Nuclear Chemistry

By

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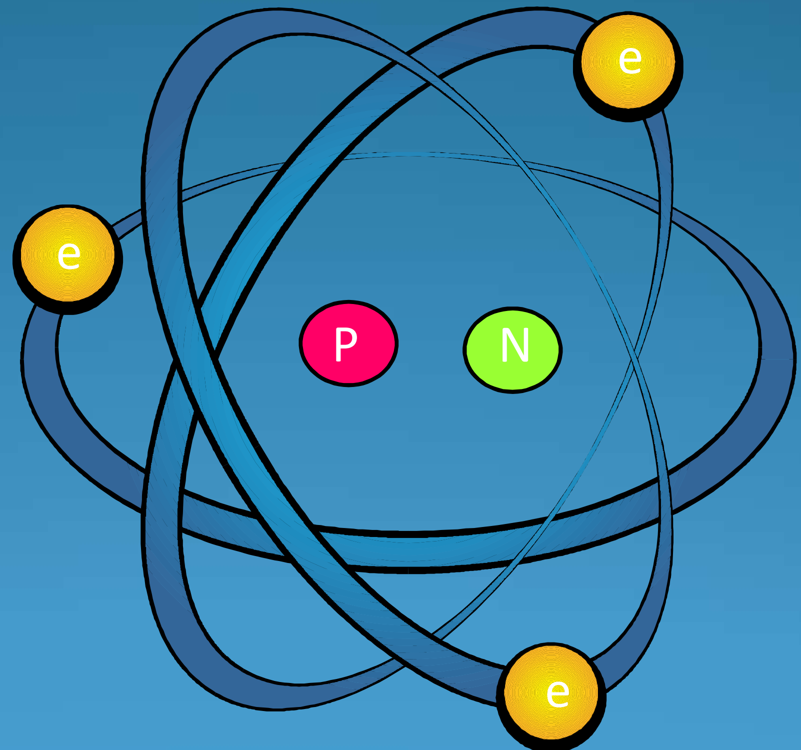
Nuclear chemistry

