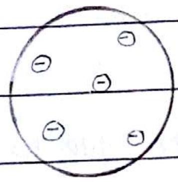
Atoms

Atom:

The smallest particle of substance are called atoms.

Thomson's Model of Atom

According to J.J Thomson an atom is a +vely charged solid sphere with -vely charged particles are embeded in it such that the atom as a whole is electrically nuetral.

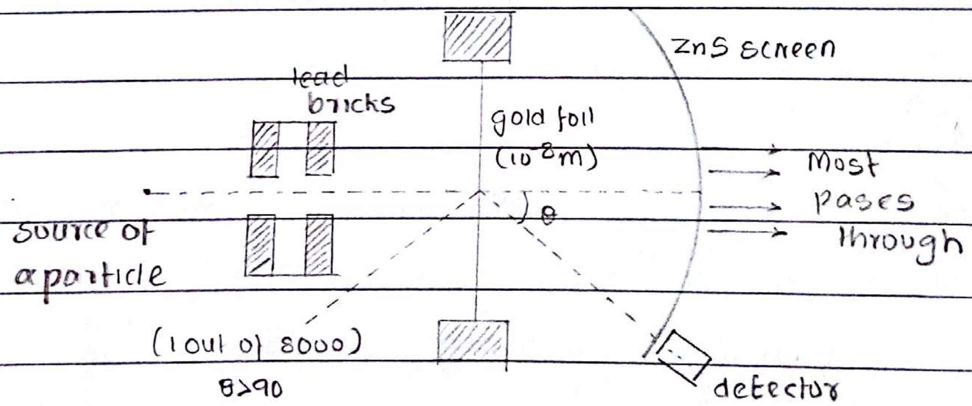


This model is also known plum pudding model.

Failures of Thomson Model:

- It failed to explain the atomic spectra.
- When cathode rays are allowed to pass through an atom it is found that most of the rays are passing without any deviation. Thomson model couldnt explain the reason for this.

Rutherford's Alpha scattering experiment.

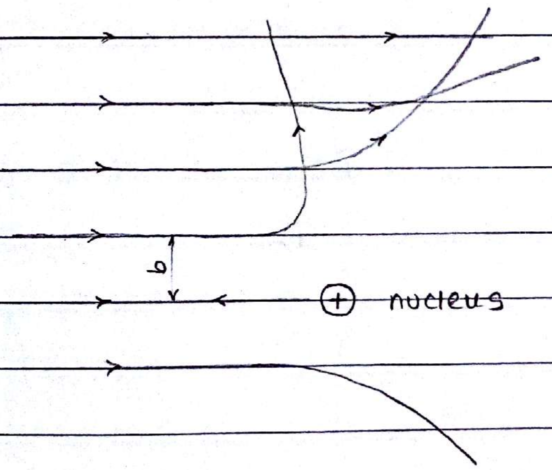


It is observed that most of the α particles were passed through the gold foil without any deviation and it implies that most of the volume of an atom is empty. Some α particles are found to be deviated through a small angle. A very few (1 out of 8000) were observed to deviate for very high angle ($\theta > 90$)

Rutherfords Atom Model (Conclusions of α particle scattering exp.)

- Most of the space of an atom are empty.
- The entire +ve charge and most of the mass of the atom is concentrated at the centre and is called the nucleus.
- -vely charged e⁻s are revolving around the nucleus in fixed orbits. The necessary centripetal force is provided by the electrostatic force of attraction between the nucleus and the e⁻s

Trajectory of α particle.



Impact parameter (b).

It is the ⊥r distance of initial velocity vector of α particles from the centre of the nucleus. When impact parameter is large, the angle of deviation is less.

The force experienced by the α particle is given by

$$F = \frac{1}{4\pi\varepsilon_0} \frac{2e \cdot Ze}{r^2}$$

where Z is the atomic no of gold (79) and r is the distance between the α particle and the gold particles.

