Complete notes of Nuclei

Here physics classes by Nayan jha providing complete notes of nuclei , but before to read this notes students must have to complete the chapter **atoms** first .

INTRODUCTION TO NUCLEUS

The nucleus is the central and extremely small part of an atom in which almost the entire mass of the atom is concentrated.

It was discovered by **Ernest Rutherford** through his alpha-particle scattering experiment.

A nucleus consists **Protons (** Positively charged particles), **Neutrons** (Electrically neutral particles). So we can say,Protons and neutrons are collectively called **nucleons**.

Atomic Number (Z)

The total number of protons present in the nucleus of an atom is called its atomic number.

\[Z = \text{Number of protons} \]

Mass Number (A)

The total number of protons and neutrons present in the nucleus is called its mass number.

A=Z+N

Where: Z = Number of protons , N = Number of neutrons

Therefore, N=A-Z

Representation of a Nucleus

A nucleus is represented as: ${}^{A}X_{Z}$

Where: X = Symbol of the element, A = Mass number, Z = Atomic number

Example:

${}^{23}Na_{11}$

Here: Number of protons = 11; Number of neutrons = 23 − 11 = 12; Number of electrons in a neutral atom = 11

physics classes by Nayan jha

Atomic Mass Unit (u)

Atomic mass unit (u) is defined as **1/12th of the mass of one carbon-12 atom**.

It is used to express the masses of atoms, nuclei, protons and neutrons.Its value in SI units is: $1u=1.66 \times 10^{-27}$ kg,

Isotopes

Atoms having the same atomic number but different mass numbers are called isotopes.

In other words, isotopes have the same number of protons but different numbers of neutrons.

Example:

$^{1}H_{1}$ $^{2}H_{1}$ $^{3}H_{1}$

These are isotopes of hydrogen.

Isobars- Atoms having the same mass number but different atomic numbers are called isobars.

Example: $^{40}Ar_{18}$ and $^{40}Ca_{20}$

Isotones- Atoms having the same number of neutrons but different atomic numbers are called isotones.

Example: $^{14}C_{6}$, and $^{15}N_{7}$

Both have 8 neutrons.

SIZE OF THE NUCLEUS

The size of a nucleus is extremely small compared to the size of an atom.

The radius of a nucleus is given by the following empirical relation: Volume of the nucleus is directly proportional to its mass no (A)

i.e. $4/3\pi R^3 \alpha A$

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

Where:

Physics classes by Nayan Jha

- R = Radius of nucleus, A = Mass number , R_0 = Constant

The value of R_0 is approximately:$R_0 = 1.2 \times 10^{-15}$ Or ; $R_0 = 1.2fm$, Here, fm represents femtometre.

NUCLEAR DENSITY- Of a nuclus of an atom is given as the ratio of mass of nucleus to the volume of the nucleus . Nuclear density is approximately constant for all nuclei.

Or,

Nuclear density is defined as the mass per unit volume of a nucleus.

ϱ = Mass/Volume

We know that:

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

Volume of nucleus:

$V = 4/3\pi R^3$

Substituting the value of R:

$V = 4/3\pi R_0 {}^3A$

Mass of nucleus is approximately,

Mass , $M = A u$

$\varrho = A u / (4/3\pi R_0 {}^3A)$

Cancelling A and putting all the values we get, $\varrho = 2.3 \times 10^{17}$ kg /m^3

This expression shows that nuclear density is independent of mass number.

MASS-ENERGY RELATION

According to Einstein's mass-energy equivalence principle, mass and energy are interchangeable.

A small amount of mass can be converted into a large amount of energy.

Physics classes by Nayan Jha

Einstein gave the famous equation: $E=mc^2$

Where: E = Energy , m = Mass , c = Speed of light in vacuum

[$c=3x10^8$ m/s]

Mass-Energy Conversion

For nuclear calculations, the following conversion is very important:

1u=931.5 MeV

in mass-energy equivalent.

Also,

$1MeV=1.6 \times 10^{-13}$ J

Important: Nuclear reactions involve very small changes in mass, but these changes correspond to enormous amounts of energy.

Mass defect-

The difference between the sum of the masses of individual nucleons and the actual mass of the nucleus is called mass defect. It is represented by δm.

Suppose a nucleus contains: A = mass no , Z = no. of protons , then no. of nutrons = A-Z.

The total mass of individual nucleons is, Z Mp + (A-Z) Mn

But it is supposed that the actual mass of the nucleus is M.

