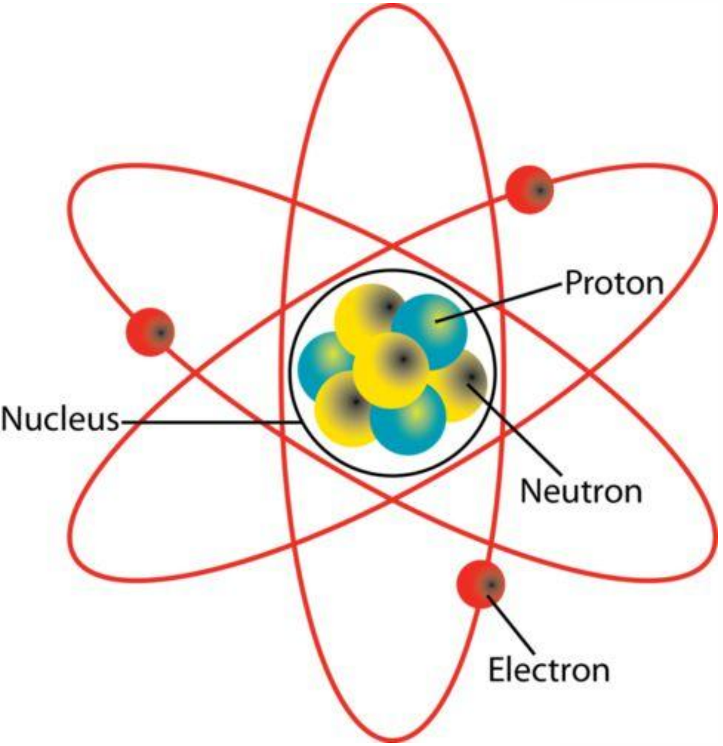
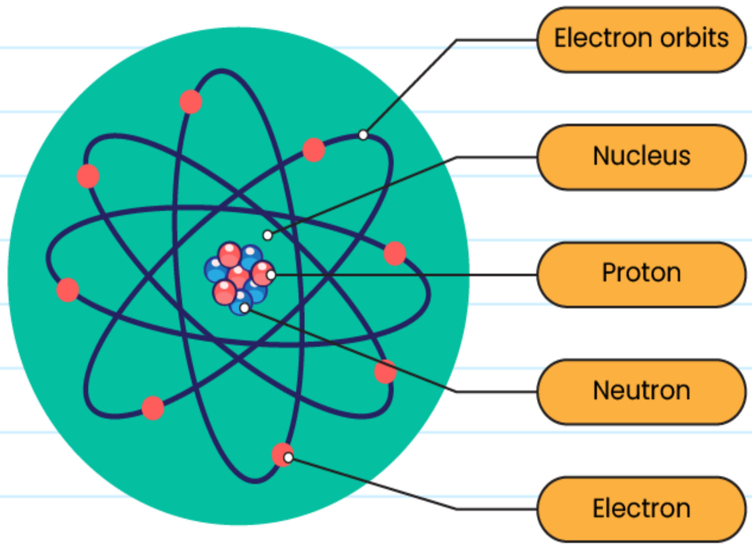
Physics Grade 12 LS/ GS



Chapter 18

Atom nucleus



Prepared & Presented by: Mr. Mohamad Seif

OBJECTIVES

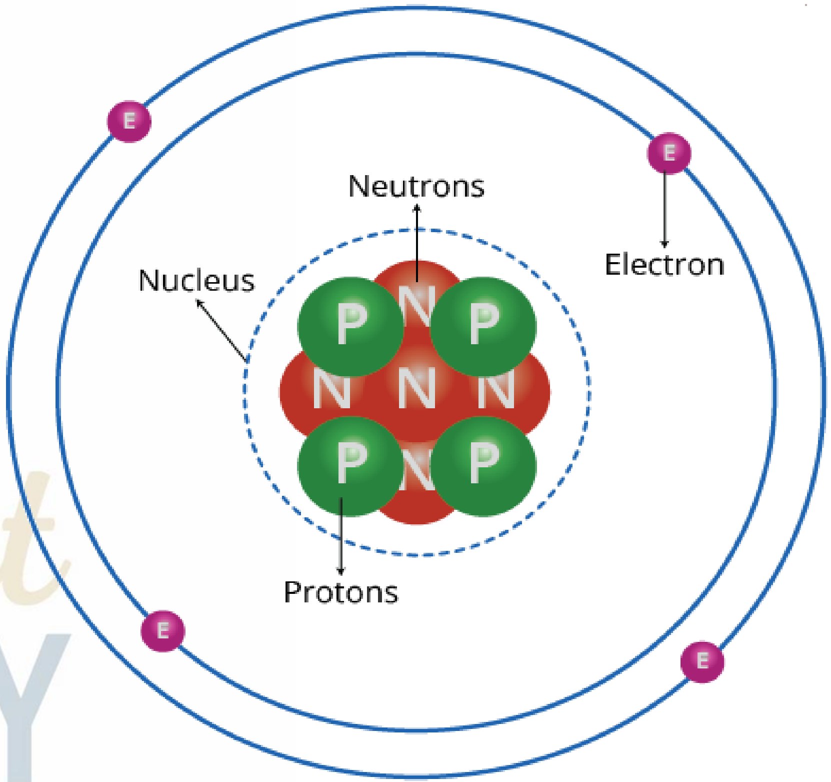
1. Identify the composition of the atom
2. Define the isotopes of an element
3. Determine the dimensions of the atomic nucleus

Composition of the atom

The atom consists of a nucleus and electrons revolving around it.

The nucleus represents the most of the mass of the atom.

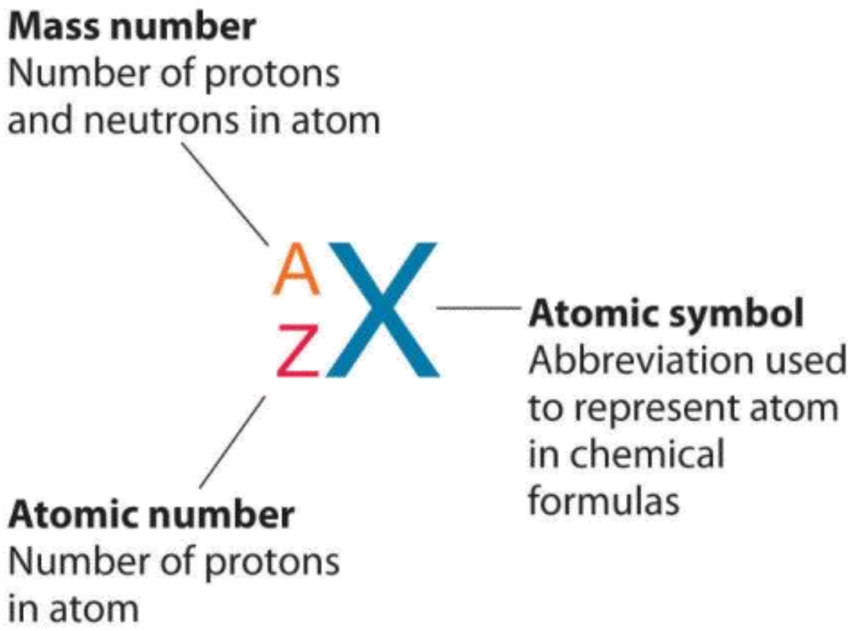
The nucleus contains protons and neutrons both called nucleons.



