MPM: 203 NUCLEAR AND PARTICLE PHYSICS

UNIT –I: Nuclear Stability

Lecture-15

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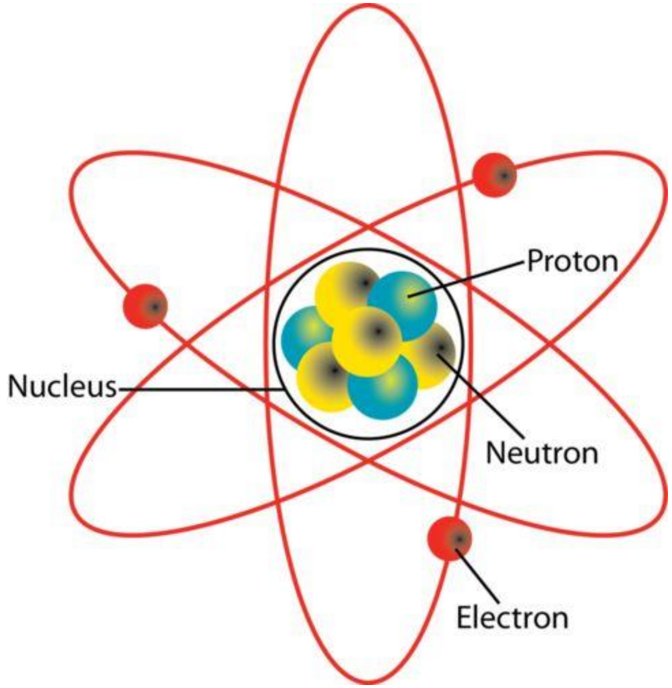
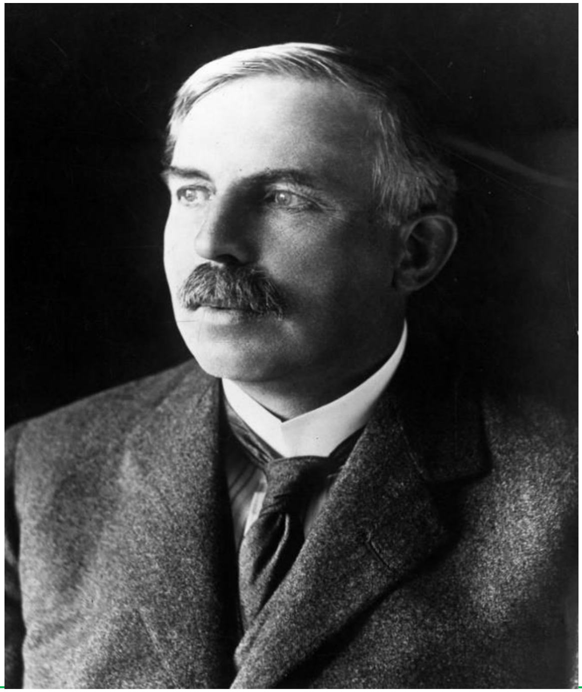
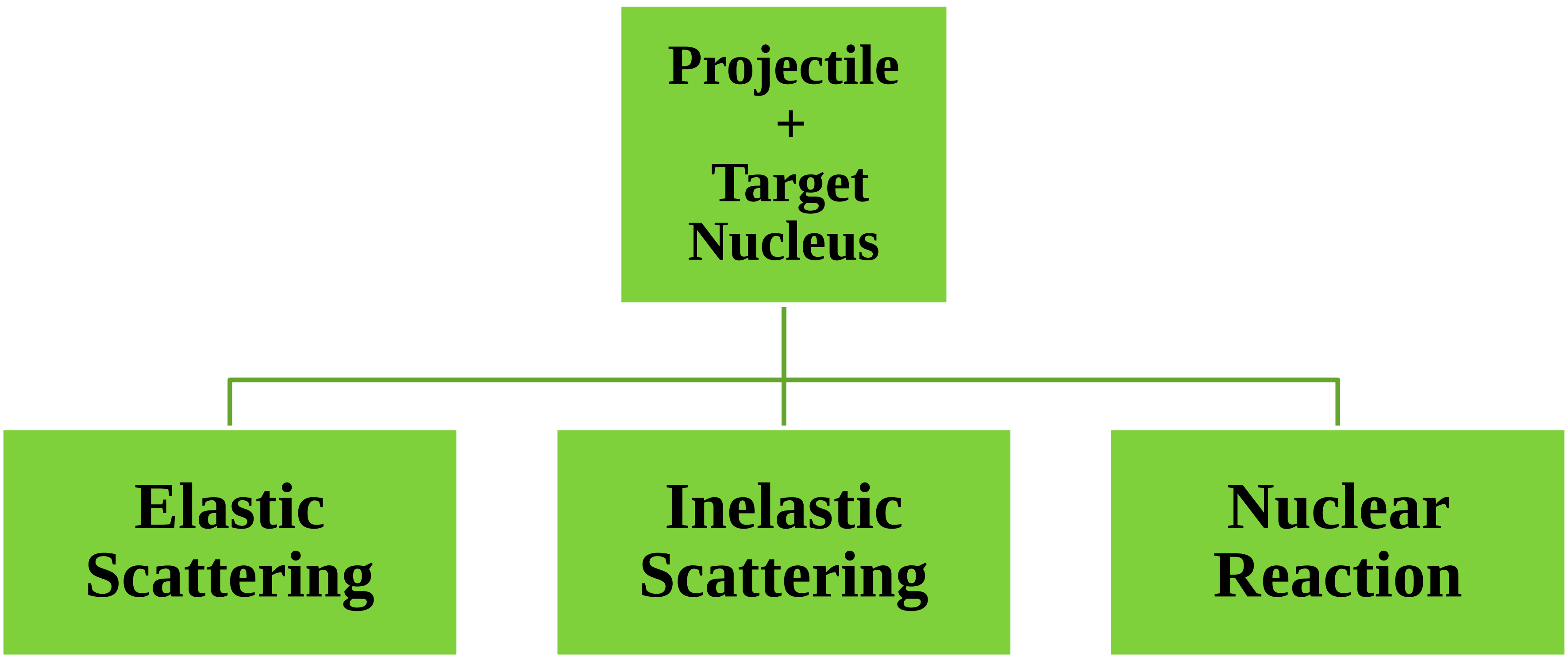




