Nuclear fusion and Nuclear fission:-

Nuclear fusion or Thermonuclear energy:- The process of formation of heavy nucleus from two lighter nuclei is known as nuclear fusion. If two very high nuclei like $_1H^1$ or $_1D^2$ are made to fuse, the heavier nucleus formed has a higher binding energy per nucleon than that of reactants. Thus there is a decrease in nuclear mass and the corresponding difference in energy is released in the process. Fusion can take place at very high pressure and temperature of the order of 10^6 K because it is only under these conditions that nuclei are able to overcome their mutual Coulomb repulsion. This energy is known as thermonuclear energy and it is possible to produce it under controlled conditions.

The simplest process of fusion known as proton-proton cycle consists in fusion of two hydrogen nuclei which finally give a $_2He^4$ nucleus in accordance with the following reaction

$$_1H^1 + {_1H^1} = {_1D^2} + e^+ + \nu + 0.42\text{ MeV}$$

$$_1D^2 + {_1H^1} \longrightarrow {_2He^3} + \gamma + 5.49\text{ MeV}$$

$$2\,{_2He^3} \longrightarrow {_2He^4} + 2\,{_1H^1} + 12.86\text{ MeV}.$$

In the first stage; two hydrogen nuclei combine to form a deuteron with release of 0.42 MeV of energy, a positron and a neutrino. In the second stage $_1D^2$ nucleus combines with another $_1H^1$ nucleus to form a $_2He^3$ nucleus with release of 5.49 MeV of energy and a γ-radiation. The above cycle is repeated to produce another He^3 nucleus. Finally the $_2He^3$ nuclei combine to give a $_2He^4$ nucleus and two $_1H^1$ nuclei with release of 12.86 MeV of energy. The two $_1H^1$ nuclei allow the process to repeat and make itself sustaining. The total energy released = 2(0.42+5.49) + 12.86 = 24.68 MeV. If the annihilation energy of two positrons (2.04 MeV) is added, the total energy released = 26.72 MeV.

Another self sustaining process is known as Carbon-nitrogen cycle. In this process carbon only act as a catalyst four hydrogen nuclei fuse to yeld a Helium nucleus.

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The process is as follows.

$$_1H^1 + {}_6C^{12} \rightarrow {}_7N^{13} \rightarrow {}_6C^{13} + e^+ + \nu$$

$$_1H^1 + {}_6C^{13} \rightarrow {}_7N^{14}$$

$$_1H^1 + {}_7N^{14} \rightarrow {}_8O^{15} \rightarrow {}_7N^{15} + e^+ + \nu$$

$$_1H^1 + {}_7N^{15} \rightarrow {}_6C^{12} + {}_2He^4$$

It is supposed that the above cycle takes place in the Sun and the stars and is the source of their energy.

Importance of Thermonuclear energy in the universe.

The thermonuclear energy liberated by the fusion of hydrogen nuclei into helium nuclei by the two process explained above is probably the source of nearly all energy in the universe.

Source of energy of sun and stars — Self sustaining fusion reaction can occure only under condition of very high Tempr and pressure so that the participating nuclei have sufficient energy to react inspite of their mutual electric repulsion. The reaction under these conditions occure very frequently and produces much more energy than that lost to the surroundings and thus becomes a continuous source of energy. The interior of the Sun and stars have conditions favourable for thermonuclear-reactions. The proton-proton cycle predominates in stars having internal Tempr below 1.6×10^7 K and carbon cycle in stars having internal Tempr higher than that. The Tempr of the sun is about 1.5×10^7 K. Therefore the proton-proton cycle is responsible for about 90% of the energy produced by the sun.

The thermonuclear energy makes use of cheap and easily available materials like deuterium (available in sea water) and Tritium (obtained by neutron bombardment of the two isotopes of Lithium i.e. Li^6 and Li^7). The greatest difficulty in the way of producing thermonuclear energy on the earth is the production of very high temp of the order of 10^8 K and high pressure. At such high Tempr and pressure matter exists as fully ionised gas known as plasma. If n is the particle density of plasma and t the Time for which density is maintained Then the product nt must be atleast 10^{28} m^3 for the reaction to take place. Such high Temp is difficult to maintain for a sufficiently long Time. The Second difficulti is that the plasma cannot be contained within ordinary walls since every material will melt at such high Tempr.

