Nuclear stability

❖ The nucleus occupies a very small portion of the total volume of an atom, but it contains most of the atom's mass?!

✓ Because both the protons and the neutrons reside there.

It is help full to know something about density of atomic nucleus?!

Because it tells us how tightly the particles are packed together.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

The highest density known for an element is 22.6 g/Cm^3, for Osmium (Os).

Coulomb's Law: → like charges repeal and unlike charges attract one another.

There are two types of force in nucleus

Repulsion force: → between like charges as protons which repel one another particularly when they are closed to each other.

Short-range attraction force: → between proton and proton, proton and neutron and neutron and neutron.

The stability of any nucleus: → the difference between columbic repulsion and the short range attraction.

If repulsion outweighs attraction:
↓
The nucleus disintegrates.

If attraction outweighs repulsion:
↓
The nucleus is stable.

Neutron to proton ratio (n/p):→ Principal factor that determine whether the nucleus is stable.

For stable atoms of element having low atomic number: → n/p value is close to (1).

As atomic number increases: → the neutron to proton ratios become greater than (1).

Predicting nuclear stability

1) Nuclei that contain 2, 8,20,50,82 or 126 protons or neutrons are generally more stable than nuclei that do/not possess these numbers.

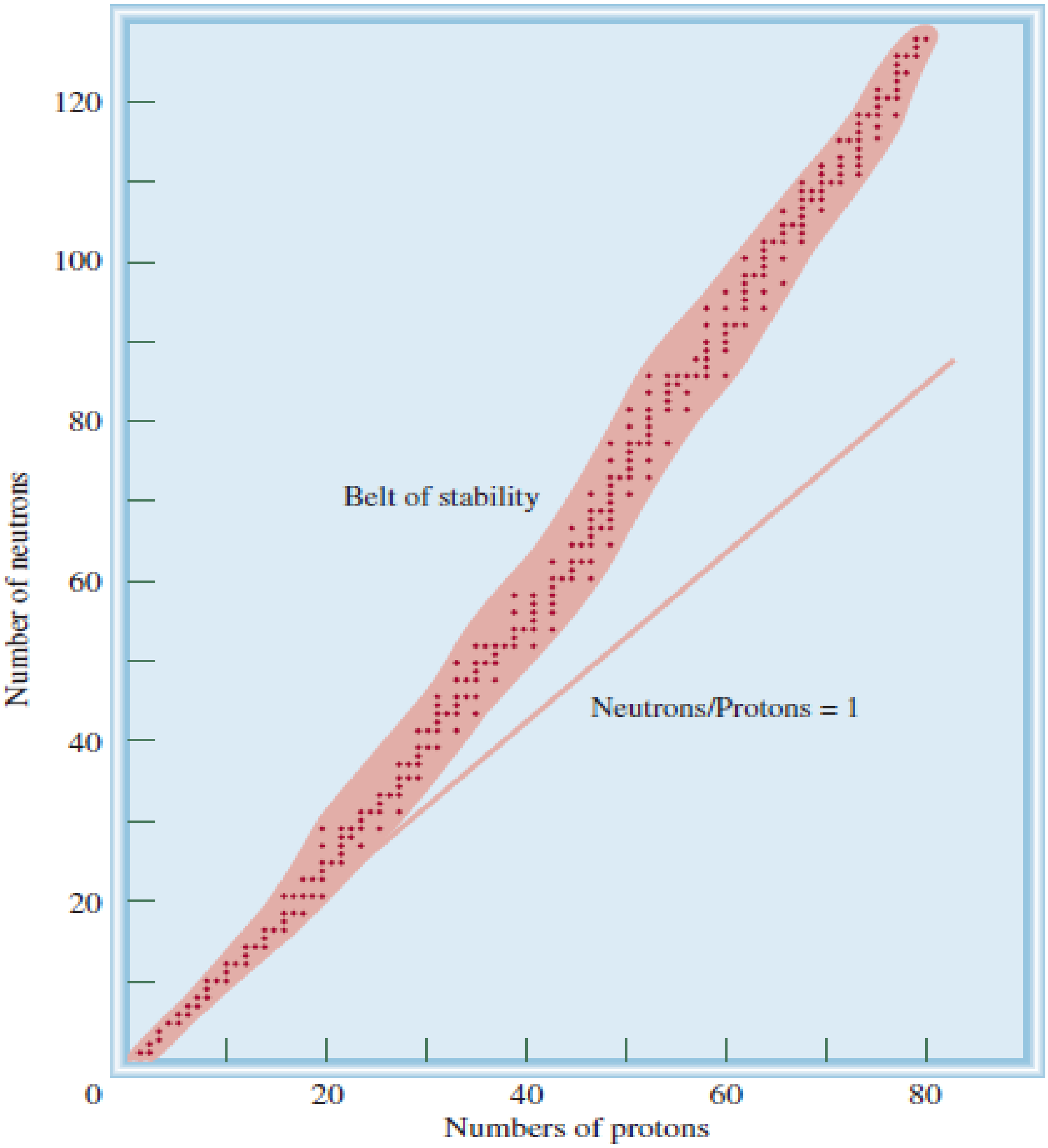
- The numbers 2, 8,20,50,82 and 126 are called magic number.