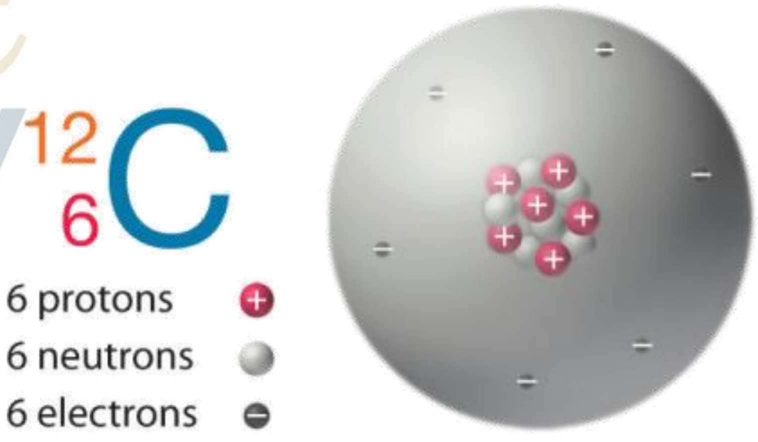
Composition of the atom

An atomic nucleus is symbolized by: ${}^{A}_{Z}X$:

- **X:** symbol of the chemical element (Na, H, C…).
- **Z:** atomic number (charge number) = number of protons (in neutral atom).
- **A:** mass number or number of nucleons (protons +neutrons): $A = Z + N$.

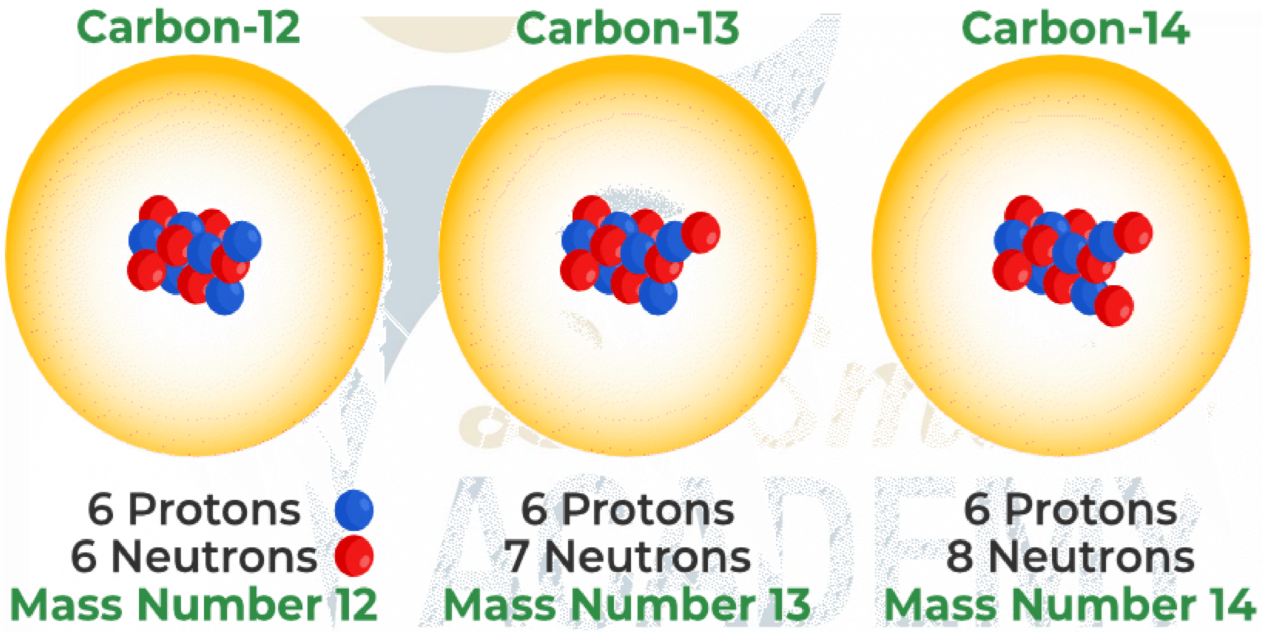


An electron has negative charge, proton has positive charge and neutrons has no charge.



Isotopes of an element

Isotopes of an element are nuclei having the <u>same charge number (Z)</u> but <u>different mass numbers (A)</u>.



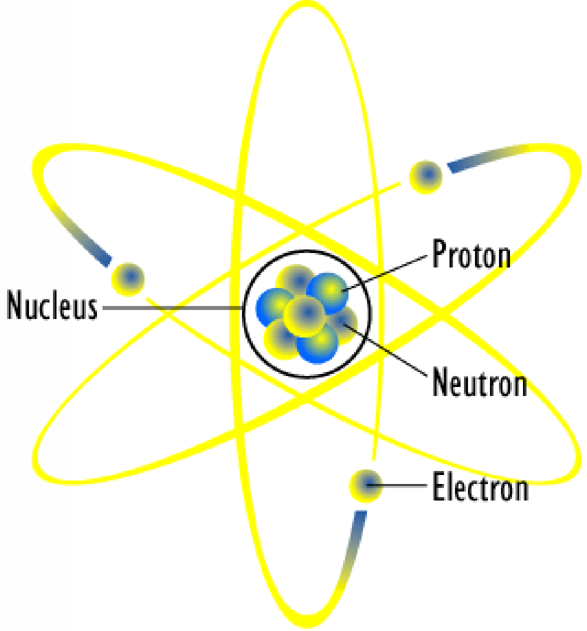
$^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$

Dimensions of the atomic nucleus

Consider a nucleus of radius **r** and of volume **V**. Each nucleon (proton or neutron) is a sphere of radius r_0 and of volume V_0:

$$V = AV_0$$

The volume of the nucleus is: $$V = \frac{4}{3}\pi r^3$$



The volume of the nucleon is: $$V_0 = \frac{4}{3}\pi {r_0}^3$$

Where $r_0 = 1.2 \times 10^{-15}\text{m} = 1.2\text{fm}$

Dimensions of the atomic nucleus

Finally, the relation between the radius of nucleus and that of nucleon is:

$$V = A \times V_0$$

$$\frac{4}{3}\pi r^3 = A \times \frac{4}{3}\pi r_0^3$$

$$r^3 = A \times r_0^3$$

$$r = r_0 \times A^{\frac{1}{3}}$$

Dimensions of the atomic nucleus

Application 1:

Consider a nucleus of uranium-238. Given $r_0 = 1.2 fm$.