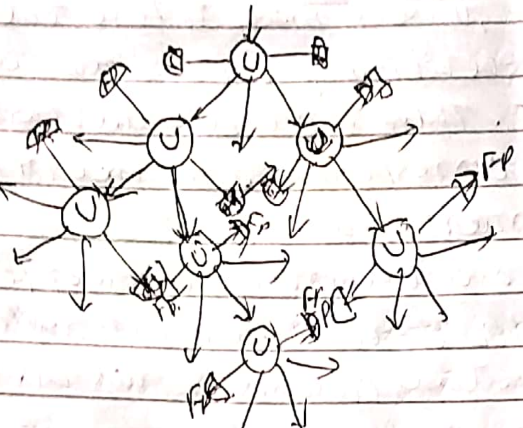
It has been proposed that a magnetic field in the form of Torus (dough nut) can contain the plasma. The high tempr and pressure required for the purpose is obtained by the explosion of a fission bomb. Alternatively it has been suggested that energetic 'Laser' beams or beams of high energy electrons protons may be used to heat and compressed tiny deuterium, tritium pallets resulting in minimum energy bombs, a succession of which could supply a steady ~~steam~~ stream of energy. The fusion energy can thus be obtained from readily available fuel, has almost not radioactive waste and has no possibility of being used for war purposes.

Emmations:— All the three radio active series contain an element of atomic number 86 which has the chemical property of rare gas and is called emmations. We have radium emmation, thorium emmation and actinium emmation.

Radioactive hazards:— Like X-rays, the various radiation form radioactive nuclides are able to ionize the matter through which they pass. All ionising radiations are harmful to the living tissues. If the damage is slight the ~~bee~~ living tissue can repair itself and there is no permanent damage done. However a strong dose of radiation may prove permanently harmful. It is not very easy to know the radiation hazard immediately because usually there is a delay of many years between the exposure and some possible harmful effects. In some cases radiation is an unwanted by-product particularly in the operation of nuclear reactors and the disposal of nuclear waste. The harmful effect of radiation include cancer, Lukemia, and ~~genetic~~ genetic changes that may causes the children to be born handicapped.

Nuclear fission

The process of breaking up the nucleus of a heavy atom into two, more, or less equal segments with the release of a large amount of energy is known as fission.



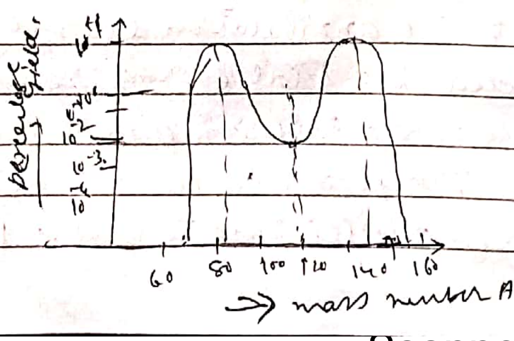
In 1938 Hahn bombarded uranium with a thermal neutrons (energy 0.025 ev) and observed that the isotope of uranium of atomic weight 235 showed a queer disintegration. It broke up into two nuclei of atomic number 56 and 36 and liberated 3 neutrons in addition to a tremendous amount of energy. The element of atomic number 56 is barium and that of 36 is krypton. The nuclear reaction is represented as $_{92}U^{235} + {_0}n^1 \rightarrow {_{56}}Ba^{141} + {_{36}}Kr^{92} + 3\,n^0 + E$

The presence of Barium in the disintegration products was chemically identifyed.

The U^{235} nuclei do not all split up into those Ba and Kr. They may divide in to the nuclei of several pairs of elements lying in the central region of the periodic table with slightly unequal nuclear masses. These are known as Fission fragments. Thus another mode of U^{235} fission is

$$_{92}U^{235} + n^1 \rightarrow {_{92}}U^{236} \rightarrow {_{40}}Zr^{98} + {_{52}}Te^{135} + 3n^1 + E.$$

If we plot percentage yield as function of the atomic mass number A. we get a curve of the type shown in the fig.



The yield is maximum at A = 95 and 139 and the distribution is called asymmetric. The yield is minimum at 118 A = 118 which corresponds to symmetric spliting of U_{235} nucleus.

Fission may occur spontaneously or it may be induced. Most of the heavier isotopes of the elements with Z ≥ 82 shows spontaneous fission. In such a case, the number of protons in the nucleus is very large so that the electrostatic force of repulsion between them exceeds the nuclear binding force.

Induced fission takes places when energy is supplied to the heavy nucleus by an impinging particle, thus making it unstable. Positively charged projectiles require sufficient energy to overcome the nuclear potential barrier of the target. The neutrons are the most effective fission producing particles. They carry no charge and are therefore neither effected by the presence of orbital electrons nor by the positive charge on the nucleus. The elements of low atomic weight have an atomic number approximately half the atomic weight. Thus the nuclei of the atoms consist of an equal no. of protons and neutron. The proton-neutron pair being the most stable formation in atomic structure, the light elements are highly stable. Heavy nuclei with even Z and odd (A-Z) can undergo fission by slow or thermal neutrons. As these nuclei are less tightly held than those with even (A-Z), the neutron binding energy alone is sufficient to cause fission in U^{235}_{92} and Pu^{239}_{94} etc. The nuclei with even (A-Z) can be split by fast neutrons having K.E greater than 1 Mev.

