NUCLEAR PHYSICS

INTRODUCTION

J.J. Thomson discovered negatively charged electron and then positively charged nucleus was discovered by Rutherford from his experiment. Rutherford developed a nuclear model of the atom. This model of the atom consisted of a small, dense, positively charged nucleus with negative electrons orbiting around it. Then Rutherford suggested the existence of neutral particles called neutrons inside the nucleus. James chadwick discovered neutrons in 1932.

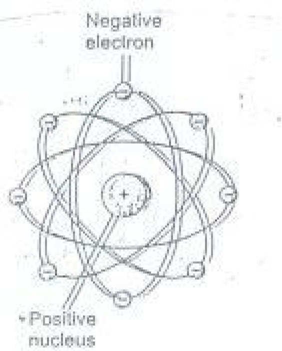
NUCLEAR PHYSICS

The branch of Physics that deals with elementry particles like proton, neutron, electrons and there properties is called nuclear physics.

ATOMIC NUCLEUS

DEFINITION

"It is the infinitesimal central small part of an atom"



From α particles scattering experiments Lord Rutherford concluded that most of the part of an atom is empty and that mass is concentrated in a very small region called nucleus.

CHARGE, MASS & SIZE OF NUCLEUS

The entire positive charge of atom and about 99.9% of its mass is concentrated in the nucleus.

Size (radius) of nucleus $\approx 10^{-15}$ m

Size of atom $\approx 10^{-10}$ m

$\Rightarrow$ Size of nucleus $= \frac{1}{10^5} \times$ Size of atom

So the size of nucleus is 10 times smaller than that of atom.

NUCLEONS

A nucleus consists of nucleons comprising of protons and neutrons. A proton has

EXAMPLES

As $1U = 1.6606 \times 10^{-27}$ Kg, So

Mass of proton $= 1.673 \times 10^{-27}$ Kg $= \frac{1.673 \times 10^{-27}}{1.6606 \times 10^{-27}} = 1.007276u$

or mass of proton $= 1.007276$ amu $= 1.007276u$

Similarly,

Mass of neutron $= 1.675 \times 10^{-27}$ Kg $= 1.008665u$

Mass of electron $= 9.11 \times 10^{-31}$ Kg $= 0.00055u$.

CHARGE ON ATOM.

The charge on a proton is equal in magnitude to the charge on an electron. The charge on the proton is positive while that of an electron is negative. As an atom, on the whole is electrically neutral, therefore, we can conclude that the number of protons inside the nucleus is equal to the number of electrons outside the nucleus.

ATOMIC NUMBER OR CHARGE NUMBER

DEFINITION

"The number of protons inside a nucleus is known as its atomic number or charge number."

SYMBOL

The symbol of atomic number is Z.

CHARGE ON NUCLEUS

Charge on any nucleus = Ze, where 'e' is charge on proton.

MASS NUMBER / NUCLEON NUMBER

DEFINITION

"The combined number of all the protons and neutrons inside a nucleus is known as its mass number".

SYMBOL

The Symbol of Mass Number is A.

$A = P + N \Rightarrow A = Z + N \qquad (\because P = Z)$

a positive charge equal to 1.6×10^{-19} C and its mass is equal to 1.673×10^{-27} Kg. A neutron has no charge on it, but its mass is 1.675×10^{-27} Kg. The mass of neutron is almost equal to mass of proton.

ATOMIC MASS UNIT OR UNIFIED MASS SCALE

To indicate the mass of atomic particles, we use unified mass scale (U) instead of Kilogram.

Definition

"1 atomic mass unit or unified mass unit U is exactly one twelveth the mass of one carbon atom"

SYMBOL

Its Symbol is U.

Mathematical Form.

$$1\ U = \frac{1}{12}(\text{Mass of } C\text{-}12)$$

$$1\ U = 1.6606 \times 10^{-27}\ Kg.$$

SHOW THAT $1U = 1.6606 \times 10^{-27}$ Kg.

As, we know that $1U = \frac{1}{12}$ (Mass of one carbon atom).

Now,

$$1 \text{ mole of } C = 6.022 \times 10^{23} \text{ atom} = 12g$$

$$\therefore \text{ Mass of } 6.022 \times 10^{23} \text{ atom of } C\text{-}12 = 12g$$

$$\Rightarrow \text{Mass of one } C\text{-}12 \text{ atom} = \frac{12}{6.022 \times 10^{23}} g.$$

Putting the value in Eq (1), we get

$$1\ U = \frac{1}{12}\left(\frac{12}{6.022 \times 10^{23}}\right) g$$

$$1\ U = 1.6606 \times 10^{-24} g \qquad \because 1g = 10^{-3} Kg$$

$$\Rightarrow 1U = 1.6606 \times 10^{-27} Kg$$

Hence Proved.

The number of neutrons N present in a nucleus is given by...

$$N = A - Z.$$

Mode Of Writing Nucleus (Atom)

$${}^{A}_{Z}X$$ where, Z = Atomic or charge no.
A = Mass number.
X = Symbol of element.

e.g. ${}^{23}_{11}Na$, ${}^{1}_{1}H$ etc.

Examples Of Atomic Nuclei.

In the periodic table, hydrogen is the lightest element with only one proton inside its nucleus. So for hydrogen, Z=1 and A = 1. That is why hydrogen is represented by the Symbol ${}^{1}_{1}H$. Helium is the next element in the periodic table with two protons and two neutrons inside its nucleus. So, for helium, Z = 2, A = 4 and number of neutron, N = A - Z = 2. That is why, helium is represented by the symbol ${}^{4}_{2}He$. Uranium is a heavy element in the periodic table with symbol ${}^{235}_{92}U$. Here Z = 92, A = 235 and N = A-Z = 143. In this way, the number of proton and neutrons in atoms of all the elements of the periodic table can be determined.

Important Experimental Observation About Nucleus

It has been observed that the number of neutrons and protons in the initial light elements of the periodic table is almost equal but in the later heavy elements the number of neutrons is greater than the number of proton in the nucleus.

ISOTOPES

DEFINITION

"Isotopes are such nuclei of an element that have the same charge number Z, but have different mass number A. i-e they have same number of protons but different number of neutrons"

EXPLAINATION BY EXAMPLES

Helium has two isotopes...

1:- $^{3}_{2}He$ 2:- $^{4}_{2}He$

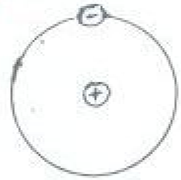
In both isotopes, Z = Number of protons = 2 in helium nucleus

In first isotope, N = Number of neutron = 3-2 = 1

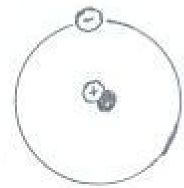
In Second isotope, N = A - Z = 4-2 = 2

Hydrogen has three isotopes...

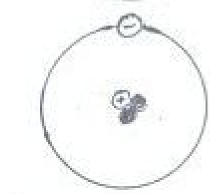
1:- $^{1}_{1}H$ → Called ordinary "hydrogen" or "protium". Its nucleus contains only one proton and no neutron.



2:- $^{2}_{1}H$ → Called "deuterium". Its nucleus is called deutron. It contains one proton and one neutron inside its nucleus.



3:- $^{3}_{1}H$ → called "tritium". It contains two neutrons and one proton inside its nucleus.



CHEMICAL & PHYSICAL PROPERTIES OF ISOTOPES & THEIR SEPERATION.

The chemical properties of all the isotopes of an element are alike, as chemical properties depend upon the number of electrons around the nucleus i-e. depend upon the charge number Z, which is same for all the isotopes of an element. But their physical properties are different. It is therefore, not possible to separate the isotopes of an element by chemical methods. Physical methods are found to be successful for this purpose, (One method is in mass spectrograph) because isotopes have different physical properties.

INTERESTING INFORMATION

Both Xenon and Cesium each have 36 isotopes.

SOME ATOMIC MASSES

The commonly used atomic masses of some elements are given as

$e = 0.00055\,u$

$p = 1.007276\,u$

$n = 1.008665\,u$

${}^{2}_{1}H = 2.014102\,u$

${}^{3}_{2}He = 3.01605\,u$

${}^{3}_{2}He = 3.01603\,u$

${}^{4}_{2}He = 4.002603\,u$

${}^{7}_{3}Li = 7.016004\,u$

${}^{10}_{4}Be = 10.013534\,u$

${}^{14}_{7}N = 14.0031\,u$

${}^{17}_{8}O = 16.9991\,u$

MASS SPECTROGRAPH

OBJECT

A device with the help of which not only the isotopes of an element can be separated from one another but their masses can also be determined quite accurately is called mass spectrograph.

PRINCIPLE

Electric and magnetic fields are applied simultaneously at right angle to each other. Electric field accelerates the ions (particles) and the magnetic field moves the particles in a semicircular path.

CONSTRUCTION & THEORY

A simple mass spectrograph is shown in figure. The atom or molecules of the element under investigation, in vapour form, are ionized in the ions source S. As a result of ionization, one electron is removed from the particle, leaving it with a net positive charge of +e. The positive ions, escaping from the list S_1 are accelerated through a potential difference V applied between the two slits of S_1 and S_2. The ions pass through the slit S_2 in the form of a narrow beam. As work done on unit +ve charge is equal to P.D = V. So, work done is converted into K.E of singly charge ion at the slit S_2.

$$\therefore Ve = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2Ve}{m}} \longrightarrow (i)$$

The ions after passing through slit S_2, enter into a uniform and perpendicular magnetic field B in a vacuum chamber, where they are deflected in semicircular paths towards a detector. The detector records the number of ions arriving per second. Here centripetal force Fc is provided by magnetic force F i.e,

$$F = Fc \Rightarrow qvB\sin\theta = \frac{mv^2}{r}$$

$$\therefore \quad qB\sin 90^\circ = \frac{mv}{r} \qquad \because \theta = 90^\circ \text{ angle between } V \,\&\, B.$$

$$qB = \frac{mv}{r} \Rightarrow eB = \frac{mv}{r} \qquad \because q = e$$

$$\therefore \quad m = \frac{Ber}{v}$$

Putting the value of v from eq.(i) we get...

$$m = \frac{Ber}{\sqrt{\frac{2Ve}{m}}}$$

Squaring it

$$m^2 = \frac{B^2e^2r^2}{\frac{2Ve}{m}}$$

or $$m^2 = \frac{B^2e^2r^2m}{2Ve}$$

$$\Rightarrow m = \left(\frac{er^2}{2V}\right)B^2$$

$$\Rightarrow m \propto r^2$$

SEPARATION OF ISOTOPES

The above equation shows that if "V", "B" and "e" are kept constant, then radius "r" of semicircle depends upon mass "m" of ion. For different isotopes, "m" will be different and hence there will be more than one radius of semicircle.

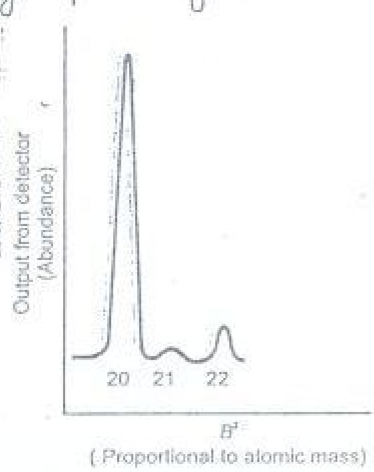
ABUNDANCE OF ISOTOPES & THEIR MASSES

We know that...

$$m = \left(\frac{er^2}{2V}\right)B^2$$

The above equation shows that mass of each ion reaching the detector is proportional to B^2. By adjusting the value of B and keeping $\left(\frac{er^2}{2V}\right)$ constant, ions of different masses are allowed to enter the detector. A graph of the detector output and B^2 shows what masses are present and their relative abundance? The graph shows that three isotopes for neon gas whose atomic mass numbers are 20, 21 and 22. The larger is the peak, the more abundant is the isotope. Thus

The mass spectrum of naturally occurring neon, showing three isotopes whose atomic mass number are 20, 21 and 22. The larger the peak, the more abundant the isotope.



most abundant isotope of neon is neon-20.

MASS DEFECT OR MASS DEFICIT

"The mass of constituent (nucleons) of a nucleus in free state is greater than that of the total mass of the same constituents in combined state as nucleus. This difference is called mass defect"

Its symbol is "Δm".

Mathematical form,

The result of experiments on the masses of different nuclei show that the mass of the nucleus is always less than the total mass of all the proton and neutron making up the nucleus. This missing mass is called mass defect Δm.