1) Calculate the radius of uranium nucleus.
2) The radius of uranium atom is 2×10^4 times greater than that of its nucleus. Deduce the volume of this atom.
3) Among the following nuclei, specify the isotopes of the same element. ${}^{238}_{92}U$; ${}^{3}_{1}X$; ${}^{234}_{92}L$; ${}^{16}_{8}Z$ and ${}^{235}_{92}M$
4) The radius of the nucleus of the oxygen isotope ${}^{A}_{8}O$ is 3.0855fm.

   a) Calculate the mass number of this isotope.

   b) Deduce the number of neutrons inside the nucleus of this isotope.

Dimensions of the atomic nucleus

1) Calculate the radius of uranium nucleus.

$$\mathbf{r} = r_0 \times A^{\frac{1}{3}}$$

$$\mathbf{r} = 1.2 \times 10^{-12} (238)^{\frac{1}{3}}$$

$$\mathbf{r} = 7.44 \times 10^{-15} m$$

Dimensions of the atomic nucleus

2)The radius of uranium atom is 2×10^4 times greater than that of its nucleus. Deduce the volume of this atom.

$$r_{at} = 2 \times 10^4 \times r_0$$

$$r_{at} = 2 \times 10^4 \times 7.44 \times 10^{-15}$$

$$r_{at} = 1.48 \times 10^{-10} m$$

$$V_{at} = \frac{4}{3}\pi r_{at}^3$$

$$V_{at} = \frac{4}{3}\pi (1.48 \times 10^{-10})^3$$

$$V_{at} = 1.37 \times 10^{-29} m^3$$

Dimensions of the atomic nucleus

3) Among the following nuclei, specify the isotopes of the same element. ${}^{238}_{92}U$; ${}^{3}_{1}X$; ${}^{234}_{92}L$; ${}^{16}_{8}Z$ and ${}^{235}_{92}M$

The isotopes of the same element are ${}^{238}_{92}U$; ${}^{234}_{92}L$ and ${}^{235}_{92}M$, since they have the same charge number but different mass numbers

Dimensions of the atomic nucleus

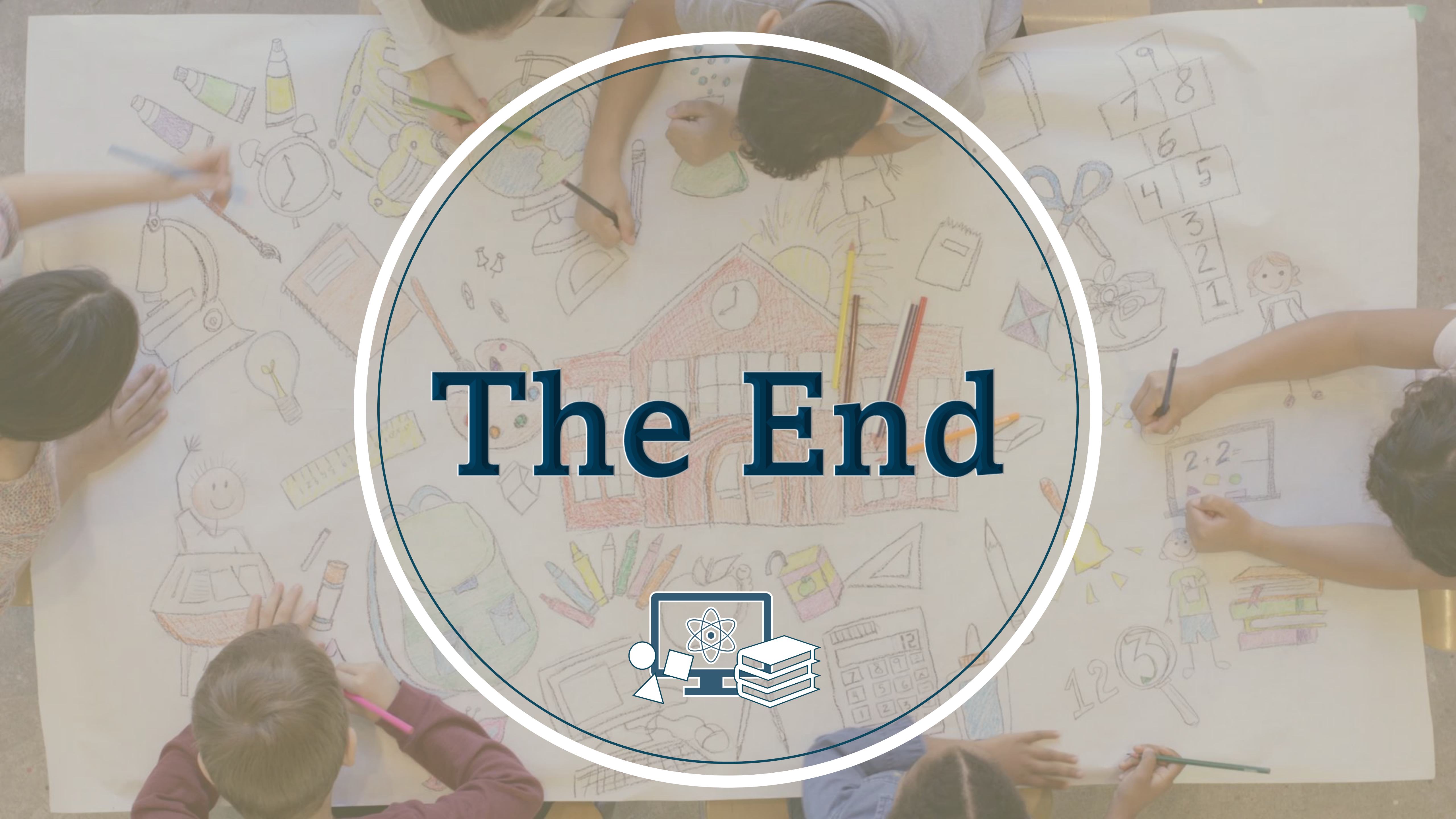
4) The radius of the nucleus of the oxygen isotope $^{A}_{8}O$ is 3.0855fm.