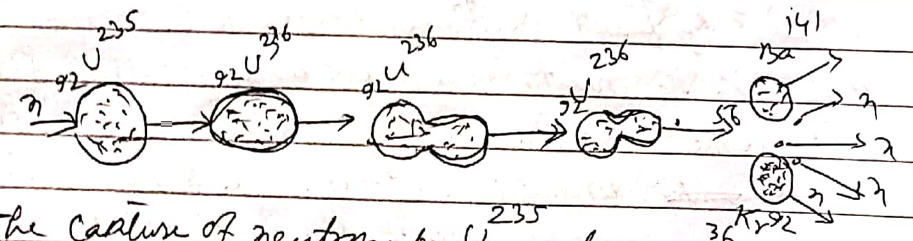
About 99% of neutrons ejected as a result of fission of uranium emerge within a time interval of 10^{-14} sec and are called ~~prompt~~ prompt neutrons. The remaing 1% are ejected later and are called delayed neutrons. The delayed neutrons play an important rule in nuclear reactors.

It is now known that fission can be induced under proper conditions in practically all the heavy nucleides. The fission activation energy can be supplied to the nucleus by particles other than neutrons such as protons, deutrons, α-particles, γ-rays, negative π mesons, high energy carbon ions and som

The fission induced by γ- rays is called photo fission. The threshold photon energy for inducing fission in many heavy nucleides is just more than 5 MeV.

Explanation of Fission on the basis of liquid drop model :-

Bohr and wheeler explain the phenomenon of nuclear fission on the liquid drop model of the nucleus. The fissil nucleus is normally maintained in equilibrium under the combined action of short range nuclear ~~as such~~ forces of attraction among the nucleons in it which try to maintain the shape of the nucleus as such and the Coulomb force of repulsion among the protons in it which try to distort its shape. When some energy is imparted to the drop, say through the capture of a neutron, oscillation are setup in the drop which ~~to~~ tend to distort the spherical shape of the nucleus, while the surface tension forces try to restore it. When the excitation energy is sufficiently large, the compound nucleus formed is in an excited state and is sufficiently distorted in shape like that of a dumb-bell. When the Coulomb force of repulsion between the two ~~halt~~ halves of this dumb-bell exceeds the nuclear forces holding the nucleons, the nucleus breaks up into two fragments and fission is said to take place. The varius steps from neutron capture to fission of U^{235} nucleus are shown in the fig.



The capture of neutron by $_{92}U^{235}$ nucleus results in the formation of a compound nucleus $_{92}U^{236}$. The compound nucleus undergoes distortion due to excitation energy to attain the shape of a dumb-bell and finally splits up into fission products $_{56}B^{141}$ and $_{36}Kr^{92}$ with release of three neutrons. ~~For~~

For a spherical charged drop, the surface energy is given by $E_s = 4\pi R^2 \sigma = 4\pi r_0^2 A^{2/3} \sigma = a_s A^{2/3}$ and the Coulomb energy $E_c = \frac{3}{5}\frac{Z^2 e^2}{R} = \frac{3}{5}\frac{Z^2 e^2}{r_0 A^{1/3}} = a_c \frac{Z^2}{A^{1/3}}$

As shown above for the fission process to bigin, the shape of the nucleus must be deformed. This means R must become large resulting in an increase of surface energy and decrease in Coulomb energy. The net change in energy

$$\Delta E \propto (2E_s - E_c)$$

$$\therefore \Delta E = 0 \text{ if } 2E_s - E_c = 0 \text{ or } E_c = 2E_s.$$

$$\text{or } \frac{a_c Z^2}{A^{1/3}} = 2a_s A^{2/3}$$

$$\text{or } \frac{Z^2}{A} = 2a_s/a_c \qquad \text{Now } a_s = 18\,MeV \text{ and } a_c = 0{\cdot}8\,MeV$$

$$\therefore Z^2/A = \frac{2\times 18}{0{\cdot}8} = 45 \text{ (approx)}$$

Thus according to Bohr-Wheeler theory, spontaneous fission should occur in nuclides with Z^2/A values greater than 45. For nucleids with Z^2/A value less than 45, fission is not expected to occur unless some particle is captured by the nuclei which supplies the activation energy required.