NUCLEAR CHEMISTRY

1.Define the following terms:

i) Atom ii) Atomic number (Z) iii) Mass number (A)

iv) Neutron number v) Isotopes vi) Isobars

vii) Radioactivity viii) Isotones

i) Atom : It is the smallest particle of an element which can take part in a chemical reaction.

ii) Atomic number(Z) : It represents the total number of protons present in the nucleus which also indicates the total number of electrons present in a neutral atom.

iii) Atomic mass number:The total number of neutrons and protons present in the nucleus of an atom contributing to its total mass is called as mass number.

iv) Neutron number: It represents the number of neutrons present in the nucleus of an atom.It is equal to the difference between mass number and atomic number, ie. N=A-Z.

v) Isotopes: Atoms of the same element having same atomic number but different atomic mass number are called isotopes .

vi)Isobars :Atoms of different elements having same atomic mass number but different atomic number are called isobars.

vii)Radioactivity : The spontaneous emission of radiations from heavy, unstable nuclei of radioactive elements is called radioactivity.

viii)Isotones: Atoms having same number of neutrons but different mass numbers and hence having different atomic numbers are called isotones. e. g., 2.Describe the properties of electrons, protons and neutrons.

Ans.

i)Electrons : These are negatively charged particles which revolve around the nucleus in close orbits. Mass of an electron is 5.5×10^{-4} a. m. u. or 9.11×10^{-31} kg. Electron carry a charge of 4.8×10^{-20} e.s. u. or 1.6×10^{-19} coulomb.It exhibits dual character i.e . a particle as well as a wave . An electron is represented by the symbol $_{-1}e^0$

ii)Neutrons : These are electrically neutral particles present in the nucleus of all atoms except hydrogen. The mass of a neutron is 1.0086 a.m.u which is 1840 times heavier than that of an electron . It is represented as $_0n^1$.

iii) Protons : These are positively charged particles present in the nucleus of an atom . They have a mass of 1.0078 a.m.u . They are present in the nuclei of all atoms . A proton carries a positive charge equal and opposite to the charge of an electron . Thus, on a electron scale its charge is +1.It is represented as $_1H^1$ or $_1P^1$

Factors affecting stability of nucleus

A)'Mass defect'.

It is the difference between the total mass of the nucleons of an atom and the experimentally measured mass. i.e. isotopic mass.

Explanation:

In case of Helium, the experimentally measured mass is 4.0128 a.m.u. while mass of two protons and two neutrons are 4.0331 a.m.u. Therefore, mass defect Δm is given by

$$\Delta m = 4.0331 - 4.0128 = 0.0203 \text{ a.m.u.}$$

For a nucleus having atomic number 'Z' and neutron number (A-Z), if m_p, m_n and M represent the masses of a proton, a neutron and isotopic mass respectively, then the mass defect is given by

$$\Delta m = [Z.m_p + (A-Z).m_n] -M$$

The mass defect represents the amount of energy given out when the protons and neutrons combine to form a new nucleus. This according to the Einstein's equation is

$$E = \Delta m .c^2$$

Higher the mass defect, greater the stability of the nucleus.

B)'Binding energy':

Ans.It is the energy required to break the nucleus into its constituent nucleons.i.e. neutrons and protons.

<u>Explanation</u>:

During the formation of the nucleus, it is observed that some amount of mass is lost. This loss in mass is responsible for binding the nucleons together in the nucleus. Formation of nucleus is accompanied by the release of energy. The relationship between mass and energy is given by Einstein's equation :

$$E = \Delta m.c^2$$

Where Δm = mass defect

E = energy in ergs

c = velocity of light

Relation between mass defect and binding energy:

$$\text{Binding energy} = \Delta m \times 931 \text{ MeV}$$

For nucleus with A no. of nucleons,

$$\text{Binding energy per nucleon} = \frac{\Delta m \times 931}{A} \text{ MeV.}$$

Calculate the binding energy for a mass defect of 1 a.m.u.

Ans. 1 a.m.u. = 1.66×10^{-24} gm = 1.66×10^{-27} kg.

For Δm = 1 a.m.u.

