Further investigations proved that an $\alpha-$ particle has a mass 4 amu and charge +2e. In other words, $\alpha-$ particles are helium nuclei. The charge and mass of a $\beta-$ particle are the same as those of an electron. Thus $\beta-$ particles are electrons. The $\gamma-$rays are electromagnetic waves of very high frequencies, i.e. very small wavelengths.

When $\alpha-$ particle is emmited by nucleus of radioactive substance an atom, its atomic number decreases by 2 and mass number decreases by 4.

When $\beta-$ particles is emited by nucleus of radioactive substance atomic number increases by 1 but mass number remains same.

The decaying nucleus is called the ***parent nucleus*** while the nucleus produced after the decay is called the ***daughter nucleus.*** The process is called ***radioactive decay*** or ***radioactivity*** and was discovered by Becquerel (1852-1908) in 1876. Radioactive decays occur because the parent nuclei are unstable and get converted to more stable daughter nuclei by the emission of some particles. These decays are of three types as described below.

Alpha Decay:

In this type of decay, the parent nucleus emits an alpha particle which is the nucleus of helium atom. The parent nucleus thus loses two protons and two neutrons. The decay can be expressed as

$$ {}_{Z}^{A}X \rightarrow {}_{Z-2}^{A-4}Y + \alpha $$

X is the parent nucleus and Y is the daughter nucleus. All nuclei with A > 210 undergo alpha decay. The reason is that these nuclei have a large number of protons. The electrostatic repulsion between them is very large and the attractive nuclear forces between the nucleons are not able to cope with it. This makes the nucleus unstable and it tries to reduce the number of its protons by ejecting them in the form of alpha particles. An example of this is the alpha decay of bismuth which is the parent nucleus with A = 212 and 2 = 83. The daughter nucleus has A= 208 and 2 = 81, which is thallium. The reaction is

$$ {}_{83}^{212}Bi \rightarrow {}_{81}^{208}T1 + \alpha $$

The total mass of the products of an alpha decay is always less than the mass of the parent atom. The excess mass appears as the kinetic energy of the products. The difference in the energy equivalent of the mass of the parent atom and that of the sum of masses of the products is called the Q-value, Q of the decay and is equal to the kinetic energy of the products. We can write,

$$ Q = \left[m_X - m_Y - m_{He} \right] C^2 $$

m_X, m_Y and M_{He} being the massses of the parent atom, the daughter atom and the helium atom. Note that we have used atomic masses to calculate the Q factor.

Beta Decay:

In this type of decay the nucleus emits an electron produced by converting a neutron in the nucleus into a proton. Thus, the basic process which takes place inside the parent nucleus is

$$ n \rightarrow p + e^- + \text{antineutrino} $$

Neutrino and antineutrino are particles have very little mass and no charge. During beta decay, the number of nucleons i.e., the mass number of the nucleus remains unchanged. The daughter nucleus has one less neutron and one extra proton. Thus, Z increases by one and Ndecreases by one, A remaining constant. The decay can be written as,

$${}_{Z}^{A}X \rightarrow {}_{Z+1}^{A}Y + e^{-} + \text{antineutrino}$$

An example is

$${}_{27}^{60}Co \rightarrow {}_{28}^{60}Ni + e^{-} + \text{antineutrino}$$

There is another type of beta decay called the ***beta plus decay*** in which a proton gets converted to a neutron by emitting a positron and a neutrino. A positron is a particle with the same properties as an electron except that its charge is positive. It is known as the antiparticle of electron. This decay can be written as,

$$\text{p} \rightarrow \text{n} + \text{e}^{+} + \text{neutrino}$$

The mass number remains unchanged during the decay but Z increases by one and N decreases by one. The decay can be written as

$${}_{Z}^{A}X \rightarrow {}_{Z-1}^{A}Y + e^{+} + \text{neutrino}$$

An example is

$${}_{11}^{22}Na \rightarrow {}_{10}^{22}Ne + e^{+} + \text{neutrino}$$

An interesting thing about beta plus decay is that the mass of a neutron is higher than the mass of a proton. Thus the decay described by cannot take place for a free proton. However, it can take place when the proton is inside the nucleus as the extra energy needed to produce a neutron can be obtained from the rest of the nucleus.

