Nuclear Physics
Part -I

Dr.R.Priscilla, HoD of Physics,
ADM. College for Women,
Nagapattinam.

Nuclear Physics

CONTENT:

- Nucleus-
- Nuclear size-
- Charge-
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What is nucleus?

Ans: The nucleus is the center of an atom. Atoms are composed of particles called protons, electrons and neutrons. Protons carry a positive electrical charge, electrons carry a negative electrical charge and neutrons carry no electrical charge at all. The protons and neutrons cluster together in the central part of the atom, called the nucleus, and the electrons 'orbit' the nucleus.

What is nuclear size?

Ans: Atomic nucleus is made up of nucleons called (protons and neutrons) and is surrounded by the electron cloud. The size (diameter) of the nucleus is between 1.6 fm (10 −15 m) to about 15 fm.

The nuclear size can be determined as- $r = R_o$ A 1/3 Where r is the radius of nucleus and A is the mass no. of atom and R_0 is constant The nuclear radius is of order of 10 -14, therefore very small.

What is nuclear Charge?

Ans: The charge of the nucleus is due to the protons contained in it. Each proton has a positive charge of 1.6×10^{-19} C. The nuclear charge is Ze where Z is the atomic number of the nucleus.

What is nuclear Spin?

Ans: Electrons and protons have a spin of ½. Thus nuclei with an even number of protons and electrons should have integral spins, while those with an odd number of protons and electrons should have half – integral spins.

Define nuclear fission.

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

$$_{92}\mathbf{U}^{235} + {}_{o}n^{1} \rightarrow {}_{92}\mathbf{U}^{236} \rightarrow \text{x + y + neutrons.}$$

A typical fission reaction is,

$$_{92}\mathbf{U}^{235} + {}_{o}n^{1} \rightarrow {}_{92}\mathbf{U}^{236} \rightarrow {}_{56}\mathbf{Ba}^{141} + {}_{36}\mathbf{Kr}^{92} + 3\,{}_{0}\mathbf{n}^{1} + \text{energy}$$

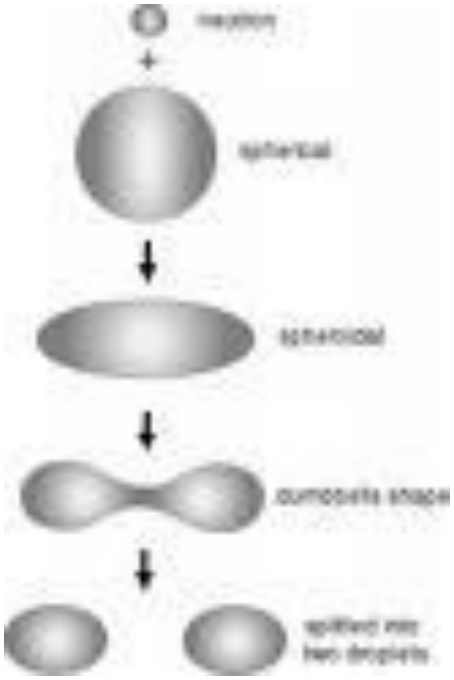
Define nuclear fusion.