Mass defect = (Total mass of all protons) + (Total mass of all neutrons) − (Experimentlly measured mass of nucleus) → (1)

If Z = charge number = Number of protons.
and m_p = Mass of one proton.
then Total mass of all protons = Zm_p
If A = Mass number, N = number of neutrons = $A-Z$
and m_n = Mass of one neutron.
then total mass of all neutrons = $(A-Z)m_n$.
So, eq (1) becomes.

$$\Delta m = Zm_p + (A-Z)m_n - m_{nucleus} \longrightarrow (2)$$

EXPLAINATION BY EXAMPLES.

Let us calculate the mass defect Δm for deutron containing one proton and one neutron.

$$\Delta m = m_p + m_n - m_D$$

m_D → (mass of deutron)

m_p → (mass of proton)

m_n → (mass of neutron)

$$\Delta m = 1.007276 + 1.008665 - 2.0134289$$
$$= 0.0025121\ u$$

Similarly for ${}^4_2He$ nucleus.

$$\Delta m = 2m_p + 2m_n - m_{He}$$
$$= 2.01519 + 2.01796 - 4.00281$$
$$= 0.03034\ u$$

Reasons For Mass Defect

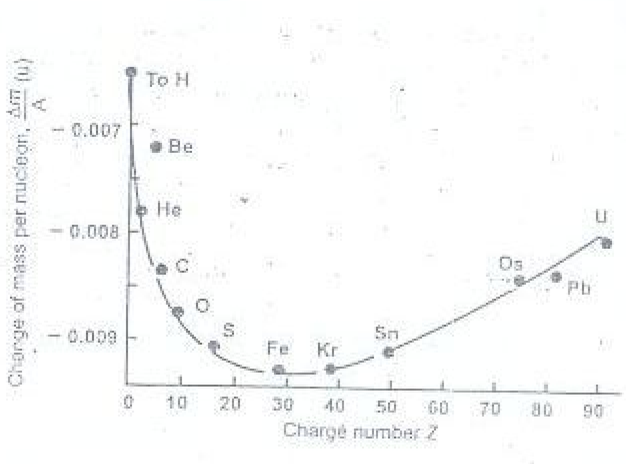
This decrease in mass is due to the fact that protons & neutrons are slowed down when they are combined to form a nucleus and this decrease in mass is converted into energy according to EINSTIEN'S EQUATION $E = mc^2$. So, energy is released when a nucleus is formed.

Graph Between Mass Defect Per Nucleon $\frac{\Delta m}{A}$ and Charge Number Z.

Mass defect per nucleon is obtained by dividing mass defect m by mass number or nucleon number A.

$$\therefore \quad \frac{\Delta m}{A} = \frac{Zm_p + (A-Z)m_n - m_{nucleus}}{A}$$

The graph shows that $\frac{\Delta m}{A}$ is maximum for Fe (iron), whose charge number Z is 30. From the definition of mass defect it is quite obvious that for hydrogen, mass defect is zero.



Binding Energy

The energy that must be supplied to break the nucleus apart into its constituents, protons and neutrons is called binding energy".

OR

"It is the amount of energy that must be supplied to a nucleus if the nucleus is to be broken up into protons and neutrons".

It's Symbol is B.E or E_B.

REASONS FOR BINDING ENERGY

As, we know that the mass of nucleus is less than the total mass of its constituent protons and neutrons. This is called mass defect Δm. The mass defect is made clear with "Einstein's Equation" $E = mc^2$. This equation shows that if for any reason, a mass Δm is lost, then it is converted into energy. So, the missing mass called the mass defect Δm is converted into energy called the binding energy E_B. of the nucleus. If this energy released is supplied back to the nucleus, then it splits into its constituent protons and neutrons.

SHOW THAT $E_B = \Delta m \times 931$ MeV, where Δm is in u.

OR, SHOW THAT $1u = 931$ MeV.

PROOF

As, we know that $1u = 1.6606 \times 10^{-27}$ kg

So, $E = mc^2 = 1.6606 \times 10^{-27} \times (3 \times 10^8)^2$ J

As, $1eV = 1.6 \times 10^{-19}$ J, So, above eq becomes

$$E = \frac{1.6606 \times 10^{-27} \times (3 \times 10^8)^2}{1.6 \times 10^{-19}}$$

$$= 931 \times 10^6 \text{ eV}$$

$\therefore$ $1\,u = 931$ MeV $\quad \because 10^6 = 1M$

So, for Δm in u

$$E_B = \Delta m \times 931 \text{ MeV}.$$

Mathematical form,

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

Using eq (2) of page , we get

$$B.E = Zm_p c^2 + (A-Z)m_n c^2 - m_{nucleus}c^2 \quad \text{(in Joules)}$$

EXPLAINATION BY EXAMPLES

For deutron, $\Delta m = 0.0025121\,u$

$$\therefore B.E = \Delta m \times 931 \text{ MeV} = 0.0025121 \times 931$$
$$= 2.33 \text{ MeV}$$

This means that one proton and one neutron combine to form deutron and 2.33 MeV energy is released.

For Helium-4, $\Delta m = 0.03034\,u$

$$\therefore B.E = \Delta m \times 931 \text{ MeV} = 0.03034 \times 931$$
$$= 28.2 \text{ MeV}$$

This means that when two protons and two neutrons fuse together to form a helium nucleus then 28.2 MeV energy is released

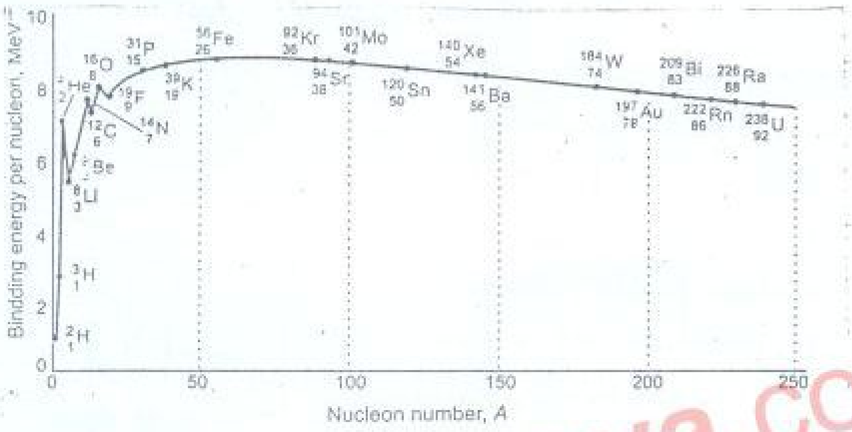
If this energy is given to helium nucleus, then it breaks up into two protons and two neutrons.

$$^4_2He + \text{Binding Energy} \rightarrow 2p + 2n$$

In this way we can conclude/calculate the binding energy of every element.

GRAPH BETWEEN BINDING ENERGY PER NUCLEON E_B/A AND MASS NUMBER A.

This graph shows that binding energy per nucleon increases with the mass number till it reaches a maxium value of 8.8 MeV at mass number 56, for iron (Fe) and then it gradually decreases to a value of 7.6 MeV at mass number 238 of Uranium. This shows that of all the elements, iron is the most stable element.



RESULT

Greater the mass defect and binding energy the more stable is the nucleus.

RADIOACTIVITY

"Those elements whose charge number Z is greater than 82 are unstable, and emit invisible radiations, that can affect the photographic plates, are called radioactive elements and the phenomenon is called radioactivity"

EXPLAINATION

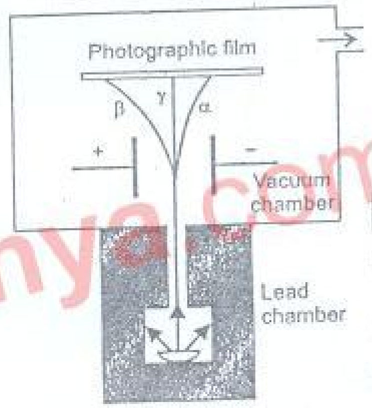
Radioactivity was discovered by HENRI BECQUEREL in 1896. He found that an ore containing uranium (Z = 92) emits an invisible radiation that penetrates through a black paper wrapping a photographic plate and affect the plate. After BECQUEREL'S discovery, MARIE

Curie and Pierre Curie discovered two new radioactive elements that they called polonium and radium.

Analysis Of Radioactive Radiations By Experiment

Consider a radioactive material that is placed at the centre of a block of lead, by drilling a hole in the block.

Radioactive radiations enter a vacuum chamber after emerging out of this hole. After passing between the two parallel plates the radiations strike a photographic plate. These radiations, insted of impinging at one point, fall at these different points due to the potential difference or electric field between the plates as shown in figure.



From this experiment it can be concluded that all radiations from the radioactive material are not alike.

(i) The radiation that bends towards the negative plate is made up of positively charged particles. These are called α-particles {(alpha) particles}

(ii) Those radiations that bend towards the positive plate are composed of negatively charged particles. These are called β-particles (beta).

(iii) Those radiations that go straight without bending have no charge on them. These are called γ-rays (Gamma).

FURTHER INFORMATION ABOUT RADIOACTIVE RADIATION

Further experiments reveal that (i) α-particles are helium nuclei. The charge on them +Ze while their mass is 4U (atomic mass unit). Every α-particle has two protons and two neutrons.

(ii) β-particles are in fact fast moving electrons which come out of the nucleus of a radioactive element.

(iii) γ-rays like X-rays are electromagnetic waves which are emitted by the neucleus of a radioactive element. The wavelength of these γ-rays is much shorter than that of the wavelength of X-rays.

NUCLEAR TRANSMUTATION

"Whenever any particle/radiation is emitted out of any radioactive element, then there is always some changes in the nucleus of the element and therefore this element changes into a new element. This phenomenon is called radioactive decay or nuclear transmutation"

EXPLANATION

Radioactivity is purely a nuclear phenomenon. This is not affected by any physical or chemical reaction. The element formed due to radioactive decay is called daughter element. The original element is called the parent element. During the nuclear changes the law of conservation of mass, energy, momentum and charge remain applicable. we know that three types of radiations are emitting during radioactivity.

(i) α - Emission

When α - particle is emitted out of any nucleus then due to law of conservation of mass, the mass number A of the nucleus decrease by 4, and due to law of conservation of charge, the charge number Z of nucleus decreases by 2. It is due to the fact that the mass number and charge number of α - particle are 4 and 2 respectively. The emission of α - particle is represented by the equation.

$$^{A}_{Z}X \longrightarrow \, ^{A-4}_{Z-2}Y + \, ^{4}_{2}He \rightarrow \alpha\text{-particle}$$

Where X represents the parent element and Y is the daughter element.

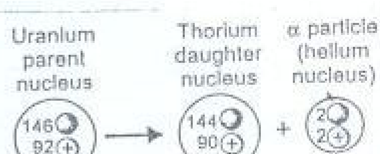
e.g

$$^{226}_{88}Ra \longrightarrow \, ^{222}_{86}Rn + \, ^{4}_{2}He$$

(Radium) (Radon)

★ It must be noted that the sum of the mass number and charge numbers on both sides of the equation are equal.

Another example of α - emission is shown in figure below



$^{238}_{92}U$ $^{234}_{90}Th$ $_{2}He$

α - decay occurs when an unstable parent nucleus emits an α - particle and in the process it is converted into a different (or daughter) nucleus.

In nuclear reaction form, we have

$$^{238}_{92}U \longrightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He$$

(ii) β- Emission

When a β-particle is emitted out of any nucleus then its mass number does not undergo any charge but its charge number increases by one. The emission of β-particle from any element X is represented by following equation.

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e \text{ (electron / } \beta\text{-particles)}$$

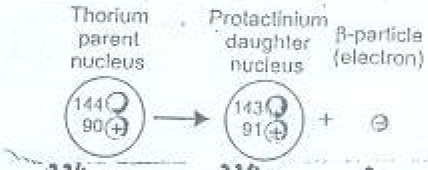
e.g. $$^{218}_{84}Po \longrightarrow {}^{218}_{85}At + {}^{0}_{-1}e$$

(Polonium) (Astatine)

Negative β-particle is an electron and its emission from the nucleus required explanation as no electron is present in the nucleus. However, the emission of electron from the nucleus can be thought of a neutron emitting an electron and becoming a proton. This means that the β-particle (electron) is formed at the time of emission. That is why, at the time of emission of a β-particle, the charge number of the nucleus increases by one but no change in its mass number takes place as mass of electron is very small as compared to the mass of proton or neutron. The transformation of a neutron into a proton and an electron (β-particle) at the moment of emission of a β-particle is given by an equation.

$$\underset{\text{neutron}}{^{1}_{0}n} \longrightarrow \underset{\text{proton}}{^{1}_{1}H} + \underset{\text{electron}}{^{0}_{-1}e}$$

Another example of β-emission is



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

β - decay occurs when a neutron in an unstable parent nucleus decays into a proton and an electron, the electron being emitted as the β - particle. In the process, the parent nucleus is transformed into daughter nucleus.

