Chapter 02

Nuclei

CONTENT

1. INTRODUCTION

Nuclear physics is a scientific discipline that studies the structure of nuclei, their formation and stability. It mainly focuses on understanding the fundamental nuclear forces in nature and the complex interactions between neutrons and protons. Nuclear Physics is defined as the branch of physics deals with the structure of the atomic nucleus and its interactions.

Experimental nuclear physics drives innovation in scientific instrumentation. Today's research in nuclear physics is enabling a range of new technologies in materials science chemistry, medicine, and biology. The application of nuclear physics lies largely in the field of power generation using nuclear energy. Once the force holding the nucleus was understood, we started splitting and fusing neutrons. The process of splitting the nucleus to generate energy is known as Nuclear Fission and the process of fusing two neutrons to generate energy is known as Nuclear Fusion.

2. NUCLEUS

- **Discovered by :** Rutherford
- **Constituents :** neutrons (n) and protons (p) [collectively known as nucleons]

(i) Neutron : It is a neutral particle. It was discovered by J. Chadwick.

- Mass of neutron, $m_n = 1.6749286 \times 10^{-27}$ kg.

(ii) Proton : It has a charge equal to +e. It was discovered by Goldstein.

- Mass of proton, $m_p = 1.6726231 \times 10^{-27}$ kg, $m_n > m_p$
- **Representation of nucleus of an element**

  ${}_ZX^A$ or ${}^A_ZX$

  where

  X $\Rightarrow$ symbol of the atom

  Z $\Rightarrow$ Atomic number = number of protons

  A $\Rightarrow$ Atomic mass number = total number of nucleons = no. of protons + no. of neutrons.
- Size of nucleus: Order of 10^{-15} m (fermi)
- Radius of nucleus: $R = R_0A^{1/3}$, where $R_0 = 1.1 \times 10^{-15}$ m (which is an empirical constant)

  A = Atomic mass number of atoms.

DETECTIVE MIND

- Density $= \dfrac{\text{mass}}{\text{volume}} \simeq \dfrac{Am_p}{\frac{4}{3}\pi R^3} = \dfrac{Am_p}{\frac{4}{3}\pi (R_0A^{1/3})^3} = \dfrac{3m_p}{4\pi R_0^3} = \dfrac{3\times 1.67\times 10^{-27}}{4\times 3.14\times (1.1\times 10^{-15})^3} = 3 \times 10^{17}\ \text{kg/m}^3$

Nuclei of all atoms have almost same density as nuclear density is independent of the mass number (A) and atomic number (Z).

➢ **Atomic Mass Unit (a.m.u.)**

1 a.m.u. = 1/12 [mass of one atom of $_6C^{12}$ atom at rest and in ground state] = 1.66×10^{-27} kg

Energy equivalence of 1 amu = $1.66 \times 10^{-27} \times (3 \times 10^8)^2$ J = 931.5 MeV.

Particle	Mass in kg	Mass in amu	Rest energy in MeV
Proton	1.67026×10^{-27}	1.007276	938.28
Neutron	1.6750×10^{-27}	1.008665	939.57
Electron	9.1095×10^{-31}	5.48×10^{-4}	0.511

SPOT LIGHT

Isotopes: The nuclei having the same number of protons but different number of neutrons are called isotopes.

Isotones: Nuclei with the same neutron number N but different atomic number(Z) are called isotones.

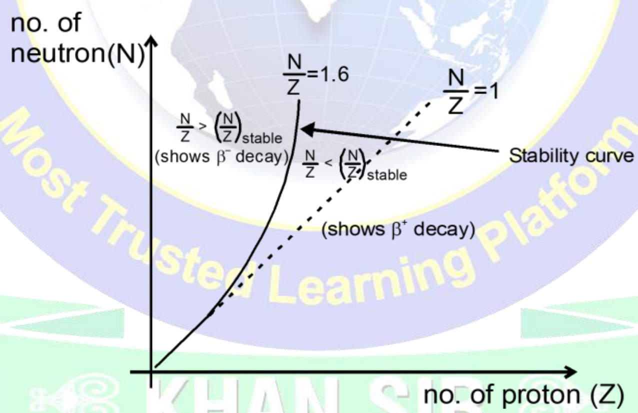
Isobars: The nuclei with the same mass number but different atomic number are called isobars.