a)Calculate the mass number of this isotope.

$$A = (\frac{r}{r_0})^3 \Rightarrow A = (\frac{3.0855 \times 10^{-15}}{1.2 \times 10^{-15}})^3 \Rightarrow A = 17$$

b)Deduce the number of neutrons inside the nucleus of this isotope.

$$N = A - Z = 17 \Rightarrow N = 17 - 8 \Rightarrow N = 9$$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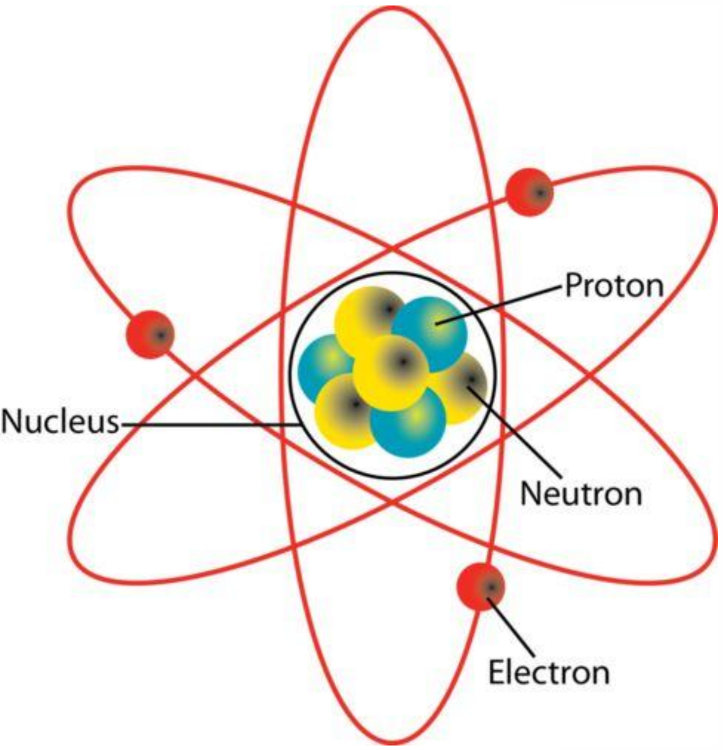
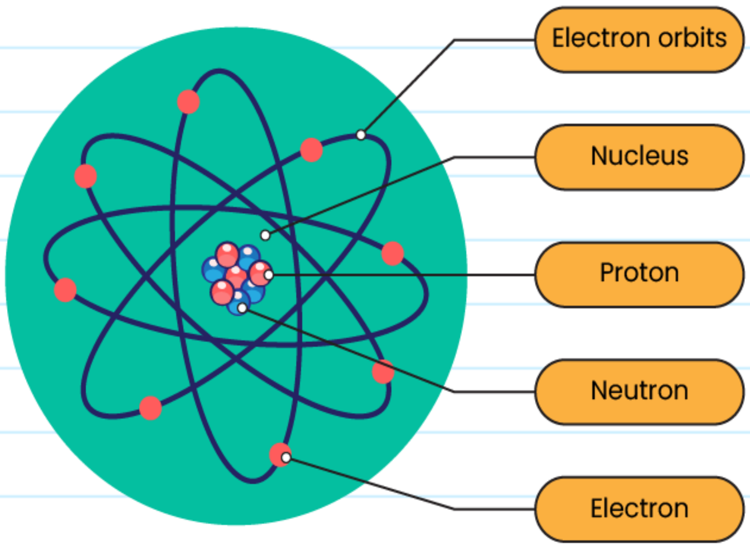


Chapter 18

Atom nucleus



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OBJECTIVES

4 **Calculate the mass and density of nucleus**

5 **Determine and use Units of mass**

Mass and density of the atomic nucleus

The mass of a nucleus represents 99.93% of the mass of the atom.

The mass of the electrons in the electronic cloud is negligible relative to the mass of the nucleus then:

$$m_{atom} = m_{elec} + m_{nucleus} \Rightarrow m_{atom} = m_{nucleus}$$

$$m_{atom} = m_{nucleus} = A \times m_0$$

Where m_0 is the mass of a nucleon

$$m_0 = m_P = m_N = 1.67 \times 10^{-27} kg$$

Mass and density of the atomic nucleus

The density ρ of the atomic nucleus is given by:

$$\rho = \frac{m}{V}$$

$$\rho = \frac{m}{V} = \frac{A \times m_0}{A \times V_0} = \frac{A \times m_0}{A \times \frac{4}{3}\pi r_0^3}$$

$$r_0 = 1.2 \times 10^{-15} m$$

$$m_0 = 1.67 \times 10^{-27} kg$$

$$\rho = \frac{1.67 \times 10^{-27}}{\frac{4}{3} \times 3.14 \times (1.2 \times 10^{-15})^3} \Rightarrow \rho = 2.3 \times 10^{17} kg/m^3$$

This means the density of any nucleus is $\rho = 2.3 \times 10^{17} kg/m^3$

Mass and density of the atomic nucleus

Application 2:

The approximate mass of a nucleon is $m_0 = 1.7 \times 10^{-27} kg$, and the radius of the hydrogen nucleus is 1.2fm.

Consider the iron isotope $^{56}_{26}Fe$.

1)Determine the volume of the nucleus of this isotope.

2)Deduce the density of the nucleus of this isotope.

Mass and density of the atomic nucleus

$m_0 = 1.7 \times 10^{-27} kg; r_0 = 1.2 \times 10^{-15} m; {}^{56}_{26}Fe.$

1)Determine the volume of the nucleus of this isotope.

$\mathrm{V} = \frac{4}{3}\pi r^3$ And $\mathrm{r} = A r_0^3$ → $\mathrm{V} = \frac{4}{3}\pi A . r_0^3$

$$\mathrm{V} = \frac{4}{3}\pi \times 56(1.2 \times 10^{-15})^3$$

$$\mathrm{V} = 4.05 \times 10^{-43} m^3$$

Mass and density of the atomic nucleus

$m_0 = 1.7 \times 10^{-27} kg; r_0 = 1.2 \times 10^{-12} m; {}^{56}_{26}Fe.$

2)Deduce the density of the nucleus of this isotope.

$$V = 4.05 \times 10^{-43} m^3$$

$$m = m_0 \times A$$

$$\rho = \frac{m}{V} \Rightarrow \rho = \frac{A m_0}{V}$$

$$\rho = \frac{56 \times 1.7 \times 10^{-27} kg}{4.05 \times 10^{-43} m^3}$$

$$\rho = 2.35 \times 10^{17} kg/m^3$$

Units of mass

The SI unit of mass is kg.

