Physics of atom

Lecture five / Theoretical

Atomic and Nuclear Physics

Nuclear Binding energy

First stage

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Atomic and Nuclear Physics

- **Fundamental particles**
- **Nuclear Binding energy**
- **Nuclear Stability**

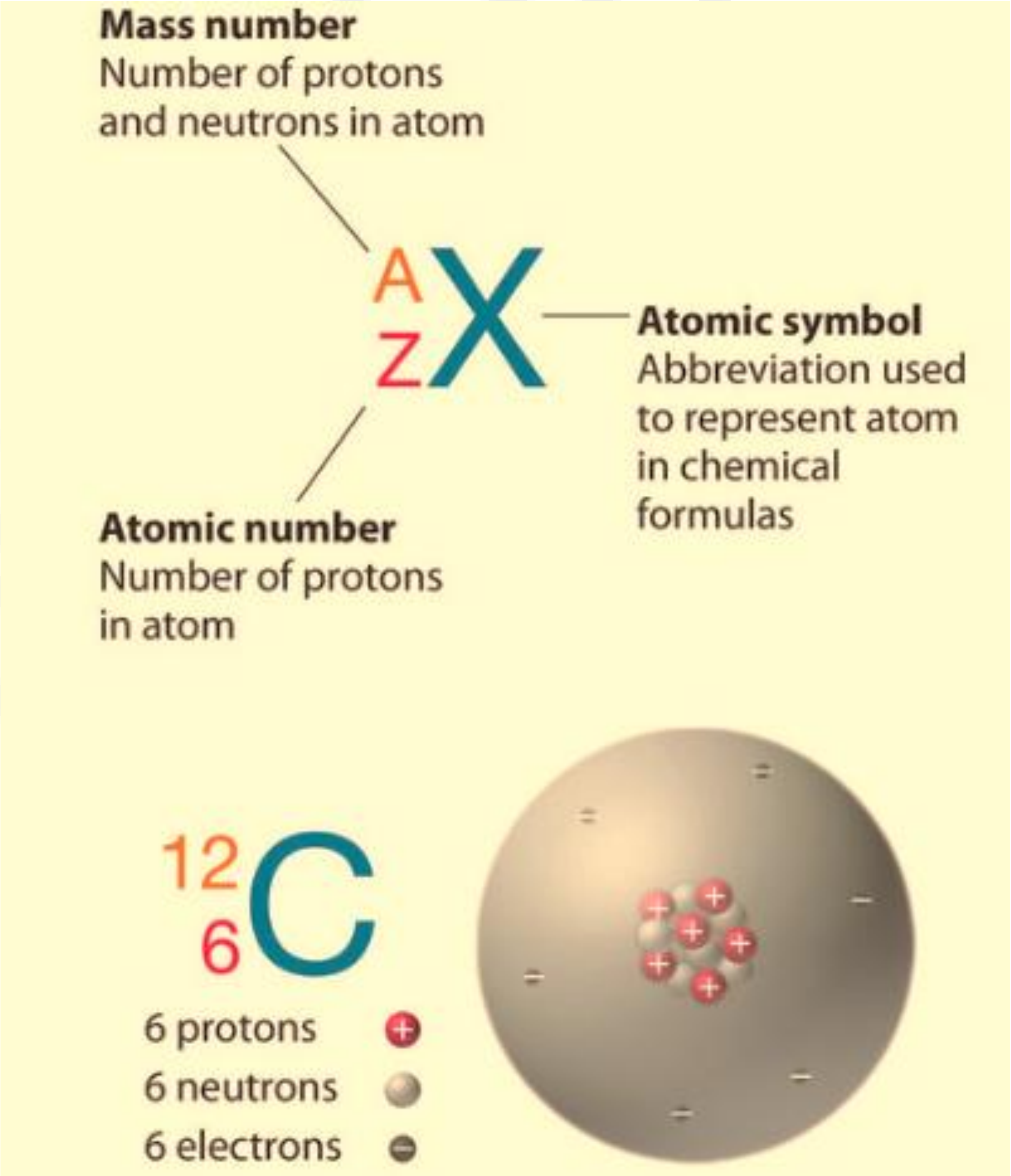
Nuclear Notation

- The atom consist of a small but massive nucleus surrounded by a cloud of rapidly moving electrons.