Therefore, δm= Z Mp + (A-Z) Mn –M ; Where: Mp = Mass of proton; M_n= mass of nutrons. M = Actual mass of nucleus

Why Does Mass Defect Occur?

When protons and neutrons combine to form a nucleus, some energy is released.

According to Einstein's mass-energy relation, this released energy corresponds to a decrease in mass.This difference in mass is known as mass defect.

Physics classes by Nayan jha

NUCLEAR BINDING ENERGY

The minimum energy required to separate a nucleus completely into its individual protons and neutrons is called binding energy.

It is represented by **B.E**.

According to Einstein's mass-energy relation: $E=mc^2$

Therefore, nuclear binding energy is:

$B.E.= \delta mc^2$

Substituting the value of mass defect:

$B.E = [Z\ Mp + (A-Z)\ Mn - M]\ c^2$

Binding Energy in MeV

If mass defect is measured in atomic mass units (u), then:

$B.E.= \delta m \times 931.5 MeV$

BINDING ENERGY PER NUCLEON

The average binding energy associated with each nucleon in a nucleus is called binding energy per nucleon.

It is represented by ; B.E/A

Where: B.E. = Total binding energy; A = Mass number

Importance of Binding Energy Per Nucleon

Binding energy per nucleon gives information about the stability of a nucleus.

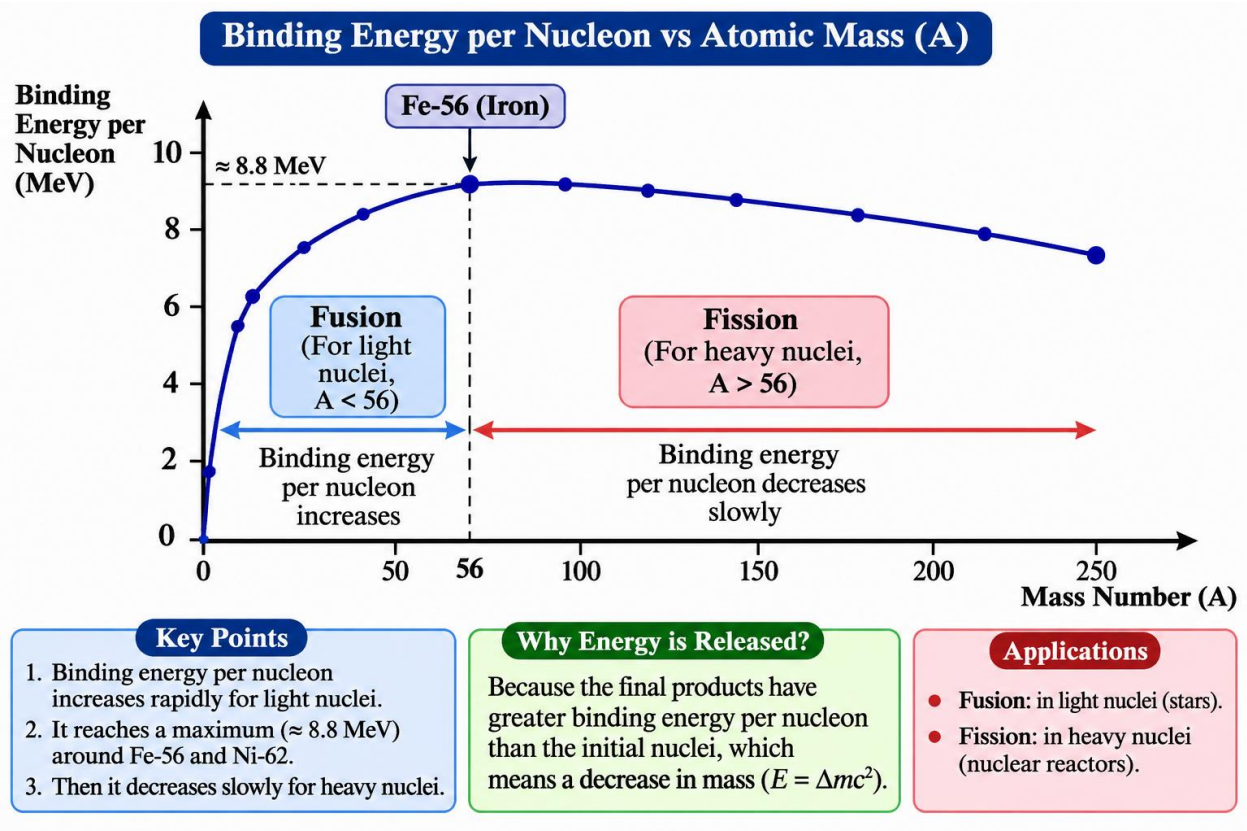
Important points:

1. Greater binding energy per nucleon generally means greater nuclear stability.
2. Iron and nickel nuclei have among the highest binding energies per nucleon.
3. Very light and very heavy nuclei generally have lower binding energy per nucleon.
4. Nuclear fission and nuclear fusion release energy because their products have greater binding energy per nucleon.