Radius of electron orbit :

The necessary centripetal force for the electron is provided by the electrostatic force of attraction i.e,

$$F_c = F_e$$

then for a hydrogen atom,

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

∴ radius of H atom, $r = \dfrac{e^2}{4\pi\varepsilon_0 mv^2}$.

Kinetic energy of electron, $KE = \frac{1}{2}mv^2$

$$= \frac{1}{2}\frac{e^2}{4\pi\varepsilon_0 r}$$

$$KE = \frac{e^2}{8\pi\varepsilon_0 r}$$

Potential energy, $u = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r}$

$$u = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

Total energy,

$$TE = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r}$$

$$TE = \frac{-e^2}{8\pi\varepsilon_0 r}$$

Atomic spectra

Each element has characteristic spectrum of radiation. When an atomic gas is allowed to discharge, radiations are emitted. the spectrum obtained is known as the emission spectrum.

Hydrogen spectra

When hydrogen gas is allowed to discharge, a series of lines with descrete wavelength are produced. The wavelengths of such lines can be calculated by the formula

$$\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

Where R is the constant called Rydberg's constant $R = 1.097 \times 10^7\ m^{-1}$.
And n_i and n_f are integers.

Spectral series

- Lyman

  $n_f = 1$ and $n_i = 3, 4, 5 \ldots$

- Balmer

  $n_f = 2$ and $n_i = 3, 4, 5 \ldots$

- Paschen

  $n_f = 3$ and $n_i = 4, 5, 6 \ldots$

- Brackett

  $n_f = 4$ and $n_i = 5, 6, 7$

- Pfund

  $n_f = 5$ and $n_i = 6, 7, 8 \ldots$

1. Find maximum and minimum wavelength of paschen series.

Ans. $\frac{1}{\lambda} = 1.097 \times 10^7 \left[\frac{1}{9} - \frac{1}{16}\right]$

$= 1.097 \times 10^{+7} \times \frac{7}{144}$

$\lambda = \frac{144}{1.097 \times 10^7 \times 7} = 2.57 \times 10^{-7} = 820\ nm$.

$\frac{1}{\lambda} = 1.097 \times 10^7 \times \frac{1}{9}$

$= 1875\ nm$

Expression for frequency

We have, $\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$

But $\lambda = \frac{c}{\nu}$

$\therefore \frac{1}{c/\nu} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$

$$\nu = RC\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

Drawbacks of Rutherford's atom Model.

- According to Rutherford's model, the electrons revolving around the nucleus has constant acceleration. $\therefore$ It has to emit continous radiation but it is observed that atomic spectra are discrete in nature.
- When an electron continuously releases electromagnetic radiation, its energy decreases and finally it has to fall to the nucleus.

Bohr's Model of Atom

Postulates of Bohr Model.

- The electrons of an atom could revolve in stable orbit without the emission of radiant energy
- The angular momentum of the revolving e^- is an integral multiple of $\frac{h}{2\pi}$.

  ie, $L = \frac{nh}{2\pi}$.

- An electron might make transition from a higher energy level to lower energy level by emitting a photon. The energy of this photon is equal to the energy difference between initial and final levels. ie

$$h\nu = E_i - E_f$$

Bohr's model of Hydrogen atom.

From Rutherford's model, we have the radius of Hydrogen atom

$$r = \frac{e^2}{4\pi \varepsilon_0 m v^2} \quad \text{---(1)}.$$

According to Bohr's second postulate,

$$L = \frac{nh}{2\pi}$$

$$mvr = \frac{nh}{2\pi}$$

$$v = \frac{nh}{2\pi m r}$$

Substitute for r,

$$v = \frac{nh \times 4\pi \varepsilon_0 m v^2}{2\pi m e^2}$$

$$v = \frac{2nh\varepsilon_0 v^2}{e^2}$$

$$\boxed{v = \frac{e^2}{2hn\varepsilon_0}}$$

Substitute this in (1) ⇒

$$r = \frac{e^2 \times 4n^2h^2\varepsilon_0^2}{4\pi \varepsilon_0 m e^4}$$

$$\boxed{r_n = \frac{\varepsilon_0 n^2 h^2}{m\pi e^2}}$$

If n=1,

$r_1 = \frac{\varepsilon_0 h^2}{m\pi e^2}$. This is the minimum possible radius of H atom and is known as the Bohr Radius. (a_0)

$$\boxed{a_0 = 5.29 \times 10^{-11}\, m.}$$

Energy of Electron.

