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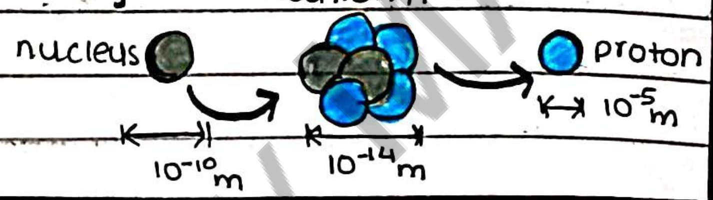
NUCLEAR PHYSICS

→ Composition of Atomic Nuclei:

"Nucleus is a bound collection of protons and neutrons which are together referred as nucleons"

Diagram:



→ Describing the nucleus:

$^{A}_{Z}X$

Symbolic representation

- Mass number(A): Number of Nucleons in the nucleus $A = Z + N$
- Atomic number(Z): Number of protons in the nucleus
- Neutron number (N): Number of neutrons in the nucleus

→ Isotopes:

"The atoms of an element having the same number of protons or the same atomic number but different number of neutrons or different atomic weights is called an isotope."

→ **Place in periodic table:** Isotopes of same element occupy the same place in the periodic table

→ **Chemical properties:** Isotopes of same element have identical chemical properties.

→ **Separation of isotopes:** Isotopes can not be separated by chemical methods but only by methods that are based on their mass differences such as mass spectrometry

→ **Isotopes of Chlorine:**

Chlorine 35	Chlorine 36	Chlorine 37	Chlorine 39
• 17 protons	• 17 protons	• 17 protons	• 17 protons
• 18 Neutrons	• 19 neutrons	• 20 neutrons	• 22 neutrons
• 17 electrons	• 17 electrons	• 17 Electrons	• 17 electrons
• Natural	• unstable trace natural	• Natural	• Most stable artifical isotope

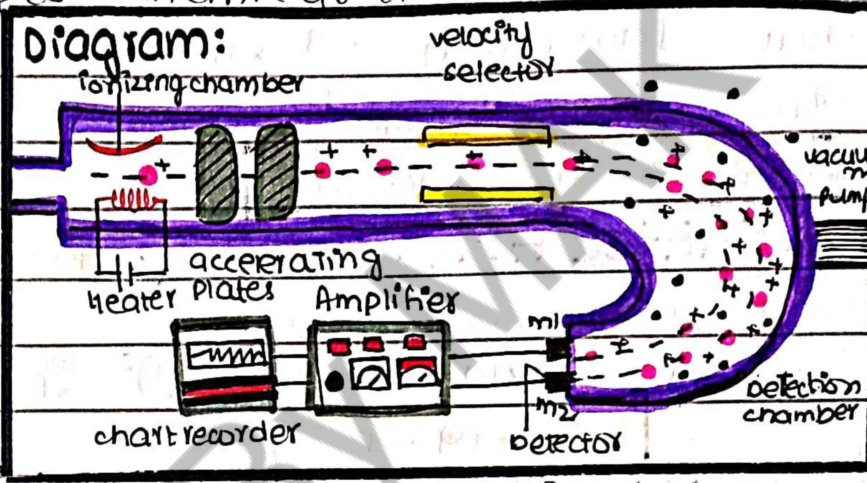
→ Mass Spectrograph:

"A device which is used to determine the mass of charged particles is called mass spectrograph."

→ Use: Used to separate isotopes of chemical element and to determine their relative abundance

→ Principle: Based upon the principle that a beam of ions moving through electric and magnetic field is deflected and this deflection depends upon the charge and mass of ions

Diagram:



→ Working: Atoms or molecules in vapour form are ionized into positive ions which are then accelerated using an electric field which imparts kinetic energy to them. After that the ions enter a magnetic field perpendicular to their direction of motion. The magnetic field causes the ions to undergo circular motion with radius depending on charge to mass ratio. Ions are thus separated on the basis of their charge to mass ratio. Separated ions are detected by a detector. The detector records the intensity of ions at different positions creating a mass spectrum that represents the abundance of ions at various mass to charge rations

→ Mass of ions ∝ Radius of circular path

→ Derivation:

Kinetic energy of ion after leaving velocity selector: $\frac{1}{2}mv^2 = qV$ or $v = \sqrt{\frac{2qV}{m}}$ ①

Centripetal force provided by magnetic field: $\frac{mv^2}{r} = qvB$ or $v = \frac{qB}{m} \times r$ ②

Comparing eq ① and ② we get $\frac{qB}{m} \times r = \sqrt{\frac{2qV}{m}}$ (Squaring Both sides)

$\frac{q^2B^2r^2}{m^2} = \frac{2qV}{m}$ $m = \frac{r^2B^2q}{2V}$ By rearranging $r = \sqrt{\frac{2Vm}{B^2q}}$

→ Nuclear Masses:

In nuclear physics we use unit 'amu' or atomic mass unit where

$$1\ amu = \frac{1}{12} \times \text{Mass of } C^{12}$$

A. Unified AMU in Kilogram:

Mass of 1 carbon atom $= \frac{12}{6.022 \times 10^{23}}$ grams

But - 1 amu (or u) $= \frac{1}{12} \times$ mass of $1C^{12}$ $= \frac{1}{12} \times \frac{12}{6.022 \times 10^{23}}$ grams

