Slide- 1

* Importance of electrical energy:

i) Convenient form.

ii) Easy to control

iii) Greater flexibility.

iv) Cheapness.

v) Cleanliness

vi) Greater transmission efficiency.

* Generation of electrical energy:

The conversion of energy available in different forms in nature into electrical energy is known as generation of electrical energy.

* Sources of energy:

i) Sun

ii) Wind

iii) Water

iv) Fuel

v) Nuclear energy.

* Comparison of energy sources:

Particular	Water-power	Fuels	Nuclear Energy
i) Initial cost	High	Low	Highest.
ii) Running cost	Low	High	Lowest.
iii) Reserves	Permanent	Exhaustible	Inexhaustible.
iv) Cleanliness	Cleanest	Dirtiest	Clean
v) Simplicity	Simple	Complex	Most complex.
vi) Reliability	Most reliable	Less reliable	More reliable

*** Nuclear power station:** The generating station which converts nuclear energy into electrical energy is known as nuclear power station.

*** Necessity:** Conventional thermal power stations use oil or coal as the source of energy. But this sources are becoming depleted in many countries and thus there is a tendency to seek alternative sources of energy.

* **Advantages:**

i) It reduces the demand for coal, oil and gas cost of which are tending to increase as the stocks are becoming depleted.

ii) The transportation facility is a great factor for conventional fuel stations. It requires huge cost and time delay. In comparison the weight required for same energy production by nuclear fuel is negligible. So, transport problems are not there.

iii) Nuclear power plant produces power as well as some very important fissile material.

iv) It requires very small area in comparison to conventional fuel power stations.

v) It is partially independent of geographical position. It only requires enough supply of water.

vi) The source of energy is clean if waste are removed safely.

vii) Large quantity of power is generated with the consumption of a small amount of fuel.

* Disadvantages :

i) Capital cost of a nuclear power plant is very high.

ii) Erection and comissioning of power plant requires greater technical knowledge.

iii) The by-products are highly radioactive and can cause pollution.

iv) Maintenance charge is very high. ~~So~~ Highly paid personnel work here.

v) It is not suitable for variable load condition as it is not easy to control power generation according to load instantaneously.

vi) Disposal of radioactive waste is also a big problem. We need to dispose them into a deep trench or in the sea far away from the sea shore.

* Basic principles of atomic physics necessary for nuclear reaction are:

i) Structure of atom.

ii) Binding energy of their nuclei.

iii) Exchange of mass and energy.

iv) How a chain reaction starts.

v) Emission of certain particles which produce radiati hazards.

* **Atom:** All matters are composed of unit particles called atom. They consist of a heavy, positively charged nucleus and a number of much lighter negatively charged electrons orbiting around the nucleus.

Nucleus → Proton + Neutrons (Nucleons).

Atomic number → no. of proton.

Atomic mass → no. of nucleons.

* 1 amu = 1.66×10^{-27} kg

* **Isotopes:** Atoms having same proton number but different mass number are called isotopes.

$^{1}_{1}H$, $^{2}_{1}H$, $^{234}_{92}U$ $^{235}_{92}U$ $^{238}_{92}U$

* **Isobars:** Atoms having same mass number but different proton number are called isobars.

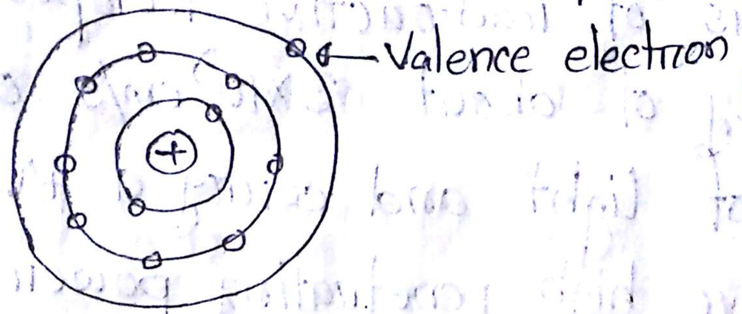
$^{40}_{18}Ar$ $^{40}_{19}K$ $^{40}_{20}Ca$, $^{235}_{92}U$ $^{235}_{93}Np$ $^{235}_{94}Pu$

* **Isotones:** Atoms having different atomic number and mass number but number of neutron is same are called isotones.

$^{15}_{7}N$ $^{16}_{8}O$

* **Positron:** Positively charged electron. $_{+1}e^{0}$, e^{+}, β^{+}.
* **Neutrino:** These are electrically neutral particles. Ejected along with β decay during nuclear fission.

* **Valence electron:** Electrons that orbit in the outermost shell of an atom are called valence electrons which decide the atom's chemical property.



* **Radioactive Decay:** Some of the isotopes of some ~~atoms~~ elements are inherently unstable and disintigrate sponteneously. This phenomenon is called radioactive decay.

* **Parent:** The original nucleus of radioactive decay is called parent.

* **Daughter:** The converted or resulting nucleus of radioactive decay is called daughter.

$$ {}_{88}^{226}Ra \longrightarrow {}_{82}^{226}Pb $$

$$ {}_{49}^{115}In \longrightarrow {}_{50}^{115}Sn + {}_{-1}^{0}e $$

* **Alpha (α) particles:** Alpha particles or Helium-4 nuclei ~~are~~ ($_2He^4$) are emitted from the nucleus of radioactive isotopes at a very high velocity of about 3×10^9 cm/s or 1/10 of the speed of light and carry a +ve charge. Do not have high penetrating power.

$$_{94}Pu^{239} \xrightarrow{\alpha\text{-decay}} {}_{92}U^{235} + {}_2He^4$$

* **Beta (β) Particles:** It is equivalent to the emission of an electron and raise the atomic number by 1 while mass number remains same at a velocity approaching to light. It's penetrating power is more than α-particles.

$$_{82}Pb^{214} \xrightarrow{\beta\text{-decay}} {}_{83}Bi^{214} + {}_{-1}e^0 + \nu$$

* **Gamma (γ) Radiation:** This is an electromagnetic radiation of extremely short wave length and very high frequency. It has the highest penetrating power.

$$[_zX^A]^* \longrightarrow {}_zX^A + \gamma$$

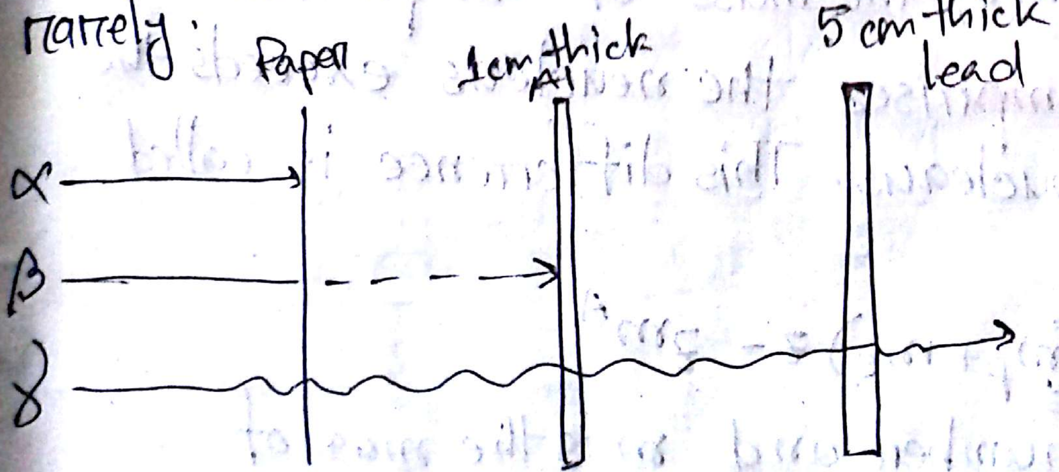
* **Positron Decay:** When a radioactive nucleus has an excess of protons then positron decay occurs. In this process atomic number is degraded one.

$$_{7}N^{13} \longrightarrow {}_{6}C^{13} + {}_{+1}e^{0}$$

* **K capture:** When a nucleus possesses an excess of protons but does not have the threshold energy of 1.024 MeV to emit a positron it captures an orbital electron from the near most or k-shell

$$_{29}Cu^{64} + {}_{-1}e^{0} \longrightarrow {}_{28}Ni^{64}$$

* **Neutron emission:** If a nucleus possesses an extremely high excitation energy it may emit a neutron. In this process daughter is an isotope of the parent. It occurs namely:



* Differences betn nuclear and chemical reaction:

Nuclear Reaction	Chemical Reaction
i) Change happens in nucleus level.	i) Change happens in atomic level.
ii) Huge energy released.	ii) Released energy is not so large.
iii) Needs special reaction chember.	iii) No need of special reaction chember.
iv) Radioactive wastes are produced.	iv) Normal nonradioactive byproducts are produced.
v) Reaction is very fast	v) Comparatively slow reaction

***Mass Defect:** Sum of the mass of the protons and neutrons that comprises the neucleus exceeds the mass of atomic nucleaus. This difference is called mass defect.

$$\Delta m = n_m m_n + (m_p + m_e) z - {}_z m^A$$

where n is the number and m is the mass of the particle.