We have the total energy of electron,

$$E = \frac{-e^2}{8\pi \varepsilon_0 r}$$

Substitute for r

$$E = \frac{-e^2 \cdot m\pi e^2}{8\pi \varepsilon_0 \times \varepsilon_0 n^2 h^2}$$

$$E = \frac{-me^4}{8\varepsilon_0^2 n^2 h^2}$$

$$E = \frac{-13.6}{n^2} eV$$

The above equation shows that energy of e^- is inversely proportional to n^2

If $n=1 \Rightarrow E = -13.6 eV$, This is the lowest possible energy.

If $n=2$,

$$E = \frac{-13.6 \, eV}{4}$$

$$E = -3.4 eV$$

If $n=3$,

$$E = -1.5 eV.$$

if $n=4$

$$E = -0.85 eV$$

Ionisation Energy

If $n=1$, $E = -13.6eV$

Then the hydrogen atom is said to be in ground state.

If $n = 2, 3, 4 \cdots$, the atom is said to be in excited state.

The minimum energy required to free an electron from its ground state is called its ionisation energy. The ionisation energy of H atom is 13.6eV

Spectral series of Hydrogen atom.

According to the third postulate by Bohr, the energy of emitted photon,

$$h\nu = E_i - E_f$$

But $E_i = \dfrac{-me^4}{8\varepsilon_0^2 n_i^2 h^2}$

$E_f = \dfrac{-me^4}{8\varepsilon_0^2 n_f^2 h^2}$

$$h\nu = E_i - E_f$$

$$= \frac{-me^4}{8\varepsilon_0^2 n_i^2 h^2} - \frac{-me^4}{8\varepsilon_0^2 n_f^2 h^2}$$

$$h\nu = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

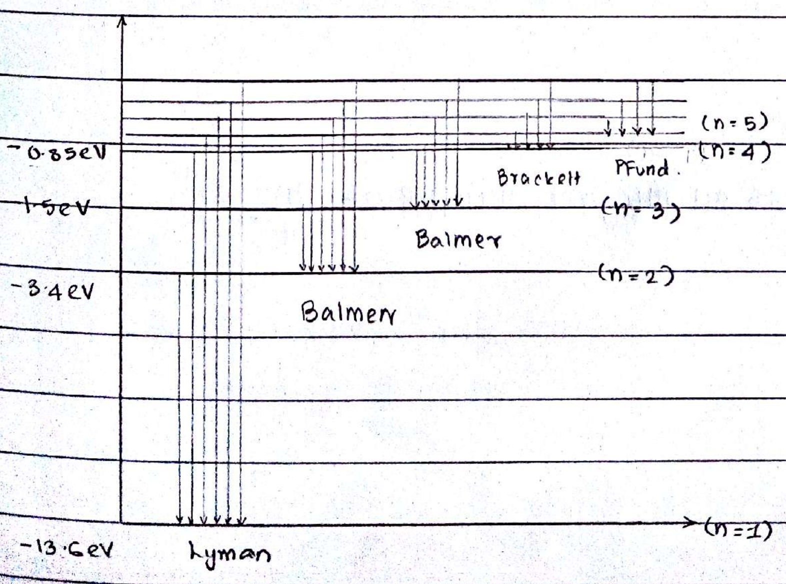
$$h\cdot\frac{c}{\lambda} = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

$$\frac{1}{\lambda} = \frac{me^4}{8\varepsilon_0^2 h^3 c}\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

$$\boxed{\frac{1}{\lambda} = 1.03\times10^7\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]}$$