In beta decay also, the total mass of the products of the decay is less than the mass of the parent atom. The excess mass is converted into kinetic energy of the products. The Q value for the decay can be written as

$$\text{Q}=\left[m_X - m_Y - m_e\right]c^2$$

Here, we have ignored the mass of the neutrino as it is negligible compared to the masses of the nuclei.

Gamma Decay:

In this type of decay, gamma rays are emitted by the parent nucleus. As we know, gamma ray is a high energy photon. The daughter nucleus is same as the parent nucleus as no other particle is emitted, but it has less energy as some energy goes out in the form of the emitted gamma ray. We have seen that the electrons in an atom are arranged in different energy levels (orbits) and an electron from a higher orbit can make a transition to the lower orbit emitting a photon in the process. The situation in a nucleus is similar. The nucleons occupy energy levels with different energies. A nucleon can make a transition from a higher energy level to a lower energy level, emitting a photon in the process. The difference between atomic and nuclear energy levels is in their energies and energy separations. Energies and the differences in the energies of different levels in an atom are of the order of a few eVs, while those in the case of a nucleus are of the order of a few keV to a few MeV. Therefore, whereas the radiations emitted by atoms are in the ultraviolet to radio region, the radiations emitted by nuclei are in the range of gamma rays.

Units for measuring masses of atoms and sab atomic particles

A: Kg

m_e - $9.109383\times10^{-31}kg$

m_p - $1.672623\times10^{-27}kg$

m_n- $1.674927\times10^{-27}kg$

B: Amu Atomic mass unit (u)

$1u = 1.6605402\times10^{-27}kg$

m_e - 0.00055 u

m_p- 1.007825 u

m_n - 1.008665 u

C: $E = mc^2$ 1 u = 931.5 Mev/c^2

m = E/c^2

Mass in terms of energy equivalent

m_e - 0.511 MeV/c^2

m_p - 938.28 MeV/c^2

m_n - 939.57 MeV/c^2

Example : Calculate mass defect and binding energy of ${}_{27}CO^{59}$ which has a nucleus of mass *58.933 u (amu)*

Given m_p = 1.0078 u m_n = 1.0087 u

${}_{27}CO^{59} \rightarrow {}_{Z}X^{A}$ Z = 27 (proton)

A - Z - 59 - 27 = 32 (Neutron)

mass defet $\Delta m = 27\times1.0078 + 32\times1.0087 - 58.933u$

$\Delta m = [27.2106 + 32.2784] - 58.933$

$\Delta m = 59.487 - 58.933$

$\Delta m = 0.556u(amu)$ $1u$ = 931 MeV/c^2

BE = 517.914 MeV

Example : Calculate radius and density of Ge nucleus given that its mass to be approximately 69.924 u.

$R_x = RoA^{1/3}$

$R_{Ge} = Ro(70)^{1/3}$

$R_{Ge} = 1.2\times10^{-15}\times4.12$

$R_{Ge} = 4.944\times10^{-15}m$

$$e = \frac{3m}{4\pi(R_{Ge})^3}$$

$$e = \frac{3\times69.924\times1.66\times10^{-27}}{4\times3.142\times4.944^3}$$ $1u = 1.66\times10^{-27}$ kg

$e = 2.29\times10^{17} kg/m^3$

Law of radioactive decay : Due to radioactive disintegration the number of atoms of the parent radioactive element in a given sample goes on decreasing. The rate at which the disintegration occurs is given by the law of radioactive decay which can be stated in the following manner.

Q. State law of radioactive decay and show that radioactive decay is exponential in nature.

The rate of radioactive disintegration, (i.e. the number of atoms of a radioactive substance disintegrating per second) at a given instant, is directly proportional of the number of atoms present at that instant.

Suppose that a sample of a radioactive element contains N_o atoms of that element at the start. As time passes the number of atoms of that element will go on decreasing due to radioactive disintegration. Let N be the number of atoms of the parent element still existing after time t.