Physics classes by Nayan Jha

GRAPH OF BINDING ENERGY PER NUCLEON v/s MASS NO.

This is one of the most important graphs of the chapter for CBSE examinations.



Physics

Explanation of the Graph

The graph represents the variation of binding energy per nucleon with mass number (A).

Region I: Light Nuclei

- Binding energy per nucleon increases rapidly with mass number.
- Light nuclei are comparatively less stable.
- Fusion of light nuclei releases energy.

Region II: Medium-Mass Nuclei

- Binding energy per nucleon becomes maximum around iron and nickel.
- These nuclei are among the most stable nuclei.

Region III: Heavy Nuclei

- Binding energy per nucleon decreases slowly with increasing mass number.
- Heavy nuclei can release energy through nuclear fission.

Important Board Examination Question

Why is energy released during nuclear fission and nuclear fusion?

Answer: As we know Nuclear fusion is the process in which two or more lighter nuclei combine to form a heavier nucleus, releasing a large amount of energy.

Example:

Two light nuclei combine to form a heavier nucleus.

$2H_1 + 3H_1 = 4He_2 + 1n_0 + 17.6\ MeV$

Explanation on the basis of the binding energy curve: Light nuclei have comparatively low binding energy per nucleon. When two light nuclei combine, they form a heavier nucleus. The binding energy per nucleon of the product nucleus is greater. Therefore, the product nucleus is more stable. The increase in total binding energy is released in the form of energy. And hence, energy is released during nuclear fusion.

Energy Released During Nuclear Fission

As we know Nuclear fission is the process in which a heavy nucleus splits into two or more lighter nuclei, releasing a large amount of energy.

Example:

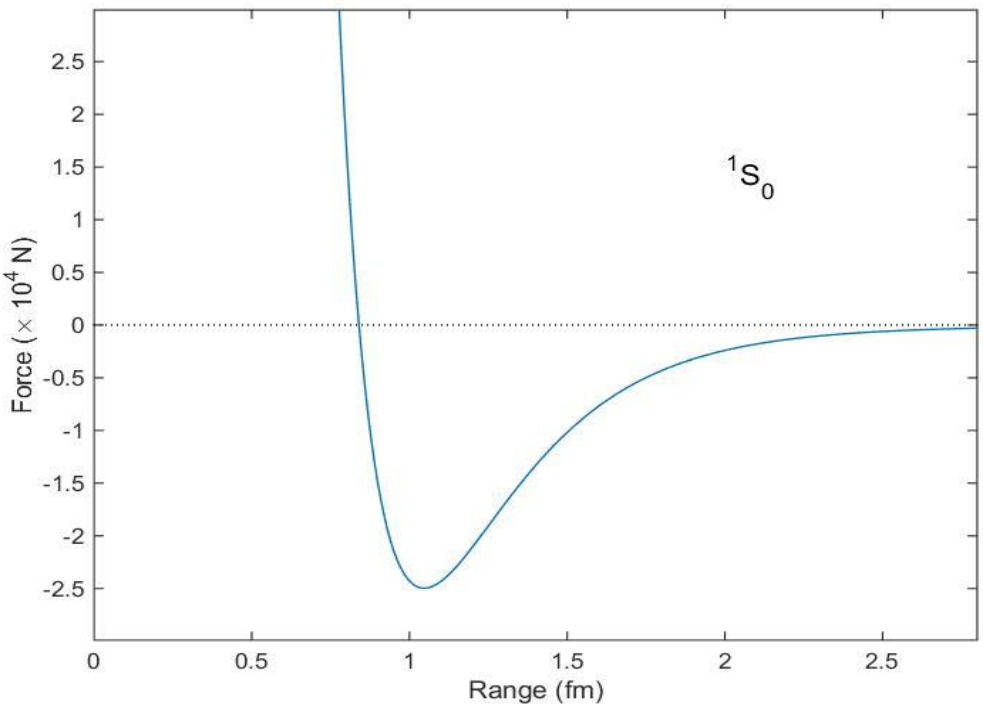
$^{235}U_{92} + {}^{1}n_0 = {}^{141}Ba_{56} + {}^{92}Kr_{36} + 3\ {}^{1}n_0 + Energy$