This result is in very much agreement with the Balmer's empirical formula which is $\dfrac{1}{\lambda} = R\left[\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right]$

$$R = 1.097\times10^7\ m^{-1}.$$



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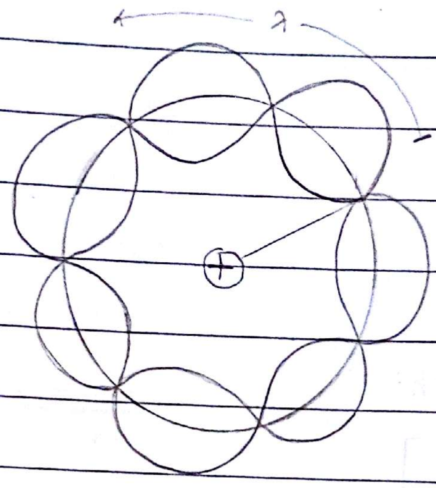
De Broglie's explanation for Bohr's second Postulate.

According to De broglie a wave is associated with a moving e's. ie when an electron is revolving around the nucleus it produces a standing wave as shown in figure.



If r is the radius of the orbit then

$$2\pi r = n\lambda$$

where λ is the wavelength

n is an integer.

But $\lambda = \frac{h}{p}$

$$\therefore 2\pi r = \frac{nh}{p}$$

$$2\pi r = \frac{nh}{mv}$$

$$mvr = \frac{nh}{2\pi}$$

$$L = \frac{nh}{2\pi}$$

ie, angular momentum is an integral multiple of $\frac{h}{2\pi}$.

Limitations of Bohr's Model.

- This model is applicable for Hydrogen atom. (If some complex atoms are considered then the electrostatic repulsive force will come into play).
- It doesn't give the explanation for the intensity variation of atomic spectra.

Chapter:

Nuclei

Nuclei

The center of an atom is called the nucleus. Most of the mass and the entire +ve charge of the atom is concentrated inside the nucleus. It consists of protons and nuetrons. Protons are having +ve charge ($+1.6\times10^{-19}$ C) and nuetrons are electrically nuetral.

Atomic mass unit (u)

It is a unit of mass used to represent the mass of subatomic particles. It can be defined as $\frac{1}{12}$th the mass of carbon 12 atom

$$1u = \frac{1}{12} \times \text{mass of } ^{12}C \text{ atom}$$

$$1u = 1.660539 \times 10^{-27} \text{ kg}$$

Mass of e^-, $m_e = 0.00055u$

proton, $m_p = 1.00727u$

nuetron, $m_n = 1.00866u$

Note: A proton is 1840 times heavier than e^-.

Atomic Number (Z)

The total no of protons in an atom is called its atomic no.

Nuetron Number (N)

Total of nuetrons in an atom.

Mass Number (A)

The sum of atomic number and nuetron no is called the mass no.

$$A = Z + N$$

Representation of an atom

Any atom X can be represented as ${}^{A}_{Z}X$

Ex: ${}^{4}_{2}He$, ${}^{16}_{8}O$

Isotope

Atoms having same atomic no but different mass numbers.

Ex: ${}^{1}_{1}H$, ${}^{2}_{1}H$, ${}^{3}_{1}H$

Isobars

Atoms with same mass no but diff. atomic no.s

Ex: ${}^{14}_{6}C$ and ${}^{14}_{7}N$

Isotones

Atoms with same nuetron no.s are called isotones

Ex: ${}^{198}_{80}Hg$, ${}^{197}_{79}Au$

Nuclear force

The particles inside the nucleus (nuetrons and protons) are called as nucleons.