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

(iii) **γ- EMISSION**

When a γ-radiations issues out of nucleus then neither the charge number Z nor the mass number A of the nucleus undergoes any change. It is due to the fact that a γ-radiation is simply a photon that has neither any charge nor any mass. Its emission from the nucleus has some resemblance with the emission of a photon of a light from an atom. We know that when any electron of an atom absorbs energy, it jumps from the ground state to a higher energy state and the atom becomes excited.

When the electrons of this excited atom returns to its ground state then it emits the absorbed energy in the form of photon. In much the same way the nucleus is sometimes excited to a higher state of the nucleus is unstable state and in coming back to its ground state from the excited state, γ-radiations are emitted.

The emission of γ-radiations from a nucleus is generally represented by this equation.

$$^{A}_{Z}X^{*} \longrightarrow \, ^{A}_{Z}X + \gamma\text{-radiation}$$

Here, ${}^{A}_{Z}X^{*}$ represents an excited nucleus while ${}^{A}_{Z}X$ shows ground state of the nucleus.

HALF LIFE OF A RADIOACTIVE ELEMENT

"The half life $T_{1/2}$ of a radioactive element is that period in which half of the atoms of a radioactive sample to decay".

Symbol used for represent half life of any radioactive element is "$T_{1/2}$".

EXPLANATION BY EXAMPLES.

Whenever an α-particle or a β-particle is emitted from a radioactive element, it is transformed into some other element. This radioactive decay process is quite random and is not symmetric. This means that we cannot foretell about any particular atom as to when will it decay. It may decay immediately or it may remain unchanged for millions of years. Thus we cannot say anything about the life of a particular atom of a radioactive element.

Let us take the example of a city with a population of one million and we know that on the average ten persons die every day. Even with this knowledge we cannot say with certainity that which particular person will die on which particular day. We can only say that on the whole ten persons will die. The greater the population of the city, the greater the accuracy of such predictions. Like the population of a city, it is not possible to talk about an atom of a radioactive element. For more accurate results we always talk about larger groups of atoms and laws of statistics are applied upon them.

Consider 100,000 atoms of a radioactive element. The time taken by 10,000 atoms to decay is called the half life $T_{1/2}$ of this element. If the half life of this element is 1 day, then, 75,000 atoms will decay after two half lifes i.e 2 days and 25,000 atoms will remain undecayed. Then after 3 days, 12500 atoms will remain undecayed. That is with the passage of every one day, the number of atoms remaining behind undecayed becomes half of the number already present.

Conclusion After The Example

Besides getting the definition of half-life we can deduce two other conclusions from this example. These are...

(i) No radioactive element can completely decay. It is due to the reason that in any half-life period only half of the nuceli decay and in this way an infinite time is required for all the atoms to decay.

(ii) The number of atoms decaying in a particular period is proportional to the number of atoms present in the begining of the period. If the number of atoms at the start is large then a large number of atoms will decay in this period and if the number of atoms in the beginning are small then less atoms will decay.

Decay Constant

"Decay constant of any element is equal to the fraction of the decaying atoms per unit time".

Symbol

Its symbol is "λ".

Mathematical Form

If at any particular time the number of radioactive atoms be N, then in an interval Δt, the number of decaying atom ΔN is proportional to the time interval Δt and the number of atoms N i.e

$$\Delta N \propto -N\Delta t$$

$$\text{OR} \quad \Delta N = -\lambda N \Delta t \longrightarrow (1)$$

Negative sign indicates that the decrease in the number of atoms N. λ is the constant of proportionality and is called decay constant. Eq (1) shows that if the decay constant λ of any element is large then in a particular interval more of its atom will decay and if λ is small then in the same interval less number of atoms will decay. From eq (1), we can define decay constant λ as given below.

$$\lambda = \frac{\Delta N / N}{\Delta t}$$

where, $\Delta N/N$ is the fraction of decaying atom. Thus decay constant of an element is equal to the fraction of the decaying atoms per unit time.

Unit Of "λ"

$$\lambda = \frac{\Delta N / N}{\Delta t} = \frac{1}{Sec} = Sec^{-1}.$$

Graphical Representation (Decay Curve)

The ability (decay ability) of any radioactive element can be show by the graph.

If we draw a graph between number of atoms N in the sample of radioactive element present at different times and the time t, then a curve as shown in figure is obtained. This graph shows that in the beginning, the number of atoms present in the sample of the radioactive element was N_0 and with the passage of time, the number of these atoms decrease due to their decay. This graph is called as decay curve.

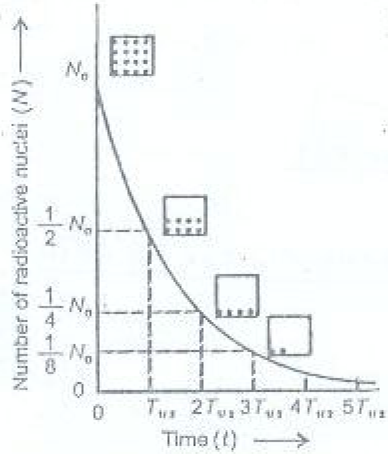


Fig. 21.6 The half life $T_{1/2}$ of a radioactive decay is the time in which one-half of the radioactive nuclei disintegrate.

After one half life $T_{1/2}$, no. of undecayed atoms

$$= \frac{1}{2} N_0.$$

After two half lives $2T_{1/2}$, no. of undecayed atoms

$$= \frac{1}{2} \times \frac{1}{2} N_0 = \left(\frac{1}{2}\right)^2 N_0.$$

After three half lives $3T_{1/2}$, no. of undecayed atoms

$$= \frac{1}{2} \times \left(\frac{1}{2}\right)^2 N_0 = \left(\frac{1}{2}\right)^3 N_0.$$

So, after "n" half lives $nT_{1/2}$, no. of undecayed atoms

$$= \left(\frac{1}{2}\right)^n N_0.$$

Result

It has been found that the estimate of decay of every radioactive element is according to this graph, but the half-life of every radioactive element is different.

Examples Of Half-Life

→ Half-life of radium-226 = 1620 years
→ " " " Uranium-238 = 4.5×10^9 years
→ " " " radon gas = 3.8 days
→ " " " Uranium-239 = 23.5 minutes.

Relation Between Half-Life & Decay Rate

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

The above equation shows that if decay constant λ of any radioactive element is known, then its half-life $T_{1/2}$ can be found.

Artificial Radioactivity

To make a stable element radioactive, high energy particles are bombarded on the stable element. This bombardment excites the nuclei and the nuclei after becoming unstable becomes radioactive element. Such radioactive elements are called artificial radioactive elements and this phenomenon is called artificial radioactivity.

Interaction Of Radiation With Matter

★ Interaction of α-Particles With Matter

An alpha particle (α-particle) traveles a well defined distance in a medium before coming to rest. This distance is called the range of the particle. As, the particle passes through a solid, liquid or gas, matter. The ionization may be due to ...

(i) Direct elastic collision or

(ii) Through electrostatic repulsion.

Ionization is the main interaction with matter to detect the particle or to measure its energy. The range depends on the ...

(i) charge, mass and energy of the particle.

(ii) the density of the medium, i-e more density means less range and ionization potentials of the atoms of the medium.

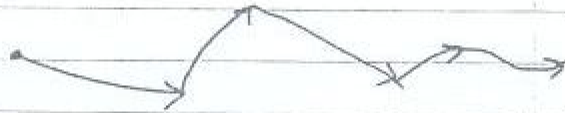
Since α-particle is about 7000 times more massive than an electron. So, usually it does not suffer any appreciable deflection from its straight path. It suffers appreciable deflection only when it passes close to the nucleus or it strikes the nucleus of the atom. Thus α-particle continues producing intense ionization along its straight path till it loses all its energy and comes almost to rest. It, then, captures two electrons from the medium and becomes a neutral helium atom.

$$\underset{\alpha\text{-particle}}{He^{+2}} + 2e^- \rightarrow \underset{\text{Helium atom.}}{He}$$

★ Interaction Of β-Particles With Matter.

β-particles (electrons) also lose energy by producing ionization. However, its ionization ability is about 100 times less than that of α particles. As a result its range ected by collision than heavy α-particles. Thus the path of β-particles in matter is not straight but shows much scattering. The range of β-particles is measured by the effective depth of penetration into the medium, not by the length of erratic path.

The more dense the material through which the particle moves, the shorter its range will be.



X-Ray Emission By Slowing Down Of α & β Particles

Both α- and β-particles radiates energy as X-rays, Photons when they are slowed by the electric field of the charged particles (proton, electrons etc) in a solid material.

★ Interaction Of γ-Rays With Matter

Photons of γ-rays cause very little ionization as these photons are unchanged. Photons are removed from a beam by either scattering or absorption in the medium. They interact with matter in three distinct ways, depending mainly on their energy.

1: At low energies (less than about 0.5 MeV), the dominant process that removes photons from a beam, is the photoelectric effect.
2: At intermediate energies (0.5MeV ~ 1.02 MeV), the dominant process is Compton scattering.

3: At higher energies (more than 1.02 MeV), the dominant process is pair production.

When γ-rays pass through air, its intensity 'I' decreases as the inverse square of the distance 'x' from the source of γ-rays. This is similar to the decrease in intensity of light from a lamp.

In solids, the intensity decreases exponentially with increase depth of penetration into the material. The initial intensity 'I_o' of a beam after passing through a distance 'x' in the medium is reduced to intensity I according to the relation $I = I_o e^{-\mu x}$

where,

μ = linear absorption coefficient of the medium. This coefficiend depends on the energy of the photon as well as on the properties of the medium.

FLUORESENCE

"Flouresence" is the property of absorbing radiant energy of high frequency and re-emitting energy of low frequency in the visible region of electromagnetic spectrum"

Charged particles α or β and γ-radiation produce fluoresence or glow on striking some substance like Zinc-Sulphide, Sodium iodide or barium platinocyanide coated screens.

penetrating particles because they are neutral particles. To be stopped or slowed, neutrons must undergo a direct collision with a nucleus or some other particle that has mass comparable to that of neutron. Materials such as water or plastic which contain more low-mass nuclei per unit volume. e.g hydrogen nuclei; are used to stop neutrons. Neutrons produce a little indirect ionization when they interact with material; containing hydrogen atom because they knock out protons.

The summary of the nature of α, β & γ radiation

Characteristics	α–particles	β–particles	γ–rays
1. Nature	Helium nuclei of charge 2e	Electrons or positrons from the nucleus of charge ±e	E. M. waves from excited nuclei with no charge
2. Typical sources	Radon-222	Strontium-94	Cobalt-60
3. Ionization (Ion pairs mm^{-1} in air)	About 10^4	About 10^2	About 1
4. Range in air	Several centimetres	Several metres	Obeys inverse square law
5. Absorbed by	A paper	1~5 mm of Al sheet	1~10 cm of lead sheet
6. Energy spectrum	Emitted with the same energy	Variable energy	Variable energy
7. Speed	~ 10^7 ms^{-1}	~1×10^8 ms^{-1}	~3×10^8 ms^{-1}

Radiation Detectors

Nuclear radiations cannot be detected by our senses. Hence we use some observable detecting methods, which utilize the interaction of radiation with matter. Most detectors of radiation make use of the fact that ionization is produced along the path of particle. These detectors include

(i) Wilson cloud Chamber.
(ii) Geiger Counter.
(iii) Solid State detectors.

Wilson Cloud Chamber

Object:

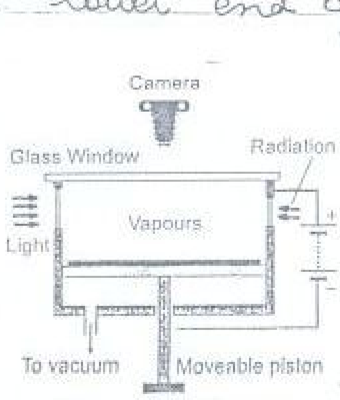
It is a device which shows the visible path of an ionizing particle.

Principle:

Ionizing particles produce a number of ions in air or gas through which they pass. The supersaturated vapours readily condense on ions and form a cloud which is visible.

Construction:

The apparatus consists of a cylindrical glass chamber closed at the upper end by a glass window and at the lower end by a moveable piston as shown in figure. A black felt pad soaked in alcohol is placed on a metal plate inside the chamber. The air soon becomes saturated with alcohal vapours.