3. MASS DEFECT & BINDING ENERGY

3.1 Mass defect :

The difference between sum of individual masses of constituent masses and actual mass of nucleus is known as mass defect.

3.2 Nuclear stability



- Solid line represents stable nuclides
- For light stable nuclides, the no. of neutrons is equal to no. of proton.
- The ratio N/Z increases for heavier nuclides and becomes about 1.6 for heaviest stable nuclides.
- The nuclides left of the stability curve shows β^- decay as they have excess neutron and nuclides right of the stability curve shows β^+ decay and K-capture due to excess of proton.

3.3 Binding Energy :

It is the minimum energy required to break the nucleus into its constituent particles.

OR

Amount of energy released during the formation of nucleus by its constituent particles and bringing them from infinite separation.

Binding Energy (B.E.) = Δmc^2

BE = Δm (in amu) × 931 MeV/amu = Δm × 931 MeV

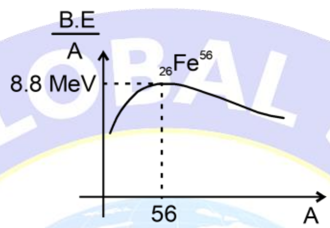
DETECTIVE MIND

If binding energy per nucleon is more for a nucleus then it is more stable.
For example :

If $\left(\frac{B.E_1}{A_1}\right) > \left(\frac{B.E_2}{A_2}\right)$ then nucleus 1 would be more stable than nucleus 2.

3.4 Variation of binding energy per nucleon with mass number :

The binding energy per nucleon first increases on an average and reaches a maximum of about 8.8 MeV for A = 56. For still heavier nuclei, the binding energy per nucleon slowly decreases as A increases.



Binding energy per nucleon is maximum for $_{26}Fe^{56}$, which is equal to 8.8 MeV. Binding energy per nucleon is minimum for deuterium($_1H^2$)

4. RADIOACTIVITY

It was discovered by Henry Becquerel.

Spontaneous emission of radiations (α, β, γ) from unstable nucleus is called **radioactivity**. Substances which shows radioactivity are known as **radioactive substance**.

Radioactivity was studied in detail by Rutherford.

In radioactive decay, an unstable nucleus emits α particle or β particle. After emission of α or β the remaining nucleus may emit γ-particle, and converts into more stable nucleus.

- **α-particle :**

  It is a doubly charged helium nucleus. It contains two protons and two neutrons.

  Mass of α-particle = Mass of $_2He^4$ atom – $2m_e$ = $4m_p$

  Charge of α-particle = + 2 e

- **β-particle :**

  (a) β^- (electron) :

  Mass = m_e ; Charge = –e

  (b) β^+ (positron) :

  Mass = m_e ; Charge = +e

  positron is an antiparticle of electron.

- **γ-particle :**

  They are energetic photons of energy of the order of MeV and having rest mass zero.

- **Antiparticle :**

  A particle is called antiparticle of other if on collision both can annihilate (destroy completely) and converts into energy. for example : (i) electron (– e, m_e) and positron (+ e, m_e) are anti particles. (ii) neutrino (ν) and antineutrino ($\bar{\nu}$) are anti particles.

5. GROUP-DISPLACEMENT LAW

(1) When a nuclide emits one α-particle ($_2He^4$), its mass number (A) decreased by 4 units and atomic number (Z) decrases by two units.

$$_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 + \text{Energy}$$

(2) When a nuclide emits a β^-particle, its mass number unchanged but atomic number increases by one unit.