At this instant, the rate of disintegration is $\frac{dN}{dt}$. According to the law of radioactive decay,

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

Where λ is a constant called the decay constant or disintegration constant of that radioactive substance. The negative sign in introduced in the above equation because dN/dt is a negative quantity, since N decreases as t increases. Separating the variable.

$\frac{dN}{N} = -\lambda dt$ Integration both sides

$\int \frac{dN}{N} = \int -\lambda dt \qquad \log_e N = -\lambda t + c$ ....(I)

Where c is constant of integration whose value depends on initial conditions.

At t = 0; N = N_0 (the number of original nuclei)

$\therefore \log_e N_0 = 0 + c$

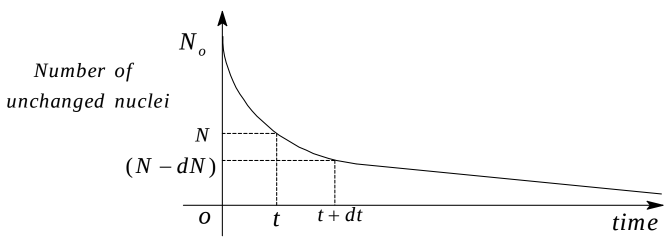
Substituting the value in above expression (I)

$$\log_e N = -\lambda t + \log_e N_0 \qquad \log_e N - \log_e N_0 = -\lambda t$$

$$\log_e\left(\frac{N}{N_0}\right) = -\lambda t \qquad \frac{N}{N_0} = e^{-\lambda t} \quad \text{or} \quad N = N_0 e^{-\lambda t}$$

This expression shows that number of nuclei of given radioactive substance decreases exponentially with time i.e., radioactive decay is exponential in nature.

Note : This equation is also writen in the form $N(t) = N_0 e^{-\lambda t}$



Q. Define Half life period.

Half life period (T) :

Half life period (T) of radioactive substance is defined as the time in which the half substance is distengrated.

We have $N = N_0 e^{-\lambda t}$ at t = T ; $N = \frac{N_0}{2}$ $\therefore \frac{N_0}{2} = N_0 e^{-\lambda T}$

or $\frac{1}{2} = e^{-\lambda T}$

or $e^{\lambda T} = 2$ $\qquad \lambda T = \log_e 2$

$\lambda T = 2.303 \times \log_{10} 2$ $\qquad \lambda T = 2.303 \times 0.3010$

$\lambda T = 0.693$ $\qquad \therefore T = \frac{0.693}{\lambda}$

Using the expression, we can determine the half life of radioactive substance if its decay constant is known. The interesting thing about half-life is that even though the number goes down from N_0 to $\frac{N_0}{2}$ in time T, **,** after another time interval T, the number of parent nuclei will not go to zero. It will go to half of the alue at t = T i.e to $\frac{N_0}{4}$. Thus, in a time interval equal to half-life, te number of parent nuclei reduces by a factor of 1/2

Decay constant :

Define decay constant or disintegretion constant of radio-active elements. If λ is the ecay constant of radio-active elements. Show that about 37% of the original nuclei remains undecayed after a time interval of $t = \frac{1}{\lambda}$

we have $\lambda = \frac{-dN/dt}{N}$

The decay constant us defined as ratio of the amount of substance disintegrated per unit time to amount of substance present at that time. We have $N = N_0 e^{-\lambda t}$

Let us define 't' as $t = \frac{1}{\lambda}$

$\therefore N = N_0 e^{-\lambda\left(\frac{1}{\lambda}\right)}$, $\quad N = N_0 e^{-1}$, $\quad N = \frac{N_0}{e}$, $\quad N = \frac{N_0}{2.718}$, $\quad \therefore$ $N = 0.37N_0$

The decay constant λ, which is equal to $1/t$, can be defined as reciprocal of time duration (t) in which the substance remains undecayed 37% of its origional quality.

Properties of $\alpha -$ Particles :

(1) They are positively charged particles. It is helium nucleus Its mass is 4 amu (6.64×10^{-27} kg) and charge is 2e ($+3.2 \times 10^{-19}$) coulomb.

