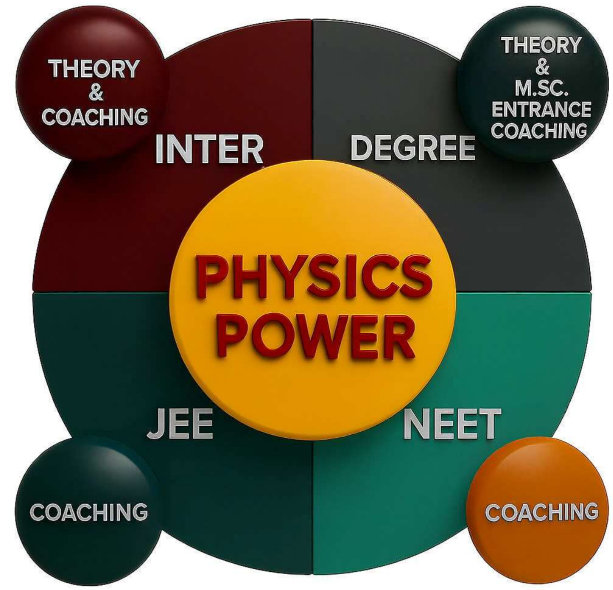
WELCOME
TO
PHYSICS CLASS



CHAPTER - 14

NUCLEI

INTRODUCTION

NUCLEI

RADIUS

DENSITY

MASS DEFECT

BINDING ENERGY

NUCLEI

RADIUS

DENSITY

MASS DEFECT

BINDING ENERGY

INTRODUCTION TO NUCLEI

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Phyiscal Quantities

- Atomic Number
- Mass / Mass Number
- Radius
- Volume
- Density
- Mass Defect
- Binding Energy
- Nuclear Forces

Atomic Number

Protons and Neutrons

The number of protons in the nucleus is called the atomic number (Z)

Atomic Mass Unit: (amu)

Smallest quantity of mass

$$1\ \text{amu} = \frac{\text{mass of one } ^{12}C}{12} = \frac{1.99 \times 10^{-26}}{12}$$

$$= 1.67 \times 10^{-27}\ kg$$

Mass Number

The total number of protons and neutrons present in the nucleus is called the *mass number* (A) of the element

The total mass of protons and neutrons present in the nucleus is called the *nuclear mass*

$$Zm_p + (A - Z)m_n$$

Number of protons in an atom = Z

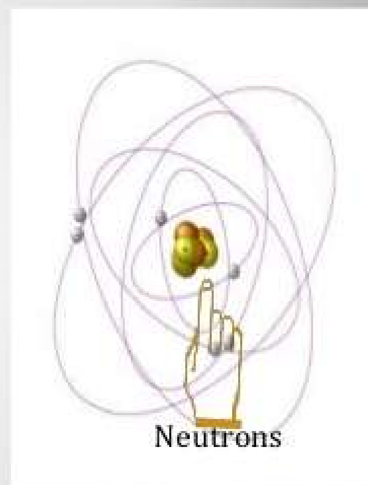
Number of nucleons in an atom = A

Number of neutrons in an atom = N = A-Z

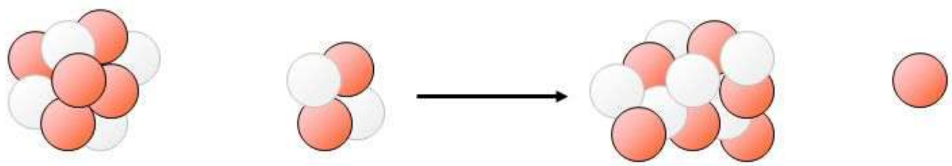
$$_{Z}X^{A}$$

DISCOVERY OF NEUTRONS

Chadwick smashed alpha particles into beryllium, a rare metallic element, and allowed the radiation that was released to hit another target: paraffin wax. The experiment results showed a collision with beryllium atoms would release massive neutral particles, which Chadwick named neutrons.



Discovery of the Neutron



$$^{9}_{4}\text{Be} + ^{4}_{2}\text{He} \longrightarrow ^{12}_{6}\text{C} + ^{1}_{0}\text{n}$$

James Chadwick bombarded beryllium-9 with alpha particles, carbon-12 atoms were formed, and neutrons were emitted.