$1u = 1.6605 \times 10^{-24}$ grams

or **$1u = 1.6605 \times 10^{-27}$ kilograms**

B. Unified AMU in Joules:

According to einstein mass can be converted into energy $E = mc^2$

$\Delta E = 1.66 \times 10^{-27} \times (3.0 \times 10^8 ms^{-1})^2$, $E = 1.49 \times 10^{-10} J$

or **$1u = 1.49 \times 10^{-10} J$**

C. Unified AMU in Electron Volts:

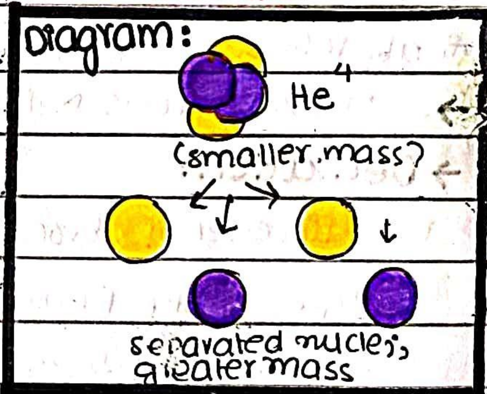
$1u = 1.4924 \times 10^{-10} J \left(\frac{1eV}{1.6022 \times 10^{-19} J}\right) = 9315 \times 10^8 eV$, **$1u = 931.5 MeV$**

→ Mass Defect & Binding Energy:

"The amount by which the mass of an atomic nucleus is less than the sum of the masses of its constituent particles is called mass deficit or mass defect." &

"The energy that holds a neucleus together is called binding energy, this amount of energy will be required to break the nucleus into separate parts. Binding energy is equal to mass defect of the nucleus."

→ **Total mass and mass of nucleons:** Total mass of a nucleus is less than the sum of masses of its individual nucleons



→ **Stability and binding energy per nucleon:** The greater the binding energy per nucleon, more stable the nucleus is

→ **Packing fraction:** Binding energy per nucleon of a nucleus is called packing fraction. Packing fraction is meausure of stability of a nucleus.

→ **Strong nuclear force:** The strong nuclear force is a very short range (2fm) attractive force that acts between all nuclear particles. The protons attract each other by means of nuclear force and at the same time, repel each other through coloumb force. The nuclear force dominates the coulomb force within the nucleus so that stable nuclei can exist.

→ **Mathematical Derivations:**

Binding Energy E_B = (Total Energy of Z protons and N neutrons) − (Total Energy of nucleus)

$E_B = ZM_pc^2 + NM_nc^2 - Mc^2$ (where ZM_p = mass of protons, NM_N = Mass of neutrons and M = Mass of nucleus) while Z, N are numbers)

$$E_B = (ZM_p + NM_n - M)c^2$$ — Binding Energy

Mass defect or mass deficit is given by

$$\Delta m = ZM_p + NM_n - M$$ — Mass deficit

(If A = N+Z is mass number then packing fraction 'f' is)

$$f = \frac{E_B}{A} = \frac{(ZM_p + NM_n - M)c^2}{A}$$; $\frac{E_B}{A} \propto$ stability of nucleus

(i) Intermediate Nuclei:

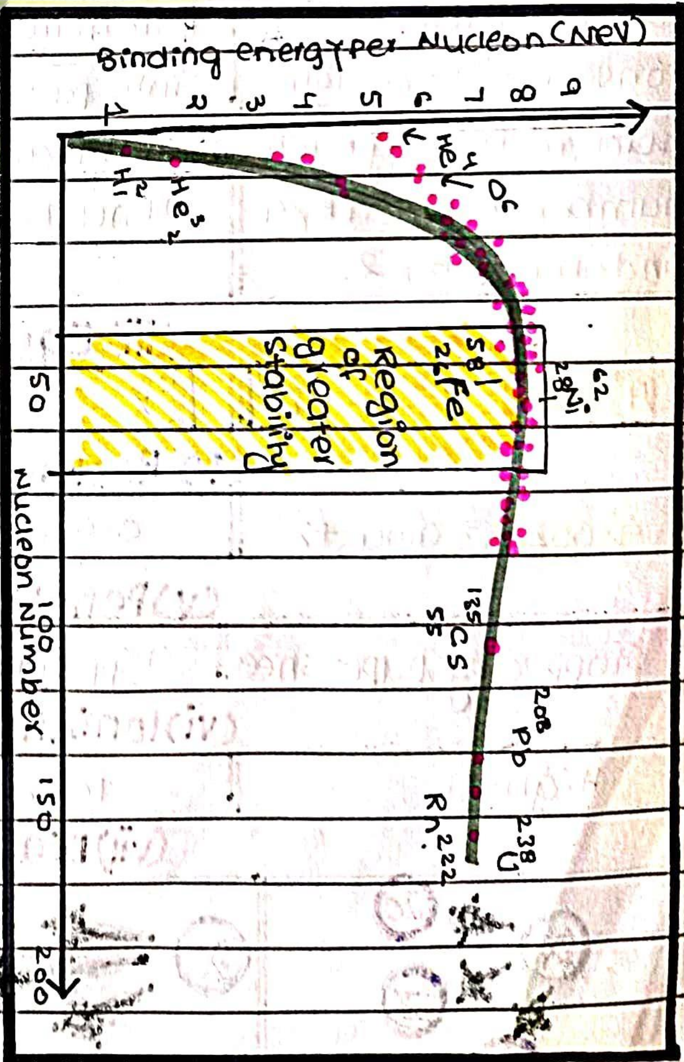
Most stable nuclei having binding energy per nucleon = 8.7 MeV. $^{62}_{28}Ni$ and $^{58}_{26}Fe$ are examples. They lie in the region of A = 50 to 60.

(ii) Small Nuclei:

Have decrease in packing fraction due to surface effect. Small nuclei are good for fusion processes.