$_ZX^A \rightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + \bar{\nu}$ + Energy, ($\bar{\nu}$ is antineutrino)

(3) When a nuclide emits a β^+ particle, its mass number remains unchanged but atomic number decreases by one unit

$_ZX^A \rightarrow {}_{Z-1}Y^A + {}_{-1}e^0 + \nu$ + Energy, (ν is neutrino)

(4) When a γ produced, both atomic and mass number remain constant.

6. NEUTRINO AND ANTI-NEUTRINO

(1) It has zero electric charge, hence shows no electromagnetic interaction.

(2) Rest mass is possibly zero. Recent experiments show that mass is neutrino is less than $\left(\frac{7}{c^2}\text{eV}\right)$.

(3) It travels with speed of light.

(4) It has spin quantum number 1/2. A spin of 1/2 satisfies the law of conservation of angular momentum when applied to β-decay.

(5) It shows very weak interactions with matter.

(6) Whenever a neutron is produced, a neutrino is also produced.

(7) Whenever a neutron is converted into a proton, an antineutrino is produced.

SOLVED EXAMPLES

Example: 1 Calculate the radius of ^{70}Ge.

(1) 2.53 fm (2) 4.53 fm (3) 6.53 fm (4) 0.53 fm

Solution: We have,

$R = R_0 A^{1/3} = (1.1 \text{ fm}) (70)^{1/3}$

$= (1.1 \text{ fm}) (4.12) = 4.53$ fm.

Example: 2 Calculate the electric potential energy of interaction due to the electric repulsion between two nuclei of ^{12}C when they 'touch' each other at the surface

(1) 5.1 MeV (2) 2.55 MeV (3) 10.2 MeV (4) 21.1 MeV

Solution: The radius of a ^{12}C nucleus is

$R = R_0 A^{1/3}$

$= (1.1 \text{ fm}) (12)^{1/3} = 2.52$ fm.

The separation between the centres of the nuclei is 2R = 5.04 fm. The potential energy of the pair is

$$U = \frac{q_1q_2}{4\pi\varepsilon_0 r}$$

$$= (9 \times 10^9 \text{ N–m}^2/\text{C}^2)\ \frac{(6\times1.6\times10^{-19}\text{ C})^2}{5.04\times10^{-15}\text{ m}}$$

$= 1.64 \times 10^{-12}$ J = 10.2 MeV.

Example: 3 Following data is available about 3 nuclei P, Q & R. Arrange them in decreasing order of stability

	P	Q	R
Atomic mass number (A)	10	5	6
Binding Energy (MeV)	100	60	66

(1) Q > R > P (2) P > R > Q (3) P > Q > R (4) Q > P > R

Solution: $\left(\frac{B.E}{A}\right)_P = \frac{100}{10} = 10$

$\left(\frac{BE}{A}\right)_Q = \frac{60}{5} = 12$

$\left(\frac{B.E.}{A}\right)_R = \frac{66}{6} = 11$

$\therefore$ Stability order is Q > R > P.

Example: 4 The three stable isotopes of neon: ${}^{20}_{10}Ne$, ${}^{21}_{10}Ne$ and ${}^{22}_{10}Ne$ have respective abundances of 90.51%, 0.27% and 9.22% . The atomic masses of three isotopes are 19.99 u, 20.99 u and 22.00 u, respectively. Obtain the average atomic mass of neon.

(1) 10.09 u (2) 5.45 u (3) 15.27 u (4) 20.18 u

Solution: $m = \frac{90.51 \times 19.99 + 0.27 \times 20.99 + 9.22 \times 22}{100} = 20.18$ u

Example: 5 A nuclear reaction is given as

$A + B \rightarrow C + D$

Binding energies of A, B, C and D are given as

B_1, B_2, B_3 and B_4

Find the energy released in the reaction

(1) $(B_1 + B_2) - (B_3 + B_4)$ (2) $(B_3 + B_4) - (B_1 + B_2)$

(3) $(B_1 + B_3) - (B_2 + B_4)$ (4) $(B_2 + B_4) - (B_1 + B_3)$

Solution: $(B_3 + B_4) - (B_1 + B_2)$

Example: 6 Calculate the binding energy of an alpha particle from the following data:

mass of ${}^{1}_{1}H$ atom = 1.007826 u

mass of neutron = 1.008665 u

mass of ${}^{4}_{2}He$ atom = 4.00260 u

Take 1 u = 931 MeV/c^2.