(2) Being charged particle, it is deflected by electric and magnetic field.

(3)The speed of emission of $\alpha -$ particles depend upon the nature of radioactive element. It varies from $\left(\frac{1}{10}\right)^{th}$ to $\left(\frac{1}{100}\right)^{th}$ of the speed of light

(4) They affect photographic plate, produce fluorenscence.
(5) They ionise gas when passed through gas. Then ionising power is more
(6) The range of $\alpha-$ particles through air varies from 2.7 cm to 8.62 cm for thorium.
(7) They are scattered when incident on mica, aluminium and gold foil.
(8) When an $\alpha-$ particle i emitted by an atom, its atomic number decreases by 2 and mass number decreases by 4. $_{Z}X^{A} \xrightarrow{\alpha\uparrow} {}_{Z-2}Y^{A-4}$
(9) Penetration power of α particle is very less

Properties of $\beta-$particles :

(1) $\beta-$ rays are fast moving electrons from nucleus.
(2) Their speed ranges from 1% to 99% of the speed of light
(3) Being charged particles they are deflected by electric and magnetic field.

(4) β -particle have a moderate ionising power. It is about 100 times less that that of α -particles, but 100 times more than that of γ - rays

(5) They have a moderate penetrating power. It is about 100 times more than that of α - particles, but 100 times less than that of γ - rays

(6) When $\beta-$ particle is radiated, the atomic number increases by 1 and mass numner does not change e.g. $\boxed{_{z}X^{A} \xrightarrow{\beta\uparrow} {}_{z+1}Y^{A}}$

Properties of $\gamma-$ rays :

(1) $\gamma-$rays are not particles but they are electromagnetic waves (photon) of very short wavelength $\left(\text{about } 10^{-12}m \text{ to } 10^{-14}m\right)$, high frequency Photons originating from the nucleus are called $\gamma-$ rays.
(2) They are neutral in charge and not affected by electric and magnetic field.
(3) They affect photographic plate and produce fluorescence.

(4) They have very low ionization power about $\left(\frac{1}{1000}\right)^{th}$ of that of α – particles.

(5) They have the maximum penetrating power. It is about 100 times that of $\beta-$particles and 10^{4} times that of α – particles.
(6) They destroy living cells and tissues and are used for destroying cancer cells.

Que. State the laws of radioactive transformation.

Ans : Laws of radioactive transformations :

1. Law of decay : when one particle is emitted from a radioactive element then its atomic number decreases by two and mass number decreases by four i.e.,

$$_{z}X^{A} \xrightarrow[+2He^{4}]{\alpha\uparrow} {}_{z-2}Y^{A-4}$$

2. Law of decay : When one particle is emitted from a radioactive element then its atomic number increases by one and mass number remains constant. i.e.,

$$_{z}X^{A} \xrightarrow{\beta\uparrow} {}_{z+1}Y^{A}$$

3. Laws of - decay : When one or more -rays are emitted from a radioactive element then there will be no change in its atomic number and atomic mass number

Ex. Half life of radium is 1620 years. Calculate the decay constant of radius imper in per second

Soln : - $T_{1/2} = 1620$ years

$T_{1/2} = \frac{0.6931}{\lambda}$, we get

$\lambda = \frac{0.6931}{T_{1/2}} = \frac{0.6931}{1620} = 4.3 \times 10^{-4}$ per year

$\lambda = \frac{4.3 \times 10^{-4}}{365 \times 24 \times 3600\,s}$ $\therefore \lambda = 1.36 \times 10^{-11}$ per second

Ex. A radioactive substant decays to $\left(\frac{1}{10}\right)^{th}$ of the original value in 56 days. Calculate its decay constant.