In nuclear physics we use another unit " atomic mass unit (u)".

The atomic mass unit is equal to $\frac{1}{12}$ of the mass of carbon atom ($^{12}_{6}C$).

The molar mass of $^{12}_{6}C$ is is M $= 12g \div 1000 = 0.12kg$

The Avogadro's number is $N_A = 6.02217 \times 10^{23}$

$$m\left(^{12}_{6}C\right) = \frac{M}{N_A} = \frac{0.12}{6.02217 \times 10^{23}} = 1.992637 \times 10^{-26} kg$$

Units of mass

$$m({}^{12}_{6}C) = 1.992637 \times 10^{-26} kg$$

$$1u = \frac{1}{2} m_{{}^{12}_{6}C}$$

$$1u = \frac{1}{2} \times 1.992637 \times 10^{-26} kg$$

$$1u = 1.66 \times 10^{-27} kg$$

Units of mass

MeV/c^2

This is a compound unit where MeV is mega-electron-volt

$$1\mathrm{MeV} = 1.6022 \times 10^{-13}\mathrm{J}$$

$c = 3 \times 10^{8}\mathrm{m/s}$ **is the speed of light in vacuum**

The relation between MeV/c^2 and u

$$1\mathrm{u} = 931.5\mathrm{MeV}/c^2$$

Units of mass

Application 3:

The mass of a neutron is $m_n = 1.67491 \times 10^{-27} kg$. Calculate the mass of neutron in u and in MeV/c^2. Given: $1u = 1.66 \times 10^{-27} kg$.

$$1u \quad \rightarrow \quad 1.66 \times 10^{-27} kg$$

$$m = ?? \quad \rightarrow \quad 1.67491 \times 10^{-27} kg$$

$$m = \frac{1u \times 1.67491 \times 10^{-27} kg}{1.66 \times 10^{-27} kg}$$

$$m = 1.00866\, u$$

Units of mass

Application 4:

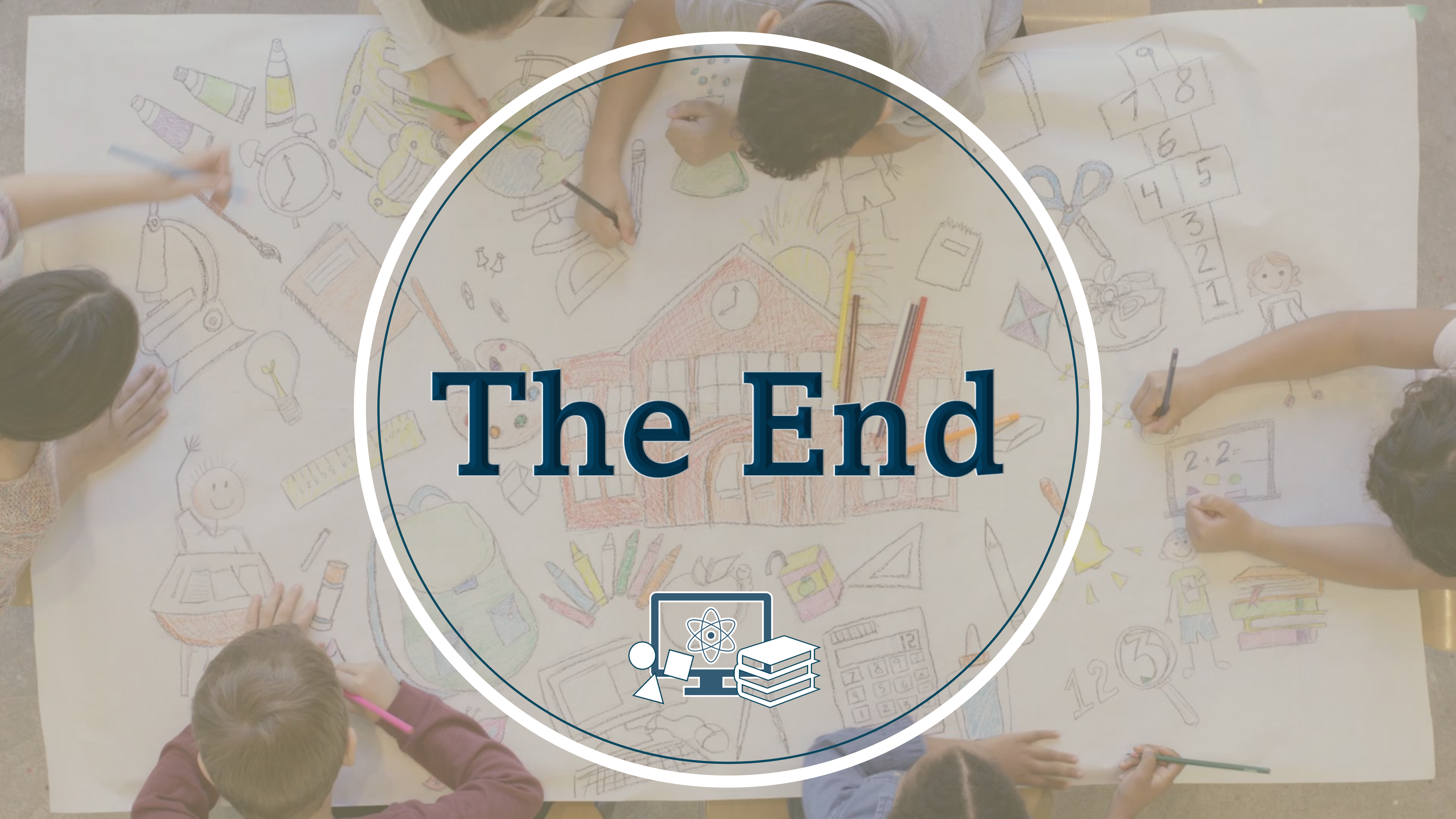
The mass of a Proton is $m_P = 1.00728u$. Calculate the mass of neutron in u and in MeV/c^2. Given: 1u = 931.5MeV /c^2.