Wilson Cloud Chamber

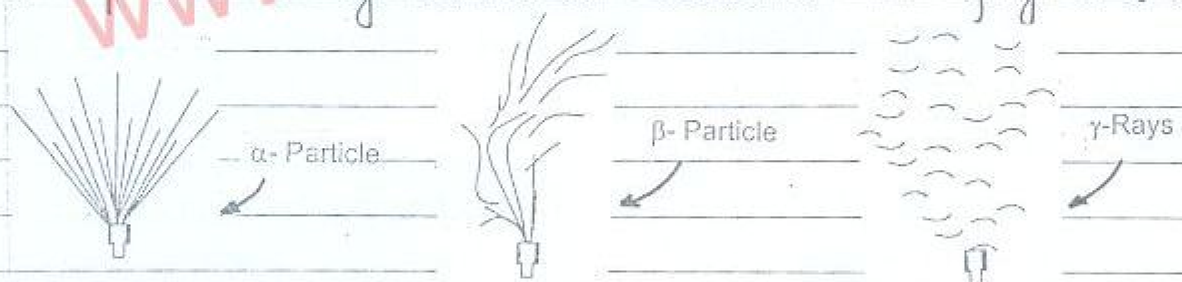
WORKING

A rapid expansion is produced by pulling quickly the piston of the bicycle pump having the leather washer reversed so that it removes air, The sudden cooling resulting from rapid adiabatic expansion helps to form supersaturated vapours. As radiations passes through the chamber, ions are produced along the path. The tiny droplets of moisture condense about these ions and form vapour tracks showing the path of th radiation. It is similar to the cloud formation.

NATURE OF TRACKS OF DIFFERENT RADIATIONS

The fog (vapour) tracks are illuminated with a lamp and may be seen or photographed through the glass window.

1: The α- particles leave thick, straight and continous tracks due to intense ionization produced by them as shown in figure (a).



2: β- particles form the thin and discontinous tracks extending in erratic manner showing frequent deflections as shown in fig (b)

3: γ-particles or X-rays leave no definite tracks along their path as shown in fig (c).

RELATION BETWEEN LENGTH OF CLOUD TRACKS & ENERGY OF PARTICLE

The length of the cloud track has

been found proportional to the energy of the indicated incident particle.

USE OF HIGH POTENTIAL DIFFERENCE

A high potential difference of the order of 1KV between the top and bottom of the chamber provides an electric field which clears away all the unwanted ions from the chamber to make it ready for use. Therefore, the tracks seen are those of rays that pass into the chamber as the expension occurs.

CHARGE, MASS & ENERGY OF RADIATING PARTICLES

The chamber may be placed in a strong magnetic field which will bend the paths providing information about the charge, mass and energy of the radiating particle. In this way, it has helped in the discovery of many new particles.

GEIGER-MULLER COUNTER

Object:

Greiger Muller tube is a device used to detect & count different types of nuclear radiations.

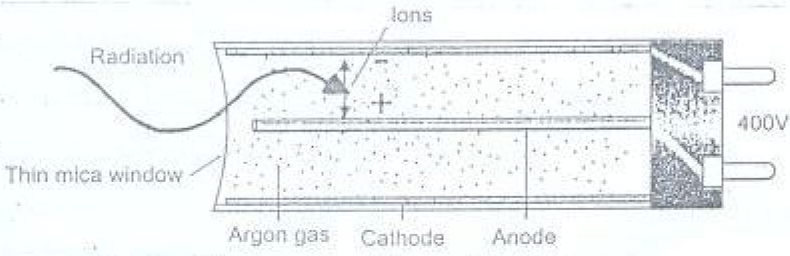
Principle:

When a nuclear particle enters the tube, it ionizes the gas in it and produces positive ions and electrons.

Construction:

It consists of a stiff central wire acting as an anode in a hollow metal cylinder acting as a Cathode, filled with a suitable mixture of a gas at about 1-atmospheric pressure. One end of the tube has a thin mica window to allow the entry of α or β-particles.

and other end is ~~not~~ sealed by non-conducting material and carries the connecting pins for the two electrodes.



Geiger – Muller Tube

A high potential difference (about 400V for neon-bromine filled tubes) but slightly less than that necessary to produce discharge (ionization and flow of current) through the gas, is maintained between the electrods.

Working:

When radiation enters the tube, ionization is produced. The free electrons are attached towards the positively charged central wire. As these electrons are attracted towards the wire by a strong electric field, they callide with other molecules of the gas and knock them out more electrons which in turn do the same and produce a cascade of electrons that move towards the central wire. This makes a short pulse of electric current to pass through an external resistor. It is amplified and registerd electronically. The counter, which also provides the power is called a scaler.

ENERGY AND PATH OF PARTICLES:

It cannot distinguish between the energies or paths of incident particles as output pulses are same.

DEAD TIME:

The entire electron pulse takes less than 1 us. As positive ions are very massive than the electrons, so they take several hundred times as long to reach the outer cathode. During this time, called the dead time ($\sim 10^{-4}$ S) of the counter, further incoming particles cannot be counted.

SECONDARY ELECTRONS

When positive ions strike the cathode, secondary electrons are emitted from the surface. These electrons would be accelerated to give further unwanted counts.

SELF GAS QUENCHING OF DISCHARGE

The unwanted counts are prevented by mixing a small amount of quenching gas e.g Br_2 with the principle gas e.g Ne.

The quenching gas must have an ionization potential lower than that of inert gas. Thus, the ions of quenching gas must reach the cathode before principle gas ions. When they reach near the cathode, they capture secondary electrons and becomes neutral molecules. Then the excess energy of the quenching molecules is used in dissociation of the molecules into atoms. In principle gas molecules, excess energy releases more electrons. For example, bromine gas is added to neon gas. The bromine molecules absorbs energy from the secondary electrons or ions and dissociate into bromine atoms. The atoms then readily recombine into molecules again for the next pulse. The gas quenching is called the self-quenching.

ELECTRONIC QUENCHING

In addition to self quenching, electronic quenching is also used. For this purpose, a large negative voltage is applied to the anode immediately after recording the output pulse. This reduce the electric field below the critical value for ionization by collision. The negative voltage remains until all the positive ions are collected at cathode thus preventing secondary electron pulses.

RANGE OR PENETRATING POWER OF IONIZING PARTICLES

The reduction in the count rate by inserting metal plates of varying thickness between the source and Geiger-Muller tube, helps to estimate the penetrating power or range of ionizing incident radiation.

DISADVANTAGES OF GEIGER COUNTER

Geiger-counter is not suitable for fast counting because of its relatively long "Death time". Dead time is of the order of more than a milli-second which limits the counting rate to a few hundred counts per second.

If particles are incident on the tube at a further rate, not all of them will be counted because some will arive during the dead time.

→ Solid state electrons are fast counters and are more efficient and accurate.

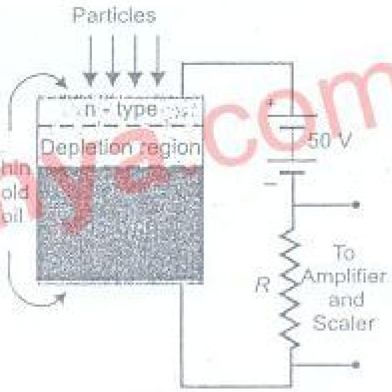
SOLID STATE DETECTOR

OBJECT:

It is a device used for detecting and counting of nuclear radiation.

PRINCIPLE:

Solid State detector is specially designed p-n junction as shown in figure. This p-n junction operates under a reverse bias in which electron-hole pairs are produced by the incident radiations. The production of these pairs causes a current to flow through the external circuit.



CONSTRUCTION:

The detector is made from a p-type silicon or germanium. An n-type thin layer is produced by doping the top surface by donor n-type impurity. The top and bottom surfaces are coated with a thin layer of gold. These layers make good conducting contacts with the external circuit. The combined thickness of n-type and gold layer absorbs so less energy to the incident particle that the junction (depletion region) may be assumed to be situated at the front (top) surface. This is known as the surface barrier type detector

WORKING

When a reverse bias is applied through the two conducting layers of gold, then this enlarges the charge free region around the junction called depletion region. Normally, when there is no incident particles then no current flows through the circuit due to reverse bias.

When an incident particle penetrates through the depletion region, it produces electron-hole pairs. These mobile electrons and holes move due to applied electric field. The arrival of these charges at the two surface gold layers, produces a potential drop across the junction. This gives rise to a current pulse through the external circuit which is amplified and registered by a scalar unit.

ADVANTAGES

(i) **DETECTION OF LOW ENERGY PARTICLES**

The size of the pulse is found proportional to the energy absorbed from the incident particle. The energy needed to produce an electron-hole pair is about 3eV to 4eV which makes the device useful for detecting low energy particles.

(ii) **FAST COUNTER**

The collection time of electrons and holes is much smaller than gas filled counters and hence a solid state detector can count very fast.

(iii) **SMALLER IN SIZE**

It is much smaller in size than any other detector.

(iv) **Low Operating Voltage**

It operates at low voltage.

Limitation

The above mentioned type detector is used for detecting α or β-particles but a specially disigned device can be used for γ-rays.

Induced Nuclear Reactions

"These are the reactions in which the identity or properties of target nuceli are changed when very fast particles collide with target nuclei".

Explaination

While studying radioactivity, we have seen that an α-particle (helium nucleus) is emitted from radium-226 and radon-222 is obtained. This spontaneous nuclear reaction is represented by the following equation.

$$^{226}_{88}Ra \longrightarrow ^{222}_{86}Rn + ^{4}_{2}He$$

Above mentioned nuclear reaction takes place spontaneously. However, Rutherford was the first scientist who showed that besides natural spontaneous radioactive decay process, other induced nuclear reactions can also occur. A particle x is bombarded on any nucleus X and this process yields a nucleus Y and a light object y is a shown.

$$X + x \longrightarrow Y + y.$$

Rutherford performed an experiment

on the nuclear reaction in 1918. He bombarded α-particles on nitrogen which excites nitrogen. He observed that as a result of this reaction oxygen is obtained and a proton (^1_1H) is emitted as given below.

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

After this reaction, innumerable nuclear reactions have been observed.

CONDITIONS FOR NUCLEAR REACTIONS

(i) CONSERVATION OF NUMBER OF PROTONS & NUMBER OF NEUTRONS

Before and after any nuclear reaction, the number of protons and neutrons must remain the same because protons and neutrons can neither be destroyed nor they be created. Consider the example given below...

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

Before Reaction	After Reaction
No. of protons = 7+2 = 9	No. of protons = 8+1 = 9
No. of neutrons = (14−7)+(4−2) = 7+2 = 9	No. of neutrons = 9+0 = 9

(ii) CONSERVATION OF MASS (ENERGY).

A nuclear reaction can take place only when the total energy of the reactants including the rest mass energy is equal to the total energy of products. Again consider the above example.

Mass of $^{14}_{7}N$ = 14.0031 u

Mass of $^{4}_{2}He$ = 4.00264.

Total mass of reactants = 18.0057 u
Mass of $^{17}_{8}O$ = 16.9991 u
Mass of $^{1}_{1}H$ = 1.0078 u.

Total mass of the products after the reaction = 18.0069 u.

This shows that the total mass after the reaction is greater than that of the total mass before the reaction by...

$$18.0069 - 18.0057 = 0.0012\,u$$

As, 1u mass = 931 MeV energy.

So, 0.0012u mass = 0.0012 × 931 = 1.13 MeV.

Hence, this reaction is possible only when an additional mass of 0.0012u is added to the reactants or the minimum kinetic energy of the α-particles is 1.13 MeV. The kinetic energy of α-particles obtained from $^{214}_{84}Po$ is 7.7 MeV which is greater than 1.13 MeV and hence these α-particles obtained from a source is less than 1.13 MeV, then the above reaction cannot take place.

CONCLUSION

From the conditions described above we can tell whether any nuclear reaction is possible or not.

NUCLEAR REACTION IN REVERSE DIRECTION

Nuclear reaction can take place in opposite direction also. We know that $^{17}_{8}O$ is obtained by the interaction of $^{14}_{7}N$ with an α-particle of appropriate energy according to the reaction given below.