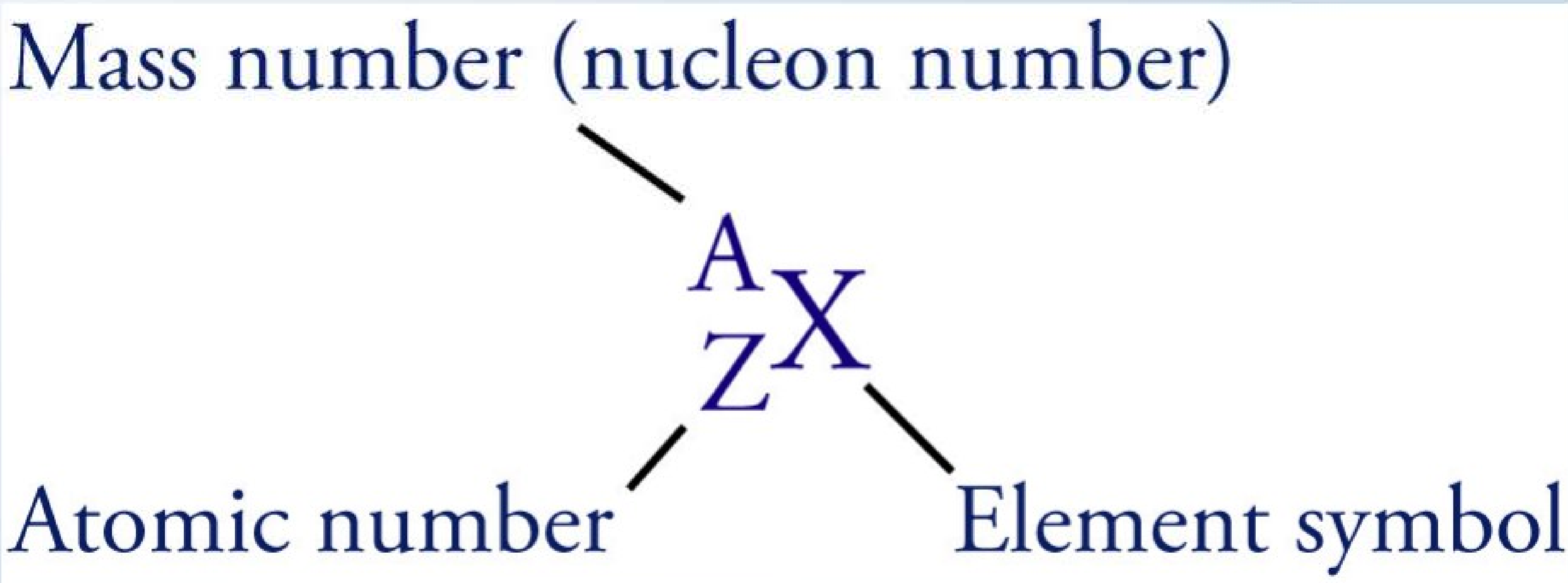
Definition

The branch of Chemistry which deals with Nuclear structure and Nuclear Reactions is called Nuclear Chemistry.



Structure of Atom

Nuclide Symbolism



- **Atomic number** is the number of protons present in the nucleus of an atom (Symbol - Z)

- **Mass number** is the sum of the total numbers of protons and neutrons presents in the nucleus of an atom (Symbol - A)

$$A = Z + n$$

- **Neutron number** is the number of neutrons present in the nucleus of an atom. ($n = A – Z$)

Composition of Nucleus of an Atom

- The Nucleus of an atom consists of a tightly packed arrangement of protons and neutrons. These are the two heavy particles in an atom and hence 99.9% of the mass is concentrated in the nucleus.
- Of the two, the protons possess a net positive charge and hence the nucleus of an atom is positively charged on the whole and the negatively charged electrons revolve around the central nucleus.
- The protons are in such close vicinity to each other inside the tiny nucleus and therefore the electrostatic forces of repulsion also act inside the nucleus.
- The total number of protons in a nucleus is equal to the number of electrons revolving around the nucleus and hence the atom, on the whole, is electrically neutral.

Sub-atomic particles

Sr. No.	Properties	Protons	Electrons	Neutrons
1.	Charge	Positive $(+1.6 \times 10_{-19}$ C)	negative	neutral
2.	Mass	1.0078 amu.	0.00055 amu.	1.0086 amu.
3.	Symbol	$_{+1}p^{1}$	$_{-1}e^{0}$	$_{0}n^{1}$
4.	Location	nucleus	outside nucleus	nucleus
5.	Deflection	negative plate	positive plate	no deflection
6.	Discoverer	Goldstein (1897)	Thomson (1897)	Chadwick (1932)

Isotopes

Isotopes are the atoms of the same element having same atomic number but different mass number

e.g.

i) A = 1, Z = 1: $^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

ii) A = 16, Z = 8: $^{16}_{8}O$ $^{17}_{8}O$ $^{18}_{8}O$

iii) A = 35, Z = 17: $^{35}_{17}Cl$ $^{37}_{17}Cl$

Isotopic Mass [Atomic Mass]

$^{35}_{17}Cl$: $^{37}_{17}Cl$

3 : 1

$$\text{Isotopic Mass (Atomic Mass)} = \frac{3(35)+1}{3+1}$$

$$= \frac{105+37}{4}$$

$$= \frac{142}{4}$$

$$= 35.5$$

Isobars

Isobars are the atoms of different elements having same mass number but different atomic number.

e.g. $A = 40$, $Z = 18$: $^{40}_{18}Ar$ $\quad ^{40}_{19}K$ $\quad ^{40}_{20}Ca$

Isotones

Isotones are the atoms of different neutron number but different atomic number and different mass number

e.g. $A = 13$, $Z = 6$: $^{13}_{6}C$ $\quad ^{14}_{7}N$

$N = A - Z$

$= 13 - 6$

$N = 7$

$N = A - Z$

$= 14 - 7$

$N = 7$

Isodiaphere

Isodiaphere are the atoms of different elements having same difference between neutron number and atomic number.