$= 1.66 \times 10^{-24} kg \ (3 \times 10^{8})^{2}$

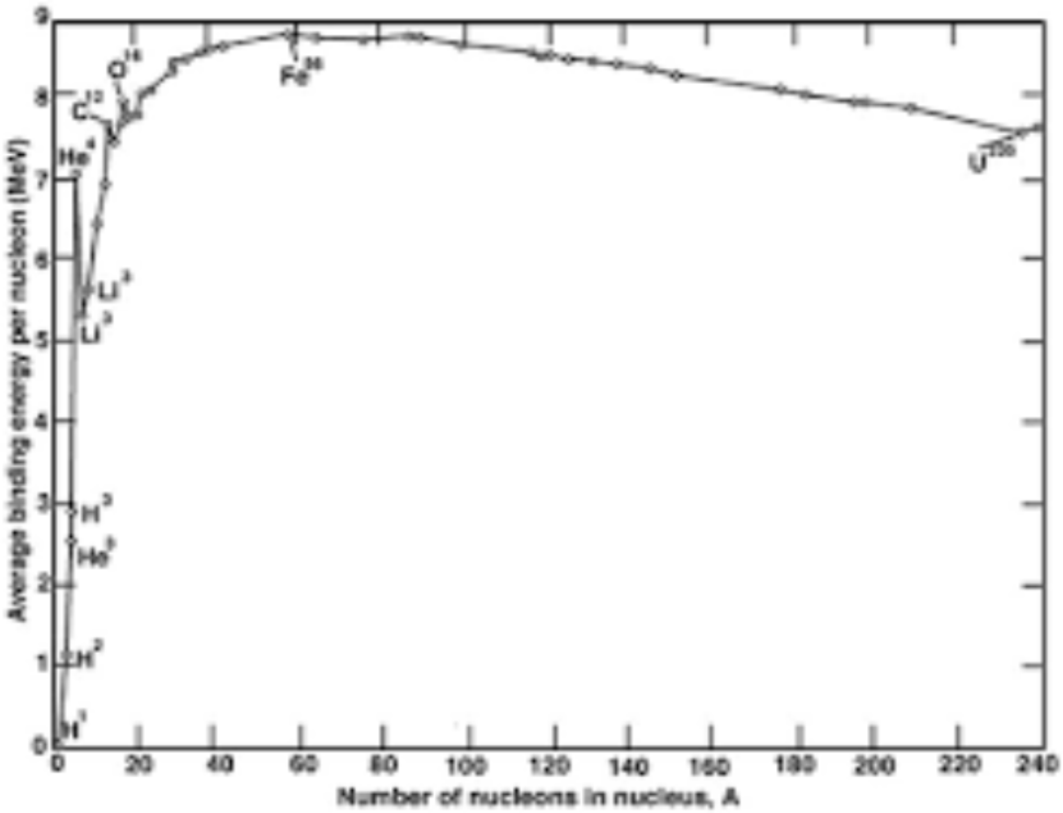
$= 14.94 \times 10^{-11}$ Joules

Now 1 MeV = $1.603 \ X \ 10^{-6}$ ergs = 1.603×10^{-13} Joules.

$\therefore$ Binding energy = $14.94 \ X \ 10^{-11} / 1.603 \times 10^{-13} \approx 931$ MeV.

Binding Energy Curve

Ans.It is a plot of average binding energy per nucleon against the mass number 'A'. It gives the information leading to condition of the stability of the nucleus.



Following conclusions can be drawn from the curve :

i) Binding energy per nucleon for elements with atomic mass number below 20 is very low (< 8 MeV). These elements have a tendency for nuclear fusion. But as the mass number increases from 20 to 60 , the binding energy per nucleon increases from 8 to 8.5 MeV. It becomes maximum of 8.7 MeV for nucleus with atomic mass number 64. Thus, elements with mass number varying from

20 to 64 have stable nuclei and the binding energy slowly decreases with increases in mass number.

ii) Elements with mass numbers ranging from 60 to 140 have constant binding energy value of 8.5 MeV indicating the most stable nuclei of these elements.