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

If we accelerate protons $_1H^1$ with the help of a machine like cyclotron to increase their velocity and bombard these high velocity protons on $^{17}_{8}O$, then the above reaction will proceed in the backward direction as

$$^{17}_{8}O + ^{1}_{1}H \longrightarrow ^{14}_{7}N + ^{4}_{2}He$$

Discovery Of Neutron

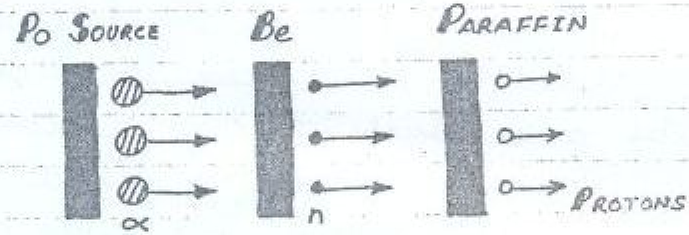
By bombarding different elements with α-particles, protons and neutrons, many nuclear reactions have been produced. Now we describe one such nuclear reaction with the help of which James Chadwick discovered neutron in 1932. When $^{9}_{4}Be$ was bombarded with α-particles $^{4}_{2}He$ emitting out of $^{210}_{84}Po$, then as a result of nuclear reaction $^{12}_{6}C$ and a neutron $^{1}_{0}n$ were obtained.

$$^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ^{1}_{0}n$$

Identification Of Neutrons

As, neutrons carry no charge, so it is difficult to identify it. To identify it, neutrons were passed through a block of parafin when neutrons were passed through paraffin, then fast moving protons were ejected out and these were easily identified. The ejection of protons is due to the fact that a large amount of hydrogen is present in paraffin and the nuceli of hydrogen atoms are protons. The emission of proton is the concequence.

of elastic collisions between the neutrons and the protons. This indicates that mass of neutron is equal to the mass of proton. According to elastic collision, if an object of certain mass collides with another object of equal mass at rest, then after collision the moving object comes to rest and the stationary object begins to move with the velocity of colliding object. Figure shows the arrangement of chadwick experiment for the discovery of neutron.



Use Of Neutron In Nuclear Reactions

The discovery of neutron has brought in a new revolution in nuclear reactions, as the neutrons carry no charge so they can easily enter the nucleus.

Nuclear Fission

"Such a reaction in which a heavy nucleus like that of Uranium split up into two nuclei of equal size along with the emission of energy during the reaction is called nuclear fission reaction".

Explanation

Otto Hahn and Firtz Strassman of Germany while working upon nuclear reactions observed that when slow moving neutrons are bombarded on ${}^{235}_{92}U$, then as a result of nuclear reaction, ${}^{141}_{56}Ba$, ${}^{92}_{36}Kr$ and an average of three neutrons are obtained. It was observed that the mass of both Krypton and Barium is less than that of mass of Uranium.

Equation Of Fission Reaction Of $^{235}_{92}U$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + Q$$

Here Q is the energy given out in this reaction.

Difference Between Nuclear Fission And Other Nuclear Reactions

This nuclear reaction is different from other nuclear reactions in two ways.

(i) First, as a result of the breakage of the uranium nucleus, two nuclei of almost equal size are obtained whereas in the other nuclear reactions, the difference between the masses of the reactants and the product was not large.

(ii) Secondly, a very large amount of energy is given out in this reaction.

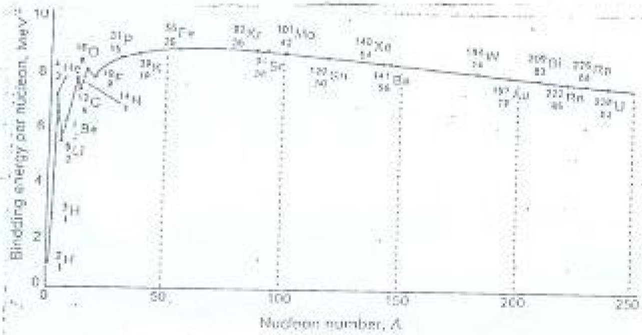
Conservation Of Mass 'A' And Charge Number 'Z'

Before Reaction	After Reaction
$Z = 92+0 = 92$	$Z = 56+36 = 92$
$A = 235+1 = 236$	$A = 141+92+3(1) = 236$

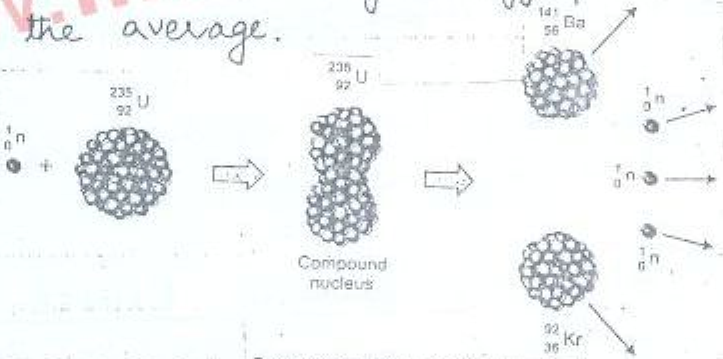
Energy Released In Nuclear Fission

Energy released in fission reaction can be easily explained with the help of graph between BINDING ENERGY PER NUCLEON and MASS NUMBER A.

This graph shows that the binding energy per nucleon is greater for the middle elements of periodic table like Krypton, Barium etc. and binding energy per nucleon is less for light elements like H or very heavy elements like Uranium i-e the nucleons in the light or very heavy elements are not so rigidly bound.



For example the binding energy per nucleon for heavy uranium is about 7.6 ~ 7.7 MeV and the products of the fission reaction of Uranium namely barium and Krypton have more binding energy per nucleon i-e 8.5 MeV on the average.



Process of Fission reaction

As products have more binding energy, So their mass defect is more which means that product of form have less mass as compared to the mass of reactants. This decrease in mass is converted into energy. Thus when a Uranium nucleus breaks as a result of fission reaction into Barium and Krypton, then an energy at the rate of 8.5 − 7.6 ≈ 0.9 MeV per nucleon is given out.

∴ Total energy released in fission of one Uranium nucleus ^{235}U = $235 \times 0.9 \approx 211.5$ MeV.

(235 → Number of nucleons.)

Two Possible Fission Reactions (Products Of Fission)

In fission process of uranium, the fission fragments (Ba, Kr) are not always same. In fact any of the two middle element nucleus could be produced. The middle element nuclei are present in the horizontal part of the the graph on the previous page. Two possible fission reactions of uranium are given below as an example:

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{132}_{50}Sn + ^{101}_{42}Mo + 3\,^{1}_{0}n + Q$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n + Q$$

Hence in the fission reaction of uranium, several products may be produced. All of these products (fragments) are radioactive.

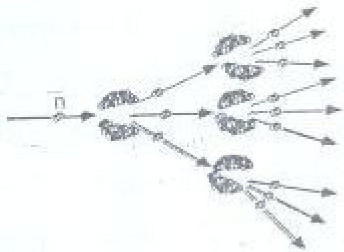
Note

Fission reaction is not confined to Uranium alone, it is possible in many other heavy elements. However, it has been observed that fission takes place very easily with slow neutrons in Uranium-235 and plutonium-239, and most of these two are used for fission purposes.

Fission Chain Reaction

What is Fission Chain Reaction?

We know that during fission reaction a nucleus of Uranium-235 absorbs a neutron and breaks into two nucleus of almost equal masses besides emitting two or three neutrons. By properly using these neutrons fission reaction can be produced in more uranium atom such that a fission reaction can continously maintain itself. This process is called fission chain reaction.



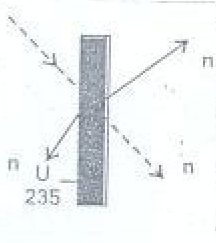
Types Of Fission Chain Reaction

(i) Uncontrolled Fission Chain Reaction

Suppose that we have a definite amount of $^{235}_{92}U$ and a slow neutron emitted from a source produces fission reaction in one atom of uranium. Out of this reaction about three neutrons are emitted. If more than one of these neutrons produce fission in some more atoms of uranium. In this way this process rapidly proceeds and in an infinitesimal small time, a large amount of energy along with huge explosion is produced. Figure 1 shows that uncontrolled fission chain reaction. This reaction is the principle of atom bomb.

(ii) Controlled Fission Chain Reaction

It is possible to produce such conditions in which only one neutron, out of all neutrons created in one fission reaction becomes the cause of further fission reaction. The other neutron either escape out or are absorbed in any other medium except uranium. In this case, fission chain reaction proceeds with its initial speed and is called controlled fission chain reaction. This is the principle of nuclear reactor.



CONDITIONS FOR FISSION CHAIN REACTION

In order to understand these conditions carefully see figure 2 (a), (b) and (c).

In figure 2(a), fission reaction in a thin sheet of $^{235}_{92}U$ is shown in figure, to be in progress. The resulting neutrons scatter in the air and so they cannot produce only fission chain reaction.

Figure 2(b) shows some favourable conditions for chain reaction. Some of the neutrons produced in the first fission reaction produces only one more fission reaction but here also no chain reaction is maintained.

Figure 2(c) shows a sphere of $^{235}_{92}U$. If sphere is sufficiently big, then most of the neutrons produced by the fission reaction get absorbed in the $^{235}_{92}U$ before they escape out of the sphere and produce chain reaction.

CRITICAL MASS

"Such mass of uranium in which one neutron out of all the neutrons produced in one fission reaction, produces further fission i-e that mass which produces controlled fission chain reaction".

CRITICAL VOLUME

"The volume of critical mass of uranium is called critical volume".

RELATION BETWEEN MASS OF URANIUM & CRITICAL MASS

→ If the mass of uranium is much greater than the critical mass, then the chain reaction proceeds at a rapid speed and a huge explosion is produced. Atom bomb works at this principle.

→ If the mass of uranium is less than the critical mass, then the (mass) reaction does not proceed.

→ If the mass of uranium is equal to the critical mass, then the chain reaction proceeds at its initial speed and in this way, we get a source of energy. Energy, in an atomic reactor is obtained according to this principle.

HOW CHAIN REACTION IS CONTROLLED IN A NUCLEAR REACTOR?

Energy released in nuclear reactor is according to principle of controlled fission chain reaction. So the chain reaction in a nuclear reactor, is not allowed to run wild, as in an atomic bomb, but is controlled by a series of rods, usually made of cadmium, that are inserted into the reactor. Cadmium is an element that is capable of absorbing a large number of neutrons without becoming unstable or radioactive. Hence, when the cadmium control rods are inserted into the reactor, they absorb neutrons to cut down on the number of neutrons that are available for the fission process. In this way the fission reaction is controlled.

NUCLEAR REACTOR

Object: Nuclear reactor produces heat energy by controlled fission chain reaction.

Principle: It works on the principle of controlled fission chain reaction.

COMPARISON BETWEEN NUCLEAR AND THERMAL POWER STATIONS

In a nuclear power station, the reactor plays the same part as does the furnace in a thermal power station. In a furnace, coal or oil is burnt to produce heat, while in a reactor fission reaction produces heat.

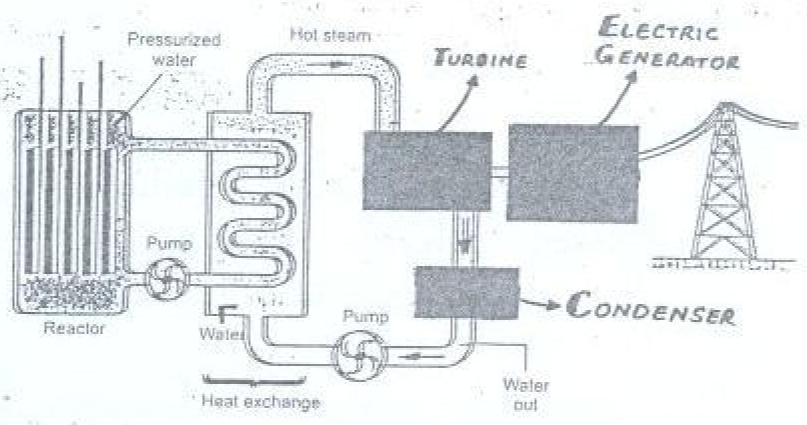
HOW HEAT IS PRODUCED IN NUCLEAR REACTOR?

When fission takes place in the nucleus of any heavy atom then energy is produced. This energy appears in the form of kinetic energy of the fission fragments. These fast moving fragments besides colliding with one another also collide with the uranium atoms. In this way their kinetic energy gets transformed into heat energy in a nuclear reactor.

HOW HEAT IS CONVERTED IN TO ELECTRICITY IN NUCLEAR REACTOR?

The heat produced is used to produce steam which in turn rotates the turbine. Turbine rotates the generator coil which produces electricity

SKETCH OF A NUCLEAR POWER STATION



CONSTRUCTION & WORKING

A reactor usually has four important parts.

1- REACTOR CORE :

The most important and vital part of a reactor is called core. Here the fuel is kept in the shape of cylindrical tubes. Reactor fules are of various types. Uranium was used as fuel in the elementry reactors. In this fuel the quantity of $^{235}_{92}U$ is increased from 2 to 4 percent. This process is called enrichment of Uranium. In naturally occurring uranium, the quantity of $^{235}_{92}U$ is only 0.7% while $^{238}_{92}U$ is 99.3%. Now a days plutonium-239 and uranium-233 are also being used as fuel.