Soln : Given : - $N = \left(\frac{1}{10}\right)N_0$, $t = 56$ days

To Find : - Decay constant $(\lambda) = ?$

We have, $N = N_0 e^{-\lambda t}$

$$\frac{1}{10} N_0 = Noe^{-\lambda t}$$

$$\therefore \frac{1}{10} = e^{-\lambda t}$$

$\therefore e^{\lambda t} = 10$ $\therefore \lambda t = \log_e 10$

$$\therefore \lambda = \frac{\log_e 10}{t}$$

$\therefore \lambda = \frac{2.303 \times \log_{10} 10}{t} = \frac{2.303}{56}$ $\therefore \lambda = 4.112 \times 10^{-2}$ per day

Ex. ${}_{90}Th^{232}$ **emits 'x'** α **- particles and** 'y' β **particle in succession and is converted into** ${}_{82}pb^{200}$**. Find 'X' and 'Y'**

Let x be number of α **particle and y be number of** β **particles emitted**

$${}_{90}Th^{232} \xrightarrow[y\beta]{x\alpha} {}_{82}pb^{200}$$

Mass number (A)

When 1 α particle is emitted by nucleus of radio-active substance its mass number deegree by i.e. Hence for x α particles emitted mass-number decreases by 4x there is no change in mass number due to β emission and hence net change in mass number

$4x - 0 = 232 - 200$ $4x = 32$ $x = 8$

Atomic number

When 1 α particle e is emitted by nucleus of radio-active element atomic number decreas by 2 for $x\ \alpha$ particles are emitted atomic number decrease by 2x

When 1 β particles is emitted by nucles of radio-active sabstance atomic number increases by 1 for y' β particles are emitted atomic number increase by y net charge in atomic number

$$2x - y = 90 - 82$$
$$2 \times 8 - y = 8$$
$$y = 16 - 8 \qquad \therefore y = 8$$

Thus 8 α and 8 β particles are emitted

Que. How is the nuclear size determined? State the relation between nuclear size (radius) and mass number.

Ans : The nuclear size is determined from particle scattering experiments using fast electrons or neutrons. The de Broglie wavelength of the bombarding electrons or neutrons should be less than the radius of the nucleus under study.

It is found that the volume of a nucleus is directly proportional to the mass number A, i.e., to the number of nucleons in the nucleus. For most purposes, nuclei may be assumed to be spherical. Thus, a nucleus of radius R has a volume $\frac{4}{3}\pi R^3$.

$$\therefore \quad R^3 \propto A \quad \text{or} \quad R \propto A^{\frac{1}{3}} \quad \therefore \quad R = R_0 A^{\frac{1}{3}}$$

Where $R_0 \approx 1.2 \times 10^{-15} m = 1.2\, fm.$ $\quad \therefore R \approx 1.2 A^{\frac{1}{3}} fm$

Note : 1 femtometer or 1 fm = 10^{-15} m

Que. What is the significance of binding energy per nucleon?

Ans : The greater the binding energy per nucleon in a nucleus, the greater is the minimum energy needed to remove a nucleon from the nucleus. Thus, binding energy per nucleon indicates the stability of a nucleus.

Que. Explain the composition of nucleus in brief.

Ans : **1**.Nucleus was first discovered by Rutherford in 1911. According to Rutherford, atom consist of small, central, massive and positive core called as nucleus. Nucleus is surrounded by electrons, which are revolving round the nucleus in different circular orbits.

2. Radius of nucleus is of about to 10^{-15} m (1 fermi) and it is 10,000 times smaller than size of the atom.

3. Nucleus consists of positively charged photons (Z) and uncharged neutrons (N). The total number of protons and neutrons are called as nucleons. The total number of protons and neutrons i.e, A=Z+N is also called as atomic mass number. The total number of protons in the nucleus of an atom is called as atomic number (Z). The total number of electrons in n^{th} orbit = $2n^2$.

4. The atomic number gives total number of protons and electrons. However total number of neutrons in the nucleus of an atom is, N = A -Z.

5. Protons : It was discovered by Rutherford in 1919, while positive rays was discovered by Goldstein. The charge of proton is $1.602 \times 10^{-19} C$. The rest mass of proton is, $1.6726 \times 10^{-27} kg$.

6. Neutron : It was discovered by Chadwick in 1932. Neutron is chargeless and it is present in nucleus. It is unstable during radioactivity. It splits into proton and electron. The rest mass of neutron is $1.6749 \times 10^{-27} kg$.