Explanation on the basis of the binding energy curve: Heavy nuclei such as uranium have comparatively low binding energy per nucleon. When a heavy nucleus undergoes fission, it splits into two medium-sized nuclei. The binding energy per nucleon of the product nuclei is greater. Therefore, the product nuclei are more stable. The increase in total binding energy is released in the form of energy. And Hence, energy is released during nuclear fission.

Physics classes by Nayan Jha

NUCLEAR FORCE

The strong attractive force that holds protons and neutrons together inside the nucleus is called nuclear force.



Properties of Nuclear Force

1. Nuclear force is extremely strong.
2. It is attractive at intermediate nuclear distances.
3. It is short-range in nature.
4. It acts between proton-proton, neutron-neutron and proton-neutron pairs.
5. It is approximately charge-independent.
6. It is a saturation force, meaning that each nucleon interacts significantly with only a limited number of nearby nucleons.

Why Does the Nucleus Remain Stable?

Protons are positively charged and repel each other due to electrostatic force. However, the strong nuclear force between nucleons is attractive and dominates over electrostatic repulsion at nuclear distances. As a result, the nucleus can remain bound.

NUCLEAR FISSION

The process in which a heavy nucleus splits into two or more lighter nuclei, releasing a large amount of energy, is called nuclear fission.

Example: Fission of Uranium-235

When a uranium-235 nucleus absorbs a slow neutron, it becomes unstable and splits into smaller nuclei.

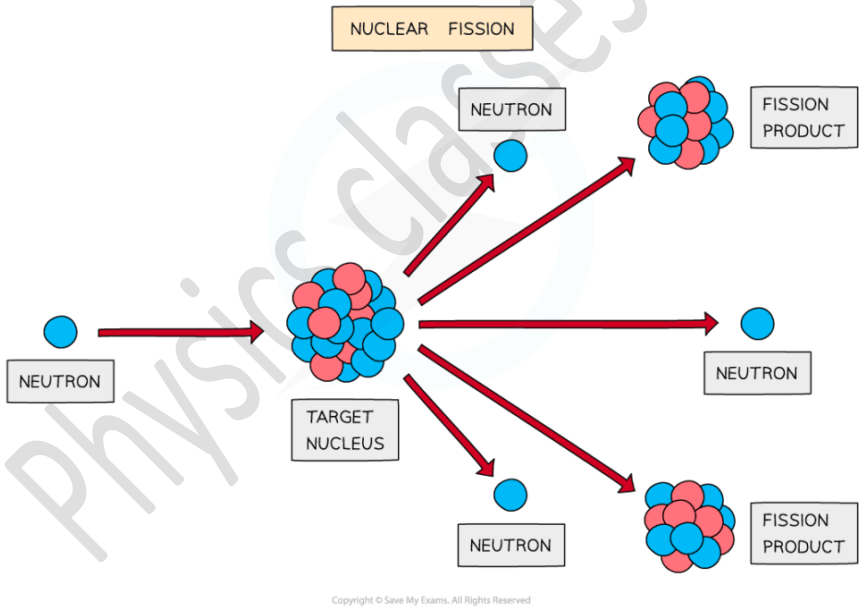
One possible reaction is:

$$^{235}U_{92} + {}^{1}n_{0} = {}^{141}Ba_{56} + {}^{92}Kr_{36} + 3\,{}^{1}n_{0} + Q$$

Where Q represents the energy released.

Approximately 200 MeV of energy is released per fission event.

Nuclear Fission Diagram



Important Features of Nuclear Fission

1. A heavy nucleus splits into lighter nuclei.
2. A large amount of energy is released.
3. Additional neutrons are produced.

Physics classes by Nayan Jha

4. These neutrons can cause further fission reactions.
5. It is used in nuclear reactors to generate electricity.

CHAIN REACTION

A chain reaction is a self-sustaining nuclear reaction in which neutrons released during one fission reaction produce further fission reactions.

Explanation

1. A neutron strikes a uranium-235 nucleus.
2. The uranium nucleus undergoes fission.
3. More neutrons are released.
4. These neutrons cause further fission reactions.
5. The process continues.

