Nuclear Physics

Mass Defect and Nuclear Binding Energy

$$\lambda = \frac{h}{p}$$ ∴ Debroglie's wavelength

$$f\lambda = \frac{fh}{p}$$ ∴ Multiply both sides with f.

$$c = \frac{E}{p}$$ ∴ $v = f\lambda$ → speed of light ⇒ $c = f\lambda$, $E = hf$ → energy of photon

$$E = pc$$

$$E = mc^2$$ ∴ Equation shows energy-mass equivalence → Mass can be converted into energy and vice versa.

- E → binding energy (J)
- m → mass defect (kg)
- c → speed of light (ms^{-1})

Mass Defect

- Experiments reveal that total mass of nucleus is less than its constituents (protons and neutrons).
- This difference is called mass defect
- The difference between the mass of a nucleus and the sum of the individual masses of its protons and neutrons, separated to infinity.

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

DATA BOOKLET

$^{A}_{Z}X$

- A: Mass Number
- Z: Proton Number
- A−Z: No. of neutrons.
- Z: No. of protons.
- m_p: mass of a proton → Given usually in terms of u
- m_n: mass of a neutron → Given usually in terms of u
- M_{total}: mass of a nucleus

$$\Delta m = Zm_p + (A-Z)m_n - m_{total}.$$

Due to energy mass equivalence, the energy released is explained by the decrease in mass.

Since nuclei are made up of protons and neutrons, there are forces of repulsion between protons, hence it takes energy to bind the nucleus (or hold the nucleus together).

Binding Energy

The energy required to break a nucleus into its constituent protons and neutrons.

Energy and Mass are proportional, hence total energy of a nucleus is less than the sum of the energies of its constituent nucleons.

Hence the formation of a nucleus from a system of isolated protons and neutrons is an exothermic reaction.

The energy can be calculated using

$$E = mc^2$$

Q. Find the binding energy released in the formation of a He-4 nucleus.

$^{4}_{2}He$

mass of proton = 1.0073u

mass of neutron = 1.0087u

mass of He-nucleus = 4.0015u

Step 1

Find Δm

Step 2

Find ΔE

Note:
Show that 1u is equivalent to 934 MeV.

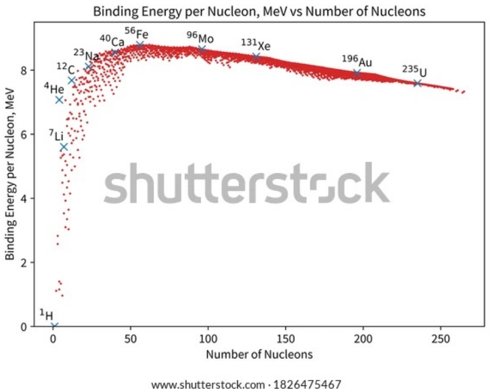
$$\Delta E = \Delta m c^2$$

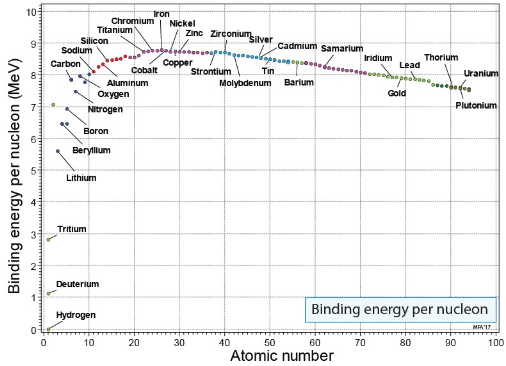
Binding Energy Per Nucleon

- Binding energy is not a measure of stability.
- Binding energy per nucleon is the true measure of stability.

$$\text{Binding Energy Per Nucleon (BEpN)} = \frac{\text{Binding Energy of nucleus}}{\text{Nucleon Number}}$$

- A higher binding energy per nucleon indicates higher stability (greater energy is needed to break the nucleus)