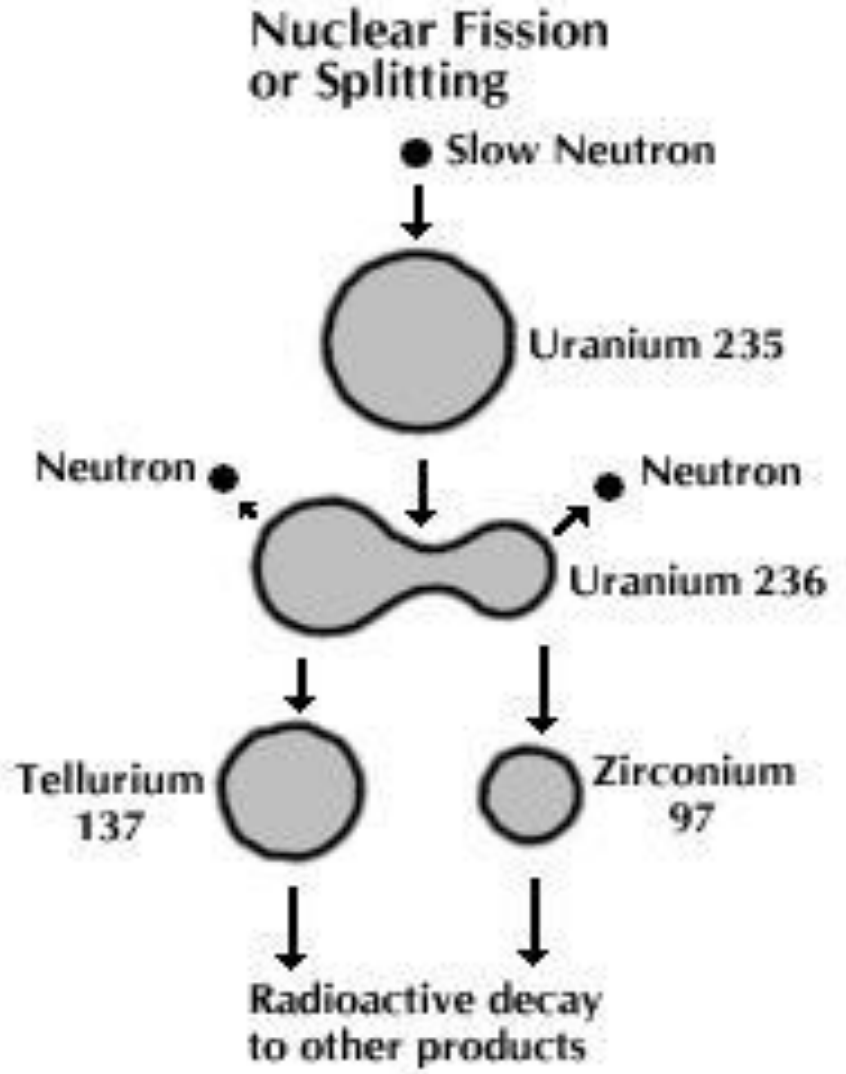
Ans: In this process, two or more light nuclei combine together to form a single heavy nucleus.

The mass of the single nucleus formed is always less than the sum of the masses of the individual light nuclei.

The difference in mass converted into energy according to E=mc2

$$_{1}H2 + {}_{1}H2 \rightarrow {}_{2}He\,4$$




Nuclear Fission
or Splitting
Slow Neutron
Uranium 235
Neutron
Neutron
Uranium 236
Tellurium
137
Zirconium
97
Radioactive decay
to other products

Nuclear model

- **Nuclear model:**
- The precise nature of the force acting in the nucleus is unknown.
- Nuclear models are restored to for investigation and theoretical prediction of its properties.
- Such models may be based on the extrinsic analogy between an atomic are called the **Liquid Drop Model.**

Liquid Drop Model

- In the liquid-drop, the forces acting in the nucleus are assumed to be analogical to the molecular forces in a droplet of some liquid.
- There are certain marked similarities between an atomic nucleus and a liquid-drop.
- The similarities between the nucleus and a liquid drop are the following.

- (i) The nucleus is supposed to be spherical in shape in the stable state, just as a liquid drop is spherical due to the symmetrical surface tension forces.
- (ii) The force of surface tension acts on the surface of the liquid drop. Similarly, there is a potential barrier at the surface of the nucleus.
- (iii). The density of a liquid- drop is independent of its volume. Similarly, the density of the nucleus is independent of its volume.
- (iv). The intermolecular forces in a liquid are short range forces. The molecules in a liquid- drop interact only with their immediate neighbours. Similarly, the nuclear forces are short range forces. Nucleons in the nucleus also interact only with their immediate neighbors.

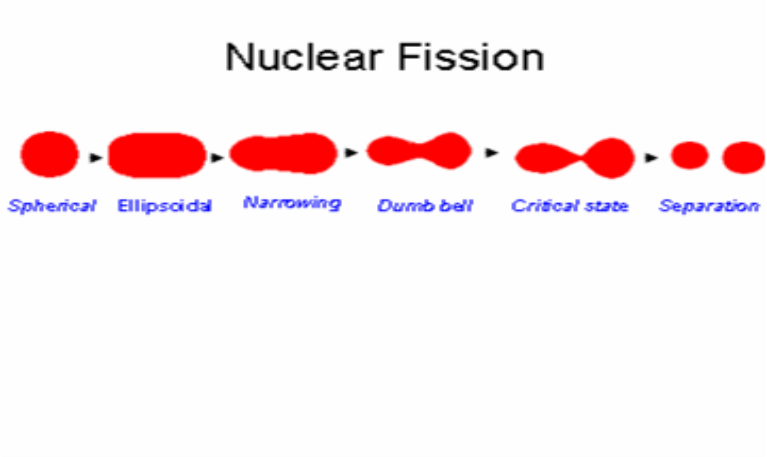
- **(v). The molecules evaporate from a liquid drop on raising the temperature of the liquid due to their increased energy of thermal agitation. Similarly, when energy is given to a nucleus by bombarding it with nuclear projectiles, a compound nucleus is formed which emits nuclear radiations almost immediately.**
- **(vi). When a small drop of liquid is allowed to oscillate, it breaks up into two smaller drops of equal size. The process of nuclear fission is similar and the nucleus breaks up into two smaller nuclei.**