* **Binding Energy:** The energy associated with mass defect is termed as binding energy of nucleus.

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

where E = energy in joule.

Δm = mass defect in kg.

c = velocity of light = 3×10^8 m/s

Energy associated with 1g of mass,

$\Delta E = 1\times10^{-3} \times (3\times10^8)^2 = 9\times10^{13}$ Joule

Energy associated with 1 amu mass,

$\Delta E = 1.66\times10^{-27} \times (3\times10^8)^2 = 1.494\times10^{-10}$ J.

$= \frac{1.494\times10^{-10}}{1.6\times10^{-19}} = 9.34\times10^8$ eV

$= 934$ MeV.

≈ 931 MeV

$\therefore$ 1 amu mass $\longrightarrow$ 931 MeV energy.

* **Binding energy per nucleon:**

${}_2He^4 \longrightarrow 2\,{}_0n^1 + 2\,{}_1p^1$

Now, $m_p = 1.007277$ amu. $= 1.00759$ amu

$m_n = 1.008665$ amu $= 1.00898$ amu

$m_e = 0.0005486$ amu. $= 0.00055$ amu

$\Delta m = (2m_p + 2m_n) - 4.00277$

$= 0.03037$ amu.

$\therefore \Delta E = 0.03037 \times 931$ MeV $= 28.2$ MeV

BE/nucleon $= \frac{28.2}{4} = 7.07$ MeV

For Duterium:

$${}_1H^2 \longrightarrow {}_0n^1 + {}_1p^1$$

$\therefore \Delta m = (m_p + m_n) - 2.01355$ ~~$- 0.00055$~~

$= 3.02 \times 10^{-3}$ amu.

$\therefore \Delta E = 3.02 \times 10^{-3} \times 931$ MeV

$= 2.81162$ MeV

$\therefore$ BE/nucleon $= \frac{2.81162}{2} = 1.40581$ MeV

For Uranium:

$${}_{92}U^{238} \longrightarrow 92p + 146n$$

$$\Delta m = (92 \times 1{\cdot}00759 + 146 \times 1{\cdot}00898) - 238{\cdot}0507$$
$$= 1{\cdot}958 \text{ amu}$$

$$\therefore \Delta E = 1{\cdot}958 \times 931 \text{ MeV}$$
$$= 1823{\cdot}5 \text{ MeV}$$

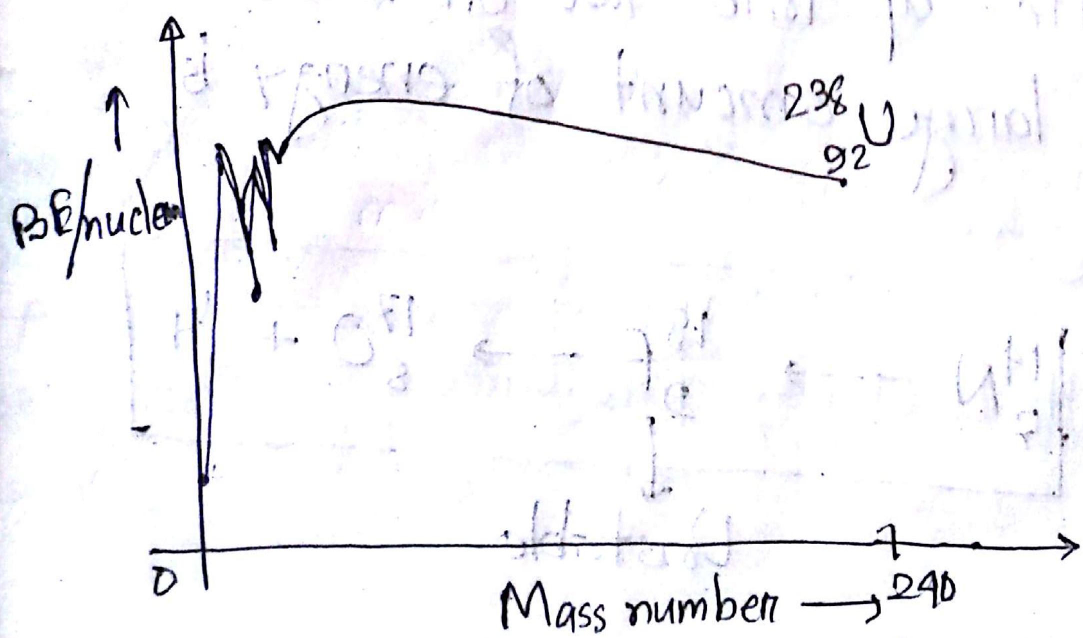
$$\therefore BE/\text{nucleon} = \frac{1823{\cdot}5}{238}$$
$$= 7{\cdot}66 \text{ MeV}$$

$${}_{92}U^{235} \longrightarrow 92p + 143n$$

$$\Delta m = (92 \times 1{\cdot}00759 + 143 \times 1{\cdot}00898) - 235{\cdot}0439$$
$$= 1{\cdot}938 \text{ amu}$$

$$\therefore \Delta E = 1{\cdot}938 \times 931$$
$$= 1804{\cdot}76 \text{ MeV}$$

$$\therefore BE/\text{nucleon} = \frac{1804{\cdot}76}{235} = 7{\cdot}68 \text{ MeV}$$



* Low mass no $\longrightarrow$ Fusion
* High mass no $\longrightarrow$ Fission
* Even-even combination of proton and neutron are more stable. So, we use ${}_{92}U^{235}$ rather than ${}_{92}U^{238}$ for nuclear reaction.

* <u>Fusion</u>: The nuclear reaction in which two different atomic nucleus combine together to form another nucleus is termed as Fusion.

$$ {}_{1}^{1}H + {}_{1}^{1}H \longrightarrow {}_{2}^{2}He \longrightarrow {}_{1}^{2}H + {}_{+1}e^{0} $$

* <u>Fission</u>: The nuclear reaction in which one nucleus is splitted up into two or more nucleus and releases a large amount of energy is called fission.

$$ {}_{2}^{4}He \longrightarrow \boxed{{}_{7}^{14}N \longrightarrow {}_{9}^{18}F \longrightarrow {}_{8}^{17}O + {}_{1}^{1}H} $$

${}_{9}^{18}F$ $\downarrow$ Unstable.

* Reasons behind nuclear stability:

i) Higher binnding energy per nucleon.

ii) Even number of neutron and proton are very stable.

iii) Neutron to proton ratio is well above unity.

* Decay Law (Rutherford and Soddy Theory):

Suppose at any time t there are N radioactive atoms.

The disintegration rate is $\frac{dN}{dt}$

$\therefore$ Rate of disintegration $\propto$ no. of atoms present

$$\Rightarrow \frac{dN}{dt} \propto N$$

$$\Rightarrow \frac{dN}{dt} = -\lambda N$$

where λ is decay constant and it is defined as the ratio of rate of disintegration to the present no of atom at any given time.

~~Now integrating wrt dt we have,~~

~~$$\int \frac{dN}{dt}$$~~

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We have,

$$\frac{dN}{dt} = -\lambda N$$

$$\Rightarrow dN = -\lambda N \, dt$$

$$\Rightarrow \int \frac{dN}{N} = \int -\lambda \, dt$$

$$\Rightarrow \ln N = -\lambda t + K$$

at $t = 0$, $N = N_0$

$$\therefore \ln N_0 = K$$

$$\therefore \ln N = -\lambda t + \ln N_0$$

$$\Rightarrow \ln N - \ln N_0 = -\lambda t$$

$$\Rightarrow \ln \frac{N}{N_0} = -\lambda t$$

$$\Rightarrow \frac{N}{N_0} = e^{-\lambda t}$$

$$\Rightarrow N = N_0 e^{-\lambda t}$$

This is called decay law.

* ~~for~~ Half life: ~~which~~ This is defined as the time required for a quantity to reduce to half it's value. In other words the time need for a radioactive material to disintegrate half of it's initial given amount is called half life.

for half life, $t = T$, $N = \frac{N_0}{2}$

Now, $N = N_0 e^{-\lambda t}$

$$\Rightarrow \frac{N}{N_0} = e^{-\lambda t}$$

$$\Rightarrow \frac{N_0}{2N_0} = e^{-\lambda T}$$

$$\Rightarrow e^{\lambda T} = 2$$

$$\Rightarrow T = \frac{0.693}{\lambda}$$

$$\therefore T \propto \frac{1}{\lambda}$$

1 curie = 3.615×10^{10} dis/s

1 bequerel (Bq) = 1 dis/s

Present amount, $N = N_0 - \frac{3}{4} N_0 = \frac{1}{4} N_0$

and $\lambda = 1.44 \times 10^{-3}$

$\therefore N = N_0 e^{-\lambda t}$

$\Rightarrow \frac{1}{4} = e^{-\lambda t}$

$\Rightarrow -\lambda t = \ln(0.25)$

$\Rightarrow t = -\frac{\ln(0.25)}{1.44 \times 10^{-3}}$

$= 962.70$ hour.