$$1u \rightarrow 931.5MeV/c^2$$

$$1.00728\,u \rightarrow m = ??$$

$$m = \frac{1.00728u \times 931.5MeV/c^2}{1u}$$

$$m = 938.3MeV/c^2$$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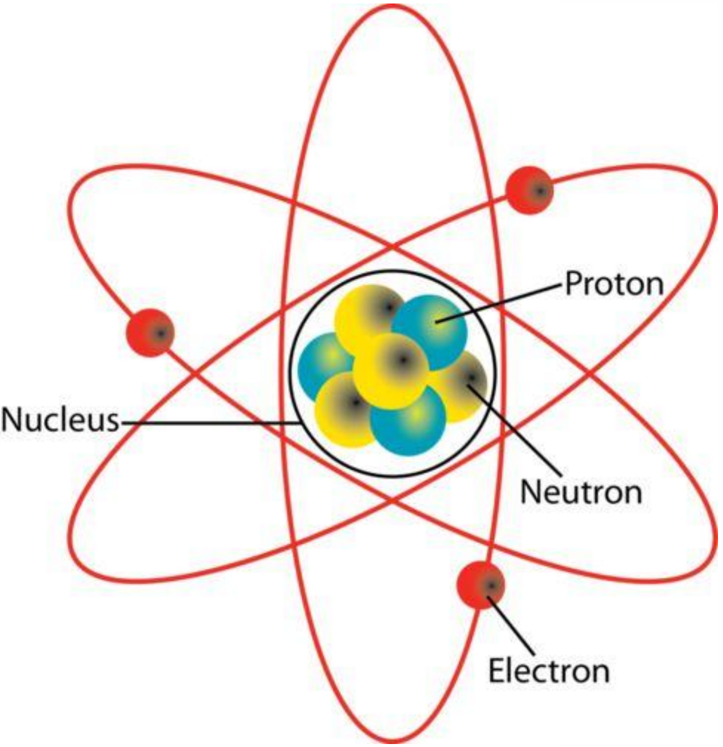
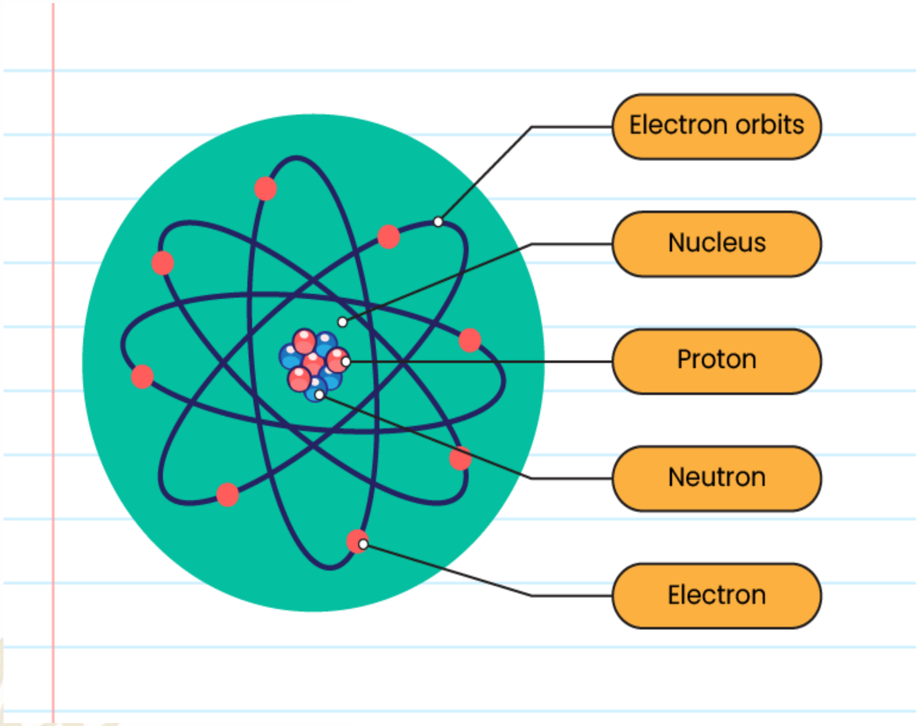


Chapter 18

Atom nucleus



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OBJECTIVES

6	**Calculate the Nuclear Binding energy**
7	**Determine the stability of the atom**

Nuclear Binding energy

To understand the concept of the nuclear binding energy, consider the iron isotope $^{56}_{26}Fe$ of mass $m_{nucleus} = 55.92067u$.

This isotope is composed of 26 protons and 30 neutrons.

The mass of neutron is $m_n = 1.00866u$ and the mass of proton is $m_P = 1.00728u$.

Nuclear Binding energy

The mass of the nucleons forming this nuclide is:

$$Z.m_P + N.m_n = 26(1.00728) + 30(1.00866)$$

$$Z.m_P + N.m_n = 26.18928u + 30.2598u$$

$$Z.m_P + N.m_n = 56.44908u$$

Nuclear Binding energy

$m_{nucleus} = 55.92067u$ **and** $Z.m_p + N.m_n = 56.44908u$

By comparing the above two values we notice that:

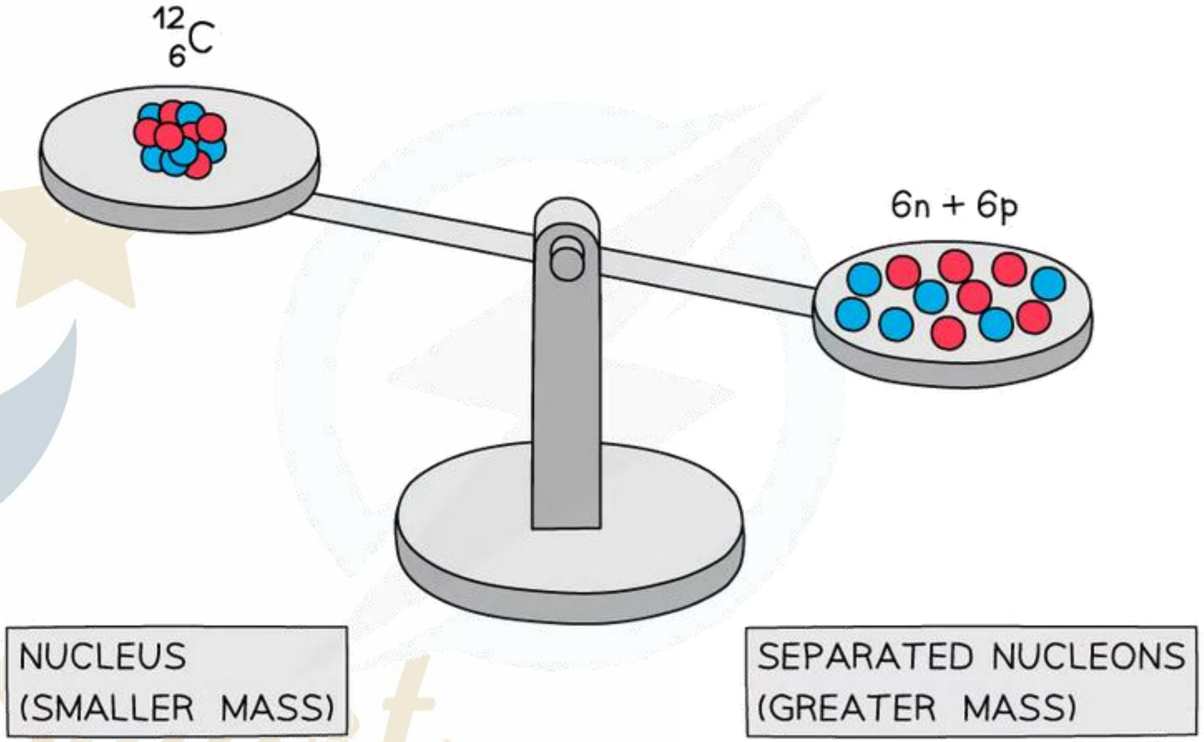
$$m_{nucleus} < Z.m_p + N.m_n$$

This result is true for all nuclei

The mass defect of a nucleus is the difference between the masses of the nucleons taken separately and the mass of nucleus