2- MODERATOR :

The fuel rods are placed in a substance of small atomic (bomb) wei, such as water, heavy water, carbon or hydrocarbon etc. These substances are called moderators. The function of these moderators is to slow down the speed of the neutrons produced during the fission process and to direct them towards the fuel. Heavy water is made of ^2_1H which is an isotope of hydrogen. The neutrons produced in the fission reaction are very fast and energetic and are not suitable for producing fission in reactor fuel like $^{235}_{92}U$. For this purpose slow neutrons are more useful to achieve this moderators are used.

3. <u>CONTROL & SAFETY RODS</u>:

There is an arrangment for the control of number of neutrons, so that of all the neutrons produced in fission, only one neutron produces further fission reaction. This control is achieved by using rods of either cadmium or by boron rods because they have the property of absorbing fast neutrons. The control rods made of cadmium or boron are moved in or out of the reactor core to control the neutrons that can initiate further fission reaction. In this way the speed of the chain ~~rate~~ is kept under control. rods are allowed to ~~fall back to~~ repair purposes control rods are allowed to fall back to maximum depth into the reactor and thus chain reaction is stopped and reactor is shut-down.

4. <u>HEAT EXCHANGER</u>

Heat is produced due to chain reaction taking place in the core of the reactor. The temperature of core rises to about 1200°c due to heat. To produce steam from this heat, it is transported to heat exchanger with the help of water, heavy water on any other liquid under great pressure. In the heat exchanger this heat is used to produce steam from ordinary water.

<u>THEORY</u>

The steam is then used to run the turbine which in turn rotates the generator to produce electricity. The temperature of the steam coming out of the turbine is about 300°C. This is further cooled to convert it into water again. To cool this steam, water from some river or sea is generally used. In Karachi nuclear power plant (KANUP), heavy water is being used as moderator and for the transportation of heat also from the reactor core to heat exchanger, heavy water is used. To cool steam coming out of the turbine, sea water is being used.

Waste Radioactive Products & Their Disposal

After a few months, used fuel is removed and fresh fuel is fed instead. In the used up fuel, intensely radioactive substance remain. The half-life of these radioactive element materials is many thousand years The radiations and the particles emitted out of this nuclear waste is very injurious and harmful to the living things. Unfortunately there is no proper arrangement for the disposal of the nuclear waste. This cannot be dumped into oceans or left in any place where they will contaminate the environment. They must not be allowed to get into the drinking water. The best place so far found to store these wastes is in the bottom of old salt mines, which are very dry and are thousands of meters below the surface of the Earth. Here they can remain and decay without polluting the environment.

Types Of Reactors

There are two main types of nuclear reactors.

(i) Thermal Reactors (ii) Fast Reactors

Thermal Reactors

Reasons for name:

Thermal reactors are called "Thermal"

because the neutrons must be slowed down to "thermal energies" to produce further fission (Thermal energy is comparable to K.E of air molecules at room temperature)

FUEL

They use natural uranium or slightly enrichment uranium as fuel. Enrichment uranium contains a greater percentage of U-235 that natural uranium does.

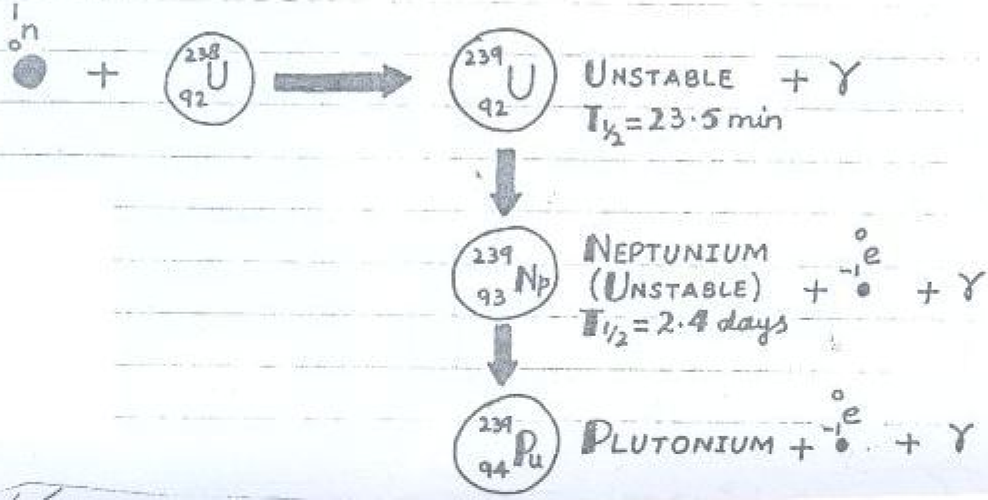
PWR

There are several designs of thermal reactors. Pressurized water reactors (PWR) are the most widely used reactors in the world. In this type of reactors, water is prevented from boiling because it is kept under high pressure. This hot water is used to boil another circuit of water which produces steam. This steam rotates turbines which in turn rotate the coil of generators to produce electricity.

(ii) FAST REACTORS

FUEL

Fast reactors are designed to make use of U-238, which is about 99% content of natural uranium. In this reactor, an induced nuclear reaction takes place in which each U-238 nucleus absorbs a fast neutron and changes into transuranium element plutonium-239. This reaction is given below.



No Moderator

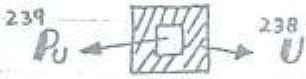
Plutonium can be fissioned by fast neutrons are given below.

$$ {}_{0}n^{1} + {}_{94}^{235}Pu \longrightarrow \underbrace{X + Y}_{\text{fission fragments}} + 2\,{}_{0}n^{1} + Q $$

So moderator is not needed in fast reactors.

Core

The Core of fast reactors consists of a mixture of plutonium and uranium dioxide surrounded by a blanket of uranium-238.



Advantage

Neutrons that escape from the core interact with U-238 in the blanket and hence plutonium-239 is produced. Thus more plutonium fuel is bred in this way and natural uranium is used for reactor more effectively.

Nuclear Fusion Reaction

"Such nuclear reaction in which lighter nuclei combine to form a heavy nucleus with the release of tremendous energy"

Examples

Let us take the example of a fusion reaction when two smaller nuclei combine.

$$ \underbrace{{}_{1}^{2}H + {}_{1}^{2}H}_{\text{(deutrons)}} \longrightarrow \underbrace{{}_{2}^{4}He}_{\text{(Helium nucleus)}} + 24\,MeV $$

But the probability of occurence of above reaction is very small. The probability is great where one proton or one neutron is produced as given below:

$$ {}_{1}^{2}H + {}_{1}^{2}H \longrightarrow {}_{1}^{3}H + {}_{1}^{1}H + 4.0\,MeV \quad \left(\frac{B.E}{\text{nucleon}} = \frac{4}{4} = 1\,MeV \right) $$

$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n + 3.3 \text{ MeV} \quad \left(\frac{B.E}{\text{nucleon}} = \frac{3.3}{4} = 0.825 \text{ MeV} \right) $$

In both of these reactions about 1 MeV energy per nucleon is produced which is equal to the energy produced during fission of uranium.

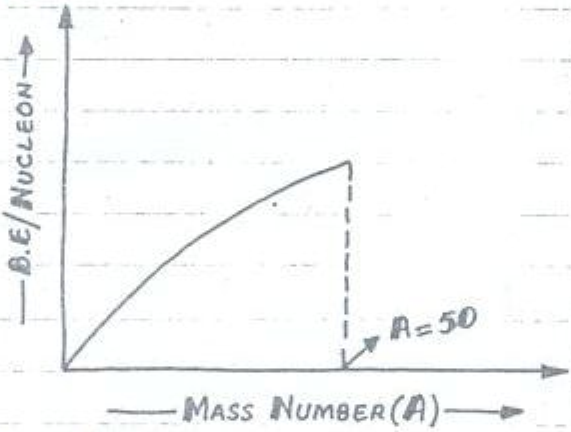
But if ${}^{2}_{1}H$ and ${}^{3}_{1}H$ are forced to fuse then energy released is 17.6 MeV. i-e,

$$ {}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + 17.6 \text{ MeV} $$

$$ \therefore \frac{B.E}{\text{nucleon}} = \frac{17.6}{5} = 3.52 \text{ MeV} $$

Why Energy Is Released In Nuclear Fusion?

We know that energy is released from any nuclear reaction in which the binding energy per nucleon of the products increases. This graph shows that the binding energy per nucleon increases upto A = 50. Hence when two light nuclei merge together to from a heavy nucleus whose mass number A is less than 50, then energy is given out.



Fusion Is More Energetic Than Fission

During a fusion reaction some mass is lost and it equivalent energy is given out according to $E = mc^2$. In a fusion reaction, more energy per nucleon can be obtained as compared to the fission reaction as explained in example 3 of fusion.

Difficulty In Producing Fusion (Condition For Fusion).

It is compaitively more difficult to produce fusion than fission because two positive charged nuclei must be bought very close to one another. To do so work has to be done against the electrostatic force of repulsion between the positively charged nuclei. Thus a very large amount of energy is required to produce fusion reaction. It is not difficult to start fission reaction because neutron has no charge on it and has to face no repulsive force while reaching the nucleus.

How Condition For Fusion Is Satisfied?

For fusion of two light nuclei the work has to be done to overcome the repulsive force which exists between them. For this two nuclei are thrown towards eachother with great speed.

1st Method (Accelerator)

To start fusion, the smaller nuclei are given a very large velocity with the help of an accelerator. This method has been used in the research study of nuclear fusion of ^2_1H and ^3_1H. But this method of nuclear fusion for getting energy cannot be used on a large scale.

2nd Method (High Temperature)

In this method, to start fusion, the temperature is increase to a very high value so that the speed of smaller nuclei (atoms) also becomes greater and hence the smaller nuclei fuse to form a heavy nucleus. To start a fusion reaction the temperature at which the required speed of the light nuclei can be obtained is about 10 millions.

degree celcius. At such extraordinary high temperature the reaction that takes place is called thermo-nuclear reaction Ordinary such a high temperature can not be acheived. However during the explosion of an atomic bomb this temperature can be acheived for a very short time.

HYDROGEN BOMB

Until now the fusion reaction is taking place only in a hydrogen bomb. The extraordinary high temperature is obtained during the explosion of an atom bomb and due to this high temperature, the fusion reaction between $_1^2H$ and $_1^3H$ takes place. In this way a very large amount of energy is given out with the explosion.

FUSION NOT UNDER CONTROL

Till now the fusion reaction has not been brought under control like a fission reaction and so is not being used to produce electricity. It is hoped that in near future some method would be found to control this reaction.

NUCLER REACTION IN THE SUN (PROTON - PROTON REACTION)

The sun is composed primarily of hydrogen. It has a little amount of helium and a slight amount of other heavy element. It keeps on emitting a tremendous amount of energy continously at all times. The temperature of its core is about 20 million degree celsius and its surface temperature is about 5 million degrees celsius. Its energy is due to fusion reaction called (p-p) (proton-proton reaction).

In this reaction, two hydrogen nuclei or two protons fuse to form deutron as given below.

$$_1^1H + _1^1H \rightarrow _1^2H + _1e^0 + \text{Energy}$$

(Two protons) (Deutron) ↘ Position.

With the fusion reaction of deutron with proton, $_2H$ an isotope of helium is formed i-e,

$$^2_1H + ^1_1H \longrightarrow ^3_2He + \gamma\text{-radiations} + \text{Energy}.$$

In the last stage, the two nuclei of ^3_2He produced by above two reactions, react in the following manner:

$$^3_2He + ^3_2He \longrightarrow ^4_2He + ^1_1H + ^1_1H + \text{Energy}.$$

Conclusion

In the above reactions, six protons take part and finally a helium nucleus ^4_2He and two protons are formed. So the result of difference stages of this reaction is that 4 protons have formed one helium nucleus.

i-e The next reaction is

$$4\,^1_1H \longrightarrow ^4_2He + 2\,^0_1e + \gamma\text{-radiation} + \text{Energy}.$$

It has been estimated that in this p-p chain reaction, 25.7 MeV energy is given out. i-e $\frac{25.7}{4} = 6.4$ MeV per nucleon energy is obtained which is much greater than the energy given out per nucleon (1 MeV) during a fission reaction.

Radiation Exposure

What are background radiations?

This is the radiations present around us although no radioactive source is close to us. When a Geiger tube is used in any experiment, it records radiation even when a radioactive source is nowhere near it. This is caused by radiation called brackground radiation.

SOURCES OF BACKGROUND RADIATION

(i) Cosmic radiation which comes to us from outer space.

