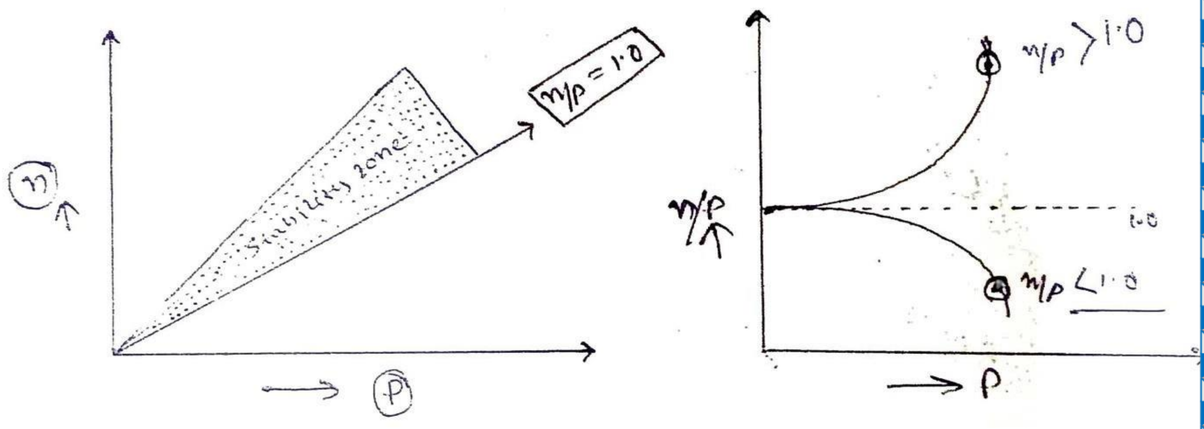
1.12.49. Nuclear stability: The stability of nucleus depends on the nuclear composition that is neutron proton ratio ($n/p=1.0$).

$n/p=1.0$ (stable)
$n/p>1.0$ (unstable)
$n/p<1.0$ (unstable)

1.12.50. The nuclear stability depends on the several factors like-

- n/p ratio i.e. neutron proton ratio.
- Nuclear binding energy (NBE)
- Packing fraction (f)
- Magic number

1.12.51. **n/p ratio vs stability**: The n/p ratio value depends on the atomic number (z) of the element. The n/p ratio is plotted with the Z called as **Segre chart** to explain the stability of the nucleus.



1.12.52. n/p>1.0, in such case nucleus are β^- emitter.

1.12.53. n/p<1.0, in such case nucleus are β^+ emitter.

1.12.54. K electron computing process: proton which nucleus prefer to accept K orbital electron and increases the n/p ratio. For that is series of Gamma ray is appeared.

${}_1P^1 + {}_{-1}e^0$ (K shell) ❼ ${}_0n^1$

1.12.55. Neutron rich nucleus is always beta minus active.

1.12.56. **Nuclear binding energy (NBE)**: Amount of energy released when definite number of nucleus come within the distance 10^{-13}cm is called its NBE or the amount of energy required to break a nucleus into its constituent particles also called its NBE.

- Higher the NBE of A nucleus higher will be its stability.

1.12.57. Representation of a nucleus: $_XZ^A$

Z=atomic number

A=mass number

A-Z=number of neutrons

1.12.58. Mass defect: Mass defect is the difference of the calculated mass of the nucleus and the experimental mass of the nucleus. Always the actual mass is lower than the calculated mass because small amount of mass may be converted to an energy which binds the nucleus.

1.12.59. Mass defect (Δm) = Calculated mass- Isotopic mass.

1.12.60. Mathematical expression of mass defect:

$$\Delta m = [Z \times (m_P + m_e) + (A - Z)m_n - M]$$

1.12.61. Total NBE(B) = $(\Delta m \times 931)MeV$

1.12.62. Average NBE($\bar{B}$) = $\frac{(\Delta m \times 931)}{A} MeV$

1.12.63. 1amu = $1.66 \times 10^{-27} kg$

1 amu = 931MeV

1.12.64. Initially the $\bar{B}$ value increased with increasing the mass number but after reaching a maximum (7.6~8.0MeV). Again, the $\bar{B}$ value decreases with increasing the mass number.

1.12.65. The mass number belonging 50-60 range suggest the stability zone of nucleus.

1.12.66. The lighter element (<20) have a smaller NBE, indicates these are constable and artificial radioactive element but for heavier element the $\bar{B}$ value is lower suggesting these are all-natural radioactive element.