Dorin, Demmin, Gabel, Chemistry The Study of Matter 3rd Edition, page 764

*Walter Boethe

RADIUS AND DENSITY
OF
THE NUCLEUS

Radius

Volume α mass number

$4/3\,\pi R^3 \;\alpha\; A$

$R \;\alpha\; A^{1/3}$

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

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

$$\frac{R_1}{R_2} = \left[\frac{A_1}{A_2}\right]^{1/3}$$

Nuclear Density

If the m is the average mass of the nucleon and A is the mass number of element,

the mass of the nucleus = mA

$$\text{Volume of nucleus} = \frac{4}{3}\pi R^3$$

$$= \frac{4}{3}\pi\left[R_0 A^{1/3}\right]^3$$

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

$\therefore$ Density of nucleus $= \dfrac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$

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

$$\Rightarrow \rho = \frac{3m}{4\pi R_0^3}$$

$$= 2.3 \times 10^{17}\ kg/m^3$$

MASS – ENERGY EQUIVALENT

Mass – Energy Equivalent

$$E = mc^2$$

$$E = 1.66 \times 10^{-27} \times \left[3 \times 10^{8}\right]^2 \quad J$$

$$= \frac{1.66 \times 10^{-27} \times 9 \times 10^{16}}{1.6 \times 10^{-19}} \quad eV$$

$$= 9.316 \times 10^{-27+35}$$

$$= 9.316 \times 10^{+8} = 9.316 \times 10^{2} \times 10^{6}\ eV$$

$$E = 931.6\ MeV$$

for 1 amu

$$mc^{2} = 931.6\ MeV$$

$$m = 931.6\ \frac{MeV}{c^{2}}$$

1 amu

$$1\ \text{amu of mass} = 931.6\ MeV/c^{2}$$

MASS DEFECT
AND
BINDING ENERGY

Mass Defect

The difference between the total mass of all the nucleons of the nucleus and the actual mass of a nucleus is called mass defect

Mass of the nucleons = $Zm_p + (A-Z)m_n$

Actual mass of the nucleus = **M**

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

Binding Energy

$$BE = \Delta m c^2$$

$- \Delta m$ in amu

The binding energy can be defined as the energy released when protons and neutrons combined to form a nucleus

Or

The energy required to break the nucleus into its constituent protons and neutrons

Or

Energy equivalent of mass defect is called binding energy

$$B.E = \left[Z m_p + (A - Z) m_n - M \right] c^2$$

$$B.E = \left[Z m_p + (A-Z) m_n - M\right] c^2$$

$$BE = \Delta m c^2$$

$$- \Delta m \text{ in amu}$$

$$= \Delta m \cdot 931.6 \frac{MeV}{c^2} \cdot c^2$$

$$= \Delta m (931.6 \ MeV)$$

Binding Fraction

The average binding energy per each nucleon is called Binding Fraction

$$\frac{B.E}{A} = \frac{\Delta m \times 931.6}{A} \text{ MeV}$$

BINDING ENERGY PER NUCLEON OF HELIUM NUCLEUS

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Calculate the mass defect, binding energy and binding energy per nucleon of an alpha particle? Mass of the proton = 1.007825 u, mass of the neutron = 1.008665 u and mass of helium atom M = 4.00260 u.

Given

$m_p = 1.007825\ u$

$m_n = 1.008665\ u$

$Z = 2$

$A = 4$

$m_{He} = 4.00260\ u$

$\frac{BE}{A} = ?$

$BE = \Delta m c^2$

$\Delta m = Z m_p + (A-Z) m_n - M$

Mass of the protons = Zm_p = 2.01565 u

2×1.007825

Mass of the neutrons = $(A-Z)m_n$ = 2.01733 u

2×1.008665

Total mass of the nucleons = 4.03298 u

Actual mass M = 4.00260 u

$\therefore \Delta m = [Zm_p + (A-Z)m_n - M] = 0.03038\ u$

$\therefore$ Binding Energy $B.E = \Delta m c^2$

$= 0.03038 \times 931.6 \frac{MeV}{c^2} \times c^2$

$= 28.3\ MeV$

$\therefore \frac{B.E}{A} = \frac{28.3}{4} = 7.075\ MeV$

Find the ratio of the radii of the nuclei of $_{13}Al^{27}$ and $_{52}Te^{125}$

Given

$A_1 = 27$

$A_2 = 125$

$\frac{R_1}{R_2} = ?$

$R \propto A^{1/3} \Rightarrow \frac{R_1}{R_2} = \left[\frac{A_1}{A_2}\right]^{1/3}$

$\Rightarrow \frac{R_1}{R_2} = \left[\frac{27}{125}\right]^{1/3}$

$$\Rightarrow \frac{R_1}{R_2} = \left[\frac{27}{125}\right]^{1/3} = \left[\frac{3^3}{5^3}\right]^{1/3}$$

$$= \left[\left(\frac{3}{5}\right)^3\right]^{1/3}$$

$$\Rightarrow \frac{R_1}{R_2} = \frac{3}{5}$$

BINDING ENERGY PER NUCLEON OF LITHIUM NUCLEUS

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Calculate the mass defect, binding energy and binding energy per nucleon of $_3Li^7$? Mass of the proton = 1.007825 u, mass of the neutron = 1.008665 u and mass of Li M = 7.016003 u.