(iii) Large Nuclei:

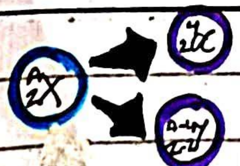
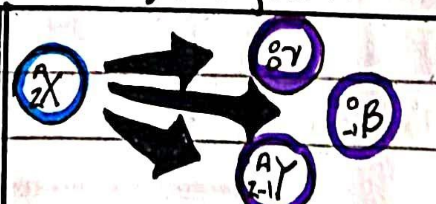
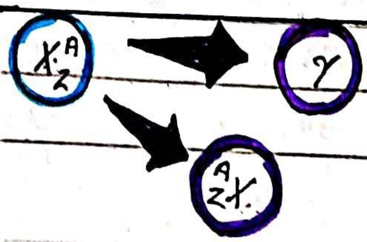
Decrease in 'f' is because of large number of protons. Binding effect of nuclear force is opposed by coloumb repulsive force thus leading to an unstable nucleus. $^{222}_{86}R$, U^{238}_{92} are examples. These are part in Fission.



→ Radioactivity:

"The spontaneous release of subatomic particles or gamma rays by unstable atoms as their nuclei decay to attain stability is called radioactivity. The element which possess such property is termed as radioactive element."

→ **Types of radiations:** alpha (α) in which particles are He^4 nuclei, Beta (β) in which particles are electrons or positrons and gamma (γ) in which emitted rays are high energy photons.

→ Alpha (α)	→ Beta (β)	→ Gamma (γ)
	(i) Emission	
occurs when ratio of neutrons to protons in nucleus is too low.	Occurs when the ratio of neutrons to protons in the nucleus is too high.	occurs when nucleus of radioactive atom has excess energy
	(ii) Decay Process	
Parent nucleid is converted to daughter nucleid having nucleon number reduced by 4 and charge by 2.	Parent neutron decays into proton and electron no change in number of nucleons occurs	when nucleus changes from excited state to lower energy state, a photon called γ-ray is emitted
	(iii) Equation	
$A^{A}_{Z}X = {}^{A-4}_{Z-2}Y + \alpha + Q$	${}^{A}_{Z}X = {}^{A}_{Z+1}Y + \beta^{-1} + \bar{\nu} + Q$	$({}^{A}_{Z}X) = {}^{A}_{Z}X + \gamma$
	(iv) Rest mass and charge	
4.002603 amu, +2	0.000594 amu, -1, +1	0 amu, 0
	(v) Penetrating Power	
Stopped by paper sheet	Stopped mm of Aluminum	several cm of lead
	(vi) Ionizing Ability	
Highest	Medium	Lowest
	(vii) Diagram	
		

Random Nuclear Decay	Spontaneous Nuclear Decay
A process without pattern rule or method which is unpredictable as precise moment of disintegration isn't known for a particular nuclei is called random nuclear decay.	A process occuring without external cause. Nuclear decay is spontaneous because the process of radioactive decay cannot be speeded up or slowed down by physical or chemical means.

→ **Half Life & Rate of Decay**: "The time it takes for half of the radioactive nuclei in a sample to decay is called half life."

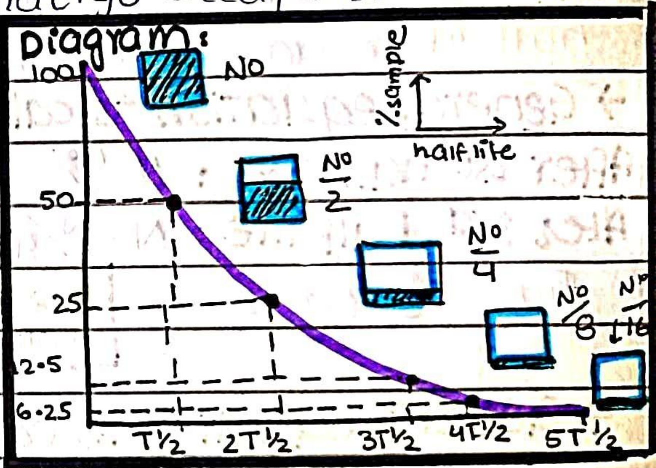
"The rate of Decay or activity of radioactive sample is defined as the number of disintegrations that occur per second."

→ **Things to remember:**

(i) Radioactive decay is random and spontaneous this means it can be predicted which nuclei of sample will undergo decay first and when.

(ii) Rate of decay is independent of external conditions (Temp, pressure etc)

(iii) It will take infinite time for a radioactive sample to decay completely ($t=\infty$ to achieve $N=0$)



→ **Mathematical Derivation:**

(Firstly, lets discuss symbols we'll use)

N_o = initial nuclei of sample , ΔN = number of radioactive nuclei that disintegrate in time Δt.

N = undecayed nuclei

t = time , $t_{1/2}$ = half life.

(Derivation) $\Delta N \propto -N$ (i) (initially at $t=0$ $N_o=N$) and $\Delta N \propto \Delta T$ (ii)

$-N\Delta t \propto \Delta N$ (By i and ii) (iii) constant of Proportionality $= \lambda$

$$\frac{\Delta N}{\Delta t} = -\lambda N \quad \text{(iv)}$$

(- sign shows that as time passes, nuclei of sample decreases due to decay)

→ λ or radioactive decay constant are specific to element and do not change for a particular sample eq(iv) can be written as $\Delta N/\Delta t = dN/dt$