Nuclear Binding energy

The mass defect (Δm) of a nucleus is the difference between the masses of the nucleons taken separately and the mass of nucleus.



$$\Delta m = [Zm_p + (A - Z)m_n] - m_X$$

Where m_X is the mass of nucleus

Nuclear Binding energy

$$\Delta m = [Zm_p + (A - Z)m_n] - m_X$$

The minimum energy needed to break down the nucleus into nucleons or to bind the nucleons to form a nucleus:

The energy produced in binding the nucleons or the energy needed to break down these nucleons, is called the binding energy (B.E) of the nucleus.

$$B.E = \Delta mc^2 = [Zm_p + (A - Z)m_n - m_X]c^2$$

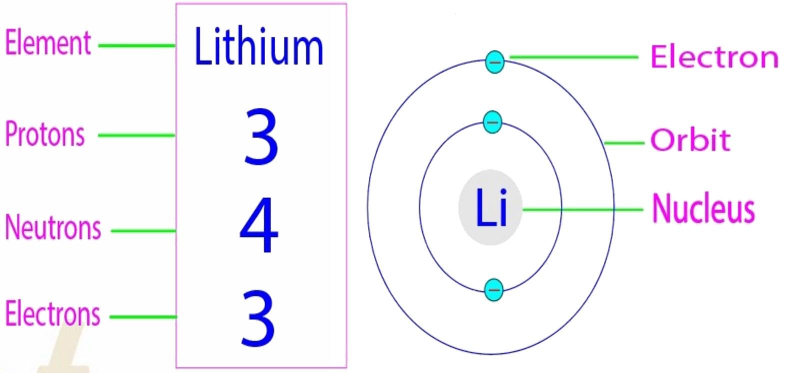
Nuclear Binding energy

Application 5:

The lithium nucleus is formed of 3 protons and 4 neutrons.

$m_{nucleus} = 7.014357u$; $m_n = 1.00728u$; $m_p = 1.00866u$;

$1u = 931.5 MeV/c^2$ and $1eV = 1.6 \times 10^{-19} J$.



Determine the binding energy of this isotope in MeV and in J

Nuclear Binding energy

$$\Delta m = [Zm_p + (A - Z)m_n] - m_X$$

$$\Delta m = [3 \times 1.00728 + 4 \times 1.00866] - 7.014357$$

$$\Delta m = [3.02184 + 4.03464] - 7.014357$$

$$\Delta m = 7.05648 - 7.014357$$

$$\Delta m = 0.042123\text{u}$$

Nuclear Binding energy

$$\Delta m = 0.042123\text{u}$$

$$\Delta m = 0.042123 \times 931.5MeV/c^2$$

$$\Delta m = 39.2376MeV/c^2$$

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

$$B.E = 39.2376\frac{MeV}{\cancel{c^2}} \times \cancel{c^2}$$

$$B.E = 39.2376MeV$$

Nuclear Binding energy

$$B.E = 39.2376MeV$$

$$1\text{MeV} \rightarrow 1.6 \times 10^{-13}\text{J}$$

$$39.2376MeV \rightarrow ??$$

$$B.E = \frac{39.2376MeV \times 1.6 \times 10^{-13}\text{J}}{1MeV}$$

$$B.E = 62.78 \times 10^{-13}.J$$

Stability of the atom

The binding energy per nucleons $\frac{B.E}{A}$ is considered as a measure of the stability of the nuclide.

A nuclide is more stable than another one if the binding energy per nucleon of the first is greater than that of the other.