*<u>Nuclear reactions</u>: When charged particles such as protons or α-particles are accelerated they acquire enough energy to cause a nuclear reaction when they hit a target nucleus.

* <u>Bombardment particles</u>:

i) Proton

ii) α-particle or ${}_2He^4$

iii) ${}_1H^2$

iv) ${}_0^1n$

v) γ ray.

$^{15}_{7}N + ^{1}_{1}H \longrightarrow ^{12}_{6}C + ^{4}_{2}He$

* Advantages of neutrons:

i) It is charge neutral so requires less K.E.

ii) It moves long distance and very fast through matter.

* Methods of producing neutron:

i) Particle accelerators such as cyclotrons or Van De Graff generators speed up charged particles to bombard a target nucleus which produces neutron beam.

ii) α-particle: $^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ^{1}_{0}n$

iii) Special case: γ rays.

$$^{9}_{4}Be + ^{0}_{0}\gamma \longrightarrow ^{8}_{4}Be + ^{1}_{0}n$$

iv) Neutrons are used in chain fission reaction to produce high speed neutron in nuclear reactor.

$$^{235}_{92}U + \underset{\text{Low speed}}{^{1}_{0}n} \longrightarrow ^{137}_{56}Ba + ^{97}_{36}Kr + 2\underset{\text{High speed}}{^{1}_{0}n} + \gamma \longrightarrow \text{Fission Product}$$

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* <u>Fertile material</u>: The material which can be transformed into fissile material and can't sustain chain reaction are known as fertile material. Example :- U-238, Th-232.

* <u>Fissile material</u>: When fertile material is hit by neutrons and absorbs some of them it is converted to fissile material.

(I) $^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U + \gamma$

$^{239}_{92}U \xrightarrow{\beta\text{-decay}} ^{239}_{93}Np$

$^{239}_{93}Np \xrightarrow{\beta\text{-decay}} ^{239}_{94}Pu$

(II) $^{232}_{90}Th + ^{1}_{0}n \longrightarrow ^{233}_{90}Th + \gamma$

$^{233}_{90}Th \xrightarrow{\beta\text{-decay}} ^{233}_{91}Pa$

$^{233}_{91}Pa \xrightarrow{\beta\text{-decay}} ^{233}_{92}U$

* Energy from fission and fuel burnup:

$${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{137}_{56}Ba + {}^{97}_{36}Kr + 2\,{}^{1}_{0}n$$

By mass balancing,

$$235.0439 + 1.00898 \longrightarrow 138.9061 + 96.9212 + 2\times 1.00898$$

$$\Rightarrow 236.0526 \longrightarrow 235.8446$$

$$\therefore \Delta m = 235.8446 - 236.0526$$

$$= -0.2080 \text{ amu}$$

$$\therefore \Delta E = (-0.2080)\times 931 = -193.6 \text{ MeV} \approx 200 \text{ MeV}.$$

∴ The complete fission of 1g of U-235 produces

$$\text{energy}, = \frac{\text{Avogadro constant}}{\text{Mass of U-235}} \times 200 \text{ MeV}$$

$$= \frac{6.023\times 10^{23}}{235.0439} \times 200 \times 1.6\times 10^{-19} \text{ J}.$$

$$= 8.2\times 10^{10} \text{ J}$$

$$= \frac{8.2\times 10^{10}}{24\times 3600}$$

$$= 0.949 \text{ MW-day} \approx 1 \text{ MW-day}$$

Neutron energy,

$E_n = \frac{1}{2} m_n v^2$

$= \frac{1}{2} \times 1.67 \times 10^{-27} \times v^2$ J

$= 5.23 \times 10^{-13} v^2$ eV

(v → cm/s)

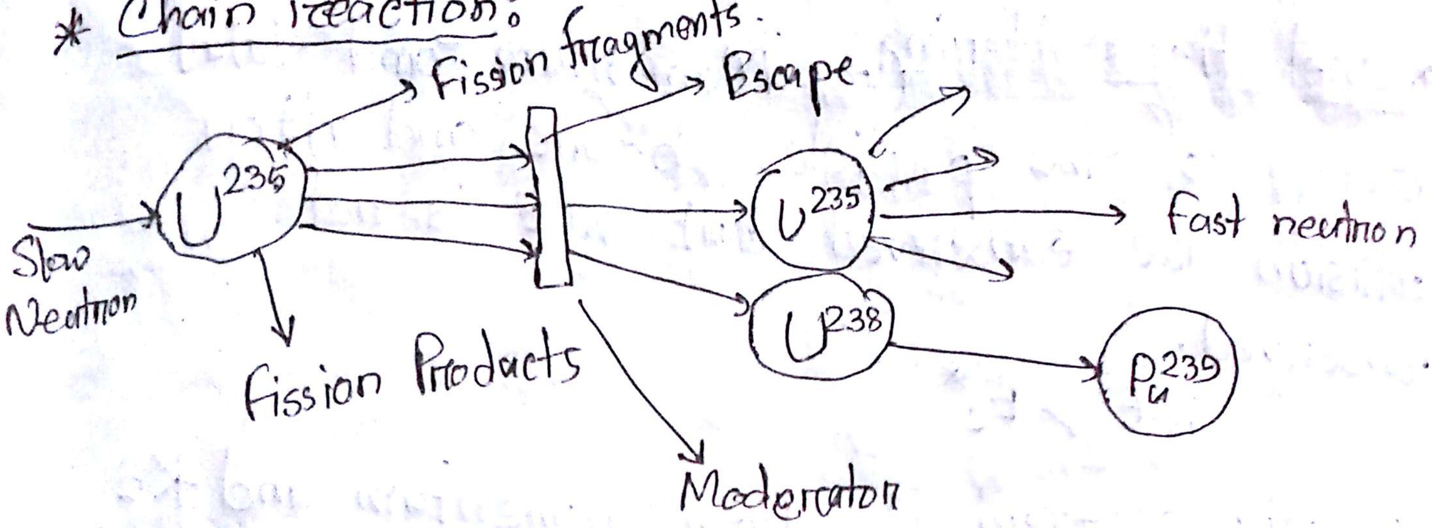
1 W-hr = 3600 J

* Classification	Neutron energy (eV)	Corresponding velocity (m/s)
Fast	$>10^5$	$>4.4 \times 10^6$
Moderate	$1 \sim 10^5$	$(1.38 \sim 4.4) \times 10^6$
Slow	<1	$<1.38 \times 10^4$

* **Moderator:** Some substances help in reducing the speed of neutrons and make them loose their energy by collision.

i) Light water
ii) Heavy water.
iii) Carbon
iv) Beryllium.

* **Chain reaction:**



* **Scattering:** As neutrons travel through matter they collide with other nuclei and get slowed down.

* Two reasons : i) Absorption
  ii) Leakage.

* **Critical size:** The minimum size of core for which chain reaction is possible is called critical size.

* **Critical mass:** The mass of fuel of critical sized core.

* **Neutron scattering:** In scattering process the energy balance of colliding particles before and after collission gives,

$$(E_n + kE_c)_1 = (E_n + kE_c + E_c^*)_2$$

E_c^* → Excitation energy.

* **Inelastic scattering:** Momentum and ~~total~~ energy of the particles before and after collision are conserved but K.E. is not conserved.

$$K.E. > E_c^*$$

* **Elastic scattering:** Both momentum and KE are conserved.

$$(E_n + kE_c)_1 = (E_n + kE_c)_2$$

The amount of energy lost depends on,

i) mass of the nucleus.
ii) angle of scatter

Let, $E_{n,i} \rightarrow$ initial KE of neutron.
$E_{n,min} \rightarrow$ KE after a head on collision.

$$E_{n,min} = E_{n,i}\left(\frac{M - m_n}{M + m_n}\right)^2$$

$$\Rightarrow \frac{E_{n,min}}{E_{n,i}} = \left(\frac{A-1}{A+1}\right)^2$$

where A is the mass number.