$dN/dt = -\lambda N$, $\frac{dN}{N} = -\lambda dt$ integrating both sides

$\int -\frac{dN}{N} = \int -\lambda dt$, $\ln N = -\lambda \int 1 dt$

$\ln N = -\lambda t + \text{constant}$ (v), initial condition At $t=0$, $N=N_0$

$\ln N_0 = -\lambda(0) + \text{constant}$

$\ln N_0 = \text{constant}$ (vi) putting (vi) in (v) we get

$\ln N = -\lambda t + \ln N_0$ or $\ln N = \ln e^{-\lambda t} + \ln N_0$ ($\ln e = 1$)

$\ln N = \ln e^{-\lambda t} \cdot N_0$ (Taking anti log)

$N = N_0 e^{-\lambda t}$ (vii)

→ **After 1st Half life:** $N = N_0/2$ and $t = t_{1/2}$ thus eq (vii) becomes

$N_0/2 = N_0 e^{-\lambda t_{1/2}}$, $\frac{1}{2} = e^{-\lambda t_{1/2}}$ or $\frac{1}{2} = 1/e^{\lambda t_{1/2}}$ taking log after inverting both sides

$\log(2) = \lambda t_{1/2}$, $0.69 = \lambda t_{1/2}$ (viii)

→ **What does this equation (viii) tell us?** it suggests $\lambda \propto 1/t_{1/2}$

where $t_{1/2}$ is half life. It means that as rate of decay increases, half life duration decreases.

→ **General equation to calculate $N_{undecayed}$ left in sample:**

After 1st half life: $N = N_0/2$ **After 2nd Half life:** $N = N_0/2 \div 2 = N = N_0/4$

After 3rd half life: $N = N_0/4 \div 2$ or $N = N_0/8$

thus we conclude $N_{undecayed} = N_0/2^n$ (where n = number of half lives passed)

→ **General equation to calculate $N_{decayed}$ in sample:**

We can write N_0(initial) = $N_{undecayed} + N_{decayed}$ from above eq we know $N_{undecayed} = N_0/2^n$ thus $N_0 = N_0/2^n + N_{decayed}$

thus $N_0 - N_0/2^n = N_{decayed}$

→ **General formula to calculate number of halflives:**

T (total) $\div t_{1/2}$ (half life) $= n$ (number of half lives)

→ **Activity:** Number of disintegrates per second $A = -\Delta N/\Delta t = \lambda N$

→ **Units of Radioactivity:** Common unit curie $Ci = 3.70 \times 10^{10}$ decays/s

SI unit becquerel $Bq = 1$ decay/s

$1 Bq = 2.7027 \times 10^{-11} Ci$

→ Interaction of Radiation With Matter:

→ Charged Particles	→ Photons	→ Neutrons
e^-, e^+, Protons, deuterons(d) alphas (α) travelling through matter lose energy through;	Gamma rays (γ) or X-rays can interact in following ways;	Nuclei aren't charge thus they interact through nuclear force interactions are divided into;
① Coulomb interaction	① Photoelectric effect	① Scattering
② Emission of electromagnetic rays	② Compton scattering	② Absorption
③ Nuclear interactions	③ Pair Production	

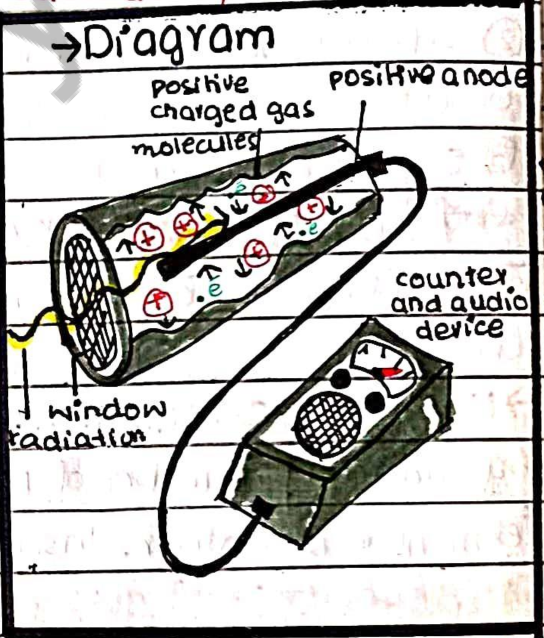
→ Radiation Detectors:

"Devices used to measure and detect the presence of ionizing radiations such as alpha, Beta and gamma rays."

→ Types: There are many types but we'll discuss

① Geiger-Muller counters

② Semiconductor detectors

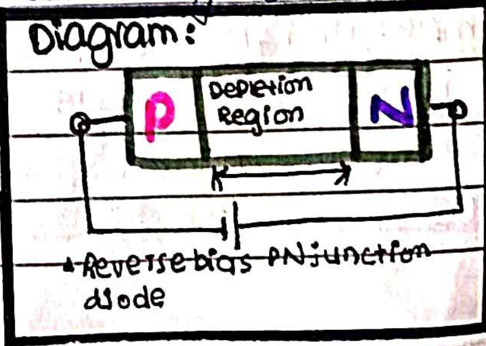


1. Geiger-Muller Counters:

→ Principle: "GMC detects ionizing radiation by counting electrical pulses generated"

→ Construction: ① GM-tube containing gaseous medium ② stiff central wire acting as anode ③ voltage source ④ Detection system

→ Working: Radiation sled in through window of tube ionizes gas molecules causing cations to move towards cathode and electrons towards anode wire. In the journey of e's towards anode they ionize other gas molecules producing an avalanche of electrons. This avalanche produces pulse at detection system which is amplified and counted by counter resulting in sound production.



2. Solid State Detectors:

→ Principle: "Solid state radiation detectors use semiconductors to measure"

→ **Construction:** ① Reversebiased PN junction using semiconductor (usually silicon or germanium. ② Votage source.