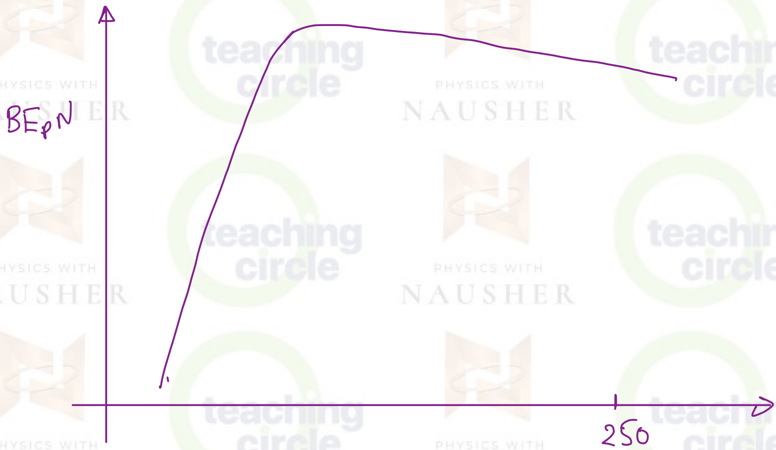
Key features:

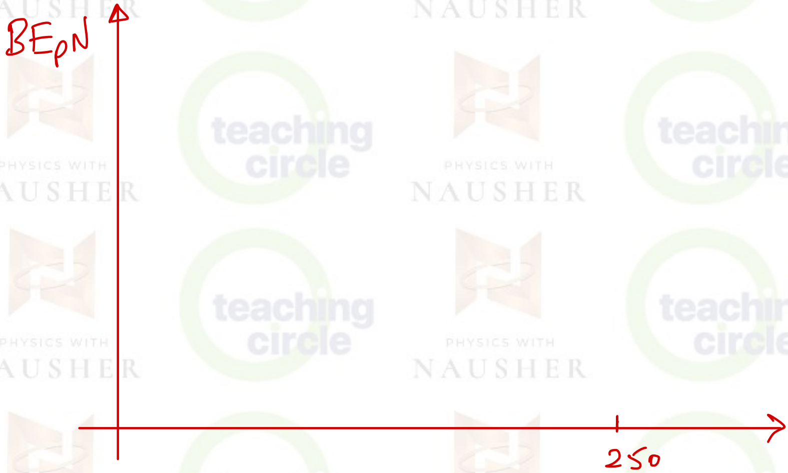
- At low mass numbers, nuclei tend to have low BEpN, hence they are unstable.
- This means, they will most likely undergo fusion.

- At high nucleon numbers, the general BEpN is high and it gradually decreases with increasing mass number.
- This means, the heaviest elements are most unstable and will undergo fission.

• Graph doesn't start from zero. Peak BEpN is for Iron-56.

Note: Identify the problem in the graph.





Note: When a high BEpN nucleus is formed, its protons and neutrons will be more tightly bound, causing a release of energy, making the nucleus more stable.

9 (a) State what is meant by the binding energy of a nucleus.

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(b) Table 9.1 shows the masses of two sub-atomic particles and a polonium-212 ($^{212}_{84}Po$) nucleus.

Table 9.1

	mass/u
proton	1.007 276
neutron	1.008 665
polonium-212 nucleus	211.942 749

For the polonium-212 nucleus, determine:

(i) the mass defect Δm, in kg

Δm = ... kg [3]

(ii) the binding energy

binding energy = ... J [2]

(iii) the binding energy per nucleon.

binding energy per nucleon = ... J [1]

(c) (i) On Fig. 9.1, sketch the variation with nucleon number *A* of binding energy per nucleon for values of *A* from 1 to 250.

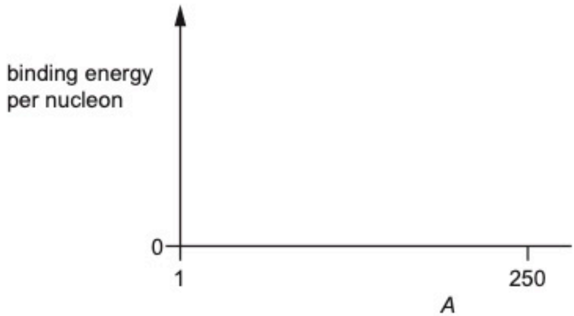

Fig. 9.1

[2]

(ii) On your line in Fig. 9.1, draw an X to show the approximate position of polonium-212. [1]

(iii) Polonium-212 is radioactive and undergoes alpha-decay.

Suggest and explain, with reference to Fig. 9.1, why the alpha-decay of polonium-212 results in a release of energy.

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