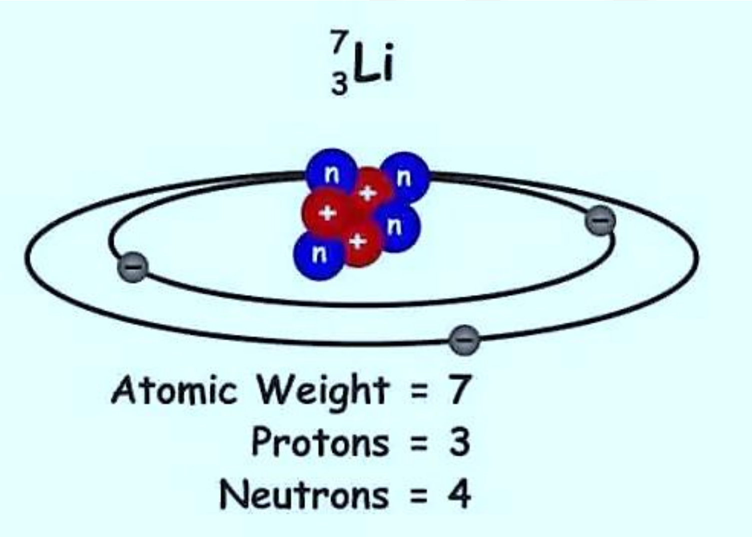
- The nucleus is composed of protons and neutrons. **The total number of protons in the nucleus is called the atomic number (or the proton number) of the atom and is given the symbol Z**. The total electrical charge of the nucleus is therefore **+Ze**, where e (elementary charge) equals **1.602×10^{-19} 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: ($^{9}_{\text{؟}}Be$, N = 5), ($^{\text{؟}}_{8}O$, N = 8), ($^{20}_{10}Ne$, N =?)

($^{\text{؟}}_{2}He$, N = 2), ($^{235}_{92}U$, N =?),($^{56}_{\text{؟}}Fe$, 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**

Relation to Energy (Mass-Energy Equivalence)

We remember Einstein's famous equation **$E=mc^2$**, where c is the speed of light **($c=3\times10^8$ m/s)**, the mass-energy equivalence of (1u) can be calculated:

$$E=mc^2$$

$$E=(1u)\cdot c^2$$

Substituting (1u = 1.66054×10 −27 kg) :-

$$E=(1.66054\times10^{-27})\cdot(3\times10^8)^2 \rightarrow$$

$$E = 1.4924\times10^{-10}\text{J}$$

Converting this energy into electron-volts ($1\ eV=1.60218\times10^{-19}$ J) :

$$E=\frac{1.4924\times10^{-10}}{1.60218\times10^{-19}}=931.5\times10^6\ \text{eV} \rightarrow$$

$$E = 931.5\ \text{MeV}$$

$$E=mc^2$$

$$m=\frac{E}{c^2}$$

$$m = 1\ u = \frac{931.5}{c^2}\text{MeV} \rightarrow C^2=\frac{931.5}{u}\text{MeV}$$

Problem: what is the rest mass energy of a proton (1.007276 u) in Mev?

Sol/

$$E=mc^2$$

$$E = (1.007276\ u)\left(\frac{931.5}{u}\ MeV\right)$$

E = 938.277 Mev

H.W/ Problem: what is the rest mass energy of a neutron (1.008665 u) in Mev?

H.W/ Problem: what is the rest mass energy of a electron (0.00054858 u) in Mev?

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).

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

$$C^2 = \frac{931.5}{u}\ \text{MeV}$$

Where m_D : **Mass defect (mass "lost" during nucleus formation).**

Mass-Energy Equivalence

$$E = mc^2$$

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

$$E_B = m_D \, . \, c^2$$

Binding Energy Per Nucleon

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

Problem: **Find Binding energy per nucleon for helium - 4**
Hint: **(m_D : 0.030377u), (A = 4)?**
Sol/

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

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

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

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

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

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

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

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