The force b/w any two nucleons is called the ~~nucleons~~ nuclear force

Characteristics:

- It is always attractive
- It is the strongest force in the universe.
- It is a short range - nuclear force is applicable if the distance b/w two nuceons is equal to or less than fermi (10^{-5}m). If the seperation goes beyond this value, the force become negligible or zero
- It is not a central force
- It is very much greater than electrostatic repulsive b/w two protons

Size of Nucleus.

Since the nucleons are bound together due to the strong attractive force, the size of nucleus is very small. The radius of mass number A is given by

$$R = R_0 A^{1/3}$$

where $R_0 = 1.2 \times 10^{-15}$ m

Therefore volume of nucleus $= \frac{4}{3}\pi r^3$

$$= \frac{4}{3}\pi R_0^3 A$$

$$\therefore V \propto A$$

ie the volume of nucleus increases with increase in mass no.

The density of nucleus is very high and is given by

$$\rho = 2.3 \times 10^{11} \text{ kg/m}^3$$

Mass Energy

The energy associated with a mass is called mass energy. Albert Einstein proposed a formula to calulated the mass energy and is given by

$$E = mc^2$$

where c is the speed of light in ~~air~~ vaccum.

Mass Defect.

The difference b/w the mass of the nucleus and total mass of its constituents is called mass defect.

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

where M is the mass of the nleus

Binding energy

The Energy which binds the nucleons together is called binding energy. It can also be defined as the energy required to seperate two nucleon.

$$E_b = \Delta mc^2$$

where Δm is the mass defect.

Binding Energy Per nucleon (E_{bn})

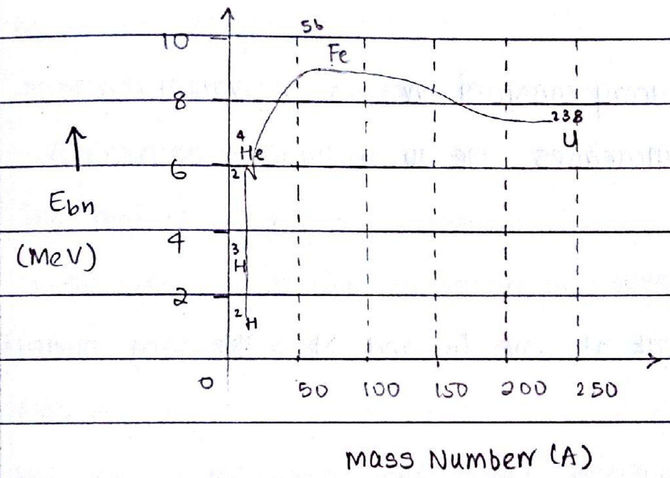
The binding energy required per nucleon to seperate it from a nucleus is called the Binding energy per nucleon

$$E_{bn} = \frac{E_b}{A}$$

A is the mass no

E_b is the binding energy

The variation of binding energy per nucleon for diff. elements with mass no. is graphically shown in figure



Following conclusions can be made from the graph

- E_{bn} is smaller for lighter nuclei ($A<30$) and for heavier nuclei ($A>170$)
- E_{bn} is almost a constant for nuclei having mass no. A lies between 30 and 170.
- E_{bn} is maximum (8.75) MeV for ^{56}Fe
- E_{bn} of uranium (238) is 7.5 MeV.
- lighter nucleus are unstable and they combine to become a bigger nuclei with the release of energy. This process is known as nuclear fussion
- Heavier nucleus are unstable. They split to become a comparitevly smaller nucleus with the release of energy. This process is called nuclear fission

Radioactivity.

The nuclear phenomenon by which an unstable nucleus undergoes decay is called Radioactivity.

Radioactive decay are of three types

- Alpha decay: in which a helium nucleus is emitted.

- Beta Deyay: An electron or positron is emitted
- Gamma decay: A high frequency electromagnetic radiation is emitted.

Law of Radio active Decay.

The law states that rate of disintegration of a radioactive sample is directly proportional to the number of nucleus initially present ie,

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

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

where λ is a constant called the decay constant or disintegration constant. The -ve sign shows that as time increases, the no of nucleus decreases.