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* The average neutron energy lost per elastic collision is expressed in terms of a quantity called the logarithmic energy decrement, ξ

$$\xi = \ln E_{n,i} - \ln E_{n,av}$$

$$= \ln \frac{E_{n,i}}{E_{n,av}}$$

$$= 1 - \left[\frac{(A-1)^2}{2A} \ln \frac{A+1}{A-1} \right]$$

when, $A = 1$, $\xi = 1$

$$\text{No of collision, } n = \frac{\ln \frac{E_{n,i}}{E_{n,f}}}{\xi}$$

where, $E_{n,f}$ is the final KE.

* <u>Thermal neutrons</u>: When a large number of neutrons are slowed down in a medium such as a moderator the lowest energy that they can attain are those that put them in ~~equ~~ thermal equilibrium with the molecules of that medium. In this state they become thermalized and are called thermal electrons.

Thermal vector, $V_m = \left[\frac{2kT}{m_n}\right]^{1/2}$

where, K = Boltzman constant = 1.38×10^{-23} j/molecule-K

$V_n = 128.4 T^{1/2}$

$kE_m = \frac{1}{2} m_n V_m^2$

$= 8.613 \times 10^{-5}$ TeV

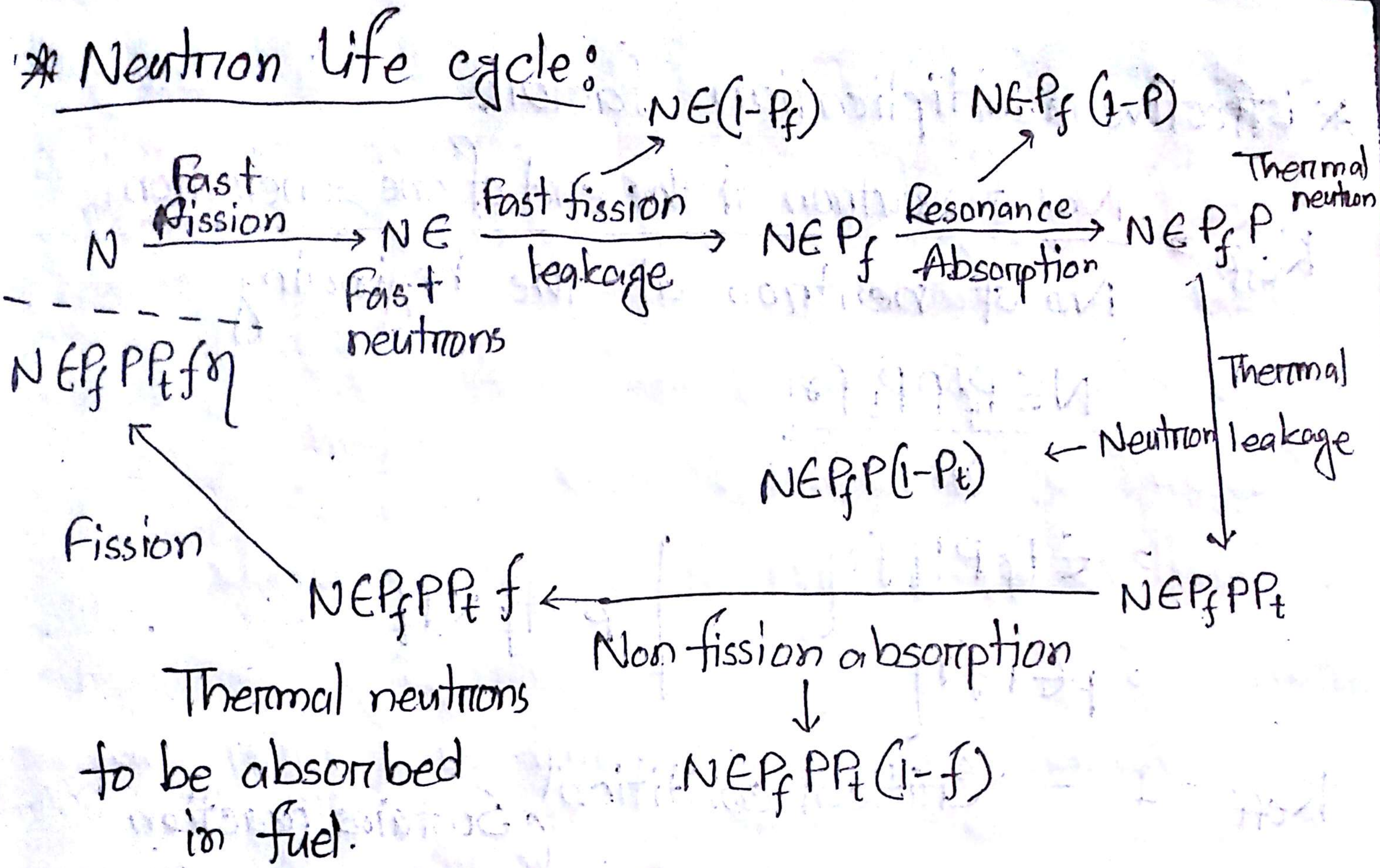
m_n = mass of neutron

T = absolute temp.

* <u>Epithermal neutrons</u>: The neutrons which possess energies greater than thermal neutrons are called epithermal neutrons.

* <u>Thermal Reactor</u>:

* Neutron life cycle:



* **Life cycle:** It is a process from birth until a new generation is born.

P_f → Fast neutron non-leakage probability.

$(1-P_f)$ → " " leakage "

P → Resonance escape "

$(1-P)$ → " absorption "

P_t → Thermal neutron non-leakage probability

$(1-P_t)$ → " " leakage "

f → " utilization factor.

η → " fission factor.

* Effective multiplication factor,

$$K_{eff} = \frac{\text{No of neutron at the end of one generation}}{\text{No of neutron at the beginning}}$$

$$= \frac{N \epsilon P_f P P_t f \eta}{N}$$

$$= \epsilon P_f P P_t f \eta \quad \Big| \quad p = P_f \times P_t$$

$$= p \epsilon P f \eta$$

$K_{eff} = 1 \longrightarrow$ Critical condition } Sustains reaction
$K_{eff} > 1 \longrightarrow$ Super " "
$K_{eff} < 1 \longrightarrow$ Sub " " } Doesn't sustain

* Selection of moderator:

i) Cost.

ii) Chemical and structural consideration.

Why Gas is not used as moderator?

Ans: For being moderator a material should have very high neutron density. But in case of gases density of neutron is not large enough to ~~ses~~ suit chain reaction. That's why gas is not used as moderator.

* Properties of moderator:

i) It should have high thermal conductivity.

ii) It should be available in large quantities in pure form.

iii) It should have high melting point for solid moderators and low melting point for liquid moderators.

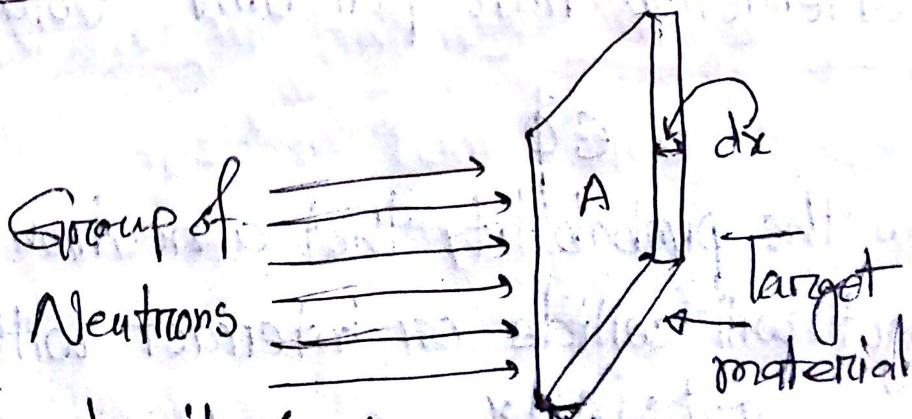
iv) It should be stable under heat and radiation.

v) It should provide resistance against corrosion.

vi) It should be able to slow down~~ne~~ neutrons.

* Nuclear cross-section:

Neutron flux,



$\phi = nv$

where,

n = neutron volume density (neutrons/cm3)

v = velocity of group of neutron (cm/s)

In the figure,

A = area of target material

dx = thickness

N = Nuclei density.

∴ Volume of material = Adx

and Total no. of nuclei of material = $NAdx$

Now,

Interaction rate ∝ Neutron flux and no of nuclei in material

$\propto \phi NAdx$

$= \sigma \phi NAdx$

$= \epsilon \phi Adx$

where,

σ = Microscopic cross-section

ϵ = Macroscopic cross-section.