1.12.67. Packing fraction:

Packing fraction (f) = $\left(\frac{Isotopic\ mass - Mass\ number}{Mass\ number}\right) \times 10^4$

$$f = \left(\frac{M - A}{A}\right) \times 10^4$$

The negative value of f suggests the stability of the nucleus whereas the positive value of f indicates that nucleus is unstable.

Modified form: $f = \left(\frac{M - actual\ mass}{A}\right) \times 10^4$

1.12.68. Magic number: Elements which have a number of electrons like 2, 10,18,36,54,86 are exceptionally stable due to cleared electronic configuration (inert gas).Similarly, number of nucleus like 2,8,20,28,50,82,126 are highly stable due to closed nuclear shell configuration. These numbers 2,8,20,28,50,82,126 (number 114,164,186 are also included) are called as magic number. Among nucleus which hole the magic number either by proton or neutron or both are highly stable than the others.

1.12.69. Harkins rule: Nuclei having an odd number of proton as well as odd number of neutrons are extremely unstable where is nucleus having an even number of proton and neutrons are highly stable.

Example: ^{18}F, ^{6}Li, ^{10}B etc.

1.12.70. $N = \frac{N_0}{2^{t/T}}$ Where, T= Half life

t= Time

N_0= Initial Amount, N= Final amount

1.12.71. Radiocarbon dating: Definition of the radiocarbon dating is based on the fundamental assumption that the intensity of cosmic Ray and hence of 14 carbon in the atmosphere has remained constant over many thousand of year.

The age of a sample is given by the expression: -

$$Age = \frac{2.303}{\lambda} \log \frac{Original\ Activity}{Final\ Activity} y$$

$$= \frac{2.303 \times 5730}{\lambda} \log \frac{Original\ Activity}{Final\ Activity} \text{ y } [\ For\ {}^{14}C \quad t_{1/2} = 5730y]$$

1.12.72. Uses of radioisotopes:

- ^{131}I has been used in locating brain tumours and malignant thyroid tumours.
- ^{32}P is used in fertilizers.
- ^{60}Cohas been used to study the migratory and breeding habits of insects which appear in swarmsand cause havoc to crops.
- Tracer iron has been used in studying the disorders associated with pregnancy.
- ^{60}Co emits high energy Gamma rays which are used for testing deeply seated cancer growth.
- RadioactiveC^{14} has been used as a tracer in studying mechanism involved in many reactions of industrial importance such as alkylation, polymerization catalytic synthesis etc.

- C^{14} in the form of $^{14}CO_2$ have been used to understand the nature of photosynthesis.
- ^{32}P has been used to locate the exact site and the position of the tumour.
- ^{24}Na may be used to detect any abnormality in the pumping action of the heart.

  It is also used to estimate the total volume of blood in a body.
- ^{67}Ga, ^{99m}Tc, ^{97}Ru are used as diagnostic aids
- ^{90}Sr may be used in charging electrical batteries in submarines and spacecrafts.
- Faults in industrial buildings and we are out of distance may be detected by ^{60}Co.
- Reactive Phosphorus in the form of phosphate is widely used in the treatment of certain blood disorder.
- ^{69}Co has been called **Poor Man's Radium**.
- Radioisotope of phosphorus is being used for the treatment of **leukaemia**.
- Radio phosphorus is good for skin disease.
- Determination of the age of the earth by Rock dating method.
- Determination of the age of recent objects by radiocarbon dating method.

1.12.73. Relative biological effectiveness (RBE):

$$RBE=\frac{Absorbed\ dose\ (in\ rad)\ of\ X-rays\ (near\ about\ 200KeV)}{Absorbed\ dose\ (rads)\ of\ the\ radiation\ that\ produces\ the\ same\ effect}$$

1.12.74. Radiation hazards: It has become a part of our life in the form of cosmic radiation, diagnostic procedures and nuclear power plants, particular after failure.

1.12.75. Meson theory of nuclear forces: According to Yukawa in 1935, the force between nucleons arises from the interchange of a new type of particle, the meson, between the nucleus. Existence of Pi meson in nucleus is well established, it may be π^0, π^- or π^+**.** Exchange of charged meson explains the mining energy of neighboring neutrons and protons but the exchange of π°explain binding energy of each kind. Conversion process are dynamic for stable nucleus. If the process stops the number of any particle increases, then equilibrium is lost and the system is unstable.