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

Let N_0 be the no of nucleus present at time T_0 and N be the no of nucleus at time t.

$$\int_{N_0}^{N} \frac{dN}{N} = \int_{t_0}^{t} -\lambda dt$$

$$[\log N]_{N_0}^{N} = -\lambda [t]_{t_0}^{t}$$

$$\log N - \log N_0 = -\lambda [t - t_0]$$

If $\log x = y$

$x = e^y$

$$\log \frac{N}{N_0} = -\lambda [t - t_0]$$

if $t_0 = 0$

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

$$\frac{N}{N_0} = e^{-\lambda t}$$

$$\boxed{N = N_0 e^{-\lambda t}}$$

Decay Rate (R)

The quantity $-\frac{dN}{dt}$ is called the decay rate. It represents ~~net~~ no of disintegration per second.

ie, $R = -\frac{dN}{dt}$ $\left(\frac{dN}{dt} = -\lambda N\right)$

$R = \lambda N$

$R = \lambda N_0 e^{-\lambda t}$

$$\boxed{R = R_0 e^{-\lambda t}}$$

where $R_0 = \lambda N_0$ the initial decay rate. The total decay rate of a sample is also known as activity.

$\therefore$ activity $\boxed{A = A_0 e^{-\lambda t}}$

The unit of activity is Becquerel.

1 Becquerel = 1 disintegration per second.

Half life

Half life of the radioactive sample can be defined as the time taken to disintegrate to become half of its initial value.

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

If $N = \frac{N_0}{2}$, then $t = T_{1/2}$, the half life.

$\therefore \frac{N_0}{2} = N_0 \cdot e^{-\lambda T_{1/2}}$

$\frac{1}{2} = e^{-\lambda T_{1/2}}$

$\frac{1}{2} = \frac{1}{e^{\lambda T_{1/2}}}$

$e^{\lambda T_{1/2}} = 2.$

$\lambda T_{1/2} = \log 2$

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

1. The half life of a radioactive sample is years 2. Find the time taken by the sample of mass 48g to become 3g.

Ans. Half life = 2.

Initial mass = 48g.

24 12 6 3

2 2 2 2

$\Rightarrow$ 8 years.

Mean life

The average time taken by a radioactive sample to disintegrate completely is called its mean life. (denoted by τ)

$$\tau = \frac{1}{\lambda}$$

$$T_{1/2} = 0.693\,\tau$$

Alpha, Beta and Gamma Decay

- Alpha decay.

When a radioactive element undergoes α decay, it emits α particle (He nucleus) ${}^{4}_{2}He$. When a α particle is emitted, the nucleus is transformed to another one with decrease in atomic no 2 and with decrease in mass no by 4.

i.e, ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$.

Ex: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$.

Q value

The difference between initial mass energy and final mass energy in a decay is called the Q value.

In α decay, $Q = (M_x - M_Y - M_{He})c^2$

where M_X is the mass of parent nucleus.

M_Y is the mass of daughter nucleus.

M_{He} is the mass of α particle.

Properties of Alpha particle

- It is He nucleus
- It deviates in electric or magnetic fields.
- Velocity is very small compared to that of light
- Penetrating power is small.
- Ionisation power is very high.

- Beta Decay

- In Beta decay, a radioactive elements emits electron or positron. If it emits an e^-, the decay is called β^- decay and if emits a positron, it is called β^+ decay.

- β^- Decay:

β^- Decay takes place when a nuetron splits into an e^-, a proton and a anti nuetrino ($\bar{\nu}$) i.e, $n \longrightarrow p + e^- + \bar{\nu}$

As a result of β^- decay the atomic no increases by 1 and mass no remains the same.