∴ Interaction rate per unit volume,

$= \epsilon \phi$

Now the probability that a neutron will enter the target will collide or interact within a distance dx,

$= \frac{\sigma \phi NAdx}{\phi A} = \sigma Ndx = \epsilon dx$

$= \epsilon$ (when $dx = 1$)

Now, Collision rate = neutron flux (in-out) × A

$\Rightarrow \sigma \phi N A dx = - A d\phi$

$\Rightarrow \frac{d\phi}{\phi} = - \sigma N dx = - \epsilon dx$

Integrating we have,

$$\int_{\phi_0}^{\phi} \frac{d\phi}{\phi} = \int_0^x -\epsilon dx$$

$\Rightarrow \ln \phi - \ln \phi_0 = - \epsilon x$

$\Rightarrow \frac{\phi}{\phi_0} = e^{-\epsilon x}$

$\Rightarrow \boxed{\phi = \phi_0 e^{-\epsilon x}}$ This is the survival equation.

where, ϕ_0 is the incident neutron flux at $x=0$.

* <u>Mean free path</u>: The average distance that a neutron travels without making a collision or interaction with a target nucleus.

$$\lambda = \frac{\int_0^\infty x \, d\phi(x)}{\phi_0} \qquad \phi(x) = \phi_0 e^{-\epsilon x}$$

$$= \frac{\int_0^\infty x(-\epsilon \phi_0 e^{-x}) dx}{\phi_0} = \frac{1}{\epsilon} \qquad \frac{d\phi(x)}{dx} = -\epsilon \phi_0 e^{-\epsilon x}$$

* Variation of neutron cross-section with neutron energy:

In most cross-sections, scattering cross-section σ_s is very small compared with absorption cross-section σ_a. So total cross-section σ_t is,

$$\sigma_t \cong \sigma_a$$

$$\sigma_a = \sigma_f + \sigma_c \quad \text{and} \quad \sigma_s = \sigma_t - \sigma_a$$

σ_s doesn't vary with neutron energy. E_n so much. The variation of σ_a with E_n can be divided into three regions.

i) $1/v$ ii) Resonance iii) fast neutron.

i) $1/v$ region: In this region σ_a is inversely proportional to the square root of E_n

$$\sigma_a \propto \sqrt{\frac{1}{E_n}}$$

$$\Rightarrow \sigma_a = C_1 \sqrt{\frac{1}{E_n}}$$

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$$\Rightarrow \sigma_a = C_1 \sqrt{\frac{1}{\frac{m_n v^2}{2}}} = C_2 \frac{1}{v}$$

where, C_1 and C_2 are constants, m_n is mass of neutron and v is velocity of neutron.

ii) <u>Resonance region</u>: Most neutron absorbers after $1/v$ region show one or more σ_a peaks at definite E_n values. These are called resonant peaks.

iii) <u>Fast neutron region</u>: As neutron energies increase beyond the resonance region, the absorption cross-section gradually decrease. At very high value of E_n,

$$\sigma_t = \sigma_a + \sigma_s$$

$$= 2\pi r_c^2$$

$$= 2\pi (1.4\times10^{-13}) A^{2/3} \text{ cm}^2$$

$$= 0.125 A^{2/3} \text{ barns.}$$

* Power of a nuclear reactor:

Let, V = volume of energy

N = Fuel atoms/cm^3

n = average neutron density

v = Speed of neutron

ϕ = neutron flux

a = fission cross section.

we have, $\phi = nv$

$S = NV$

$h = S\phi = nvNV$

x = no of ~~ato~~ neutrons causing fission per second

$= ha$

$= nvNVa$

We know, 3.1×10^{10} fission per second produce 1 watt.

So, x fission per second produce $= \frac{x}{3.1 \times 10^{10}}$ watts

$= \frac{nvNVa}{3.1 \times 10^{10}}$ watts

Mass per atom of U^{235} $= \frac{235}{6023 \times 10^{26}}$ kg

$\therefore$ Mass of NV atoms $= \frac{235 NV}{6023 \times 10^{26}}$ kg $= M$ kg (say)

$\therefore NV = \frac{6.023 \times 10^{26} M}{235}$

Now, power, $P = \frac{n v N V a}{3.1 \times 10^{10}}$ watts

$= \frac{\phi \times 6.023 \times 10^{26} \times M \times 582 \times 10^{-28}}{3.1 \times 10^{10}}$

$= 4.8 \times 10^{-12} M \phi$ watts.

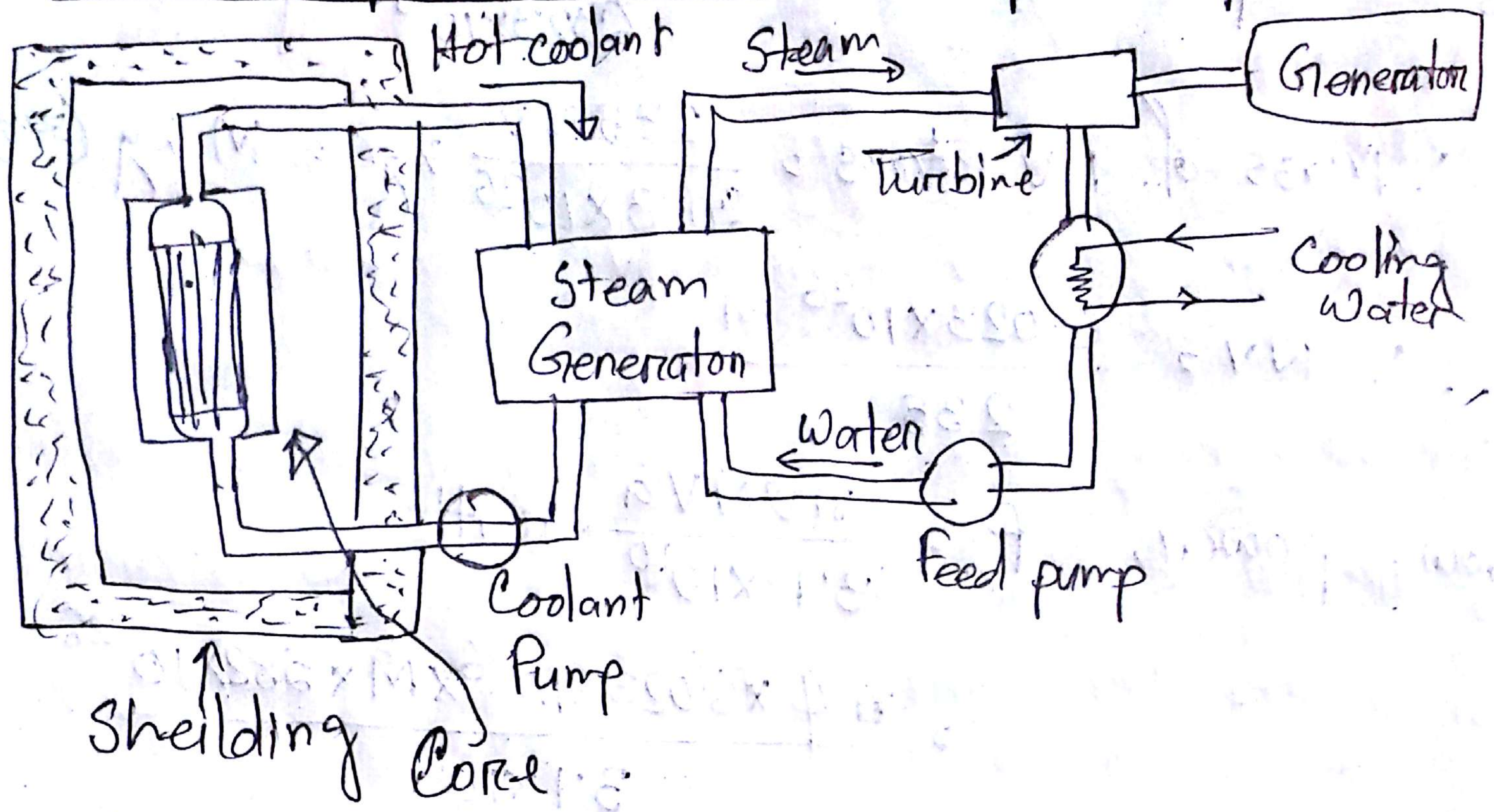
* Moderating power and moderating ratio:

Logarithmic energy decrement factor ξ, probability of scattering and absorption σ_s, σ_a and no. of neuclei of moderator per unit volume N are grouped together in two parameters called moderating power and moderating ratio.

Power $= \xi N \sigma_s = \xi \Sigma_s$

Ratio $= \xi \frac{\sigma_s}{\sigma_a} = \xi \frac{\Sigma_s}{\Sigma_a}$

* Main components of nuclear power plant:



i) Nuclear reactor
ii) Heat exchanger
iii) Turbine
iv) Electric generator
v) Condenser.

Operation

→ The reactor of nuclear power plant is similar to the furnace of steam power plant.