Given

$m_p = 1.007825\ u$

$m_n = 1.008665\ u$

$Z = 3$

$A = 7$

$m_{Li} = 7.016003\ u$

$\Delta m = ?$ ΔL $BE = ?$

$\frac{BE}{A} = ?$

$$BE = \Delta m c^2$$

$$\Delta m = Z m_p + (A-Z) m_n - M$$

Mass of the protons = Zm_p = $3.023475\,u$

$3 \times 1.007825\,u$

Mass of the neutrons = $(A-Z)m_n$ = $4.03466\,u$

4×1.008665

Total mass of the nucleus = $7.058135\,u$

Actual mass (M) = $7.016003\,u$

$\therefore \Delta m = [Zm_p + (A-Z)m_n - M] = 0.042132\,u$

$\therefore$ Binding Energy $B.E = \Delta m c^2$

$= 0.042132 \times 931.6 \frac{MeV}{c^2} \cdot c^2$

$= 39.2501712$ MeV

$\therefore \frac{B.E}{A} = \frac{39.2501712}{7}$

$= 5.607$ MeV

BINDING ENERGY PER NUCLEON OF OXYGEN NUCLEUS

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Calculate the mass defect, binding energy and binding energy per nucleon of Oxygen. Mass of the proton = 1.007825 u, neutron = 1.008665 u and mass of the $_8O^{16}$ = 15.994915 u

Mass 1 atom $^{16}O_8$		= 15.994915 amu
Mass 8 protons	= 8 x 1.007825 =	8.062600 amu
Mass 8 Neutrons	= 8 x 1.008665 =	8.069320 amu
total mass		= 16.131.920 amu

Mass Defect (Δm) = 16.131920 – 15.994915 = 0.137005 amu

<u>Binding Energy</u> = 0.137005×931.5 MeV

$$\text{BE / nucleon} = \frac{0.137005 \times 931.5}{16} = 7.976 \text{ MeV}$$

BINDING ENERGY PER NUCLEON OF IRON (Fe) NUCLEUS

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Calculate the mass defect, binding energy and binding energy per nucleon of Fe. Mass of the proton = 1.007825 u, neutron = 1.008665 u and mass of the $_{26}Fe^{56}$ = 55.934932 u

Given Mass of proton = 1.007825 amu

Mass of neutron = 1.008665 amu

Mass of Fe = 55.934932 amu

$$\text{Mass of 26 protons} = 26 \times 1.007825 \text{ amu}$$
$$= 26.20345$$

$$\text{Number of neutrons} = 56 - 26 = 30$$
$$\text{Mass of neutron} = 30 \times 1.008665 \text{ amu}$$
$$= 30.25995 \text{ amu}$$

Total mass of 56 nucleaons = 56.4634 amu

$$\text{Total mass of 56 nucleaons} = 56.4634 \text{ amu}$$

$$\text{Mass of defect, } \Delta m = 56.4634 - 55.934932 = 0.528468 \text{ amu}$$

$$\text{Total binding energy} = \Delta m \times 931.5 \text{ MeV}$$
$$= 0.528468 \times 931.5$$

$$= 492.267942 \text{ MeV}$$

$$\text{BE per nucleon} = \frac{492.267942}{56} = 8.790 \text{MeV}$$

BINDING ENERGY PER NUCLEON OF URANIUM NUCLEUS

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Calculate the mass defect, binding energy and binding energy per nucleon of Uranium. Mass of the proton = 1.007825 u, neutron = 1.008665 u and mass of the ${}_{92}U^{238}$ = 238.0508 u