e.g. $^{A\,=\,238}_{Z\,=\,92}U$ $\qquad$ $^{234}_{90}Th$

$N = A - Z$ $\qquad$ $N = A - Z$

$= 238 - 92$ $\qquad$ $= 234 - 90$

$\therefore$ $\boxed{N = 146}$ $\qquad$ $\therefore$ $\boxed{N = 144}$

$= N - Z$ $\qquad$ $= N - Z$

$= 146 - 92$ $\qquad$ $= 144 - 90$

$= 54$ $\qquad$ $= 54$

Nuclear Stability

Nuclear Stability

Radius of atom $= 10^{-10}$ m $= 10^{-8}$ cm

Radius of Nucleus $= 10^{-15}$ m $= 10^{-13}$ cm

A. Nuclear Forces

B. Mass Defect and Binding Energy

C. Neutron to proton ratio

D. Odd or Even number of proton / neutron

A. Nuclear Forces

i. p – p forces
ii. n – n forces
iii. p – n forces

Mass defect

Definition

Mass defect may be defined as the difference between the theoretical (Calculated) mass and actual isotopic mass (observed mass) of an atom

Symbol $\Rightarrow \Delta m$

Unit $\Rightarrow$ a.m.u   Mass defect = Theoretical mass - Actual mass

$$\Delta M = [\, Z \times mp + (A - Z)\, Mn \,] - M$$

$$^{23}_{11}Na = [11 \times 1.0078 + 12 \times 1.0086] - 22.986$$

$$= 23.043 - 22.986$$

Binding energy

Binding Energy:- is defined as the amount of energy released in binding nucleons together in the nuclear of an atom

Symbol $\Rightarrow$ B.E.

Units $\Rightarrow$ MeV

Energy required to break the nuclear into its constituent nuclear

Definition

B.E. is defined as the amount of energy released when the isolated nucleons (p + n) come together and constitute the nucleus.