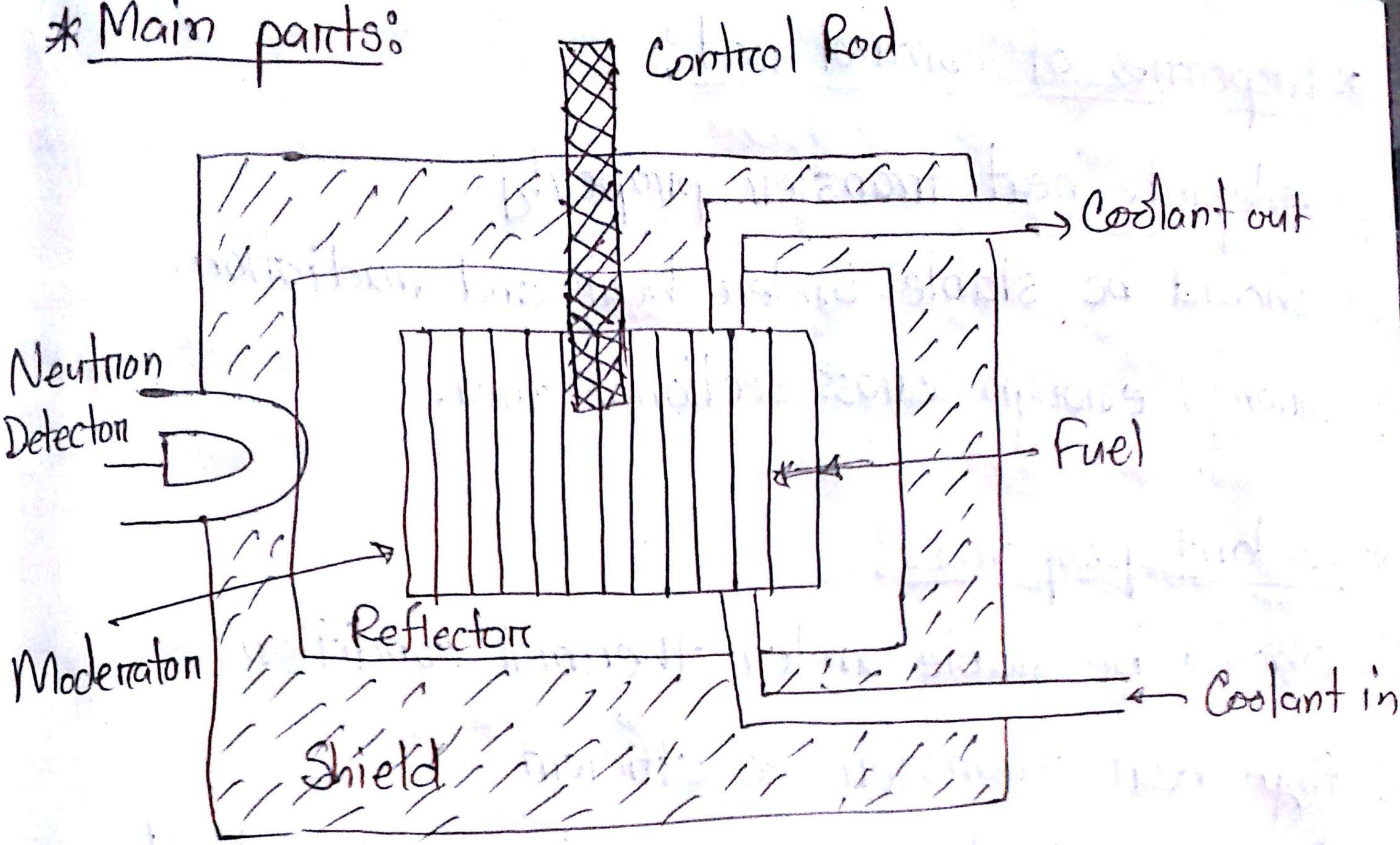
→ The heat liberation in the reactor due to nuclear fission of fuel is taken up by the coolant circulating through reactor core.

→ Hot coolant leaves the reactor at top and passes through the tubes of steam gen. and pass on it's heat to feed water.

→ The steam produced is passed through the turbine and after work has been done by the expansion of steam in the turbine steam leaves the turbine and flows to the condenser.

* **Nuclear reactor:** An apparatus in which heat is produced due to nuclear fission chain reaction.

* Main parts:



i) Reactor core: Contains fuel rods
ii) Reflector: Bounce back ~~ec~~ escaping neutrons into core.
iii) Control rod: Absorbs neutrons.
iv) Moderator:
v) Shielding
vi) Cooling system: CO_2, H_2, Air, Water, He, Na, Na-K mixture.

* Properties of control rod:

i) Adequate heat transfer property.

ii) Should be stable under heat and radiation.

iii) Strong, enough cross-sectional area.

* Coolant properties:

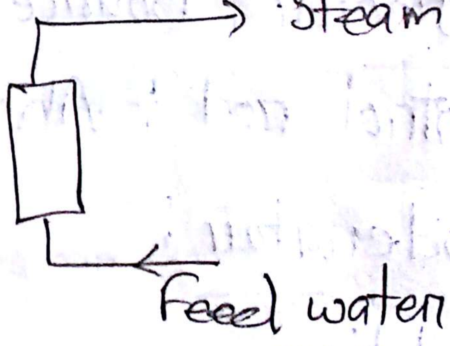
i) Should be stable under thermal condition.

ii) High heat transfer co-efficient.

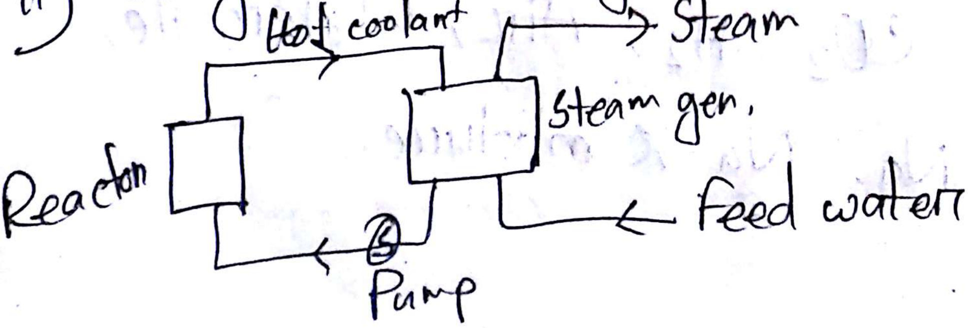
iii) Power required to pump coolant must be very low.

* Coolant cycles:

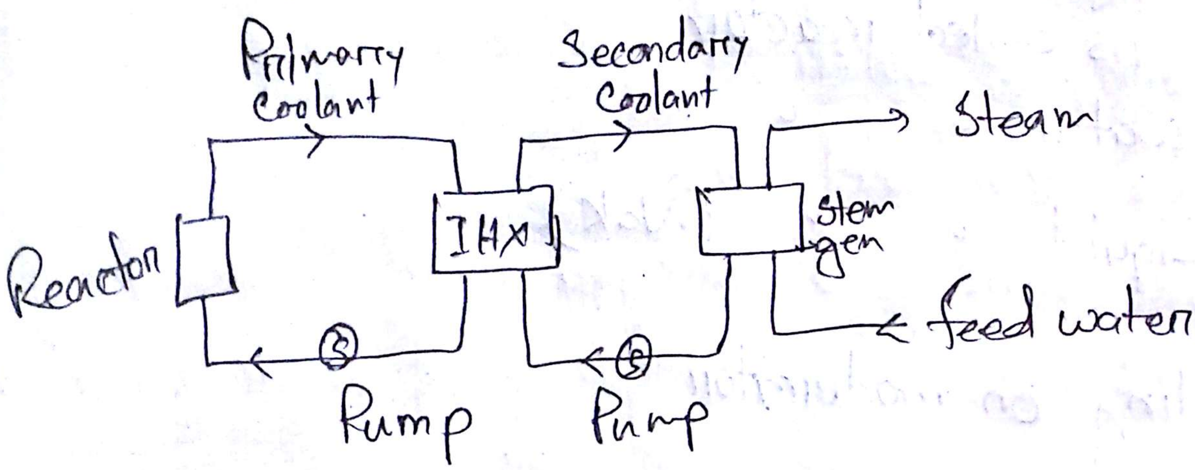
i) Direct cycle



ii) Single circuit system.



iii) Double circuit system:



* Conservation ratio:

$$X = \frac{\text{Secondary fuel}}{\text{Primary fuel}}$$

$X > 1 \longrightarrow$ Breeder Reactor

$X \leq 1 \longrightarrow$ Converter Reactor.