Given

$m_p = 1.007825\ u$

$m_n = 1.008665\ u$

$Z = 92$

$A = 238$

$m_U = 238.0508\ u$

$\Delta m = ?\quad BE = ?\quad \frac{BE}{A} = ?$

$BE = \Delta m c^2$

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

Mass of the protons = Zm_p = 92.7199 u

92×1.007825

Mass of the neutrons = $(A-Z)m_n$ = 147.26509 u

146×1.008665

Total mass of the nucleus = 239.98499 u

Actual mass of the nucleus (M) = 238.0508 u

$\therefore \Delta m = [Zm_p + (A-Z)m_n - M] = 1.93419\ u$

$$\therefore \quad B.E = \Delta m c^2$$

$$= 1.93419 \times 931.6 \, \frac{MeV}{c^2} \cdot c^2$$

$$= 1801.891404 \text{ MeV}$$

$$\therefore \quad \frac{B.E}{A} = \frac{1801.891404}{238}$$

$$= 7.57 \text{ MeV}$$

BINDING ENERGY CURVE GRAPH

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Binding Energy per nucleon values for different nuclei

$_2He^4$ = 7.075 MeV

$_3Li^7$ = 5.6 MeV

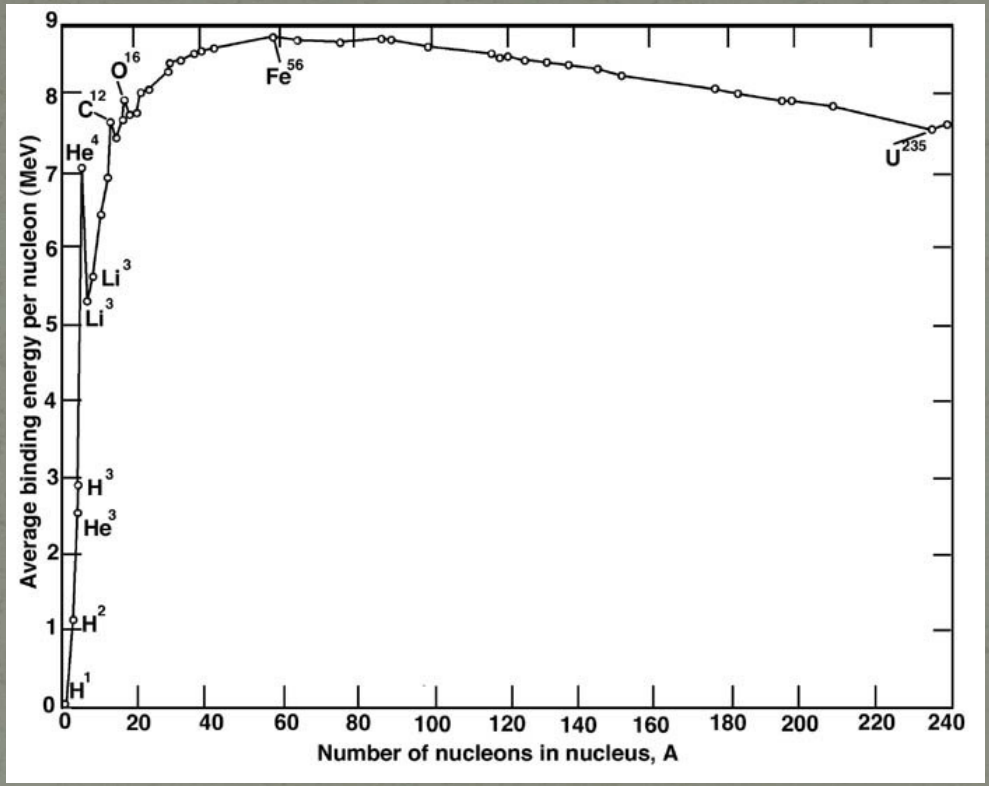
$_8O^{16}$ = 7.976 MeV

$_{26}Fe^{56}$ = 8.8 MeV

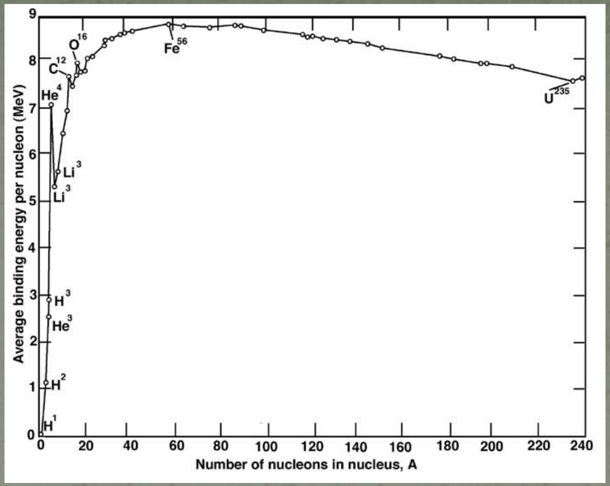
$_{92}U^{238}$ = 7.57 MeV

Binding Energy Curve

Image source: www.commons.wikimedia.org