Unit Of B.E. = MeV

It is calculated by using formula

$$B.E. = 931 \times \Delta m$$

Binding energy per nucleon

Symbol $\Rightarrow$ B.E./ A

Units $\Rightarrow$ MeV

It is defined as the ratio of total B.E. of the nucleus to its mass number

Or

The average amount of energy required to isolate one nucleon from its nucleus

B.E. Per Nucleon = 931 x Δm/A

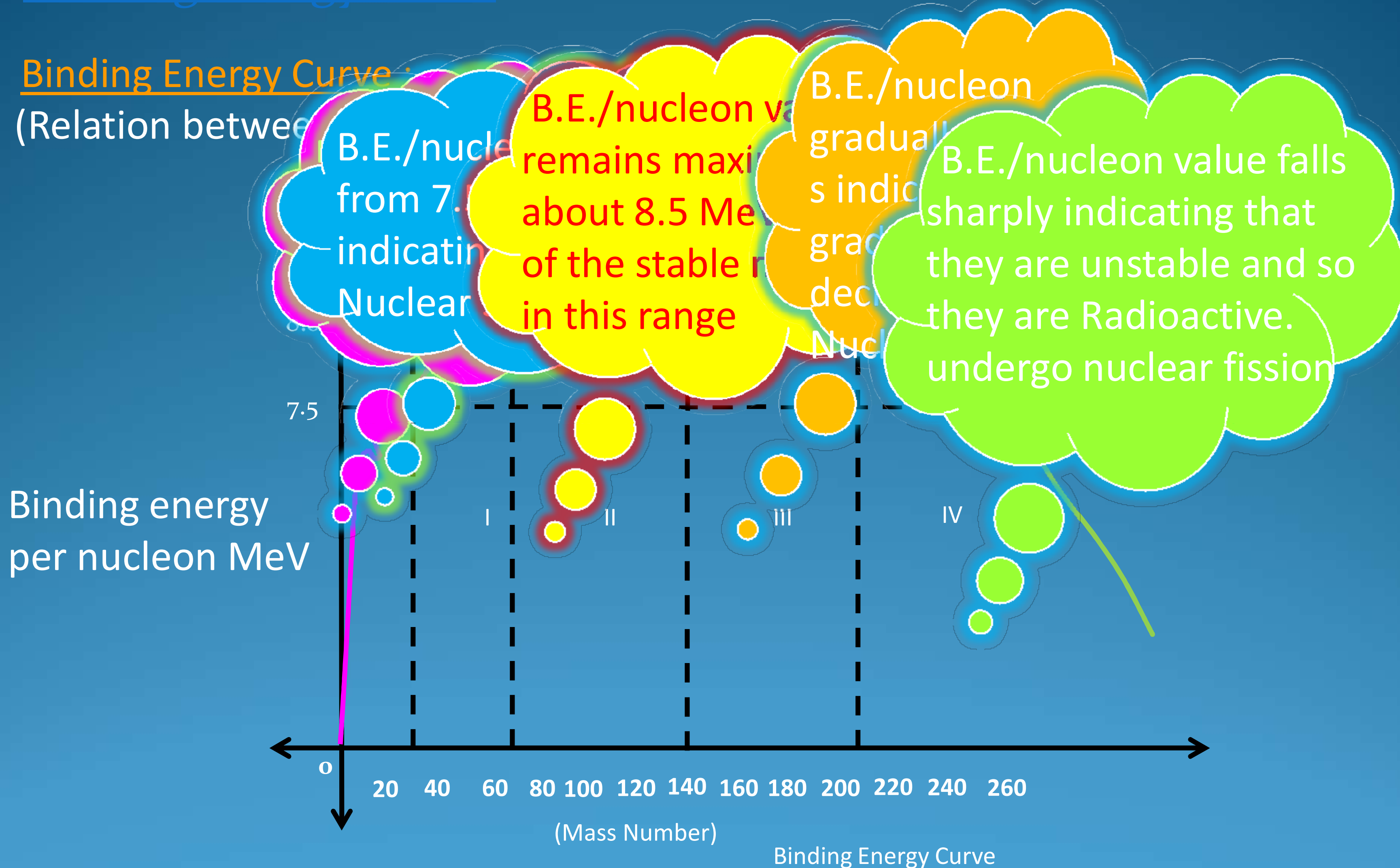
Δm = Mass defect; A = Mass number

e.g. Calculate the mass defect, B.E. and B.E. per nucleon of $_{26}Fe^{56}$ having mass 55.9375 a.m.u.

Binding energy curve

Binding Energy Curve :

(Relation betwee



B.E./nucleon increases upto **7.5** MeV. undergo nuclear fusion to become more stable

B.E./nucleon increases from 7.5 to 8.5 MeV. indicating increase in Nuclear stability.

B.E./nucleon value remains maximum i.e. about 8.5 MeV. Most of the stable nuclei lie in this range

B.E./nucleongrad uallydecreases indicating gradual decrease in Nuclear stability

B.E./nucleon value falls sharply indicating that they are unstable and so they are Radioactive. undergo nuclear fission

Binding energy curve

1. Upto Mass No. 20 :

B.E./nucleon increases upto **7.5** MeV.

undergo nuclear fusion to become more stable.

2 B.E./nucleon increases from 7.5 to 8.5 MeV. indicating increase in Nuclear stability.

3. From mass No. 60-140 :

B.E./nucleon value remains maximum i.e. about 8.5 MeV.

Most of the stable nuclei lie in this range

Binding energy curve

B.E./nucleon gradually decreases indicating gradual decrease in Nuclear stability

5. : B.E./nucleon value falls is below 7.5 mev
these nuclei are unstable and so they are Radioactive.

B.E./nucleon value falls sharply indicating that they are unstable and so they are Radioactive. undergo nuclear fission

N/Z ratio

- Nuclear stability is found to be related to the neutron to proton ratio

- The N/Z ratio for **stable nuclei** vary between 1 to 1.6. the elements lying within the stability limit (1- 1.6) constitute the stability belt or stability zone. However, the elements whose nuclei do not fall within the stability limit are said to be unstable.

- The unstable nuclei whose N/Z ration is either less than 1 or greater than 1.6 are radioactive and disintegrate giving out α, β & γ rays in their attempt to attain stability.