* Classification of reactor:

i) Depending on energy of neutrons
   a) Fast reactors
   b) Thermal "
   c) Intermediate "

ii) Depending on fuel
   a) Direct U-235
   b) Indirect Th-232 $\longrightarrow$ U-233 ; U-238 $\longrightarrow$ Pu-239

iii) Depending on coolant

a) Gas cooled reactor

b) Water " "

c) Liquid " " (NaK)

iv) Depending on moderator

a) Graphite reactors.

b) Beryllium "

c) Water "

v) Depending on core

a) Homogeneous reactor (Fuel and moderator are mixed)

b) Heterogeneous " (Moderator is inserted in fuel)

* Factors affecting design of nuclear reactor:

i) Type of reactor

ii) Type of fuel used

iii) Power rating of reactor in MW.

iv) Coolant system.
v) Controlling system
vi) Rate of neutron production and absorption.
vii) Safety of reactor.

* Reactors:

i) Boiling water reactor
ii) Pressurized " "
iii) ~~Graphite~~ Sodium Graphite reactor
iv) Fast breeder reactor.

* Waste disposal:

i) Liquid → ~~Dilution~~ Dilution
→ Concentration into small volumes and storage.
ii) Gaseous
iii) Solid

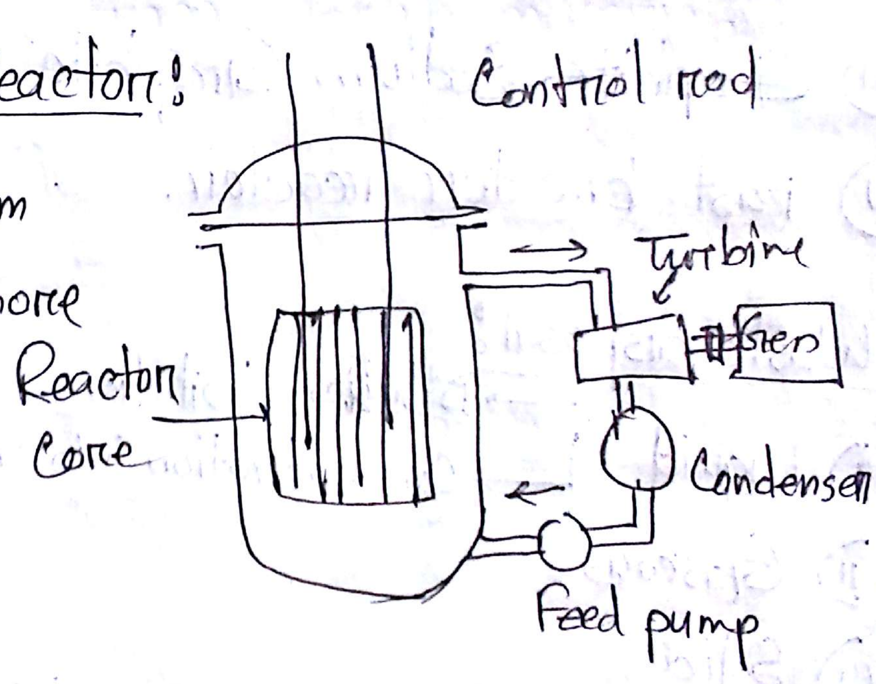
* Comparison of nuclear power plant and steam power plant:

i) Labour   ii) Capital cost   iii) Cost of generation.

* Site selection:

i) Availibility of water
ii) Distance from load centre
iii) Distance from populated area
iv) Waste disposal
v) Accessibility to site.
vi) Safeguard against earthquake.

* Boiling water reactor:



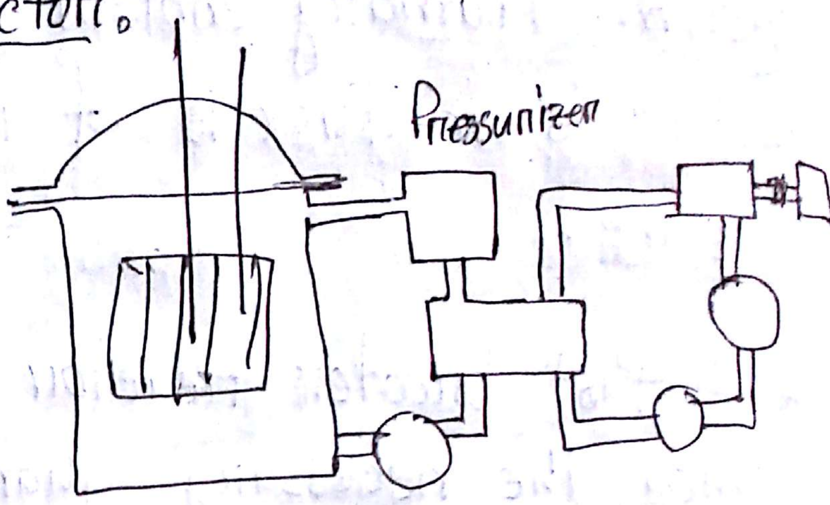
Fuel: enriched uranium U^{235}. It contains more fissionable U^{235} than naturally available.

Coolant: Water

Moderator: Water.

Coolant cycle: Direct

* Pressurized water reactor:



Fuel: Enriched U^{235}

Coolant: Water

Moderator; Water.

Coolant cycle: Singl circuit

* Sodium Graphite Reactor:

Fuel: Enriched U^{235}

Coolant: Primary ⟶ Liquid Na
Secondary ⟶ Mixture of Na-K

Moderator: Graphite.

Coolant cycle: Double circuit

* Fast breeder reactor:

In this reactor the core containing U^{235} is covered with U^{238} blanket which is a fertile material. No moderator is used. The neutrons are aborbed by U^{238} to convert into fissionable Pu^{239} which sustains chain reaction. Coolant cycle is double circuit system. Primary coolant is liquid Na. Secondary coolant is mixture of Na-K. Working principle is same.

* A fast breeder reactor is a small vessel in which the necessary quantity of enriched U or Pu is kept without a moderator.

* <u>Breeding</u>: It is the process of producing fissionable material from fertile material.

Steam Power Plant

* **Steam power station:** A generating station which converts heat energy of coal combustion into electrical energy is known as a steam power station.

* **Advantages:**

i) Fuel used is quite cheap.
ii) Initial cost is less than other generating station.
iii) It can be installed at any place irrespective of the existance of coal. Coal can be transported to the plant by rail or road.
iv) It requires less area than hydroelectric power stations.
v) It has a less generating cost than diesel power station.

* **Disadvantages:**

i) It pollutes the atmosphere due to production of large amount of smoke and fume.
ii) It's running cost is higher than hydro-electric power station.

* Site selection:

i) Supply of water.
ii) Distance from load centre.
iii) Distance from populated area.
iv) Supply of fuel.
v) Transportation facilities.
vi) Cost and type of land.

*** Thermal efficiency:** The ratio of heat equivalent of mechanical energy transmitted to the turbine shaft to the heat of coal combustion is known as thermal efficiency.

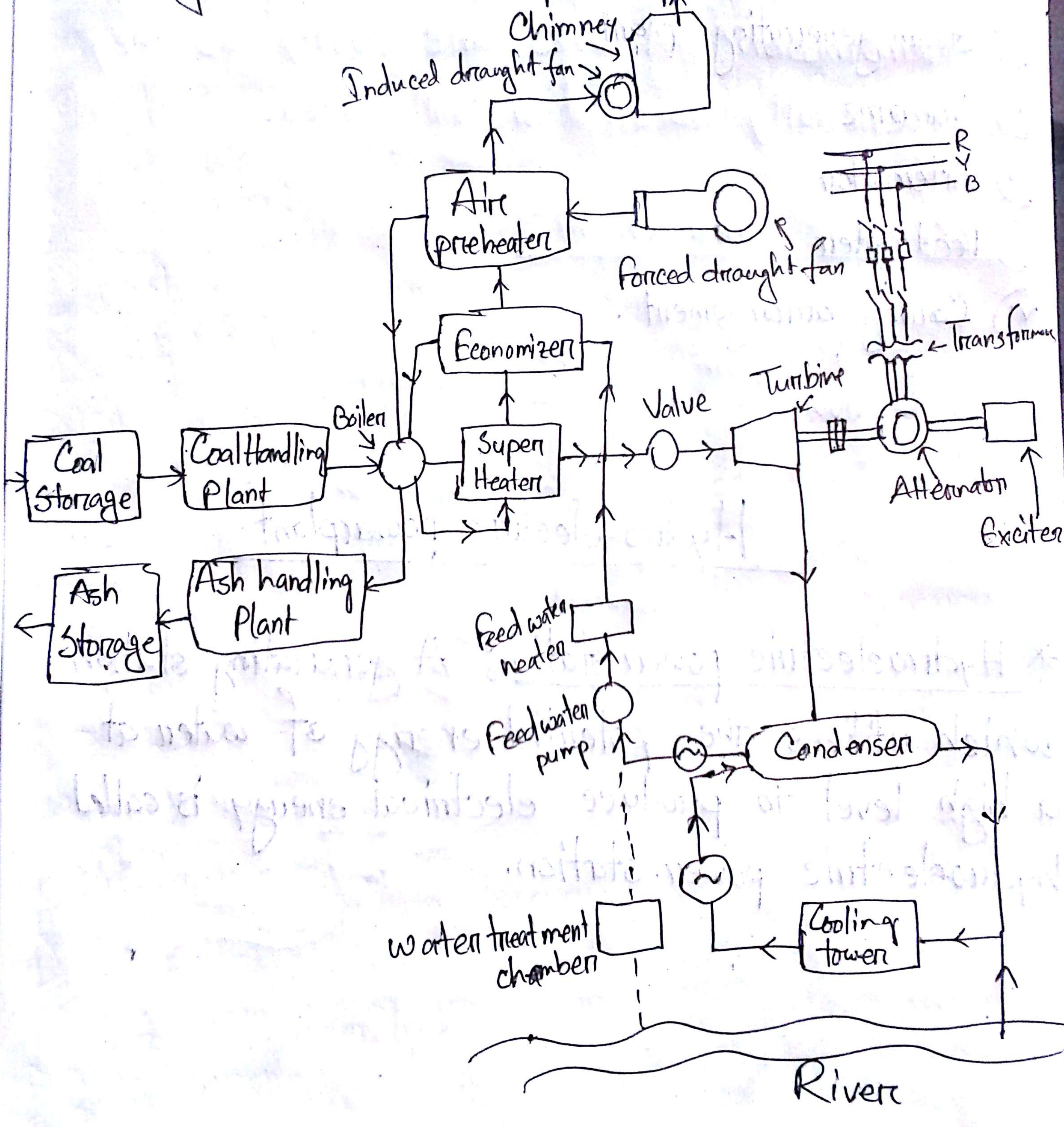
$$\eta_{thermal} = \frac{\text{Heat equivalent of mech. energy transmitted to turbine shaft}}{\text{Heat of coal combustion}}$$