(ii) Naturally occuring radioactive substance in the Earth's crust.

COSMIC RADIATIONS

The cosmic radiations consist of high energy charged particles and electromagnetic radiations.

ATMOSPHERIC SHIELD & THE EFFECT OF DEPLETION OF OZONE LAYER.

The atmosphere acts as a sheild to absorb some of the background radiations as well as ultravoilet rays. The depletion of ozone layer in the upper atmosphere has been detected. This layer filter ultravoilet rays reaching us. This depletion of layer may result in increasing eye and skin diseases.

REASON OF DEPLETION OF OZONE LAYER & ITS REMEDY

The depletion of ozone layer is suspected to be caused due to excessive release of some chemicals in the atmosphere such as chloro fluorocarbons (CFC) used in refrigeration, aerosol spray and plastic foam industry. Its use is now being replaced by environmentally friendly chemicals.

RADIOACTIVE ISOTOPES IN BUILDING MATERIALS

Many building materials contain small amount of radioactive isotopes.

RADON GAS LEVEL INSIDE THE BUILDINGS

Radioactive radon gas enters building from the ground. It gets trapped inside the building which makes radiation levels inside the building greater than the outside level.

Reduction Of Radon Gas Level Inside Buildings

A good ventilation can reduce radon level inside the building.

Radioactive Substances In Food

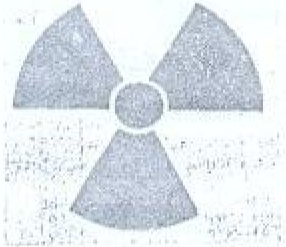
All types of food also contain a little radioactive substance. The most common are potassium-40 and carbon-14 isotopes.

Radiation Due To Human Activities

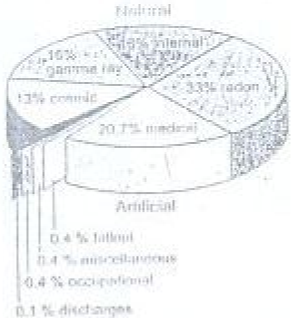
Some radiations in the environment are added by human activities. Medical practices, mostly diagnostic X-rays are mainly responsible for this. Many X-rays exposures such as routine chest X-rays and dental X-rays. X-rays are made for no strong reason and may do more harm than good. The other sources of radiation due to human activities include radioactive waste from nuclear facilities, hospitals, research and industries, color television, tobacco leaves and luminuous watches.

The Best Advice To Avoid Unnecessary Radiation Exposure.

We cannot avoid radiation exposure. However the best advice is to avoid unnecessary exposure to any kind of ionizing radiation.



This symbol is universally used to indicate an area where radioactively is being handled or artificial radiations are being produced.



Pie-chart showing proportion of radiation from different sources absorbed by average person.

Biological Effect Of Radiation

To study the effects of radiations, we need to define some of the unit of radiations.

Activity

"It is defined as the number of disintegrations of radioactive sample per second and it shows the strength of radiation"

Units Of Activity

(i) Becqueral (Bq)

1 Bq = 1 disintegration per second.

(ii) Curie (ci)

$1\,Ci = 3.7\times10^{10}$ disintegration per second.

Absorbed Dose (D)

"Absorbed dose D is defined as the energy E absorbed from ionizing radiation per unit mass m of the absorbing body"

Mathematically,

$$D = \frac{E}{m}$$

Units Of Absorbed Dose

(i) Gray (Gy)

It is the SI unit

As $D = \frac{E}{m}$, so $1\,Gy = \frac{1J}{Kg} = 1\,JKg^{-1}$.

(ii) rad

It is the old unit of D. rad is an acronym (small name) for radiation absorbed dose.

1 rad = 0.01 Gy.

Biological Effects Of Equal Doses Of Different Radiations

Equal doses of different radiations do not produce same biological effect. For the same absorbed dose, α-particles are 20-times more damaging than x-rays. The effect also depends on the part of the body absorbing the radiation. For example, neutrons are particularly more damaging to eyes than any other part of the body.

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE)

As equal doses of different radiations do not produce same biological effect and this effect also depends on the part of the body absorbing it, so the absorbed dose is multiplied by a quality factor known as relative biological effectiveness or RBE.

EQUIVALENT DOSE (D_e)

"The equivalent dose D_e of any absorbed radiation is defined as the product of absorbed dose and RBE of the kind of radiation being absorbed"

Mathematically,

$$D_e = D \times RBE$$

Note

Equal equivalent dose means same effect.

UNITS OF EQUIVALENT DOSE

(i) Sievert (SV)

It is the SI unit

$$1\,SV = 1\,Gy \times RBE$$

(ii) rem

It is the old unit

rem (radiation effective mass)

1 rem = 0.01 SV

Relative Biological Effectiveness (RBE)

Radiation	RBE
X-rays, γ-rays and α-particles of 30 keV or more	1.0
α-particles of less than 30 keV	1.7
Neutrons and protons below 10	10 (body)
MeV	30 (eyes)
α-particles from natural radioactivity	10
Heavy recoil nuclei	20

Types of Exposure	mSv
Watching television for a year	10
Radiation from nuclear power stations for a year	10
Wearing a radioactive luminous watch for a year (now not very common)	30
Having a chest X-ray	200
Radiation from a brick house per year	750
Maximum dose allowed to general public from artificial sources per year	1000
Working for a month in a uranium mine	1000
Typical dose received by a member of the general public in a year from all sources	2500
Maximum dose allowed to workers exposed to radiation per year	50000

General Information About Biological Effect Of Radiation.

(i) The background radiation to which we are exposed, on the average, is 2mSV per year.

(ii) Doses of 3SV will cause radiation burns to the skin.

(iii) For workers in the nuclear facilities or mines, a weekly dose of 1mSV is normally considered safe.

(iv) The damage from α-particles is small unless the source enters the body.

(v) α and β-particles can cause redness and sores on the skin.

(vi) Some other low level radiation effects are loss of hair, ulceration, stiffening of lungs, and a drop in the white blood cells which is followed by a sickness pattern of diarrhea, vomiting and fever known as radiation sickness.

(vii) High levels of radiation may disrupt the blood cells seriously leading to diseases such as anaemia and leukaemia.

(viii) Chromosome abnormalities or mutation may cause delayed genetic effects such as cancer, eye cataracts (A disease causing partial blindness) and abnormalities in the future generations. These may develope many years after exposure to harmful radiation.

★ Film badge dosimeter are used to monitor radiation received by workers in nuclear facilities.

Biological & Medical Uses of Radiation

If we bombard some elements with neutrons and other particles, then their radioisotopes are made. As these isotopes are inexpensive, so they are greatly used in medicine, agriculture, scientific research and industries.

(i) Radioisotopes are used to find out what happens in many complex chemical reactions and how they proceed.

(ii) Radioisotopes are used to investigate about the chemical reactions that take place in animals and plants.

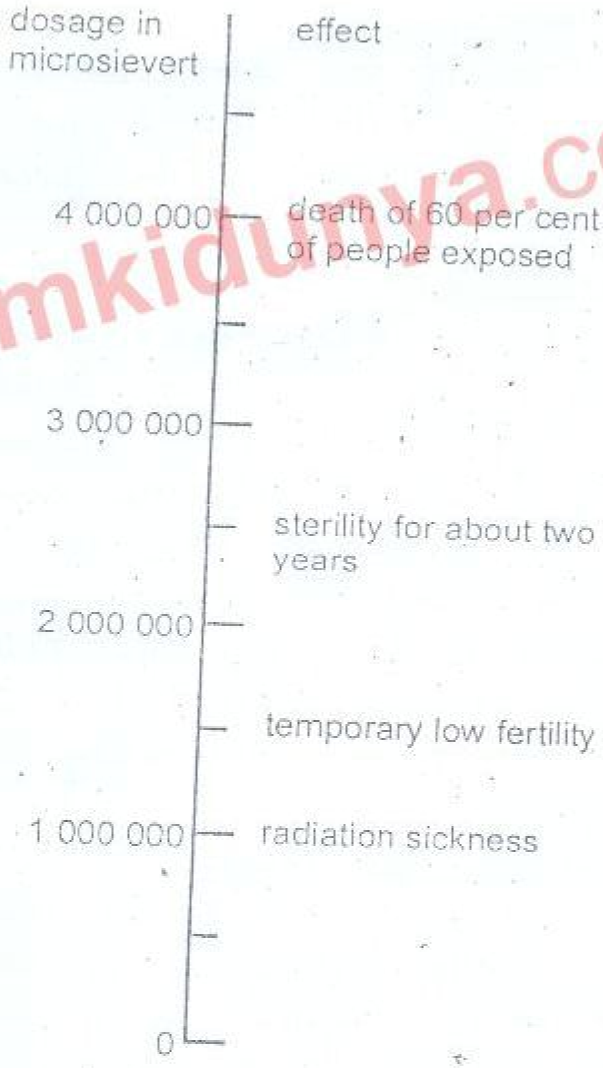
(iii) By mixing a small amount of radioactive isotope with fertilizer, we can easily measure how much fertilizer is taken up by the plant using radiation detector. From such measurements, farmers know the proper amount of fertilizer to use.

(iv) Through the use of radiation induced mutations, improved varities of certain crops such as rice, chickpea, wheat and cotton have been developed.

(v) They have improved plant structure and these plants have shown more resistance to disease and pests, and give better yield and grain quality.

(vi) Radiation is also used to treat cancer.

(vii) Radioactive tracers and imaging devices have helped in the understanding and diagnosis of many diseases.



The effects of exposure to high levels of ionizing radiation

Tracer Techniques

What is Tracer?

A radioactive isotope used to indicate or trace the path followed by chemical or biological process.

Explanation

A radioactive isotope behave in just the same way as the normal isotope inside a living organism. But the location and concentration of a radioactive isotope can be determined easily by measuring the radiation it emits. Thus, a radioactive isotope acts as an indicator or tracer that makes it possible to follow the path of a chemical or biological process. In this technique, we substitute radioactive atoms for stable atoms of the same kind in a substance and then we follow the "tagged" atoms with the help of radiation detector in the process.

Applications

★ In Agriculture

Traces are widely used in agriculture to study the uptake of a fertilizer by a plant. Also if a plant is given radioactive carbon-14, it will use it in exactly the same way as it always uses stable carbon-12. But the carbon-14 releases β-radiations and thus measuring radioactivity in different parts of the plant, the path taken by the carbon atoms are known. This technique has helped to understand more elaborately the complex process of photosynthesis.

★ Identification Of Faults

The tracer technique was also used to identify the faults in the underground pipes of the fountains system of the historical Shalimar garden of Lahore by the scientists of Pakistic Atomic Energy Comission.

MEDICAL DIAGONSTIC & THERAPY

Traces are widely used in medicine to study the process of digestion and the way chemical substances move about in the body.

Some chemicals such as hydrogen and sodium present in water and food are distributed uniformly throughout the body. Certain other chemicals are selectively absorbed by certain organs. Radio-iodine, for example, is absorbed mostly by the thyroid gland, phosphorus by bones and cobalt by liver. They can serve as tracers. Small quantity of low activity radioisotope mixed with stable isotope is given, by injection or otherwise to a patient and its location in diseased tissue can be determined by means of radiation detectors.

(a) DIAGNOSTIC OF ABNORMAL WORKING OF THYROID GLAND & ABNORMAL CIRCULATION OF BLOOD.

Radioactive iodine can be used to check that a person's thyroid gland is working properly. A diseased or hyperactive gland absorbs more than twice the amount of normal thyroid gland. A similar method can be used to study the circulation of blood using radioactive isotope sodium-24.

(b) DESTRUCTION OF CANCEROUS CELLS

Experiments on cancerous cells have shown that those cells that multiply rapidly absorb more radiation and are more easily destroyed than normal cells by ionization radiation. Radio therapy with γ-rays from cobalt-60 is often used in the treatment of cancer. The γ-rays are focussed on to the malignant tissue.

(c) THERAPY OF CANCER OF THYROID GLAND

Radioactive iodine-131 is used to combat cancer of the thyroid gland. Since iodine tends to collect in the thyroid gland, radioactive isotopes of iodine lodge where they can destroy the malignant tissue for local and short ranged treatment.

(d) Therapy of

For skin cancers, phosphorus-32 or strontium-90 may be used instead of iodine-131. These produce β-radiations.

(e) DISADVANTAGE OF RADIOACTIVE THERAPY

The dose of radiation has to be carefully controlled otherwise the radiation could do more damage than help. Patients undergoing radiation treatment often feel ill because the radiation also damages the healthy cells.

