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Module 3

Nuclear Reactions

REMYA K P

Overview

- Basics
- Structure and stability
- Magic numbers
- Detailed study of different nuclear models

  - nuclear shell model

Nuclear chemistry

- **Nucleons** - collective term for protons and neutrons
- Nuclide- a single type of nucleus
- **Notation**

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

Z is the atomic number (protons)
A is the mass number (protons + neutrons)

- **Isotopes**- Atoms with the same Z but different A.

Eg: ^{12}C, ^{13}C, and ^{14}C

- ^{1}H, ^{2}H, and ^{3}H

  Deuteron - a simple two nucleon system (1p+1n)

- Isotones - same neutron number but different proton number

  $^{36}_{16}S$, $^{37}_{17}Cl$, $^{38}_{18}Ar$, $^{39}_{19}K$ and $^{40}_{20}Ca$- isotones of 20

  $^{9}_{4}Be$, $^{10}_{5}B$- isotones of 5

- Isobars- same number of nucleons (p+n)

  $^{24}_{11}Na$, $^{24}_{12}Mg$- 24 nucleons

- With a radius of about 10^{-15} m, a nucleus is quite small.

- Nuclear Size - It was possible to measure the size of the nucleus through Rutherford's experiment.

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

r- radius, A-mass number, R_0- const.(1.5×10^{-15} m)

Eg: Radius of ^{206}Pb nucleus ? - 8.85 fm

- Nuclear density -
  Density: $\rho = m/V$, Volume: $V = 4/3\ \pi r^3$. If we know mass number, we can find mass by multiplying by a.m.u. Nuclear density remains constant throughout the entire volume of the nucleus.

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- 1 a.m.u= 1.66x10^{-27} kg
- Energy equivalence of a.m.u.:
  1 a.m.u = 931.5 MeV
- Nuclear force - Force that acts between protons and neutrons

1. Attractive force between nucleons- p-p,p-n and n-n.
2. Nuclear force operates within 0.10 fermi (10^{-16}m)
3. Referred to as short range forces.

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1. Yukawa suggested, that pi mesons oscillate between neighbouring nucleons with a velocity close to light.
2. Exchange of pi mesons between neighbouring nucleons results in attraction.
3. If the attractive force between nucleons < electrostatic repulsion then nucleus become unstable and results in decay.

Nuclear Binding Energy (B.E)

- The minimum energy required to disassemble the nucleus of an atom into its constituent nucleons (p,n). B.E for stable nuclei is always +ve. Expressed in terms of kJ/mole or MeV's/nucleon.
- Mass defect: The total mass of the bound particles is less than the sum of the masses of the separate particles by an amount equivalent to the B.E.

$$\Delta E = \Delta mc^2$$

Δm = mass defect $(Zm_p + (A-Z)\, m_n - m_{nuc})$

ΔE = change in energy

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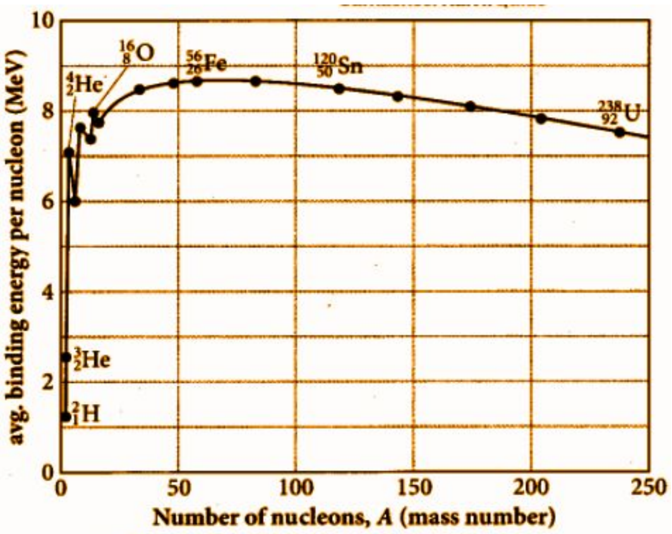
The B.E/nucleon averages about 8 MeV, but is lower for both the lightest and heaviest nuclei.

With increase in A, B.E increases reaches a max at 50-60, Then BE/nucleon decrease

This continues up to *A* ≈ 56, roughly corresponding to the mass number of iron.



Avg. binding energy of the nucleons

He, Be, C, O,Ne- have same A, multiples of 4 and they contain of equal no. of p and n.

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- Nucleons with high binding energy are more stable.

Nuclear Stability

n/p ratio

1. Atomic number less than 20, mostly have proton and ratio 1:1.
2. Low atomic 1:1, High atomic 1.5:1
3. The number of neutrons increases as the atomic number increases.
4. The first 80 elements of the periodic table have stable isotopes.
5. Elements with Z> 82 are unstable and radioactive.

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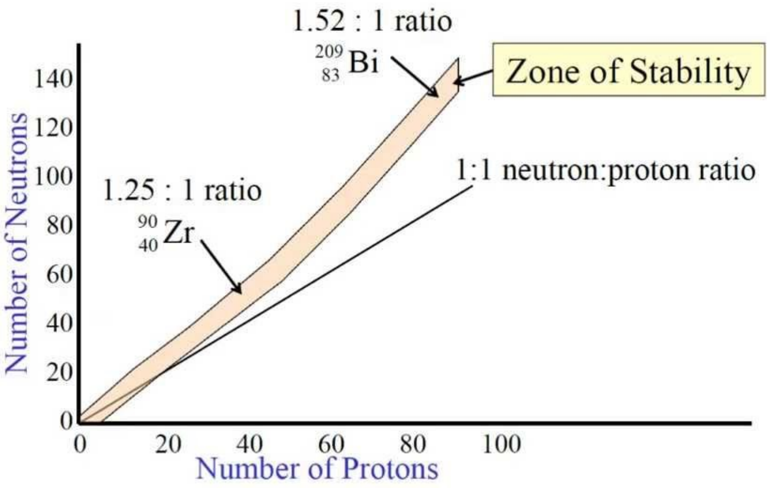
Reasons for instability

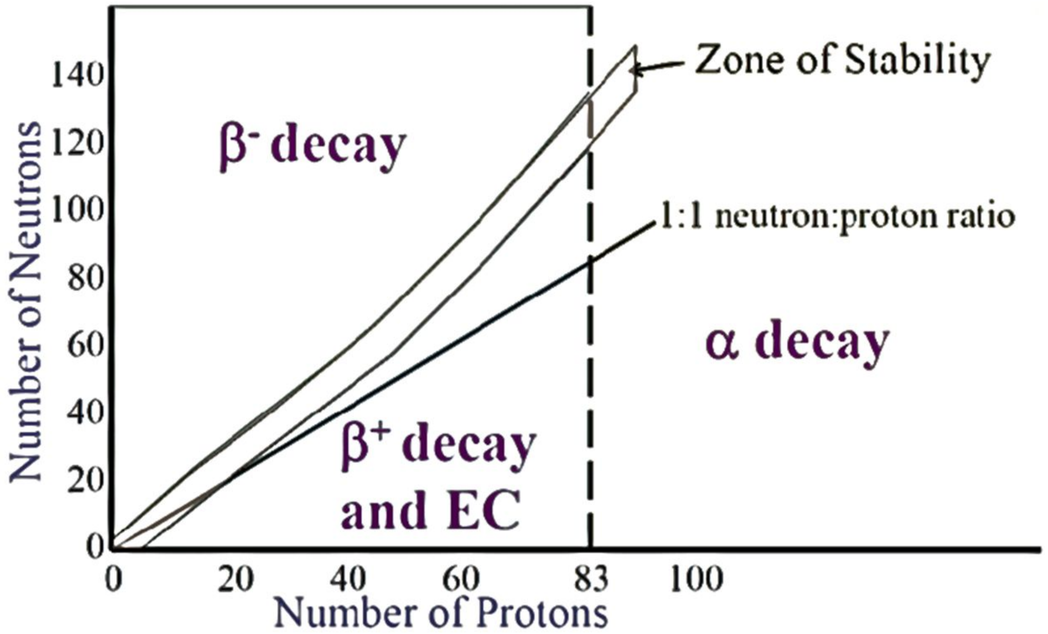
1. Too many protons
2. Too many neutrons
3. Too many of both protons and neutron (large nucleus)

Band of Stability

End of the
curve is Pb-206



Configurations for Stability



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Number of neutrons and protons

- Number of stable nucleus related to Number of p and n

p	n	stable nuclides	examples
Even	Even	168	$^{12}_{6}C$, $^{16}_{8}O$
Even	Odd	57	$^{13}_{6}C$, $^{47}_{22}Ti$
Odd	Even	50	$^{19}_{9}F$, $^{23}_{11}Na$
Odd	Odd	4	$^{2}_{1}H$, $^{6}_{3}Li$

Magic numbers

- Certain combinations confer especially stable nucleus 2,8,20,28,50,82,126.

  Eg: He, O, Ca, Ni, Sn, Pb

- The features of which is explained by nuclear shell model

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Model of Nucleus

1. **Nuclear shell model**:
   - A theoretical model to describe atomic nucleus in term of energy levels.
   - This model is based on the “Pauli exclusion principle”.
   - Shell model is similar to bohr atom model
   - Shell model describes how much energy is required to move nucleons
   - Nucleons are arranged in the shells having discrete energy levels satisfying certain quantum - mechanical conditions.

- p and n are are packed in separate shells - nuclear shells.
- The nuclei shell are associated with “magic numbers.”
- 7 numbers -2,8,20,28,50,82,126
- Some nuclei contain magic number of both protons and neutrons such as

  Eg: He (p=2, n=2), oxygen (p=8, n=8)
- These are called doubly magic numbers -Exceptionally high stability.

Features

- If neutron/proton corresponds to magic number - we need greater energy to remove last neutron.
- If number of neutrons corresponds to Magic number - stable isotones and more in number (isotones-82 ^{138}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{142}Nd, ^{144}Sm)
- If number of protons corresponds to Magic number - stable isotopes and more in number (Ca -6 isotopes)
- If both p and n corresponds to magic number- then it's the most stable nuclei. (He-4, Pb-208)

- **High natural abundance of nuclei with proton or/and neutron number equal to magic numbers.**
- **Other isotones show high stability n= 50, 20 (^{90}Zr, ^{92}Mo, ^{38}Ar, ^{40}Ca)**
- **Electric quadrupole moment of magic numbered nuclei is zero indicating the spherical symmetry of nucleus for closed shells.**

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THANK YOU