2) Nuclei with even numbers of both protons and neutrons are generally more stable than those with odd numbers of these particles.

3) All isotopes of elements with atomic numbers higher than 83 are radioactive.

4) All isotopes of technetium (Tc , Z = 43) and promethium (Pm , Z =61) are radioactive.

Plot of neutrons versus protons for versus stable isotopes



Belt of stability: → it's an area of the graph at which the stable nuclei are located in it.

Above the stability belt: → the nuclei have higher neutron to proton ratios than those within the belt.

To lower this ratio, these nuclei undergo β – particle emission.

β – Particle emission → leads to an increase in atomic number by one.

- There is no change in mass number.

$${}^{1}_{0}n \rightarrow {}^{1}_{1}P + {}^{0}_{-1}\beta$$

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$$

$${}^{40}_{19}K \rightarrow {}^{40}_{20}Ca + {}^{0}_{-1}\beta$$

$${}^{97}_{40}Zr \rightarrow {}^{97}_{41}Nb + {}^{0}_{-1}\beta$$

Below the stability belt: → the nuclei have lower neutron to proton Ratios than those within the belt.

To increase this ratio, these nuclei either emit a positron or Undergo electron capture.

Positron emission: → leads to decrease in atomic number by (1).

$$^{38}_{19}K \rightarrow {}^{38}_{18}Ar + {}^{0}_{+1}\beta$$

- There is no change in mass number.

Electron capture: → is the capture of an electron usually a 1st electron by the nucleus.

- The captured electron combines with a proton to form a neutron.
- The atomic number decreases by one.
- The mass number remains the same.

$$^{37}_{18}Ar + {}^{0}_{-1}e \rightarrow {}^{37}_{17}Cl$$

$$^{55}_{26}Fe + {}^{0}_{-1}e \rightarrow {}^{55}_{29}Mn$$

Nuclear binding energy

Nuclear binding energy: → is the energy required to break up a nucleus into its components "protons and neutrons".

- This quantity represents the conversion of mass to energy that occurs during an exothermic nuclear reaction.

Nucleons: → is a general term for the protons and neutrons in a nucleus.

Note that:

- ❖ The mass of nuclei are always less than the sum of the masses of the nucleons.

Mass defect: → The difference between the mass of an atom and the sum of the masses of its components" protons, neutrons and electrons" .

Note that

- ❖ The loss in mass shows up as energy given off to the surroundins.

Einstein's mass energy equivalence relationship

$E = mC^2$ $\Delta E = (\Delta m)\ C^2$

m→Mass.

C→ speed of light.

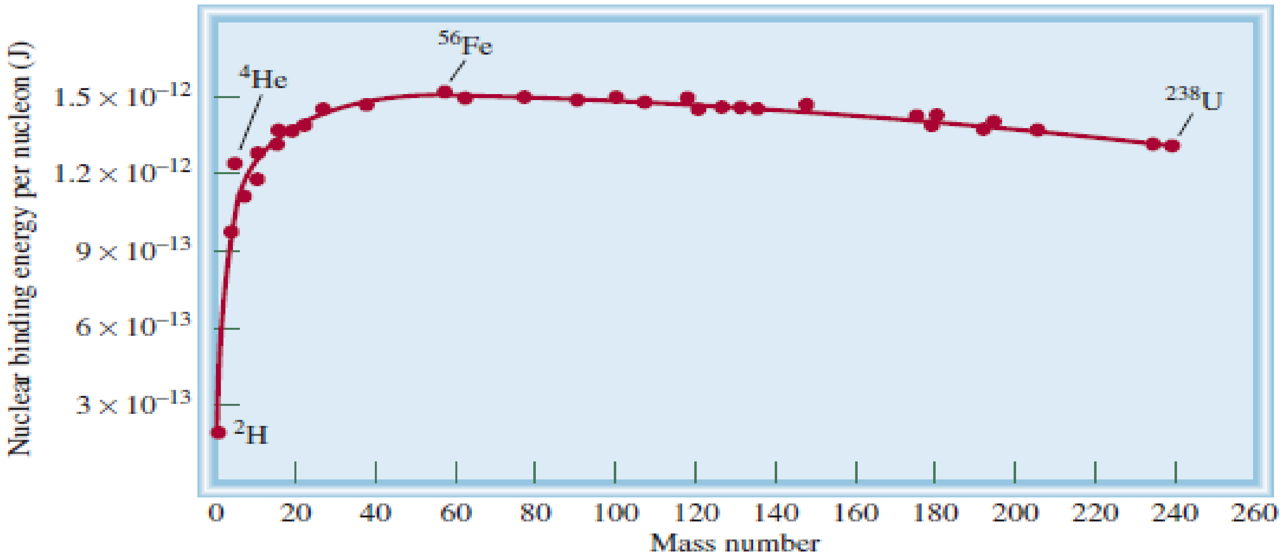
ΔE = energy of product – energy of reactant.