1.12.76. Nuclear model:

- Fermi gas model.
- Liquid drop model.
- Nuclear cell model.

1.12.77. **Fissile nuclides:** The nucleoid which are usually used as nuclear fuel.

Example: $_{92}U^{233}$, $_{92}U^{235}$, Pu^{239}

1.12.78. **Fertile nuclides:** The nucleus cell which are the raw materials of fissile fuel are known as fertile nuclides.

Example: ^{232}Th, ^{238}U.

1.12.79. **Stellar energy:** Many stars and our sun have been emitting an enormous amount of energy continuously for millions of millions of years. Now it is believed that the source of energy is nuclear fusion. There are three different cyclic process which are the source of Stellar energy are known.

- Carbon-Nitrogen cycle.
- Proton-Proton cycle.
- Carbon-Nitrogen-Oxygen cycle.

1.12.80. **Coldfusion:** Fusion at room temperature is known as cold fusion.

Low energy nuclear reaction = coldfusion.

1.12.81. **Spontaneous fission:** A nuclei with A>230 Suffer spontaneous fission due to the large coulombic repulsion in nucleus of high Z.

- Nuclei with z^2/A exceeding 45-51 will all suffer spontaneous fission.

1.12.82. Threshold Energy:

$$= Q \times \frac{Total\ mass\ of\ reactant}{Mass\ of\ target\ nuclei}$$

1.12.83. Reaction cross section: The probability of a nuclear process is expressed in terms of a cross-section which is denoted by σ**.** The probability for the reaction between a target nucleus and impinging particle is proportional to the cross-sectional target area presented by the nucleus.

- For a beam of particles striking a thin target, the cross section for a particular process is defined by the equation

$$R_i = Inx\sigma_i$$

R_i=The number of processes of the type under consideration occurring in the target per unit time.
n=Number of target nuclei per cubic centimetre of target.
I=The number of incident particles per unit time.
σ_i=Precaution for the specified process expressed in square centimetres.
x =The target thickness in centimetre.

1.12.84. Unit of cross section:

- The unit of nuclear cross-section is **barn.**
- The commonly used units are millibarn (mb,10^{-3}b), microbarn (μb,10^{-6}b) and nanobarn (nb,10^{-9}b)
- 1barn(b) =100fm² =10^{-28}m²

1.12.85. For every increase of neutron energy by a factor of 10^2, the wavelength decreases by a factor of 10.

1.12.86. **1/v law:** The slow neutron capture cross section varies inversely as the neutron velocity. This is referred as 1/v law.

1.12.87. The reaction cross-section varies inversely with the square root of neutron energy.

1.12.88. Lower energy particles have a longer wavelength and as a result they can surround a larger number of target nuclei leading to larger reaction cross section.

1.12.89. If the excitation energy is high enough the shape of the nucleus is distorted to ellipsoidal followed by dumbbell shaped and finally the two halves separate out as fission fragments.

1.12.90. If the excited energy is not high enough the nucleus gets excited by losingan Alpha particle.

1.12.91. **Cumulative chain fission yield:** To explain the mass distribution between fission fragments a term called cumulative chain fission yield is used.

$$Yield(A) = \frac{Number\ of\ product\ nuclei\ of\ mass\ number(A)}{Total\ number\ of\ nuclei\ fissioned} \times 100.$$

1.12.92. **Relationship between fission energy and fission barrier:** When a nucleus $_ZN^A$ breaks into two halves killing identical fragments ($^{A/2}_{Z/2}N$) the energy released is given as:

$$E_f = [\,^{A}_{Z}N - 2\,^{A/2}_{Z/2}N]\ 931\ MeV$$

1.12.93. **Resonance:** For many nuclides the neutron capture cross-section exhibits an abrupt and marked increase for certain values of the energy of the neutron. This is known as resonance.

1.12.94. Relation between threshold energy and Q:

1.12.95. For endoergic reaction Q>0.

1.12.96. Nuclear fusion occurs at reasonable rates only at very high temperature. So, these are also called thermonuclear reaction that is **temperature dependent reaction.**

1.12.97. Energy released in the nuclear fusion of four $_1H^1$ nuclei in $_2He^4$and two positrons.

1.12.98. The half lives of odd nuclei are much longer than even nuclei.