Nuclear Reactions

When a beam of monoenergetic projectile particles get bombarded upon a target nucleus the following three processes may result singly or jointly



Elastic Scattering

- If the incident and outgoing particles are the same and the kinetic energy is conserved the process is said to be elastic scattering.

- In this process the incident particle and the target nucleus are simply scattered due to their mutual interaction without any change in their total kinetic energy.

- if incident particle is denoted by 'a' and target nucleus by X then the elastic scattering process may be expressed as:

- $$a + X \rightarrow X + a$$

- In particular
- $$\boldsymbol{{}_{0}^{1}n + {}_{92}^{238}U \rightarrow {}_{92}^{238}U + {}_{0}^{1}n}$$

Inelastic Scattering

- If the incident and outgoing particles are the same but kinetic energy is not conserved during the process then the process is said to be inelastic scattering

- In this process the internal structure of the target nucleus remains unchanged but the nucleus is raised to an excited state observing some energy of incident particle so the outgoing particle has the kinetic energy less than that of incident particle the process of inelastic scattering may be expressed as
- $$a + X \rightarrow X^* + a$$

- Where * (star) on X, indicates that the target nucleus X is left in an excited state

Inelastic Scattering

- In particular $\quad {}^{1}_{0}n + {}^{208}_{82}Pb \rightarrow {}^{208}_{82}Pb^{*} + {}^{1}_{0}n$

- Subsequently $\quad {}^{208}_{82}Pb^{*}$ ***emits*** **γ- ray to go to ground state,**

- Thus $\quad {}^{208}_{82}Pb^{*} \rightarrow {}^{208}_{82}Pb + \gamma$

Similarly

$$ {}^{1}_{1}H + {}^{14}_{7}N \rightarrow {}^{14}_{7}N^{*} + {}^{1}_{1}H $$

- Subsequently excited Nitrogen emit gamma ray to go to ground state

$$ {}^{14}_{7}N^{*} \rightarrow {}^{14}_{7}N + \gamma $$

Nuclear Reaction

- If the incident and outgoing particles are different and also the nucleus structure of target nucleus changes during the bombardment the process is said to be nuclear reaction.