Ex: $^{32}_{15}P \longrightarrow {}^{32}_{16}S + e^- + \bar{\nu}$

- β^+ Decay:

β^+ decay takes place when a proton splits into a nuetron, a positron and a nuetrino. (ν) i.e, $P \longrightarrow n + e^+ + \nu$

In β^+ decay, atomic no decreases by 1 but the mass no remains the same.

Ex: $^{23}_{11}Na \longrightarrow {}^{23}_{10}Ne + e^+ + \nu$

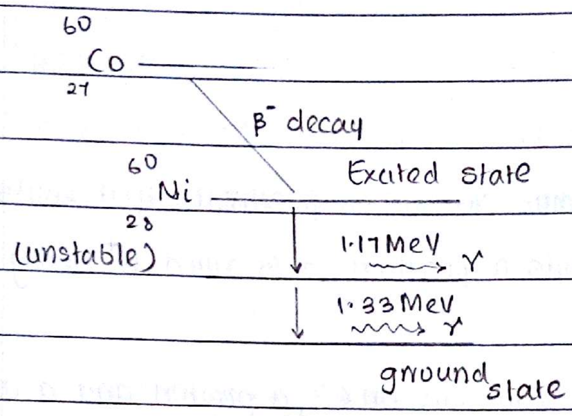
Properties of β particle

- It is an e^- or e^+
- It deviates in electric or magnetic fields.
- Velocity is greater than that of α
- Penetrating power is greater than that of α.
- Ionisation power is very less than α.

- γ Decay

In γ decay, high energy radiations are emitted. The emission of α or β particle may results in the formation of unstable daughter nuclei. To attain stability, this nuclei make transition from excited state to ground state by emitting high energy gamma radiations in one or multiple stages.

Ex:



Properties of γ decay

- These are energy radiations and doesnot have charge
- It doesnot deviative in electric or magnetic field
- Velocity is equal to that of light.
- Penetrating power is very high
- Ionisation power is 0 or minimum.

Nuclear Fission

The process by which a heavy nucleus splits into lighter nuclei with the release of large amount of energy is called nuclear fission.
When a high energy nuetron, colided with a uranium nucleus, it split into lighter nuclei and nuetrons with the release of energy.

Ex: $^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{236}_{92}U \longrightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\,^{1}_{0}n$

The nuetrons generated during fission are highly energetic and it may collide with other heavy nuclei and again release large amount of energy along with more no of nuetrons. This process continues until the entire nuclear fuel is finished. Such a nuclear reaction is known as chain reaction.

Moderators.

Moderators are light nuclei used to reduce the energy of fast moving nuetrons

Ex: water, heavy water (D_2O), graphite.

Multiplication factor (K)

It is defined as the ratio of no of fission in a given generation of nuetron to the no. of fission in the preceeding generation of nuetron.