1. Average binding energy per nucleon for lighter nuclei is small.
2. For mass numbers ranging form 2 to 20, there are sharp peaks corresponding to $_2He^4$, $_6C^{12}$, $_8O^{16}$, etc.,
3. The BE curve has a broad maximum peak in the range A = 30 to A = 120, for Iron BE maximum i.e. 8.8 MeV.
4. As mass number increases, binding energy per nucleon decreases gradually falling to about 7.6 MeV.

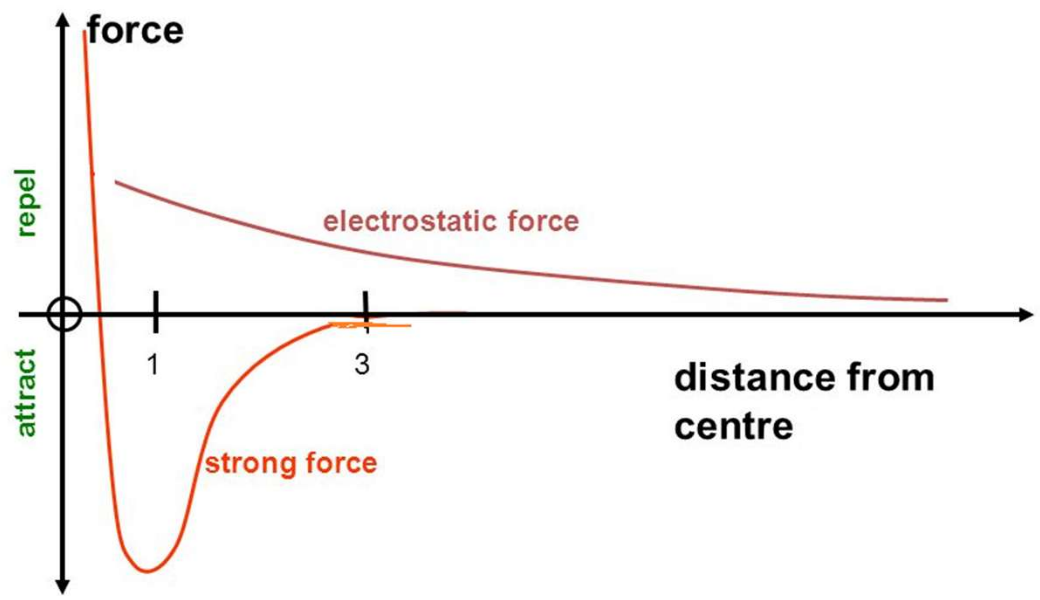


Conclusions:

1. A very heavy nucleus A = 240 has lower binding energy compared to that of a nucleus with A = 120 - nuclear fission.

2. When two light nuclei (A < 10) join to form a heavier nucleus, BE of fused heavier nuclei is more than the BE of lighter nuclei - nuclear fusion.

Nuclear Force



Properties of nuclear forces

Strongest in nature. Same for n-n, n-p and p-p

Charge independent

Spin-dependent

***Short-range* forces**

NUCLEAR

FISSION AND FUSION

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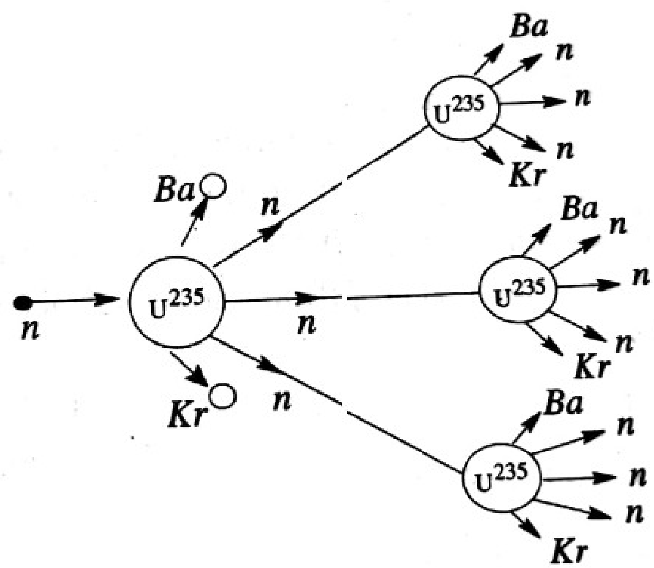
Nuclear Fission

$$_{92}U^{235} + {}_0n^1 \rightarrow \left[{}_{92}U^{236}\right] \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1 + Q$$



Q = 200 MeV

Per nucleon = 0.85 MeV

Nuclear Fusion

$$ {}_1^1H + {}_1^1H \rightarrow {}_1^2H + {}_1^0\beta^+ + \nu \text{ (nutrino)} $$

$$ {}_1^2H + {}_1^1H \rightarrow {}_2^3He + \gamma $$

$$ {}_2^3He + {}_2^3He \rightarrow {}_2^4He + 2\,{}_1^1H $$

$$ 4\,{}_1^1H \rightarrow {}_2^4He + 2\,{}_1^0\beta^+ + 2\gamma + 2\nu $$ Overall reaction

Q = 26.7 MeV

Per nucleon = 6.675 MeV

NUCEAR FISSION	NUCLEAR FUSION
When excited a massive nucleus splits into two smaller nuclei of roughly comparable mass	Two light nuclei combine to form a heavy nucleus
High temperature and pressure conditions are not required	High temperature and pressure conditions are required
Neutrons required	Protons required
Quick process	This happens in several stages
Average energy available per nucleon 0.85 MeV	Average energy available per nucleon 6.75 MeV
Produces highly harmful radioactive waste	Fusion's products are harmless
Material for fission availability is limited	Fusion material is plentiful

NUCLEAR REACTOR

NUCLEAR REACTOR

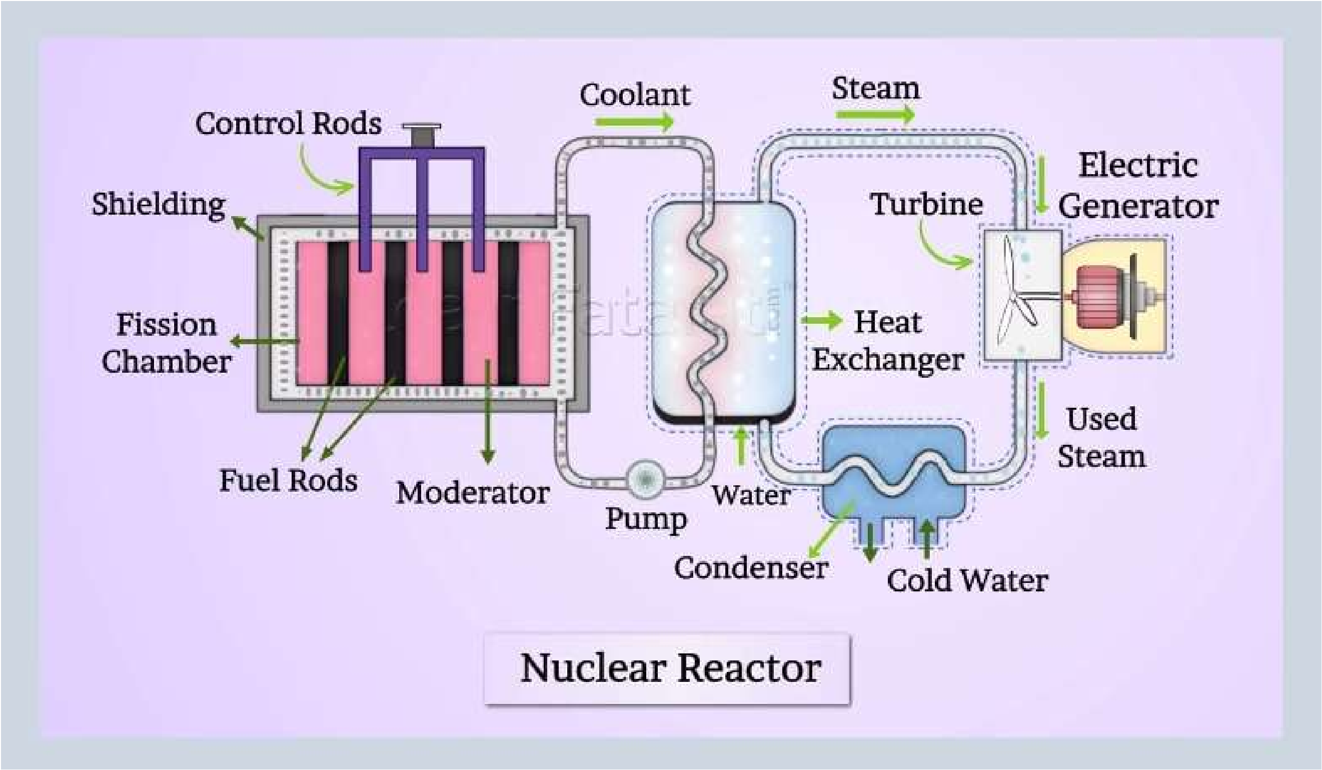


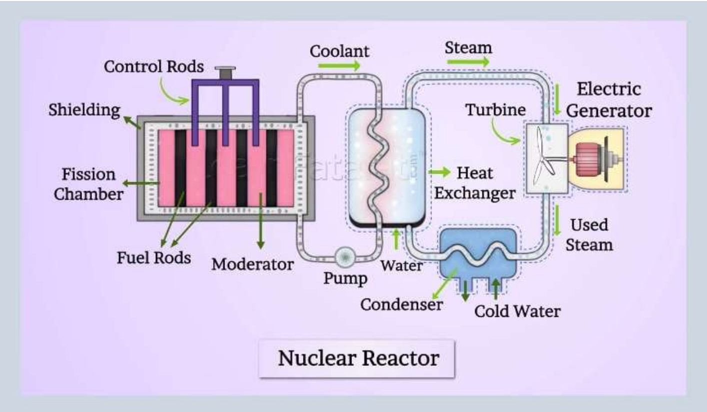
Image source: www.learnfatafat.com

NUCLEAR FUEL

Nuclear fuel is the fuel that is used in a nuclear reactor to sustain a nuclear chain reaction. The most common nuclear fuels are the radioactive metals U-235 and Pu-239

NUCLEAR REACTOR CORE

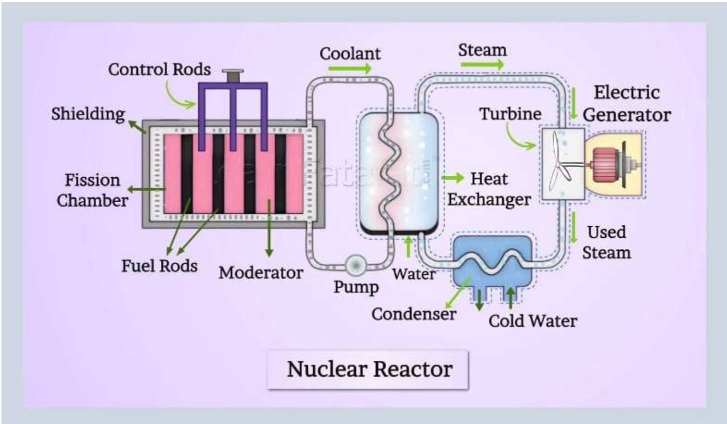
A nuclear reactor core is the portion of a nuclear reactor containing the nuclear fuel components where the nuclear reactions take place and the heat is generated.



MODERATOR

The moderator of a nuclear reactor is a substance that slows secondary neutrons produced during the fission.

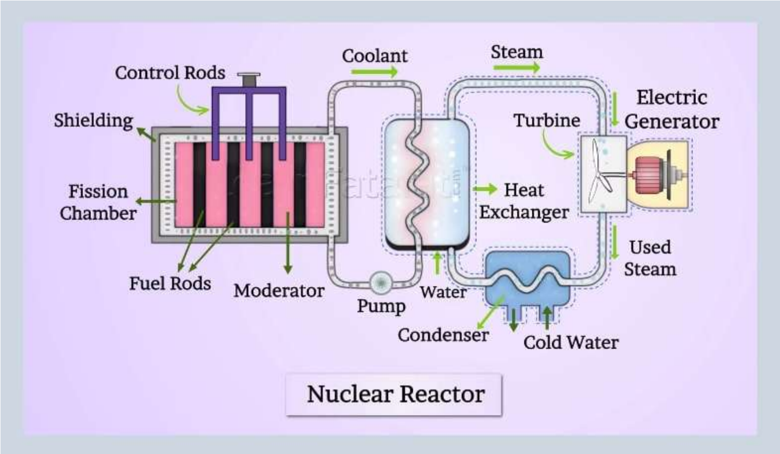
Examples: Heavy water, Graphite, paraffin, etc,.