RADIOGRAPHY

"The process in which images are obtained by passing radioactive rays through a body, is called radiography"

APPLICATION

The γ-rays radiographs are used in medical diagnosis such as internal imaging of the brain to determine precisely the size and location of a tumer or other parts of the body. Cracks or in casting or pipe can also be detected by scanning. Any sudden increase in count rate of γ-particles indicates a cavity with in the object.

The gamma is designed to γ-radiations from sites in the body where a γ-emitting isotope is located. The camera can also form a sequence of images to observe an organ such as a kidney in action.

Basic Forces Of Nature

The basic forces are

1 Magnetic forces
2 Electric force
3 The Strong force
4 Weak nuclear force
5 Gravitational force.

Isotope	Half-life	Gamma energies/ MeV	Example of USE
Sodium – ^{24}Na	15 hours	1.37,2.75	Plasma volume
Iron – ^{59}Fe	45 days	1.29,1.10, 0.19	Iron in Plasma
Technetium – ^{99}T	6 hours	0.14	Thyroid uptake scans
Iodine ^{131}I	8 days	0.72, 064, 0.36, 0.28, 0.08	Kidney tests
Iodine ^{125}I	60 days	0.035	Plasma volume Vein flow

Electromagnetic Force (Unification Of Electric And Magnetic Force)

The electric and magnetic forces were unified to get an electromagnetic force by Faraday and Maxwell. They were able to prove that a current is induced in a coil whenever the magnetic flux passing through the coil is changed. This leaves behind four fundamental forces.

1 Electromagnetic force
2 Weak nuclear force
3 The strong nuclear force
4 Gravitational force.

The electromagnetic force is long range and causes all chemical reactions. It binds together atoms, molecules, crystals, trees . This force acting on a microscopic level is responsible for a variety of apparently different macroscopic forces such as fiction, cohesion and adhension.

THE STRONG NUCLEAR FORCE

The strong nuclear force is a short range force and confines the neutron and protons within the nucleus.

WEAK NUCLEAR FORCE

The weak nuclear force is short range, like the strong nuclear force, and is responsible for spontaneous breaking up of the radioactive elements. It is a sort of repulsive force of very short range (10^{-17} m). It is masked by the effect of strong and electromagnetic forces inside the nucleus.

GRAVITATIONAL FORCE

The gravitational force like the electromagnetic force, is again long range. Its effect is upto and beyond the remotest stars and glaxies. It keeps you, the atmosphere and the seas fixed to the surface of the planet. It gives rise to ocean tides and keeps the planets moving in their orbits around the sun.

UNIXICATION OF ELECTROMAGNETIC & WEAK NUCLEAR FORCE (ELECTROWEAK FORCE).

One hundred years after the unification of electric and magnetic force into electromagnetic force in 1979, the physics nobel prize was awarded to Glashow, Weinberg and Abus-Salam for unification of electromagnetic and weak forces. They are called unified force as electroweak force.

FORCES IN NATURE AT PRESENT

1 Electro-weak forces
2 The Strong nuclear forces
3 Gravitational forces

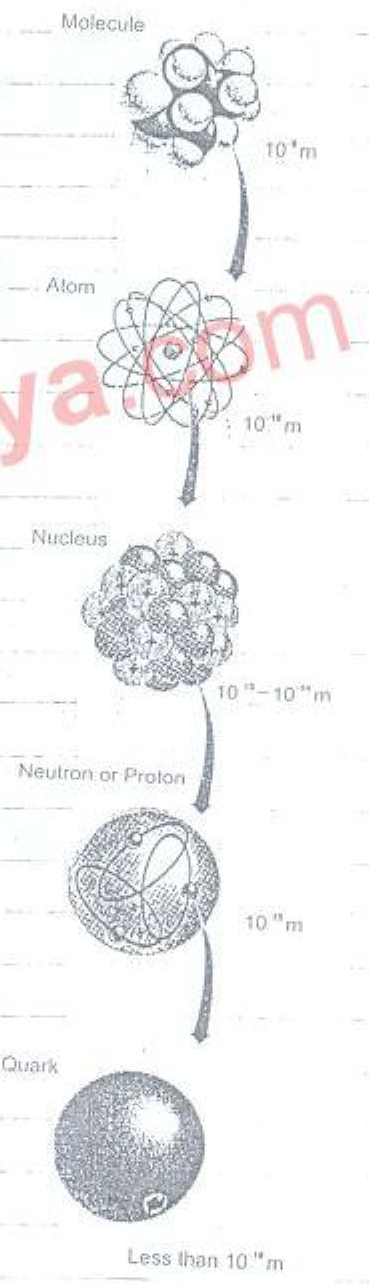
BUILDING BLOCKS OF MATTER

Subatomic particles are divided into three groups.

1 Photons   2 Leptons   3 Hadrons.

Elementry particles are particles which cannot be sub-divided. Elementry particles are the basic building blocks of matter. All photons and leptons are elementry particles. Hardons are not elementry particles but are composed of elementry particles called quarks. Scientists now believe that all matters belong to either the quark group or lepton group.

Composition of Matter



HADRONS

Hadrons are particles that experience the strong nuclear force. In addition to protons, neutrons and mesons are hadrons. There are two type of hadrons.

(i) BARYONS

The hadron particles equal in size (mass) to protons or greater than protons, are called baryons (e.g. neutrons).

(ii) MESONS

The hadrons that are lighter than protons are called mesons ($\pi^{\pm}$, π^{0}).

LEPTONS

Leptons are particles that do not experience

Strong nuclear force e.g electrons, muons and neutrinos.

Quarks

According to quark theory of M. Gell-Mann and G. Zweig, the quarks are proposed as the basic building block of the meson and baryons. A pair of quark and antiquark makes a meson and 3 quarks make a baryon. It is proposed that there are six quark, these are...

1 up 2 down 3 strange 4 Charm 5 bottom 6 top

The charges on these quarks are fraction as shown in table.

Quarks and Antiquarks			Antiquarks	
Name	Symbol	Charge	Symbol	Charge
Up	u	$+\frac{2}{3}e$	$\bar{u}$	$-\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$	$\bar{d}$	$+\frac{1}{3}e$
Strange	s	$-\frac{1}{3}e$	$\bar{s}$	$+\frac{1}{3}e$
Charm	c	$+\frac{2}{3}e$	$\bar{c}$	$-\frac{2}{3}e$
Top	t	$+\frac{1}{3}e$	$\bar{t}$	$+\frac{1}{3}e$
Bottom	b	$-\frac{2}{3}e$	$\bar{b}$	$+\frac{1}{3}$

A proton is assumed to be made up of two up quarks and one down quark as shown in figure.

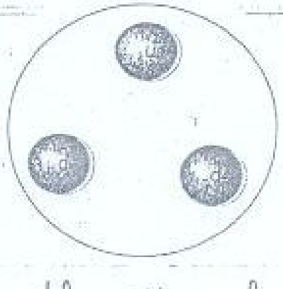
Proton

Charge
2/3 + 2/3 - 1/3 = 1

The neutron is assumed to be made up of one up quark and two down quarks as shown in fig.

P21.11

Neutron



Charge
2/3 - 1/3 - 1/3 = 0

Currently, the hundred of hydrons are assumed to be made up of quarks and their anti quarks. It is believed that quarks cannot exist on their own, their existance has been indirectly verified.

QUESTIONS

21.1. What are isotopes? What do they have in common and what are their differences?

Ans. Isotopes are those nuclei, which have same atomic number but have different mass numbers.

21.2. Why are heavy nuclei unstable

Ans. The heavy nuclei have very small value of their binding energy per nucleon. So these are un-stable. And less energy is required to split heavy nuclei.

21.3. If a nucleus has a half-life of 1 year, does this mean that it will be completely decayed after 2 years? Explain.

Ans. The half-life of a radioactive element is the time in which half of given sample of element decays. As decay rate decreases with the decrease of number of radioactive atoms, so total life is much greater than twice of half-life. Total decay is possible after infinite.

21.4. What fraction of a radioactive sample decays after two half- lives have elapsed?

Ans. The number of atoms at t = o is denoted by No then after two half lives (n = 2) we get the remaining number of radioactive atoms as follows.

$$N = \left(\frac{1}{2}\right)^n No$$

Here n = 2

So $N = \frac{1}{4}$ (No)

This means that after two half lifetime, there is only one fourth of the given sample of radioactive element while $\frac{3}{4}$ of it is decayed.

21.5. The radioactive element $^{226}_{88}Ra$ has a half-life of 1.6×10^3 years. Since the Earth is element in nature? Incomplete question

Ans. The half-life of $^{226}_{88}$ Ra is 1.6×10^3 years but its total life is equal to infinity.

This is common property of all the radioactive elements that given samples of them decays fully after infinite time

This is why $^{226}_{88}$ Ra is still found on Earth while Earth life is 5 billions years.

21.6. Describe a brief account of interaction of various types of radiations with matter.

Ans. The interaction of radiations with matter is fully explained in the article, see that article.

21.7. Explain how α and β-particles my ionize an atom with out directly hitting the electrons? What is the difference in the action of the two particles for producing ionization?

Ans. α - particle like nucleus of helium it requires electron. It is also energy. So it uses its energy to ionize thousands and thousands of atoms in its way, without hitting with them. Similar is the case of β- particles.

21.8. A particle which produces more ionization is less penetrating. Why?

Ans. The particle with greater ionizing power will loose its whole of energy in a short distance inside a medium. So its range in that medium is very small. The reverse is the case for particle of less ionizing power that it will loose less amount of energy so that its range is large.

21.9. What information is revealed by the length and shape of the tracks of an incident particle in Wilson cloud chamber?

Ans. In Wilson –cloud chamber the straight and thicker trace is for such a particle, which has greater mass as well as greater ionizing power. It is for α– particles. The β and Υ have less mass and less value of ionizing power so their tracks are cloudy shaped.

21.10. Why must a Geiger Muller tube for detecting α - particles have a very thin end window? Why does a Geiger Muller tube for detecting γ-rays not need a window at all?

Ans. The window on the top of G.M. tube provides easy way for the low energy particles, to enter into the tube. The Υ– radiations are highly penetrating so these do not require any thin window.

21.11. Describe the principle of operation of a solid-state detector of ionizing radiation in terms of generation and detection of charge carriers.

Ans. See the article of semiconductor detector.

21.12. What do we mean b y the term critical mass?

Ans. The quantity of mass which is enough to absorb most all of the neutrons produced in chain fission reaction to give tremendous energy, like atom bomb in called critical mass of fissionable material.

21.13. Discuss the advantages and disadvantages of nuclear power compared to the use of fossil fuel generated power.

Ans. The nuclear power is of large amount and it is almost permanent for a given period of months. Where as the fossil fuel generated power is of fewer amounts and may not be definite for long period of months. Moreover the nuclear power is cheaper than fossil fuel generated power.

21.14. What factors make a fusion reaction difficult to achieve?

Ans. The fusion reaction requires large energy to start and temp. of millions degrees of Celsius is required to make this reaction possible in laboratory. Also greater energy nuclei are required come close together and merge together. For this accelerators must be there to accelerate the nuclei. Even then probability of occurring the fusion process is very low.

21.15. Discuss the advantages and disadvantages of fusion power from the point of safety. Pollution and resources.

Ans. The fusion reaction is free from radioactive fossil products. It gives more energy per nucleon as compared with nuclear fission reaction.

The fusion reaction between two nuclei cannot occur without giving large energies to them. The required high energy can be given by using accelerators or by making temperature, vrery high (millions of Celsius degrees). Both of these are technically difficult.

21.16. What do you understand by "background radiation"? State two sources of this radiation.

Ans. The radiations present all around us due to cosmic rays and due to natural radioactive materials under the crest of Earth, are called back ground radiations.

21.17. If you swallowed an α / β-source, which would be the more dangerous to you? Explain why?

Ans. The α particle has very very large value of ionizing power. It can produce thousands and thousands of ions. But β - radiations are of less ionizing power so these are less dangerous than α - particles.

21.18. Which radiation dose would deposit more energy to your body (a) 10 mGy to your hand, or (b) 1 mGy dose to your entire body.

Ans. By definition

$1Gy = 1J\ kg^{-1}$

$10mGy = 10m\ J\ kg^{-1}$

and

$1\ mGy = 1m\ J\ kg^{-1}$

This shows that $10\ m\ J\ k^{-1}$ (10 mGy) is the more energy given to whole of the body is greater then 1 mGy given to hand only.

21.19. What is a radioactive tracer? Describe one application each in medicine, agriculture and industry.

Ans. Please see the article "tracer technique"

21.20. How can radioactivity help in the treatment of cancer?

Ans. Radiation are focused on the cancerous cells with more amount of radiations and also these are more damaged than the healthy cells. This is basic principle of treatment of cancer with radiations.