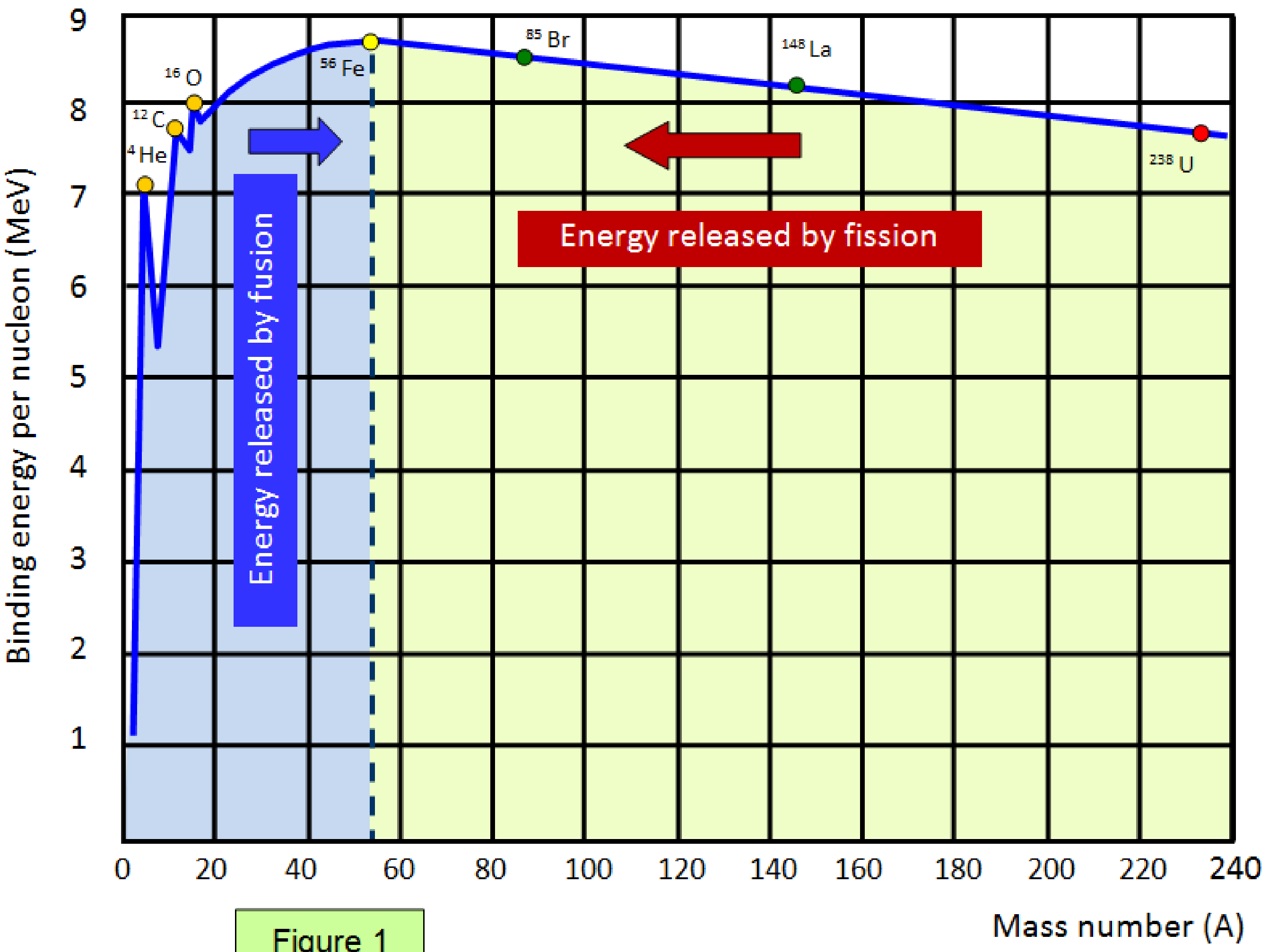


Figure 1

Stability of the atom

For $1 \leq A \leq 20$; $\frac{B.E}{A} < 8Mev$ radioactive(unstable)

For $20 \leq A \leq 190$; $\frac{B.E}{A} \geq 8Mev$: stable nucleus

For $A > 190$; $\frac{B.E}{A} < 8Mev$: radioactive(unstable)

The most stable nuclei are those, whose mass number A is between 20 and 190

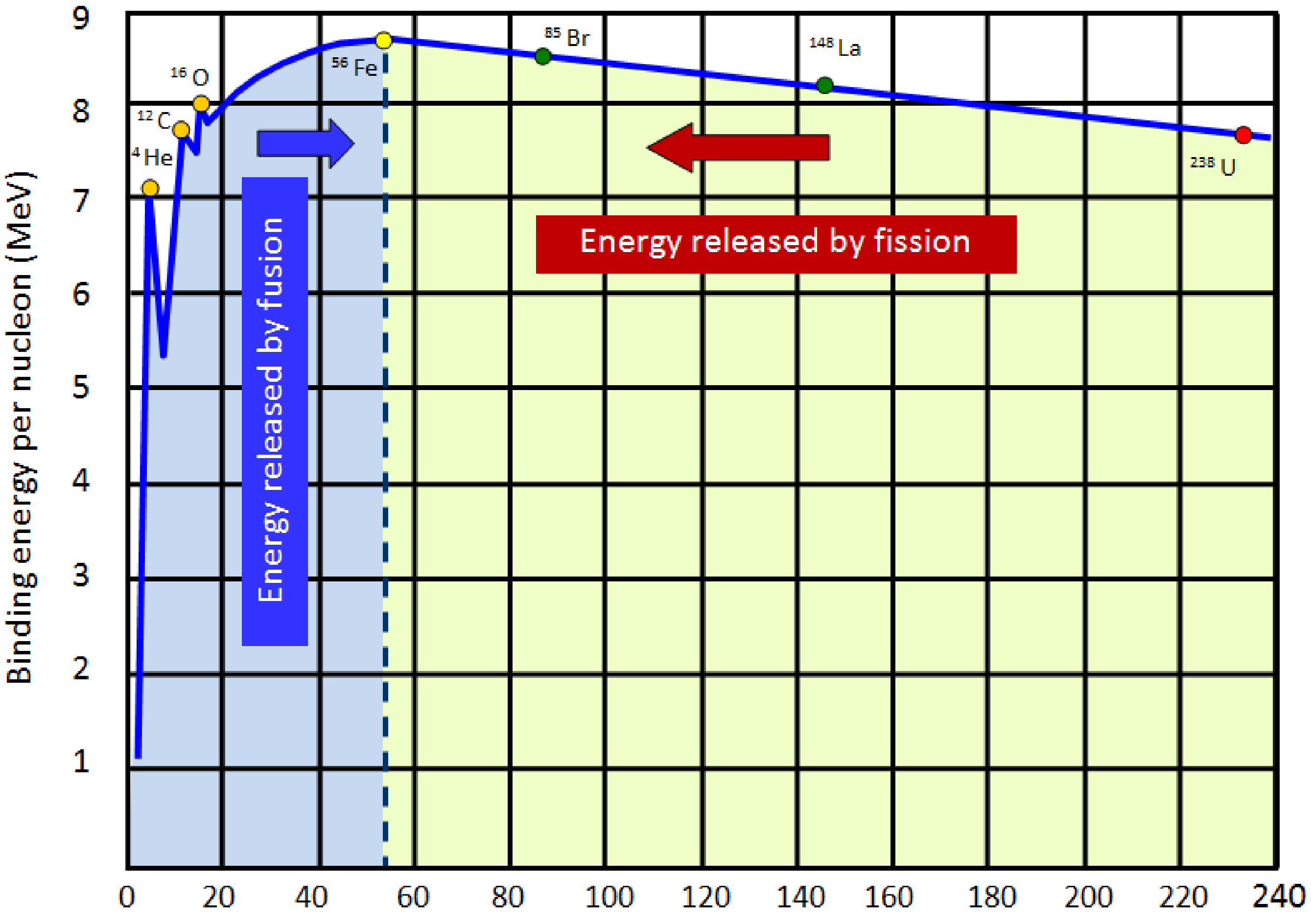


Figure 1

Stability of the atom

Application 6:

The binding energies of radium-226 and iron-56 are 1731.28MeV and 492.20MeV.

1) **Calculate the binding energy per nucleon for each atom.**
2) **Specify which one has the stronger stability.**

Stability of the atom

$\mathbf{BE(Ra) = 1731.28MeV; BE(Fe) = 492.20MeV.}$

1)Calculate the binding energy per nucleon for each atom.

For Radium-226: $\frac{BE}{A} = \frac{1731.28}{226} = 7.6605MeV$

For iron-56: $\frac{BE}{A} = \frac{1731.28}{226} = 8.7894MeV$

2)Specify which one has the stronger stability.

Since $\frac{BE}{A}$ of iron> $\frac{BE}{A}$ of Radium, then iron is more stable

The End