Liquid drop model

- Equilibrium shape and closed packing of particles.
- Constant density – independent of A.
- Short range forces.
- Binding energy similar to latent heat of condensation.
- Surface nucleons less bound compared to molecules in the interior of the drop.
- Nuclear forces resembles surface tension.
- Repulsive force plays the role of dissipative force.
- Energy of nuclei corresponds to internal thermal vibration of drop molecules.
- The formation of compound nucleus and absorption of bombarding particles related to condensation of drops.

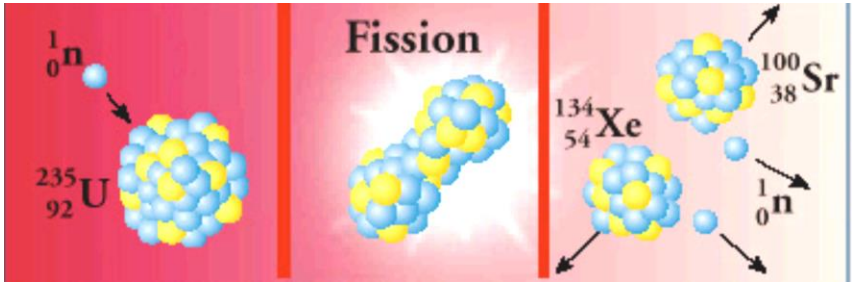
Merits

- Atomic masses can be calculated.
- Nuclear fission is successfully explained.
- Explanation given by Bohr and Wheeler in 1939.



Demerits

- It does not explain the whole nuclear structure.
- Magic numbers are not explained.
- No information of energy levels.



Nuclear Shell model

- The nuclear force that bind the nucleons in a nucleus is very different from the electro magnetic forces and gravitational forces which obey inverse square law of forces and hence infinite in range.

- The nuclear force is short range attractive force with a repulsive core and charge independent.

- It is such that leads to the saturation of nuclear forces i.e., constancy of nuclear binding energy and constancy of nuclear charge density.

- Starting from the nucleon-nucleon force to obtain the charge density and binding energy of nuclear matter is, by no means, an easy task, Several attempts have been made Bruckner and Bethe to deduce the bulk properties of matter. But the theory is too complicated.

- We shall consider a particular model for the nucleus known as Shell Model and what is amazing is the success of this model.

Shell model

The simplest evidence for the shell structure comes from the discovery of magic numbers 2,8,20, 28,50, 82,126 and so on.

The nuclei with magic no. of neutron or magic no. of proton number are known as magic number nuclei. They have different properties from nuclei with neighboring values of N and Z.

Evidence for magic number nuclei:

1. Binding energy larger for magic no. nuclei
2. Large energy is required to remove nucleon from these nuclei.
   - Single neutron and single proton separation energies minimum
3. The low lying excited states are much higher in energy

Element	Ar	K	Ca	Sn	Sb	Te
Z	18	19	20	50	51	52
Stable Isotopes	3	2	6	10	2	2
N	18	19	20	48	49	50
Stable Isotones	2	0	5	2	1	5

Reason for the existence of magic numbers:

- The nuclear single particle spectrum is not a smooth one; there are relatively large energy gaps between groups of single particle states.
- When each group of states is completely filled, the Fermi energy of the nucleus is just below one of these large energy gaps.
- As a result, more energy than usual is required to excite the nucleons i.e., by promoting one of the nucleons below the Fermi energy to an unoccupied state above.
- With all this orbits filled, the ground state of nucleus is tightly bound and spherical in shape.