Nuclear Fission and Fusion.

Nuclear fission

The process of splitting of a heavy nucleus into two lighter nuclei of comparable masses (after bombardment with an energetic particle) with liberation of energy is called nuclear fission.

The phenomenon of nuclear fission was discovered by scientist Ottohann and F. Strassman and was explained by N. Bohr and J.A. Wheeler on the basis of liquid drop model of nucleus.

(1) Fission reaction of U235

(i) Nuclear reaction:

$$_{92}U^{235} + {}_0n^1 \rightarrow \underset{\text{(unstable nucleus)}}{_{92}U^{236}} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q$$

(ii) The energy released in U235 fission is about 200 MeV or 0.8 MeV per nucleon.

(iii) By fission of $_{92}U^{235}$, on an average 2.5 neutrons are liberated. These neutrons are called fast neutrons and their energy is about 2 MeV (for each). These fast neutrons can escape from the reaction so as to proceed the chain reaction they are need to slow down.

(iv) Fission of U235 occurs by slow neutrons only (of energy about 1eV) or even by thermal neutrons (of energy about 0.025 eV).

(v) 50 kg of U235 on fission will release ≈ 4 × 1015 J of energy. This is equivalence to 20,000 tones of TNT explosion. The nuclear bomb dropped at Hiroshima had this much explosion power.

(vi) The mass of the compound nucleus must be greater than the sum of masses of fission products.

(vii) The $\frac{\text{Binding energy}}{\text{A}}$ of compound nucleus must be less than that of the fission products.

(viii) It may be pointed out that it is not necessary that in each fission of uranium, the two fragments $_{56}Ba$ and $_{36}Kr$ are formed but they may be any stable isotopes of middle weight atoms.

Same other U^{235} fission reactions are

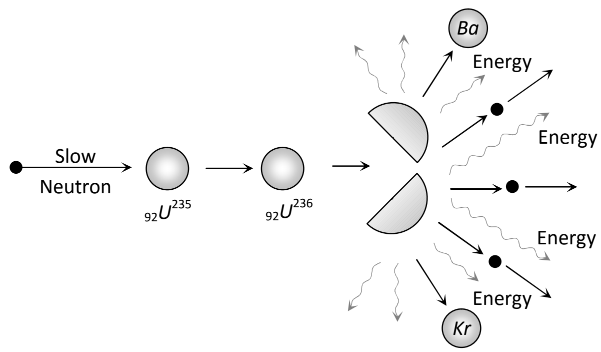
$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + 2\,{}_0n^1$$

$$\rightarrow {}_{57}La^{148} + {}_{35}Br^{85} + 3\ {}_{0}n^{1}$$

$\rightarrow$ Many more

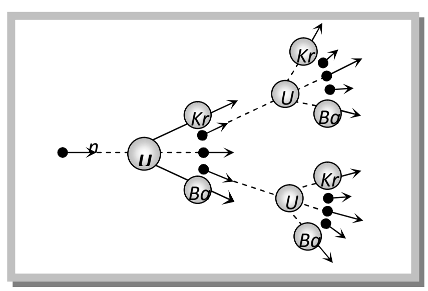
(ix) The neutrons released during the fission process are called prompt neutrons.

(x) Most of energy released appears in the form of kinetic energy of fission fragments.



(2) Chain reaction

In nuclear fission, three neutrons are produced along with the release of large energy. Under favorable conditions, these neutrons can cause further fission of other nuclei, producing large number of neutrons. Thus a chain of nuclear fissions is established which continues until the whole of the uranium is consumed.



In the chain reaction, the number of nuclei undergoing fission increases very fast. So, the energy produced takes a tremendous magnitude very soon.

Difficulties in chain reaction

(i) Absorption of neutrons by U^{238}, the major part in natural uranium is the isotope U238 (99.3%), the isotope U^{235} is very little (0.7%). It is found that U^{238} is fissionable with fast neutrons, whereas U^{235} is fissionable with slow neutrons. Due to the large percentage of U^{238}, there is more possibility of collision of neutrons with U^{238}. It is found that the neutrons get slowed on colliding with U^{238}, as a result of it further fission of U238 is not possible (Because they are slow and they are absorbed by U238). This stops the chain reaction.

Removal: (i) To sustain chain reaction ${}_{92}U^{235}$ is separated from the ordinary uranium. Uranium so obtained $\left({}_{92}U^{235}\right)$ is known as enriched uranium, which is fissionable with the fast and slow neutrons and hence chain reaction can be sustained.

(ii) If neutrons are slowed down by any method to an energy of about 0.3 eV, then the probability of their absorption by U^{238} becomes very low, while the probability of their fissioning U^{235} becomes high. This job is done by moderators. Which reduce the speed of neutron rapidly graphite and heavy water are the example of moderators.

(iii) Critical size: The neutrons emitted during fission are very fast and they travel a large distance before being slowed down. If the size of the fissionable material is small, the neutrons emitted will escape the fissionable material before they are slowed down. Hence chain reaction cannot be sustained.

Removal: The size of the fissionable material should be large than a critical size.

The chain reaction once started will remain steady, accelerate or retard depending upon, a factor called neutron reproduction factor (k). It is defined as follows.

$$k = \frac{\text{Rate of product ion of neutrons}}{\text{Rate of loss of neutrons}}$$

→ If k = 1, the chain reaction will be steady. The size of the fissionable material used is said to be the critical size and its mass, the critical mass.

→ If k > 1, the chain reaction accelerates, resulting in an explosion. The size of the material in this case is super critical. (Atom bomb)

→ If k < 1, the chain reaction gradually comes to a halt. The size of the material used us said to be sub-critical.

Types of chain reaction: Chain reactions are of following two types

Controlled chain reaction	Uncontrolled chain reaction
Controlled by artificial method	No control over this type of nuclear reaction
All neurons are absorbed except one	More than one neutron takes part into reaction
It's rate is slow	Fast rate

Reproduction factor k = 1	Reproduction factor k > 1
Energy liberated in this type of reaction is always less than explosive energy	A large amount of energy is liberated in this type of reaction
Chain reaction is the principle of nuclear reactors	Uncontrolled chain reaction is the principle of atom bomb.

Note: The energy released in the explosion of an atom bomb is equal to the energy released by 2000 ton of TNT and the temperature at the place of explosion is of the order of 107 oC