Types of Chain Reaction

1. Controlled Chain Reaction

The rate of fission is controlled by absorbing excess neutrons.

It is used in nuclear reactors.

2. Uncontrolled Chain Reaction

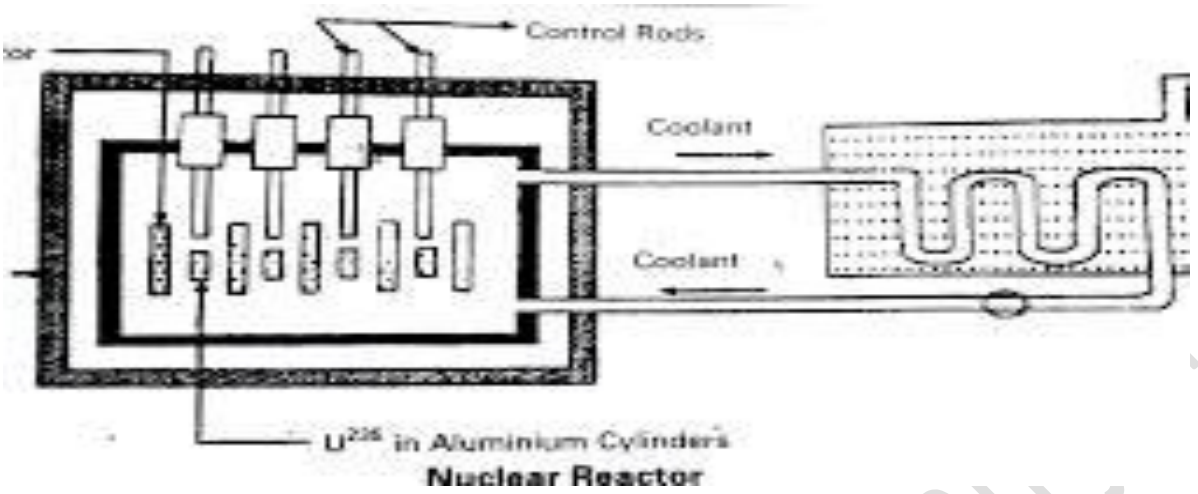
The fission reactions multiply rapidly without regulation.

NUCLEAR REACTOR

A nuclear reactor is a device in which a controlled nuclear fission chain reaction is carried out to produce useful energy.

Main Components of a Nuclear Reactor

Physics classes by Nayan jha



Nuclear Reactor

1. Nuclear Fuel

Uranium-235 or plutonium-239 is commonly used as nuclear fuel.

2. Moderator

A moderator slows down fast neutrons.

Examples: Heavy water, Ordinary water, Graphite

3. Control Rods

Control rods absorb excess neutrons and control the chain reaction.

Examples: Cadmium, Boron

4. Coolant

The coolant removes heat produced inside the reactor.

Examples: Water, Heavy water, Liquid sodium

5. Shielding

Thick concrete and other shielding materials protect the surroundings from harmful radiation.

NUCLEAR FUSION

The process in which two or more light nuclei combine to form a heavier nucleus, releasing a large amount of energy, is called nuclear fusion.

Physics classes by Nayan

Example:

Fusion of hydrogen isotopes:

$2H_1 + 3H_1 = 4He_2 + 1n_0 + 17.6$ MeV
Here:

- Deuterium = Hydrogen isotope with mass number 2.
- Tritium = Hydrogen isotope with mass number 3.
- Helium = Product nucleus.

Conditions Required for Nuclear Fusion

1. Extremely high temperature.
2. Very high pressure or sufficient confinement.
3. Sufficient energy to overcome electrostatic repulsion between positively charged nuclei.

Nuclear Fusion in the Sun

The Sun produces energy through nuclear fusion. Hydrogen nuclei combine through a series of nuclear reactions to form helium. A small amount of mass is converted into an enormous amount of energy.

Difference Between Nuclear Fission and Fusion

Nuclear Fission	Nuclear Fusion
Heavy nucleus splits into lighter nuclei.	Light nuclei combine to form a heavier nucleus.
Requires a suitable heavy nucleus.	Requires light nuclei.
Can be initiated by neutron absorption.	Requires extremely high temperature and suitable confinement.
Used in nuclear power reactors.	Responsible for energy production in stars.
Releases a large amount of energy.	Releases a large amount of energy.

Physics classes by Nayan jha