→ **Working:** Nregion has a small width so as to cause no energy change in radiation as it approaches the depletion region. As radiations reach depletion region it forms electron hole pairs there and free electrons move towards positive end and flow through outer circuit to constitute a current. voltage appears across resistor which is amplified and measured through an elelronic counter.

→ **Advantages of solid state detector over Greger Muller Counter:**

① SSD can detect low energy particles

② SSD has very short reset time whereas due to slow movement of cations in GMC, reset time is large about 10^{-4} sec

③ SSD operates as low voltage of about 50 volts.

→ **Nuclear Reactions:** "A nuclear reaction is said to occur whenever an incident nucleus, particle or photon causes a change to occur in a target nucleus."

→ **Nucleartransmutation:** Process in which nucleus of an atom is altered by changing number of protons, resulting in transformation of one element into another. In such processes, conservation laws must be followed.

→ **Conservation Laws in Nuclear Reaction:**

① Conservation of charge

② Conservation of nucleon number

③ Conservation of linear and angular momentum

④ Conservation of Energy (mass inclusive)

Nucleon No. Conservation

"Before and after reaction, the sum of no. of protons and neutrons remain constant."

Example: $^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{1}_{1}H + Q$

RHS: 17+1=18 LHS 4+14=18, thus

Nucleons of LHS = Nucleons of RHS

Conservation of Mass Energy

"Total mass and energy before and after reaction remain same."

Example: $^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{1}_{1}H + Q$

LHS: He = 4.00263u + N = 14.00307u = 18.005617u

RHS: H = 1.007825u, + O = 16.999133u = 18.006958u

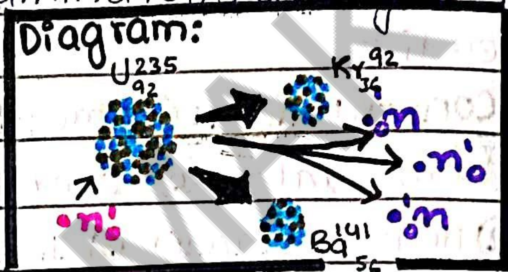
Q = 18.005617u − 18.006958u

Q = −0.001281u

→Nuclear Fission:

"The process of splitting of heavy unstable nuclei into intermediate size nuclei is called nuclear fission."

→Process: A uranium nucleus splits into two fragments after absorbing a neutron. Free nuetrons and gamma rays along with great deal of energy is also released.



→Laws obeyed: All conservation laws of Energy, charge, mass, nucleon number, momentum etc are obeyed.

→Reaction: $^1_0n + ^{235}_{92}U \rightarrow (^{236}_{92}U)^* \rightarrow Ba^{141}_{56} + ^{92}_{36}Kr + 3\,^1_0n + Q$

where Q = nuclear reaction energy, * represents excited state of uranium.

→Energy Released:

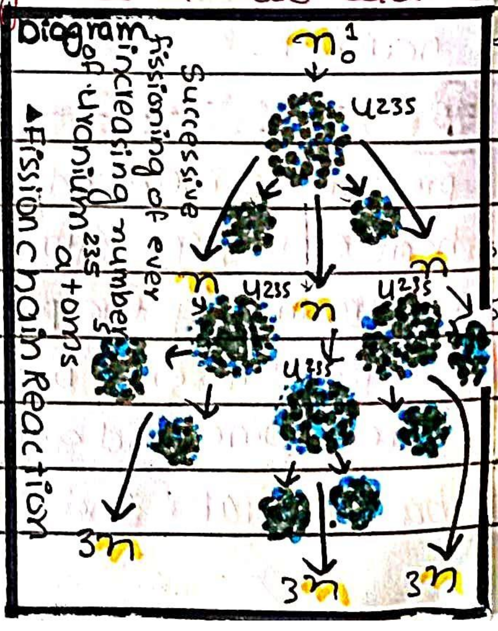
Reactants	Products
^1_0n = 1.0087u	$^{141}_{35}Ba$ = 140.9139u
$^{235}_{92}U$ = 235.439u +	$^{92}_{36}K$ = 91.8973u +
= 236.0526u	$3\,^1_0n$ = 3.0261u
	= 235.8373u

→ Q is rest mass difference
Q = 0.2153u = 200.44MeV
Thus fission of U^{235} produces 200MeV energy 80% of which appears as K.E of fragments.

mcq: Energy released in combustion of one molecule of octane used in gasoline engines is about one millionth the energy released in a single uranium fission reaction.

→Fission Chain Reaction:

"When one nuclear reaction causes an average of one or more nuclear reactions, thus a self-propagating series of these reactions is achieved and is called fission chain reaction."



→Average number of neutrons required: As long as average number of neutrons is greater than 1 per reaction, number of fission grow with time.

→critical, subcritical and super critical mass:
Minimum amount of energy required to sustain fission chain rxn is critical mass, less than critical mass is subcritical & greater one is subcritical mass.

mcq: 1kg of uranium delivers as much energy as 3000 tons of coal.

mcq: Natural uranium consists of 0.7% U^{235} and 99.3% of U^{238}.