Packing Fraction

- The difference of actual isotopic mass and the mass number in terms of packing fraction is defined as,
- Packing fraction (f) =

  Actual isotopic mass – Mass no./ Mass no. X 10^4

- The value of packing fraction depends upon the manner of packing of the nucleons with in the nucleus. Its value can be negative, positive or even zero. A **negative packing fraction generally indicates stability of** the nucleus.
- In general, **lower the packing fraction, greater is the binding energy per nucleon and hence greater is the stability.** The relatively low packing fraction of He, C and O implies their exceptional stability, packing fraction is least for Fe (negative) and highest for H (+78).

Radioactivity

Radioactivity :

Radioactivity

The phenonenon of spontaneous disintegration of unstable nuclei of heavy elements accompanied by emission of radiation is called Radioactivity.

General Characteristics of Radioactivity :

i. It is a nuclear phenomenon.

ii. It is due to the unstability of the nucleus.

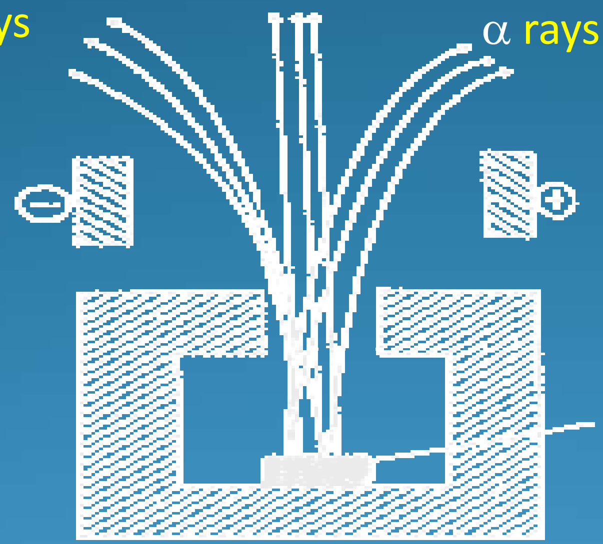
iii. It is a spontaneous, continuous **and** irreversible process.

iv. It is independent of external factors such as pressure, temperature, state of substance, electrical field, magnetic field, catalyst etc.

v. A radioactive element can emit three kinds of radioactive radiations : α, β and γ radiations.

Sub- header

Radioactivity



Deflections of Radioactive
Radiations in an electric field

Properties

	α rays		β rays		γ rays
1.	$({}_2He^4)$	**1.**	$({}_{-1}e^0)$.	**1.**	electromagnetic radiations.
2.	+2 unit.	**2.**	- 1 unit.	**2.**	no charge.
3.	It is deflected towards -ve plate.	**3.**	It is deflected towards **+ve** plate.	**3.**	No deflection in electric field.
4.	4.0015a.m.u.	**4.**	0.0005 a.m.u.)	**4.**	**It has** no mass.
5.	Its velocity is lesser than that of the velocity of light about 1-2 × 10^7 m/s.	**5.**	Its velocity is equal to 99% of velocity of light.	**5.**	Its velocity is the same as that of light.

Properties

α rays	β rays	γ rays
6. Its ionisation power is very high. It is about 100 times more than the **b** particles.	**6.** Its ionisation power is about 100 times More than γ particles.	**6.** The ionisation power is the least.
7. The penetrating power is the least.	**7.** Penetrating Power is less but 100 times more than that of α particles.	**7.** Penetrating Power is 100 times more than β particles.
8. They affect photographic plate to a little extent	**8.** They have greater effect than ∝ rays.	**8.** They affect photographic plate to a little extent.
9. They affect the ZnS screen producing fluorescence.	**9.** They have little effect on ZnS screen (less than ∝rays)	**9.** They have very little effect on ZnS screen.

Properties

	α rays		β rays		γ rays
10.	Atomic no. of the nucleus decreases by 2 units and mass no. decreases by 4 units.	**10.**	Atomic no. of the nucleus increases by 1 unit and mass no. remains unchanged.	**10.**	Large amount of energy **is** lost.