- In general a nuclear reaction may be expressed as

- $$a + X \rightarrow Y + b$$
- Where a is the energetic incident particle , X is the target nucleus, Y is residual nucleus and b is outgoing particle

- In particular

$$\boldsymbol{{}_{0}^{1}n + {}_{82}^{208}Pb \rightarrow {}_{81}^{208}Tl + {}_{1}^{1}H}$$

- In compact form the nuclear reaction may be expressed as

X(a, b) Y

Nuclear Reaction

- In Particular

- $$^{208}_{82}Pb(n,p)^{208}_{81}Tl$$

- Thus a nuclear reaction is the process in which the incident particle changes the internal structure of the target nucleus and itself is changed into other particles

Conservation Laws in Nuclear Reactions

- There are number of entities which remains conserved in the Nuclear Reactions
- **Charge:** The total electric charge is conserved in all nuclear reactions this means that the sum of atomic number of X and a is equal to the sum of atomic numbers of Y and b:
- $Z_a + Z_X = Z_Y + Z_b$ in brief $\sum Z = constant$
- For example in nuclear reaction

$$ {}_{2}^{4}He + {}_{5}^{10}B \rightarrow {}_{6}^{13}C + {}_{1}^{1}H $$

- Clearly the number of proton (i.e., sum of atomic numbers) of initial particles (${}_{2}^{4}He + {}_{5}^{10}B$) and final particles (${}_{6}^{13}C + {}_{1}^{1}H$) is same (initially 2+5 = 7) and finally (6+1=7)

Conservation Laws in Nuclear Reactions

Mass Number

- The total number of nucleons taking part in every nuclear reaction remains unchanged this means that the sum of nuclear numbers of X and a is equal to the sum of nuclear number of Y and b
- $A_a + A_X = A_Y + A_b$ in brief $\sum A = constant$
- For example in nuclear reaction
- $${}^{10}_{5}B(\alpha, p){}^{13}_{6}C$$
- We find that there are 14 nucleons at each stage of the reaction and thus, we get $\sum A = constant$

Conservation Laws in Nuclear Reactions

Linear Momentum

- In analogue with mechanical system the linear momentum in nuclear reaction remains conserved.
- If the target nucleus is initially at rest the vector sum of linear momentum of reaction products will be equal to the linear momentum of the incident particle.
- In centre of mass co-ordinate system the total linear momentum is equal at all-times.
- Analytically
- $$\overrightarrow{P_x} + \overrightarrow{P_a} = \overrightarrow{P_Y} + \overrightarrow{P_b}$$

Conservation Laws in Nuclear Reactions

Angular Momentum

- The nuclear angular momentum in the nuclear reaction is always a constant of motion
- Let I_x, I_a, I_Y and I_b represents nuclear spin (i.e,. Nuclear angular momenta) of nuclei X, a, Y and b respectively.
- Let l_x represents relative orbital angular momentum of X and a (i. e. in the initial state) and l_Y denote the relative orbital angular momentum of Y and b (i. e. in the final stage)
- Then the law of Conservation of angular momentum gives
- $I_X + I_a + l_X = I_Y + I_b + l_X$

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Conservation Laws in Nuclear Reactions

Angular Momentum

- Then the law of Conservation of angular momentum gives

- $$I_X + I_a + l_X = I_Y + I_b + l_X$$

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- For example in nuclear reaction

- $${}^{10}_{5}B(\alpha, p)\,{}^{13}_{6}C.\ {}^{10}_{5}B$$

Conservation Laws in Nuclear Reactions

Angular Momentum

- $^{10}_{5}\boldsymbol{B}$ has nuclear spin I_X =3 while the $\alpha - particle$ is spinless.
- If incident capture is by S-wave (I_a =0), then the compound intermediate nucleus must have I_c = 3.
- Both $^{13}_{6}\boldsymbol{C}$ and $^{1}_{1}\boldsymbol{H}$ ***has I***=1/2 and can add vectorially to either 0 or 1.
- The mutual angular momentum l_f $of\ the\ final\ product$ $^{13}_{6}\boldsymbol{C}$ and $^{1}_{1}\boldsymbol{H}$ is restricted by conservation of angular momentum of l_f = 2,3or 4 if I_c = 3.