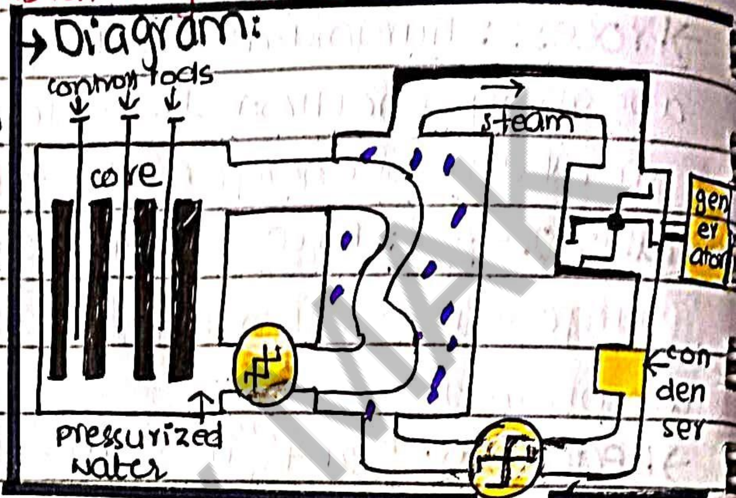
→ Nuclear Reactor:

"A nuclear reactor is a device that is designed to maintain a self sustaining fission reaction in a controlled manner."

→ Principle: Controlled fission chain reaction.

→ Construction: ① core; (a) nuclear fuel (b) moderator; (c) control rods ② Heat exchanger ③ Turbine ④ Generator ⑤ condenser

→ Diagram:



① Core: Nuclear fuel (such element which can undergo fission) is present in form of cylinderical rods. Enriched uranium 235 is used we use U^{235} and not U^{238} as U^{235} is more suitable for fission.

② Moderator: Moderator is usually D_2O or heavy water. The purpose is to slow down the fast neutrons into slow moving ones. Another component of the core is control rod. control rods control the number of neutrons formed. The material of moderator should be light and should not absorb neutrons.

③ Control Rods: Reactor operates in a critical condition meaning only one neutron proceeds the reaction this is controlled by control rods which can also be used to shut down the reaction completely. Control rods are made up of boron, cadmium or hafnium that absorb neutrons.

④ Coolant or Heat Exchanger: Fission reaction produces heat pressure is increased so that boiling point of D_2O increases. D_2O enters heat exchanger with high pressure through the pipe. Normal water surrounding the pipes gains heat and turns into steam. A pump is used to send D_2O back into core. Steam or coolant run the turbine and generate electricity. After this steam is condensed back to water and returned into heat exchanger.

⑤ Shielding: Neutrons and fission fragments in the nuclear reactor produce radiations which are harmful. There must be some process of absorbing these radiations. Usually a concrete wall with lead of a few feet thickness is used as shielding.

⑥ Types of Nuclear Reactors: Based of neutron energy, there're 2 types;

I. Thermal Reactors: Reactors in which thermal energy neutrons are used. Pressurized water Reactor (PWR) is most commonly used in which water is prevented from boiling at 100°c by providing high pressure.

II. Fast Reactors: Fast energy neutrons are used in this type. Fast reactors make use of U^{238} (99% in nature) Absorption of neutron by U^{238} followed by two beta decay reactions produces plutonium 239 which can also be used as fission fuel. The core of fast reactor consist of mixture of plutonium and uranium dioxid surrounded by U^{238} Blanket.

Reactions:

1. Neutron Absorption by U^{238}	${}^{1}_{0}n + {}^{238}_{92}U \rightarrow {}^{239}_{92}U$
2. Beta decay of U^{239}	${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$
3. Beta decay of neptunium^{239}	${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$

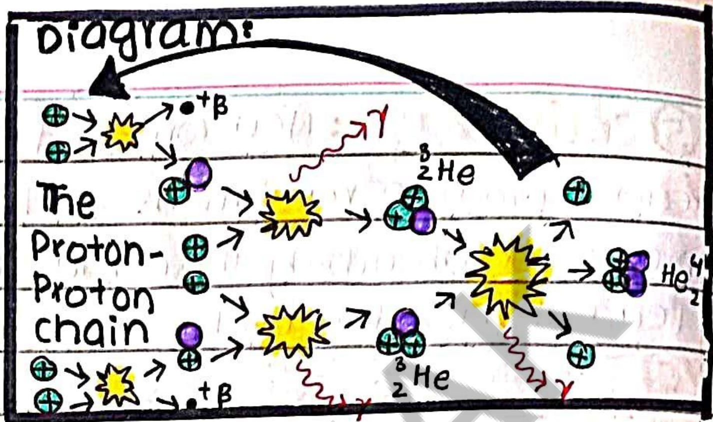
→ Nuclear Fusion: "When two light nuclei combine to form a heavy nucleus, the process is called nuclear fusion."

→ Cause of Energy Release: When two nuclei form a large nucleus, the mass of larger nucleus is less than the mass of nuclei that formed it. This loss in mass appears as energy ($E = mc^2$)

→ Fusion Reaction Cycles: Self sustaining fusion reaction is possible but energy required is possibly provided only in environments of stars including sun. This cycle of reactions can be achieved at stars in two series of processes;

A. Proton Cycle: Direct collision of protons produces heavier nuclei whose collision in turn produces helium nuclei

	Reaction	Energy
Step1	$^1_1H + ^1_1H \to ^2_1H + \beta^+ + \nu$ (2x)	0.42MeV (2x)
Step 2	$^1_1H + ^2_1H \to ^3_2He + \gamma$ (2x)	5.49MeV (2x)
Step3	$^3_2He + ^3_2He \to ^4_2He + 2^1_1H + \gamma$	12.85MeV
Step4	$^0_1\beta + ^0_{-1}\beta \to 2\gamma$ (2x)	1.02MeV (2x)
Total	$4^1_1H \to ^4_2He + 2^0_1\beta + 2\nu + 7\gamma$	26.71MeV