*** Overall efficiency:** The ratio of heat equivalent of electrical output to the heat of coal combustion is known as overall efficiency.

$$\eta_{overall} = \frac{\text{Heat equivalent of electrical output}}{\text{Heat of coal combustion}}$$

Overall efficiency = Thermal efficiency × Electrical efficiency

* Arrangement for Steam power plant:



* Generating stages:
i) Coal and ash handling plant
ii) Steam generating plant
iii) Turbine
iv) Alternator
v) Feed water
vi) Cooling arrangement.

Hydro-electric powerplant

* Hydroelectric power station: A generating station which utilizes the potential energy of water at a high level to produce electrical energy is called hydroelectric power station.

* Advantages:

i) It requires no fuel as water is used as fuel.

ii) It is neat and clean as no smoke or ash is produced

iii) It's running cost is very low as water is free.

iv) It's construction is simple and requires low maintenance

v) It is robust and has longer life.

vi) It doesn't require long starting time.

vii) It serves several purposes besides generating electricity such as controlling of flood, irrigation.

viii) Although it requires skilled person during installation but a few experienced person can do it's operation very well.

* Disadvantages:

i) It requires a very high initial cost to build water dam.

ii) There is uncertainity of availibility of huge amount of water due to weather condition.

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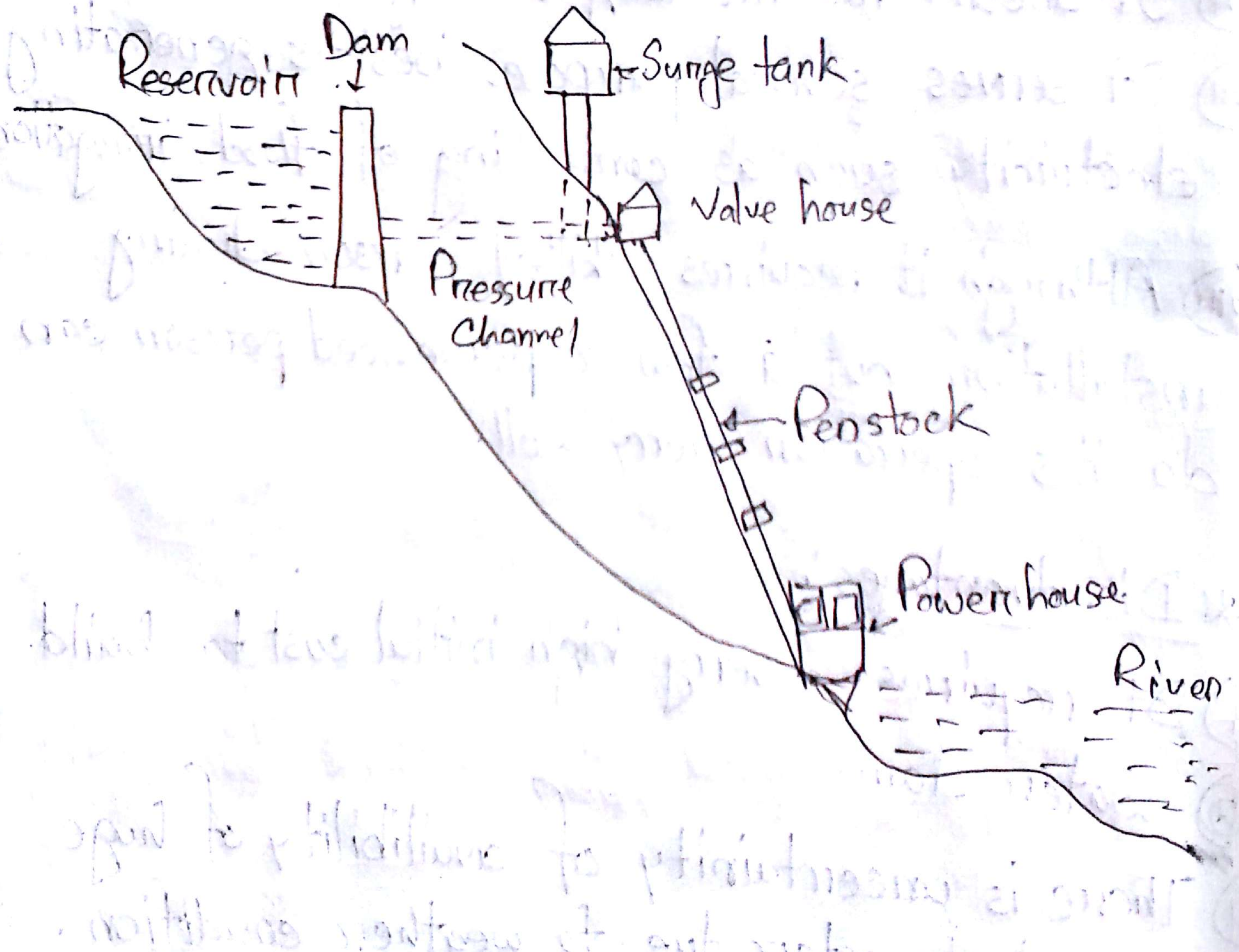
iii) It requirees highly skilled and experienced hands to build the plant.

iv) Transmission ~~ligl~~ lines are costly as they are generally located in hilly areas.

* <u>Schematic arrangement:</u>



* Site selection:

i) Availibility of water

ii) Storage of water

iii) Transportation facilities

iv) Cost and type of land.

Non-conventional Sources of Energy

* Non-renewable/ Conventional fuels:

i) Crude oil
ii) Fossil fuel.
iii) Natural gas.

* Limitation:

i) Resource is limited.
ii) Not clean source of fuel.

* Non-conventional sources of energy:

i) Solar energy
ii) Wind energy
iii) Tidal power.
iv) Fuel cell.
v) Thermo-electric generation
vi) Thermionic converter.
vii) Geothermal energy.
viii) Biomass
ix) Maneto-Hydro-Dynamic plant.

* **Advantages:**

i) They are widely available.
ii) They are non-polluting.
iii) Very suitable for decentralized use.

Solar Energy

* **Advantages:**

i) It is free.
ii) It is inexhaustible.
iii) It is non-polluting.
iv) It is devoid of political control.

* **Direct radiation:** Solar radiation that has not been scattered or absorbed and reaches the ground directly from the sun is called direct radiation.

* **Diffuse radiation:** The radiations received after scattering is called diffuse scattering. Diffuse radiation comes to the earth from all parts of the sky.

*Applications:

i) Water pumping for irrigation and drinking water supply.
ii) Community and street lighting.
iii) Microwave repeater station power supply.
iv) Communication equipment, radio and television receivers.
v) Solar water heaters.
vi) Solar refrigerators.
vii) Rail road crossing signal etc.

* Disadvantages:

i) Solar energy is effective only during day time.
ii) It is ineffective in cloudy weather or rainy season.
iii) High cost.

* A Solar cell / Photovoltaic cell: