Physics of atom

Lecture Two / Theoretical

Part Two

Atomic and Nuclear Physics

Nuclear Binding energy

First stage

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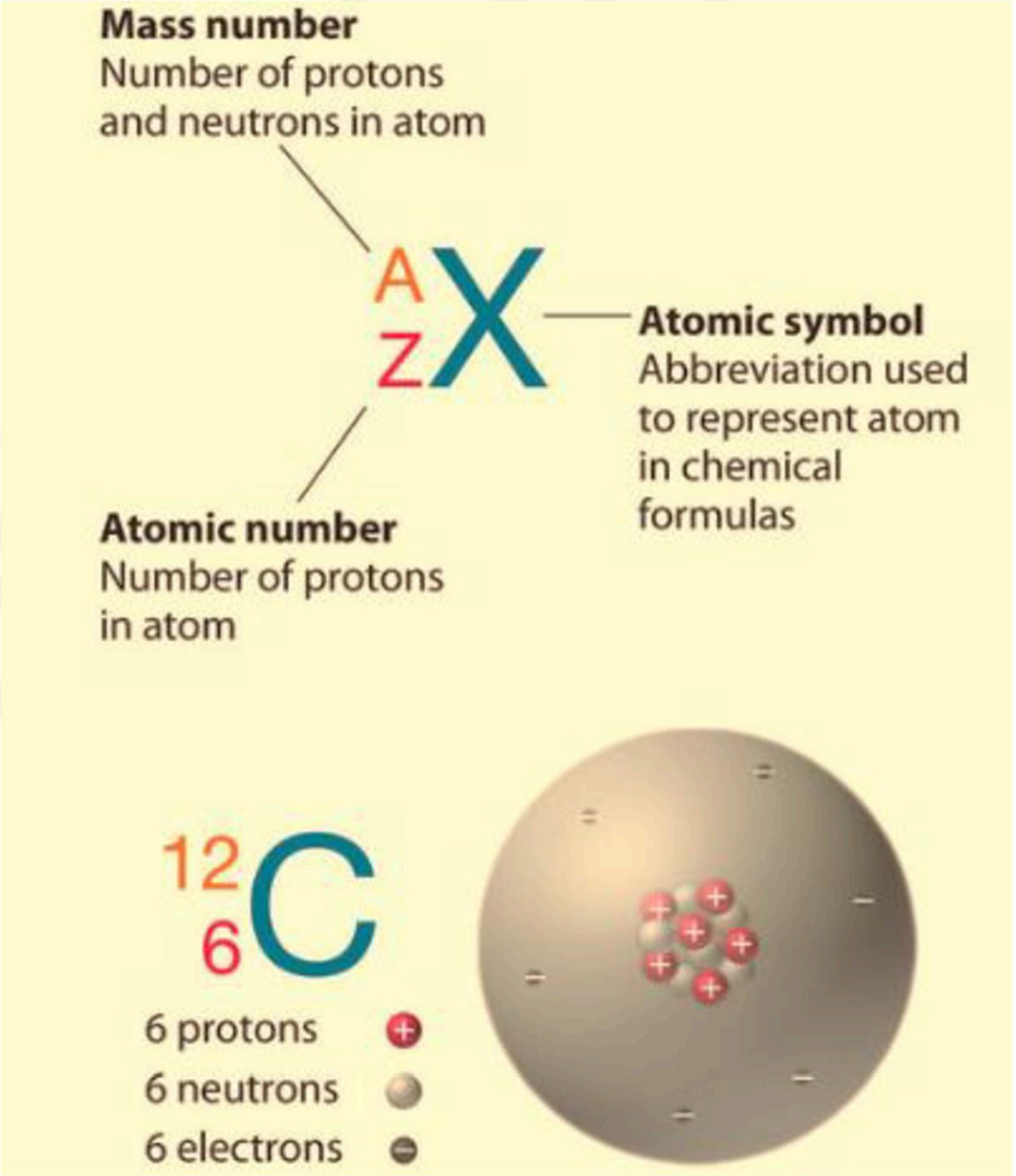
2025

Atomic and Nuclear Physics

- Fundamental particles
- Nuclear Binding energy
- Nuclear Stability

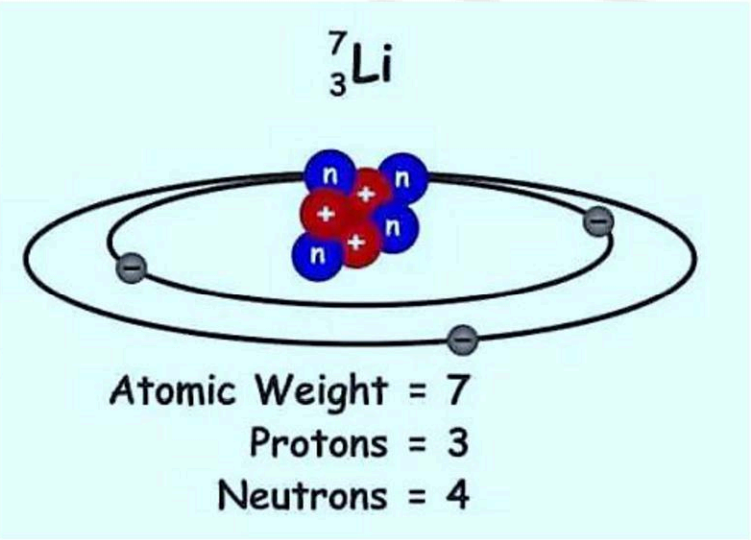
Nuclear Notation

- The atom consist of a small but massive nucleus surrounded by a cloud of rapidly moving electrons.
- The nucleus is composed of protons and neutrons. **The total number of protons in the nucleus is called the atomic number (or the proton number) of the atom and is given the symbol Z.** The total electrical charge of the nucleus is therefore **+Ze**, where e (elementary charge) equals **1.602×10^{-19} coulombs.**
- The neutrons in a nucleus is known as the **neutron number** and is given **the symbol N**.
- The **total number of nucleons, protons, and neutrons** in a nucleus are equal to **(A= Z + N),** where **(A) is called the mass number.**



Problem: Describe the nucleus of a lithium atom which has a mass number of (7) and an atomic number of (3)?

$^{7}_{3}X$



Sol/

$^{7}_{3}Li$

A= Z + N → 7= 3 + N → **Number of neutrons= (4)**

Thus, the lithium-7 nucleus contains: 3 protons, 4 neutrons

H.W / Problem: $(^{9}_{?}Be, \mathrm{N} = 5), (^{?}_{8}O, \mathrm{N} = 8), (^{20}_{10}Ne, \mathrm{N} = ?)$

$(^{?}_{2}He, \mathrm{N} = 2), (^{235}_{92}U, \mathrm{N} = ?), (^{56}_{?}Fe, \mathrm{N} = 30)$

Isotope Definition of Nucleus

The term isotope refers to atoms of the same chemical element that have **the same number of protons (Z1 = Z2)** but a **different number of neutrons** in their nuclei ➡ **(A1≠ A2)**. Since the number of protons determines the identity of an element, isotopes of a given element have **identical chemical properties** but **differ in their physical properties, such as mass and stability.**

For example:

- **Carbon-12 ($^{12}_{6}C$) has 6 protons and 6 neutrons.**
- **Carbon-13 ($^{13}_{6}C$) has 6 protons and 7 neutrons.**
- **Carbon-14 ($^{14}_{6}C$) has 6 protons and 8 neutrons.**

A= Z + N

Chemical Properties:

Since chemical properties are determined by **the number of protons and electrons** (which are equal in a neutral atom), isotopes of the same element exhibit nearly identical chemical behavior.

Physical Properties

Isotopes differ in their physical properties, such as **mass** and **nuclear stability**, **because of the difference in the number of neutrons.**

For example: Carbon-12 and carbon-13 are **stable isotopes**.

Carbon-14 is radioactive and **undergoes beta decay.**

Definition of Atomic Mass Unit (u)

The atomic mass unit (u) , also called the **unified atomic mass unit** , is a **standard unit** of mass used in chemistry and physics to express the masses of atoms, molecules, and **subatomic particles**. It is defined based on the mass of a specific isotope of carbon: carbon-12 ($^{12}_{6}C$)

Mathematically:

$$m = 1u = 1.66054 \times 10^{-27}\ kg$$

Common atomic masses

- **Mass of a proton:** mp = 1.007276 u
- **Mass of a neutron:** mn = 1.008665 u
- **Mass of an electron:** me = 0.00054858 u

Definition and Detailed Explanation of Binding Energy

Binding energy is the energy required to **completely disassemble a nucleus** into its individual protons and neutrons. Conversely, it is also the **energy released** when a nucleus is **formed** from its constituent nucleons (protons and neutrons).

Mass Defect

When nucleons **bind** to form a nucleus, the **total mass of the nucleus (M)** is **less** than the **sum** of the masses of the individual free protons (mp) and neutrons (mn).

$$m_D = (Z\ mp + N\ mn) - M$$

Where m_D : **Mass defect (mass "lost" during nucleus formation) and unit is (u)**

$$c^2 = \frac{931.5}{u}\ MeV$$

Mass-Energy Equivalence

$$E=mc^2$$

The mass defect (m_D) is converted into energy (E_B) via Einstein's equation:

$$E_B = m_D \cdot c^2\ (Mev)$$

Binding Energy Per Nucleon

$$Binding\ Energy\ Per\ Nucleon = \frac{E_B}{A} = \frac{m_D c^2}{Z+N} \quad \left(\frac{Mev}{Nucleon}\right)$$

Problem: Find Binding energy per nucleon for helium - 4

Hint: (m_D : 0.030377 u), (A = 4)?

Sol/

$$E_B = m_D \cdot c^2$$

$$E_B = (0.030377u)\left(\frac{931.5}{u}\text{ MeV}\right)$$

$$E_B = 28.2961755\text{ Mev}$$

$$\text{Binding Energy Per Nucleon} = \frac{E_B}{A} = \frac{m_D c^2}{Z + N}$$

$$\text{Binding Energy Per Nucleon} = \frac{28.2961755}{4}$$

$$\textit{Binding Energy Per Nucleon} = 7.075\ \frac{\textit{Mev}}{\textit{Nucleon}}$$

Problem: Carbon-12 ($^{12}_{6}C$)

1. How many protons and neutrons are in the nucleus?
2. Calculate the Binding energy if the mass of a proton is 1.007276 u, the mass of a neutron is 1.008665 u, and the actual mass of the carbon-12 nucleus is 12.000000 u.
3. Determine the total binding energy and the binding energy per nucleon.

Sol/

1) $A = Z + N$

$12 = 6 + N \rightarrow N = 6$

$\therefore$ Protons = 6, Neutrons = 6

2) $E_B = m_D \cdot C^2$

$$E_B = (6 \times 1.007276\ u + 6 \times 1.008665\ u - 12.000000\ u)\left(\frac{931.5}{u}\ MeV\right)$$

$$E_B = (0.095646\ u)\left(\frac{931.5}{u}\ MeV\right)$$

$E_B = 89.1$ MeV

3) $$\text{Binding Energy Per Nucleon} = \frac{E_B}{A} = \frac{89.1\ MeV}{12}$$

Binding Energy Per Nucleon = 7.425MeV

H.W.

H.W/ Problem 1: Oxygen-16 $^{16}_{8}O$

1. How many protons and neutrons are in the nucleus?

Using the following data: Mass of a proton: 1.007276u, Mass of a neutron: 1.008665u, actual mass of the oxygen-16 nucleus: 15.994915u

Calculate:

2. The total binding energy.
3. The binding energy per nucleon

H.W/ Problem 2: Uranium-235 $^{235}_{92}U$

1. How many protons and neutrons are in the nucleus?

Using the following data: Mass of a proton: 1.007276u, Mass of a neutron: 1.008665u, actual mass of the Uranium-235 nucleus: 235.043924u

Calculate:

2. The total binding energy.
3. The binding energy per nucleon