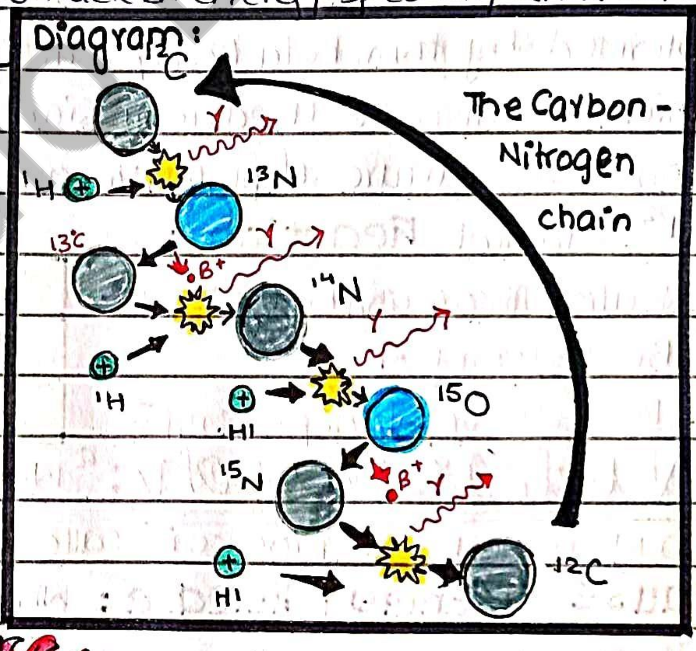


B. Carbon Cycle:

Carbon cycle is more efficient at high temprature therefore bright stars at high temprature will favour carbon cycle. Proton cycle is more efficient at lower temprature thus stars cooler as compared to sun favour proton cycle.

→ Thermonuclear Energy: Energy liberated in fusion of light nuclei into heavier nuclei is called thermo-nuclear energy specially when achieved at Earth

	Reaction	Energy
Step 1	$^1_1H + ^{12}_6C \to ^{12}_7N^*$	1.95MeV
Step 2	$^{12}_7N + ^{13}_6C \to \beta^+ + \nu$	1.20MeV
Step3	$^1_1H + ^{13}_6C \to ^{14}_7N + \gamma$	7.54MeV
Step4	$^1_1H + ^{14}_7N \to ^{15}_8O^* + \gamma$	7.35MeV
Step5	$^{15}_8O \to ^{15}_7N + \beta^+ + \nu$	1.73MeV
Step6	$^1_1H + ^{15}_7N \to ^{12}_6C + ^4_2He$	4.96MeV
Step7	$^0_1\beta + ^0_{-1}\beta \to 2\gamma$ (twice)	1.02MeV (2x)
Total		26.73MeV



→ Radiation Exposure:

Natural Background Radiations come from three sources

a. Cosmic Radiation: Radiations from space are cosmic radiations. Dose of cosmic radiation varies in different parts of the world due to differences in elevation and to the effects of Earth's magnetic field.

b. Internal Radiation: Everybody has radioactive Potassium-40, carbon-14 lead-210 and other isotopes inside their bodies from birth

C. Terrestrial Radiation: Radioactive material is in the soil, water and vegetation. Major isotopes of concern for terrestrial radiation are Uranium and the decay products of Uranium (thorium, radium & radon). Building material and ground always emit radiations.

Artificial sources like X-ray procedures, nuclear medicine, radiation therapy also contribute in radiation cell damage after radiation may lead to;

(i) Somatic Effects: Effects which appear soon after irradiation such as skin burns, loss of hair, cancer induction.

(ii) Genetic Effects: Effects which may not appear in the individual's life but damage genes and chromosomes that affect future generations.

→ Biological & Medical Uses of Radiation:

a. Biological Uses:

(i) Food Preservation: Gamma rays can be used to kill bacteria, mould and insects in food.

(ii) Sterilizing: Gamma rays are used to sterilize hospital equipment specially plastic syringes.

(iii) Insect Control: Major way of killing insects without using chemicals is the Sterile Insect Technique.

(iv) Chemical Study: Tracer Technique is used to study chemical changes occuring in living organisms.

b. Medical Uses:

(i) Medical diagnostics: Radioactive isotopes which have affinity for certain organs like bone, thyroid gland are introduced in body.

mcq Na 24 is used to study circulation of blood, it has half life of 15 hours.

Gamma ray camera (detector) observe radiations from isotopes concentrated in the organ and produce an image that shows how activity is distributed in patient.

(ii) Radiation Therapy: Radiation therapy is the use of high energy radiation to damage cancer cell's DNA and destroy their ability to divide and grow.

Cobalt 60 which emit beta particles and high energy gamma rays can be used to treat various cancers

Iodine 131 is used to detect thyroid pathology. Therapeutically it can be used to treat certain thyroid disorders

→ Basic Forces of Nature:

Particles in nature are subjected to four fundamental forces;

(i) Strong Force:

- → Range: Short about 10^{-14} m
- → Exchange Particles: Gluons
- → Role: Binding nucleons in nucleus
- → Relative Strength: 1 (strongest)
- → Lifetimes for Decay: 10^{-20} (s)

(ii) Weak Force

- → Range: 10^{-18} m (0.1% of diameter of proton)
- → Exchange Particles: $W^{\pm}$ and Z^{0} Bosons
- → Role: Transformation of one type of elementary particle into another.
- → Relative strength: 10^{-7}
- → Lifetimes for decay: 10^{-10} (s)

(ii) Electromagnetic Force:

- → Range: Infinite range
- → Exchange Particles: Photons
- → Role: Holds atoms & molecules together
- → Relative strength: 10^{-2}
- → Lifetimes for decay: 10^{-16} (s)

(iii) Gravitational Force:

- → Range: Infinite range.
- → Exchange Particles: Gravitons
- → Role: Attracts objects with mass towards each other
- → Relative strength: 10^{-43}, weakest force of all fundamental forces.

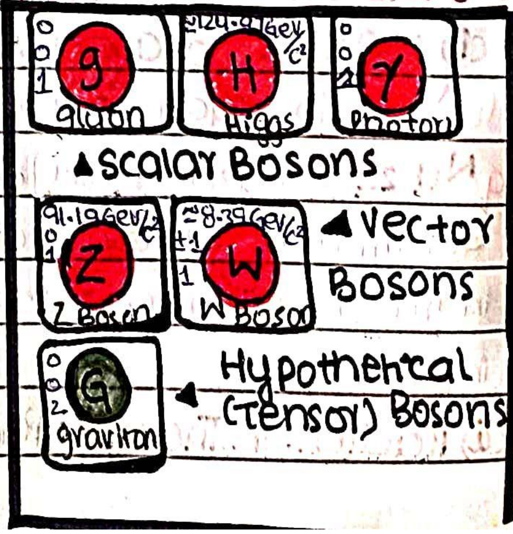
→ Building Blocks of Matter:

(i) Bosons:

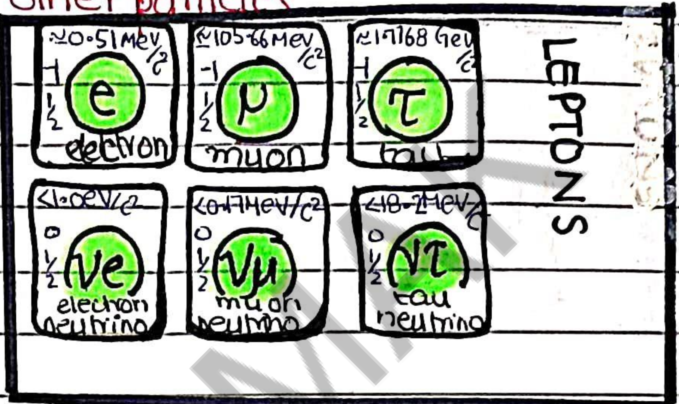
"Particles of a family that play central role in nature's fundamental forces":

→ Particles;

- Photon: Associated with electromagnetic force
- $W^{\pm}$ & Z^{0}: Associated w/ weak nuclear force
- Gluons: Associated w/ strong nuclear force
- Graviton: Associated w/ gravitational force.



(ii) Leptons: "This family consists of particles that interact by means of weak nuclear forces. Leptons can also exert gravitational and (if leptons are charged) electromagnetic forces on other particles."

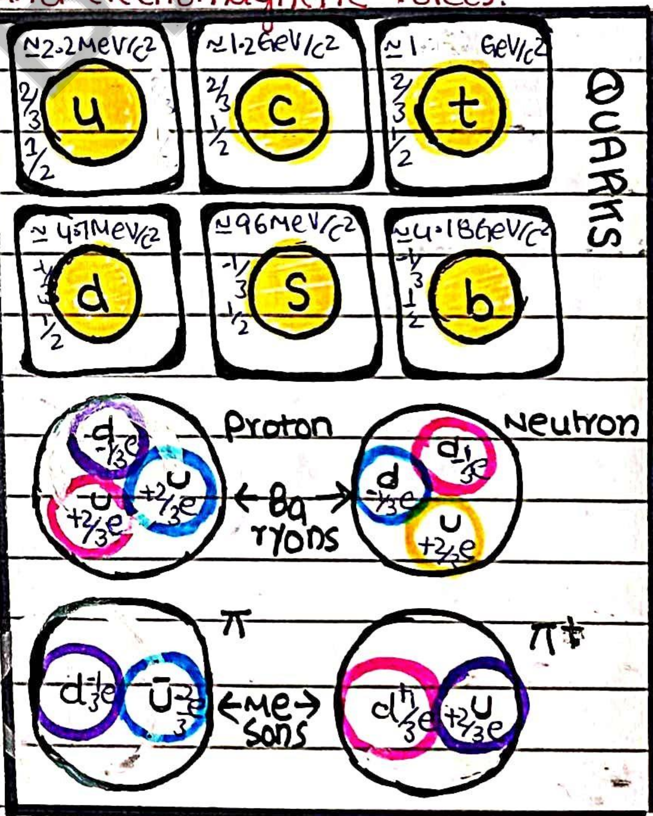


→ **Elementary Particles:** leptons are considered to be as elementary

4- Better know leptons are;

- Electron, Muon, Electron neutrino
- Muon neutrino other are Tau
- Tau neutrino

(iii) Hadrons: "This family contains particles that interact by means of both strong and weak nuclear force. At short distances strong nuclear force dominate. Hadrons can also interact by gravitational and electromagnetic forces."



→ **Two Groups;** Hadrons are subdivided into a

(i) **Mesons:** π and π+.

(ii) **Baryons:** Proton, Neutron

→ **Quark Model:** Elementary particles of hadrons are quarks.

1. There are six types of quarks; up(u) down(d), strange(s), charm(c), top (t) and bottom(b).
2. Every quark has corresponding anti quark denoted by same letter with a bar over it.

(iv) Colour Charge: "Strong charges come in three kinds (red, blue, green) each of which has an opposite (anti red, anti blue, anti green)."

→ **Free Particles:** Have a colour charge of zero. Strong force holds quarks in color less combinations (just like +ve -ve makes neutral) with zero charge.

→ **Baryon:** contains 1 quark of each colour. Red + green + blue = white, $r+g+b=0$

→ **Meson:** contains quark of one colour and anti quark of its anticolour

$r+\bar{r} = g+\bar{g} = b+\bar{b} = 0$