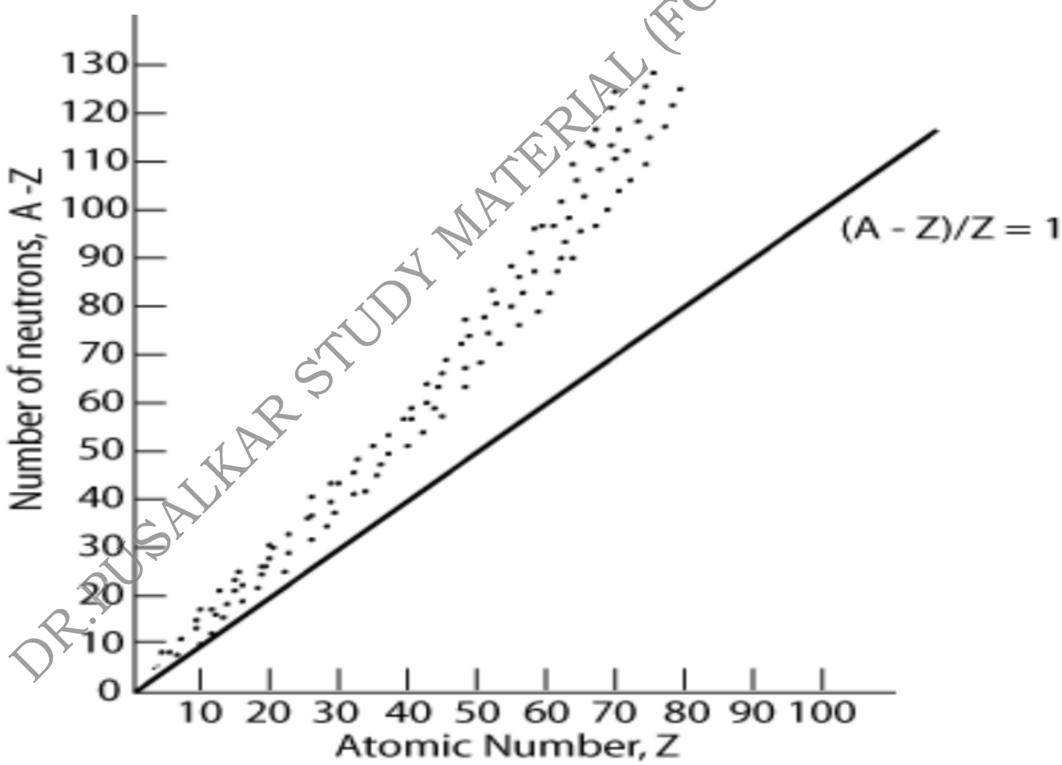
iii) However, binding energy per nucleon for element with mass number arranging from 140 to 240 decreases slowly to about 7.5MeV thereby decreasing the stability.

iv)Lastly, atoms with mass number>240 are unstable and radioactive.Therefore, they readily undergo nuclear fission.

C) Neutron-Proton ratio:

A study of the nuclei of various elements revealed that the elements with neutron-proton(N/P) ratio in the range 1 to 1.536 are more stable than the other nuclei having ratio less than this range.

For light nuclei upto $_{20}Ca^{40}$, the N/P ratio is 1 while that for $_{82}Pb^{208}$it is 1.536.As Z increases the number of neutrons also increases but not in a linear relationship as observed in the following belt of stability



From the stability belt, it is observed that

a)Nuclei upto Z=20 have N/P=1.The lower portion of the dotted curve almost lie on the ideal curve.

b) Region above the belt represent excess neutrons.

c) Region below the belt represents excess protons.

d)All nuclei with Z greater than 83 are unstable as observed from the deviation of the dotted curve from the deal one.

Conclusions:

1) Those nuclei with high N/P ratio i.e lying above the belt of stability, these nuclei lower their ratio by the emission of beta ray by the following nuclear reaction

$$_{0}n^{1} \longrightarrow {}_{1}H^{1} + {}_{-1}e^{0}$$

Thus the number of protons in the nucleus increases and these nuclei move towards the belt of stability.

2)Those nuclei with N/P ratio less than 1 i.e lying below the belt of stability, the ratio is increased to one by the protons in the nucleus getting converted into neutrons with the emission of positron as seen from the following nuclear reaction

$$_{1}p^{1} \longrightarrow {}_{0}n^{1} + {}_{+1}e^{0}$$

The neutron number is also increased by electron capture process but positron emission is common.

3) Those nuclei with Z greater than 83(which lie beyond the upper right edge end of the band of stability) they decay by alpha emission and achieve stability.

D)Magic numbers:

The numbers 2, 8,20, 50, 82 ,126 which accounts for unusual stability to the nucleus of the elements are called magic numbers.The nuclei with number of proton or number of neutron equal to the magic numbers are found to be more stable.The magic number nuclei are found to be at the end of the radioactive series.

Evidence for magic numbers”

1) The nuclear shell model describes that the neutrons and protons are arranged in a complete shell within the atomic nucleus to achieve stability(to become non-radioactive) just as elements during formation of bond achieve stability by completion of octet.

2)All naturally occurring radioactive series end with magic numbers of either N or Z

E) <u>Odd-Even number rule</u>:

The stability of their nucleus is also predicted by finding out whether the nucleus contains odd/even number of neutrons and protons.A detailed study of various nuclei reveal the following facts:

Neutron	Proton	Number of stable nuclei	Stability order	Examples
Even	Even	168	↑ Very high	$_2He^4$, $_6C^{12}$
Odd	Even	57		$_6C^{13}$
Even	Odd	50		$_7N^{15}$
Odd	Odd	04	Least	$_1H^2$, $_3Li^6$

Q.1	What is dosimetry? How it is classified? Give its application.
Ans:	Dosimetry is defined as the measurement of the observed dose delivered by ionizing radiation,which involves the assessment of radiation dose received by the human body. Types of dosimetry:- i) Internal dosimetry:- It involves the measurement of radiations when the radioactive material is orally consumed. It relies on a variety of physiological or imaging techniques.

	ii) External dosimetry:- It involves the measurement of radiation from an external source with the help of dosimeter. Applications:- i) It finds application in the fields of medical physics and health physics. ii) It is used for radiation protection and is routinely applied to occupational radiation workers. iii) It is also used to measure unexpected radiations caused due to accidents in nuclear plants. iv) It finds application in environmental dosimetry such as radon monitoring in buildings.
Q.2	Explain the terms:- 1) Absorbed dose or External dose 2) Effective dose or Equivalent dose 3) Q-factor
Ans.	1) a) <u>Absorbed dose</u>:- It is defined as the amount of energy consumed per unit mass of a human tissue or other media. b) Units SI – Gray (Gy) where 1 Gy = 1J/kg = 100 rad CGS – 1 rad = 100 erg/g c) Symbol – D d) Formula – D = $\frac{dE}{dm}$ e) It is suitable for describing localized exposures such as tumor dose in radiotherapy f) Dose level: 0 – 50 mGy range g) Absorbed dose is also termed as External dose 2) <u>Equivalent dose</u>:- a) It is a dose quantity (H) representing the stochastic health effects of low levels of ionizing radiations on human body. Stochastic effect is defined for radiation dose assessment as the probability of cancer induction and genetic damage. It is derived from the physical quantity absorbed dose and takes into consideration the biological effectiveness of radiation, which is dependent on radiation type and energy. For example, alpha particles do much more damage per unit energy absorbed than electrons. b) Unit: - CGS : Rem (Rontgen equivalent man) SI : Sievert (Sv) c) Formula to calculate equivalent dose:

Equivalent dose = D_{TR} x W_R x W_T

Where, D_{TR} = absorbed dose in Gray (Gy) in tissue T by radiation type R ,

W_R is radiation weighting factor

W_T is weighting factor

3) Q-factor:-

a) It is known as quality factor

b) Formula: H = Q.D

where H is equivalent dose

D is Absorbed dose

c) Incident radiations like X – rays and γ – rays produce electrons

d) Q value

For electrons , Q = 1

For α-particles, Q = 20

For neutrons , Q varies from 5 to 20

Q.3 Give the common unit and SI units of radiation measurement.

Ans.

	Radiations	Common unit	SI unit
1	Radioactivity	Curie Unit (Ci)	Becquerel (Bq)
2	Absorbed dose	Rad	Gray (Gy)
3	Equivalent dose	Rem	Sievert (Sv)
4	Exposure	Roentgen(R)	Coulomb/kg

Q.4 Define i) Rontgen ii) Rad iii) Rem iv) Gray v) Sievert

Ans.

i) Roentgen :- It is defined as the amount of radiation which will produce one electrostatic unit of charge of either sign in one cm^3 of air at 0^0C and one atmospheric pressure (0.001293g)

ii) Rad:- It is defined as the amount of energy absorbed per unit mass of the tissue.

iii) Rem (Rontgen equivalent mass):- It is defined as the product of radiation absorbed dose and quality factor.

iv) Gray :- It is a unit of absorbed radiation dose which is equal to 100 rem.

v) Sievert:- It is a unit of equivalent absorbed dose equal to rem.

Q.5 Write a note on i) Exposure unit ii) External dose due to natural resources

Ans.

i) Exposure unit:- All living and non-living matter is exposed to electromagnetic radiations. These include high energy radiations such as γ-rays , X-rays etc. as well as low energy radiations like radio waves, micro-waves etc. The radiations coming out from a radioactive substance such as α rays, β-rays are harmful to the health of an individual. When exposed to such radiations, they may bring about enhanced damage to tissue which may lead to cancer or bring about any genetic disorder. The magnitude of radiations exposures is expressed in terms of radiation dose. There are two types of radiation dose.

a) Absorbed dose:- It is defined by the amount of energy deposited in a unit mass in human tissue.
b) Equivalent dose:- This unit accounts for the higher damage potential caused to the tissue when exposed to radiation.

The first unit of radiation exposure accepted in the International Congress on Radiology was Roentgen. It is defined as the amount of radiation which will produce one electrostatic unit of charge of either sign in one cm^3 of air at 0^0C and at one atmospheric pressure. However, the SI exposure unit is defined as the amount of radiation which causes the formation of ions having one Coulomb of charge in 1 kg of air.

ii) External dose due to natural radiations:- The earth is exposed to radiations from natural sources such as star, sun etc where the nuclear fusion reactions are very common. In fact before the formation of solar system, it is estimated that there must have been a large number of unstable radionulei, which must have decayed to form stable nuclei. Uranium and Thorium are the sources of exposure to man as their decayed products also emit radiations. Besides another natural source of exposure of radiation to human beings is cosmic radiations. All these background radiations creates background dose which is estimated to be in the region of 0.9 to 1 mSv per year at sea level. The background dose increases with increase in altitude.