Radioactivity

viii. A radioactive element does not emit α and β particles simultaneously their emission is called primary effect.

7) γ –ray are emitted independently and their emission is called secondary effect

8) Radiation is 1^{st} order react

Group displacement law

vi. Due to the emission of α particles, atomic number decreases by 2 units and atomic mass number decreases by 4 units.

vii. Due to the emission of β particle, atomic no. increases by 1 unit and the atomic mass no. remains the same.

Group Displacement Law [Law of Radioactive Transformation] [Soddy, Fajan and Russel]

i. α – Decay $\alpha = {}^{4}_{2}He$

$${}^{A}_{Z}X - \alpha \rightarrow ?$$

$${}^{A}_{Z}X - {}^{4}_{2}He \rightarrow {}^{A-4}_{Z-2}Y$$

$$\therefore {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

On α – emission, an element will move two places behind (on L.H.S.) in Periodic table

iii. γ – Decay

No Change

ii. β – Decay $\beta = {}^{4}_{2}He$

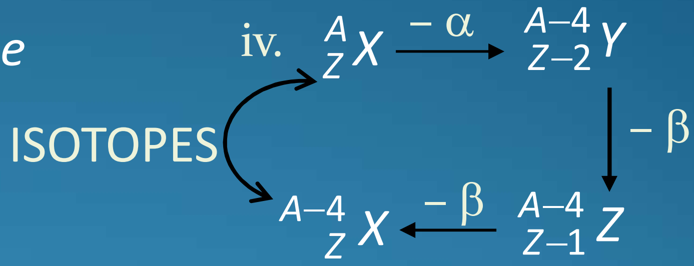
$${}^{A}_{Z}X - \beta \rightarrow ?$$

$${}^{A}_{Z}X - {}^{0}_{-1}e \rightarrow {}^{A}_{Z+1}Y$$

$$\therefore {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

On β – emission, an element will more one place Forward (on R.H.S.) in Periodic table

iv.