Δm = mass of product – mass of reactant.

What is meant by the nuclear binding energy of the nucleus is $2.37*10^{-11}$ J?

- ✓ Is the amount of energy needed to decompose the nucleus into separate protons and neutrons equal $2.37*10^{-11}$J?

Plot of nuclear binding energy per nucleon versus mass number



Nuclear binding energy is an indication of the stability of a nucleus.

Nuclear binding energy per nucleon enables us to compare the stability of all nuclei on a common basis.

From the figure:

The highest binding energies per nucleon belong to elements with intermediate mass numbers between 40 and 100.

The greatest for elements in the iron, cobalt and nickel region (the group 8 elements) of the periodic table.

This means that

The net attractive forces among the particles (protons and neutrons) are greatest for the nuclei of these elements.

Example

The atomic mass of $^{127}_{53}I$ is 126.9 Amu calculate the nuclear binding energy of this nucleus and the corresponding nuclear binding energy per nucleon.

There are 53 protons and 74 neutrons in the iodine nucleus.

The mass of 53proton is:

$$53*1.007825 = 53.414 \text{ Amu}$$

The mass of 74 neutrons is:

$$74*1.008665 = 74.64\text{Amu}$$

The total mass:

$$53.414 + 74.64 = 128.055$$

Mass defect:

$$\Delta m = 126.9 - 128 = -1.15 \text{ Amu}$$

The energy released

$\Delta E = (\Delta m) C^2$

$$= (-1.1555) * (3*10^8)^2$$

$= -1.04 * 10^{17}$ Amu.m^2/s^2

$$\Delta E = \frac{-1.04 * 10^{17}}{6.02*10^{23}*1000} = -1.73*10^{-10}\text{J}$$

The nuclear binding energy per nucleon is

$$= \frac{1.73 * 10^{-10}}{127} = -1.36*10^{-12}\text{J/nucleon}$$

Choose

1) The nucleus occupies a very small portion of……… of an atom.

A) mass
B) Volume
C) Charge
D) All of the above

2) …... of atomic nucleus tells us how tightly the particles are packed together.

A) mass
B) Volume
C) density
D) charge

3) The highest density known element is ……..

A) Cs
B) Os
C) Ti
D) Mn

4) Like charges………and unlike charges……

A) Attract - repel
B) Attract - attract
C) repel- attract
D) Repel - repel

5) There are ……. Force between protons particularly when they are closed to each other.

A) attraction
B) Short-range-attraction
C) repulsion
D) Long-range attraction

6) There are ……. Force between protons and neutron.

A) attraction
B) repulsion
C) Short-range-attraction
D) Long-range attraction

7) The nucleus …... when repulsion force outweighs attraction force.

A) stable
B) disintegrates
C) decay
D) all of the above

8) For a stable atoms of element having low atomic number the n/p value is……..

A) $\cong 1$
B) > 1
C) < 1
D) $zero$

9) The nucleus ……. when attraction force outweighs repulsion force.

A) disintegrates
B) decay
C) stable
D) all of the above

10) The nuclei that contain ……… numbers are more stable

A) real
B) magic
C) nature
D) relative

11) All isotopes of element with atomic numbers higher than …… are radioactive.

A) 85
B) 73
C) 83
D) 50

12) Its an area of the graph at which the stable nuclei are located in it.

A) Stability line
B) Stability Belt
C) Stability Formula
D) None of them

13) β – particle decay leads to an increase in……… and decrease……

A) Proton - neutron
B) Neutron - proton
C) Electron - proton
D) Neutron - Electron

14) When the nuclei have higher (n/p) ratio, to lower this ratio the nuclei undergo……..

A) Electron capture
B) alpha - emission
C) Beta - emission
D) γ - emission

15) In electron capture, the atomic number …… but mass number……..

A) decrease - increase
B) Increase - decrease
C) Constant - increase
D) decrease - remains

16)………is the energy required to break up a nucleus into its components" protons and neutrons".