CONTROL RODS

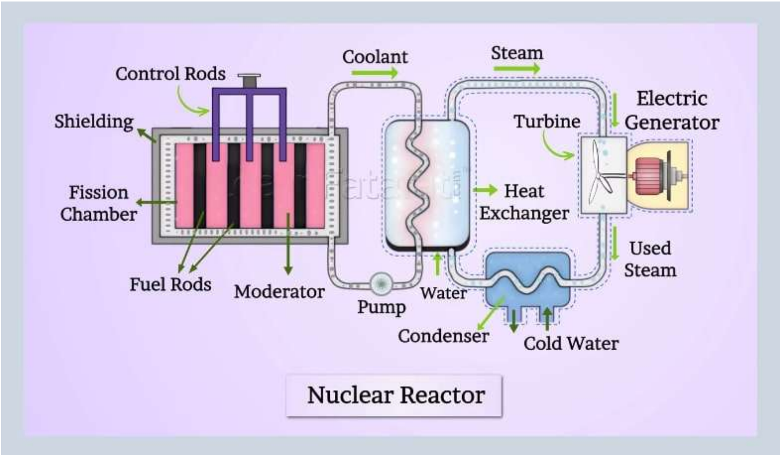
It is used in nuclear reactors to control the rate of fission reactions.

These are made up of chemical elements capable of absorbing many neutrons but should not lose their stability such as Silver, Cadmium, Indium, and Boron.



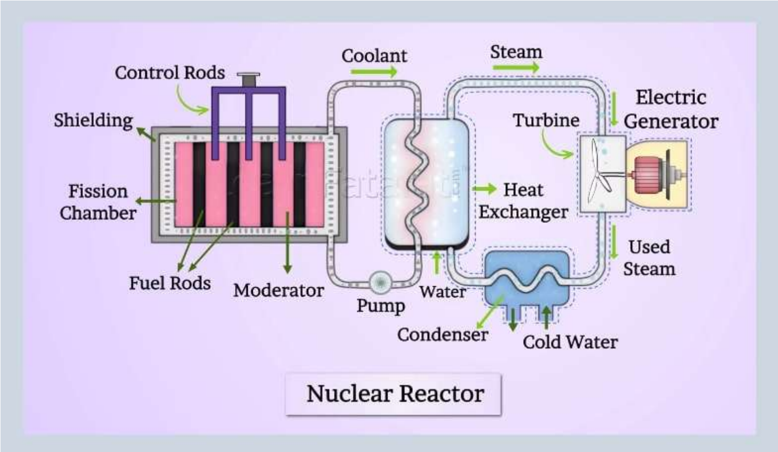
COOLANT

Coolant in a nuclear reactor is a liquid used to remove heat from the nuclear reactor core and transfer it to electrical generators and the environment



SHIELDING

It is the protective covering wall made up of concrete to protect from harmful radiation from nuclear fuel.



Carbon – Nitrogen Cycle

Carbon – Nitrogen cycle is one of the most important nuclear reactions for the production of solar energy by fusion.

$${}_1H^1 + {}_6C^{12} \rightarrow {}_7N^{13} + \gamma - \text{ray}$$

$${}_7N^{13} \rightarrow {}_6C^{13} + {}_{+1}e^0 + \upsilon\,(\text{neutrino})$$

$${}_1H^1 + {}_6C^{13} \rightarrow {}_7N^{14} + \gamma - \text{ray}$$

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

$${}_8O^{15} \rightarrow {}_7N^{15} + {}_{+1}e^0 + \upsilon$$

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

$$4\,{}_1H^1 \rightarrow {}_2He^4 + 2\,{}_{+1}e^0 + 3\gamma + 2\upsilon + 26.70\,\text{MeV}$$

The energy released during this process is 26.70 MeV.

Proton-Proton Cycle

$$_{1}H^{1} + _{1}H^{1} \rightarrow _{1}H^{2} + _{+1}e^{0} + \upsilon + 0.42 \text{ MeV}$$

$$_{1}H^{2} + _{1}H^{2} \rightarrow _{2}He^{3} + \gamma + 5.49 \text{MeV}$$

$$_{2}He^{3} + _{2}He^{3} \rightarrow _{2}He^{4} + 2\,_{1}H^{1} + \text{energy } 12.86 \text{ MeV}$$

$$4\,_{1}H^{1} \rightarrow _{2}He^{4} + 2\,_{+1}e^{0} + 2\gamma + 2\upsilon + 26.70 \text{ MeV}$$

The energy released during this process is 26.70 MeV.

THANK YOU

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