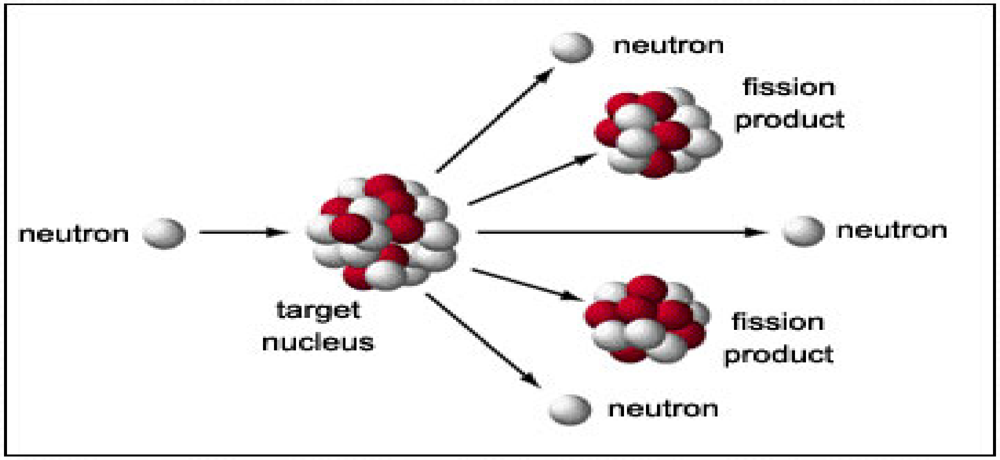


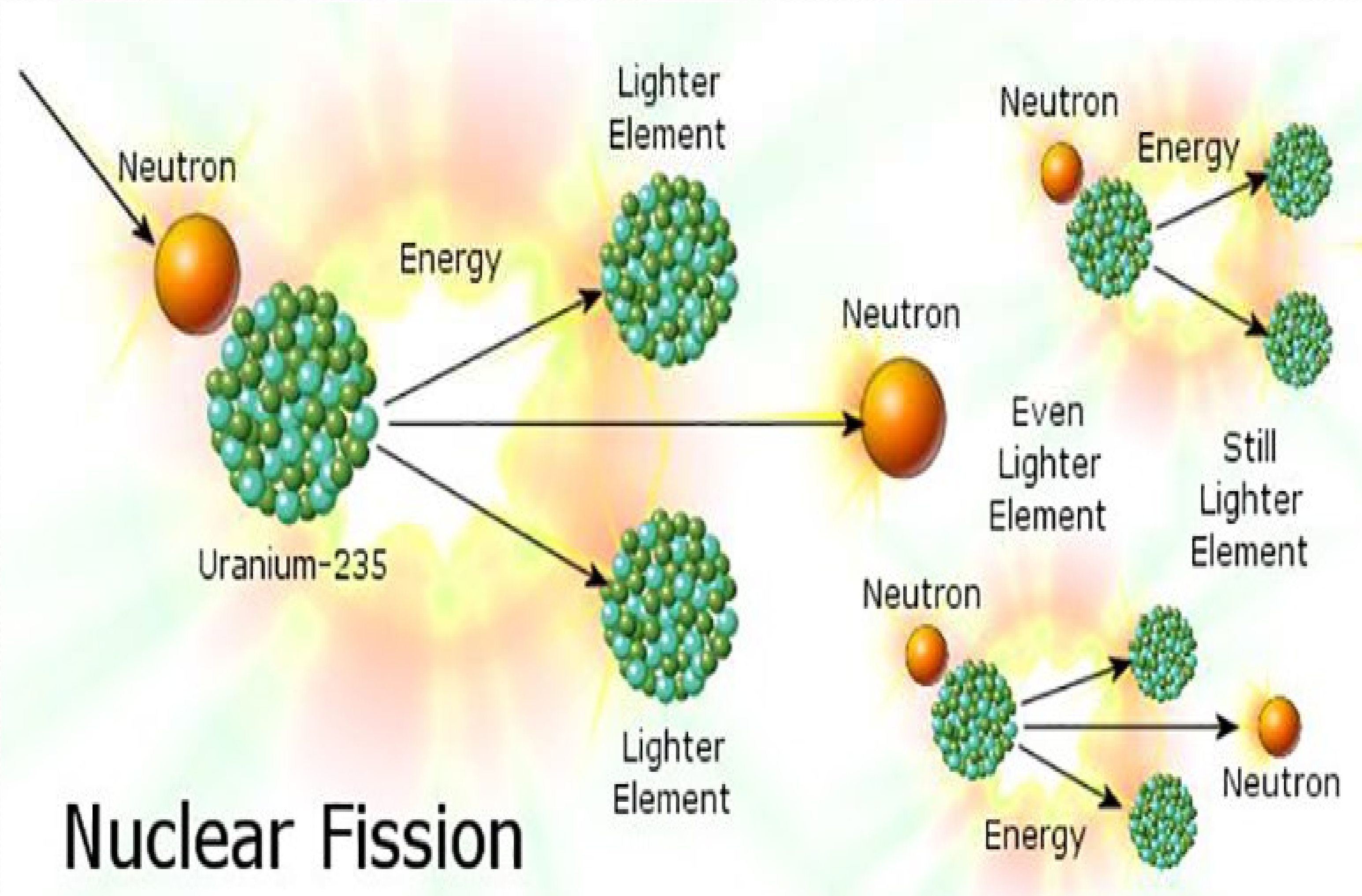
An Isotope of an element is formed on emission of 1 α and 2β– particles.

An Isotope of an element is formed on emission of One or more β– particles.

Nuclear Fission

- The process of splitting up of nuclei of heavy atom into two nuclei of comparable masses is called nuclear fission
- Nuclear fission is generally accompanied by emission of one or more neutrons.
- The nuclei with mass number over 200 when bombarded with subatomic particles like neutrons or other particles with sufficient energy show fission process.





Neutron
Uranium-235
Energy
Lighter Element
Lighter Element
Neutron
Neutron
Energy
Even Lighter Element
Still Lighter Element
Neutron
Neutron
Energy
Nuclear Fission