A) Mass defect
B) Binding energy
C) kinetic energy
D) Potential energy

17) Protons and neutrons that present in a nucleus are called……..

A) members
B) nucleons
C) atoms
D) All of the above

18) The masses of nuclei are always ………. the sum of the masses of the nucleons.

A) more than
B) equal
C) Less than
D) Greater than

19) The difference between the mass of an atom and the sum of the masses of its protons, neutrons and electron is……

A) Binding energy
B) Mass defect
C) Kinetic energy
D) Potential energy

20) Einstein's mass energy equivalence relationship is………

A) $E = m/C^2$
B) $E = mC^2$
C) $E = mC$
D) $m = EC^2$

21) 6.02×10^{26} amu is equivalent to…….

A) 1 J
B) 1 kg
C) 1 g
D) 1 mol

22) The energy equivalent of 1 amu is……..

A) 5.0×10^{-19} J
B) 5.4×10^{43} J
C) 6.6×10^{9} J
D) 1.5×10^{-10} J

23) 1 joule equals………

A) 1 kg m
B) 1 g m^2 s^2
C) 1 kg m^2/s
D) 1 kg m^2/s^2

24) The isotope with the greatest nuclear binding energy per nucleon is

A) $^{2}_{1}H$
B) $^{4}_{2}He$
C) $^{14}_{6}C$
D) $^{56}_{26}Fe$

25) What is the nuclear binding energy per nucleon, in joules, for $^{25}_{12}Mg$ (atomic mass 24.985839 amu). [Data: $^{1}_{1}H$ (atomic mass) = 1.007825 amu ; $^{1}_{0}n$ (mass) = 1.008665 amu; 1 kg = 6.022×10^{26} amu; c = 3.00×10^{8} m/s]

A) 0.22076 J/nucleon
B) 3.30×10^{-11} J/nucleon
C) 1.32×10^{-12} J/nucleon
D) 0.999 J/nucleon

26) Find the nuclear binding energy of potassium-40 (atomic mass = 39.9632591 amu) in units of joules per nucleon. [Data: neutron mass = 1.674928×10^{-24} g; proton mass = 1.672623×10^{-24} g; electron mass = 9.109387×10^{-28} g; $N_A = 6.0221367 \times 10^{23}$ /mol; c = 2.99792458×10^8 m/s]

A) 1.37×10^{-12} J/nucleon
B) 5.48×10^{-11} J/nucleon
C) 5.64×10^{-11} J/nucleon
D) 2.97×10^{-12} J/nucleon

27) Find the nuclear binding energy of uranium-234 (atomic mass = 234.040947 amu) in units of joules per nucleon. [Data: neutron mass = 1.674928×10^{-24} g; proton mass = 1.672623×10^{-24} g; electron mass = 9.109387×10^{-28} g; $N_A = 6.0221367 \times 10^{23}$ /mol; c = 2.99792458×10^8 m/s]

A) 2.97×10^{-10} J/nucleon
B) 1.27×10^{-12} J/nucleon
C) 1.22×10^{-12} J/nucleon
D) 1.30×10^{-12} J/nucleon

28) Calculate the energy released in joules when one mole of polonium-214 decays according to the equation

$$^{214}_{84}\text{Po} \longrightarrow {}^{210}_{82}\text{Pb} + {}^{4}_{2}\text{He}.$$

[Atomic masses: Pb-210 = 209.98284 amu, Po-214 = 213.99519 amu, He-4 = 4.00260 amu.]

A) 8.78×10^{14} J/mol
B) 7.2×10^{14} J/mol
C) 8.78×10^{11} J/mol
D) -9.75×10^{-3} J/mol

29) Determine how much energy is released when thorium-230 decays

$$^{230}\text{Th} \rightarrow {}^{4}\text{He} + {}^{226}\text{Ra}.$$

According to [Atomic masses: thorium-230 = 230.033127 amu; helium-4 = 4.002603 amu; radium-226 = 226.025403 amu]

A) 3.98×10^{9} kJ/mol
B) 4.60×10^{8} kJ/mol
C) 7.20×10^{11} kJ/mol
D) 4.90×10^{9} kJ/mol

30) Determine how much energy is released when polonium-210 decays

$$^{210}\text{Po} \rightarrow {}^{4}\text{He} + {}^{206}\text{Pb}.$$

According to [Atomic masses: polonium-210 = 209.982857 amu; helium-4 = 4.002603 amu; lead-206 = 205.974449 amu]

A) 4.14×10^{9} kJ/mol
B) 7.20×10^{11} kJ/mol
C) 5.22×10^{8} kJ/mol
D) 4.66×10^{9} kJ/mol