for the safe operation of reactor $K \leq 1$

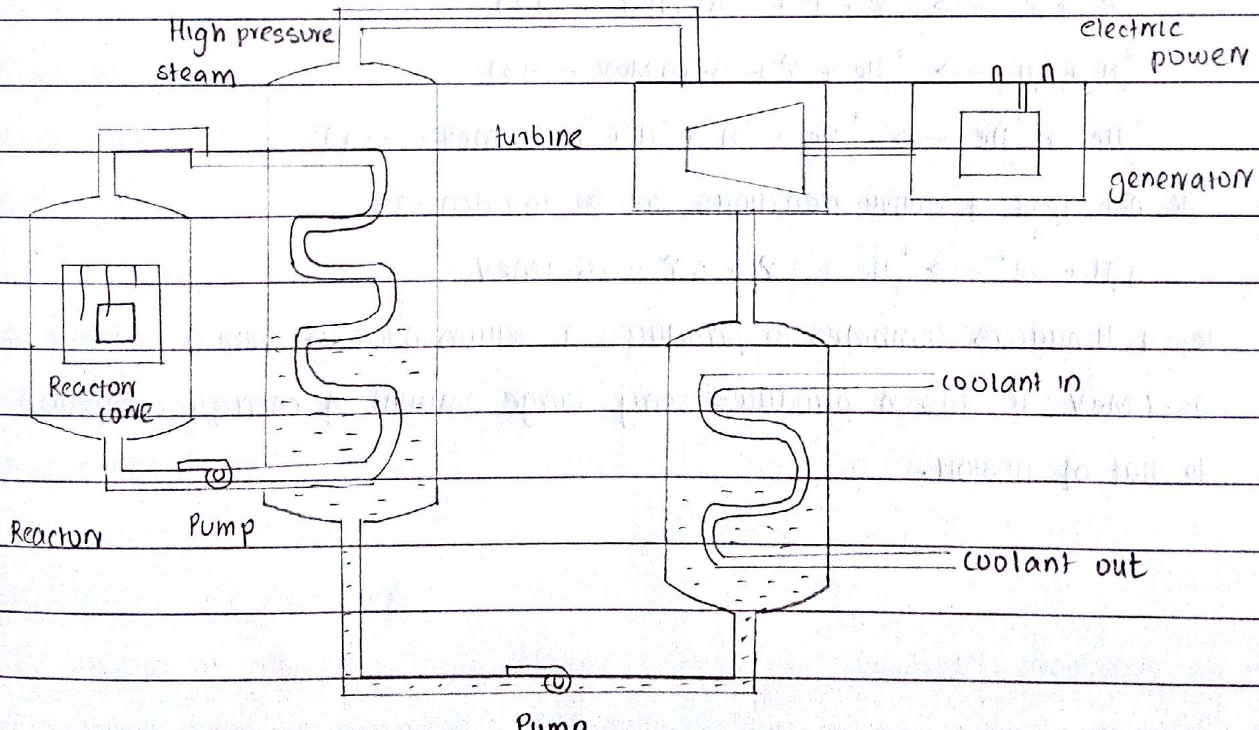
if $K > 1$ the reactor is said to be super critical.

control rods.

control Rods are nuetron absorbing material used to reduce the value of K.

Ex: Cadmium.

Nuclear Reactor



The heat energy generated in the reactor produces a steam at high pressure. The steam rotates the turbine, the trubine rotates the coil of generator and electric energy is produced. The pressure of the steam is reduced using a coolant and is converted into water. The water is pumped to the first vessel and the process repeats and continous electrical energy is generated

Nuclear fusion

The process by which lighter nuclei combines to form heavy nucleus with the release of large amount of energy is called nuclear fusion.

The basic fusion reactions are shown below

$$ {}^1_1H + {}^1_1H \rightarrow {}^2_1H + e^+ + \nu + 0.42\,meV $$

$$ {}^2_1H + {}^2_1H \rightarrow {}^3_2He + n + 3.27\,meV $$

$$ {}^2_1H + {}^2_1H \rightarrow {}^3_1H + {}^1_1H + 0.3\,meV $$

For the fusion process to be started, huge amount of heat energy is required. Such a fusion is known as thermonuclear fusion.

Fusion in stars

The process taking place in a star is known as a proton - proton cycle

$$ {}^1_1H + {}^1_1H \rightarrow {}^2_1H + e^+ + \nu + 0.2\,meV \quad (1) $$

$$ e^+ + e^- \rightarrow \gamma + \gamma + 1.02\,meV \quad (2) $$

$$ {}^2_1H + {}^1_1n \rightarrow {}^3_2He + \gamma + 5.49\,MeV \quad (3) $$

$$ {}^3_2He + {}^3_2He \rightarrow {}^4_2He + {}^1_1H + {}^1_1H + 12.86\,MeV \quad (4) $$

The net effect of above reactions can be written as

$$ 4\,{}^1_1H + 2e^+ \rightarrow {}^4_2He + 2\nu + 6\gamma + 26.7\,MeV $$

ie, 4 H nucleus combines to produces a helium nucleus with a release of 26.7 MeV, ie, fusion produces very large amount of energy compared to that of fission.