(1) 7.1 MeV (2) 14.2 MeV (3) 28.4 MeV (4) 56.8 MeV

Solution: The alpha particle contains 2 protons and 2 neutrons. The binding energy is

$B = (2 \times 1.007826\ u + 2 \times 1.008665\ u - 4.00260\ u)c^2$

$= (0.03038\ u)c^2$

$= 0.03038 \times 931$ MeV = 28.4 MeV.

Example: 7 Find the binding energy of ${}^{56}Fe$. Atomic mass of ${}^{56}_{26}Fe$ is 55.9349 u and that of ${}^{1}H$ is 1.00783 u. Mass of neutron = 1.00867 u.

(1) 492 MeV (2) 988 MeV (3) 1492 MeV (4) 1982 MeV

Solution: The number of protons in $^{56}_{26}Fe$ = 26 and the number of neutrons = 56 – 26 = 30.

The binding energy of $^{56}_{26}Fe$ is

= [26 × 1.00783 u + 30 × 1.00867 u – 55.9349 u] c^2

= (0.52878 u)c^2

= (0.52878 u) (931 MeV/u) = 492 MeV.

Example: 8 When $_{90}Th^{228}$ transforms to $_{83}Bi^{212}$, then find number of the emitted α and β-particles.

(1) $\alpha \to 4, \beta \to 1$ (2) $\alpha \to 1, \beta \to 4$ (3) $\alpha \to 2, \beta \to 3$ (4) $\alpha \to 5, \beta \to 3$

Solution: $_{Z=90}Th^{A=228} \to _{Z'=83}Bi^{A'=212}$

Number of α-particles emitted

$$n_\alpha = \frac{A - A'}{4} = \frac{228 - 212}{4} = 4$$

Number of β-particles emitted $n_\beta = 2n_\alpha - Z + Z'$

= 2 × 4 – 90 + 83 = 1.

Example: 9 Calculate the

(a) energy released in α-decay of ^{238}U

(1) 2.14 MeV (2) 4.28 MeV (3) 1.07 MeV (4) 0.56 MeV

(b) maximum KE of the emitted α-particle. The atom A masses of thorium, uranium and α-particle are 234.04364u, 238.05084u and 4.0026u respectively.

(1) 4.03 MeV (2) 2.12 MeV (3) 1.07 MeV (4) 0.56 MeV

Solution: The reaction can be given as

$^{238}U \to {}^{234}Th + \alpha$

(X) (Y)

(a) The energy of reaction is

Q = $[m_X - (m_Y + m_\alpha)]$ 931.5 meV]

= [238.0508 – (234.0436 + 4.0026)] × 931.5 MeV = 4.28 MeV

(b) The KE of the α-particle is

$$K_\alpha = \frac{m_Y}{m_Y + m_\alpha} Q$$

$$= \frac{234.0436}{234.0438 + 4.0026}(4.28)\text{MeV} = 4.03\text{MeV}$$

Example: 10 Neon-23 decays in the following way

$^{23}_{10}Ne \to {}^{23}_{11}Na + {}^{0}_{-1}e + \bar{\nu}$

Find the minimum and maximum kinetic energy that the beta particle ($^{0}_{-1}e$) can have.

The atomic masses of ^{23}Ne and ^{23}Na are 22.9945 u and 22.9898 u, respectively.

(1) 0 and 4.4 MeV (2) 0 and 8.8 MeV

(3) 2.2 MeV and 4.4 MeV (4) 4.4 MeV and 8.8 MeV

Solution: Here, atomic masses are given (not the nuclear masses), but still we can use them for calculating the mass defect because mass of electron get cancelled both sides. Thus, Mass defect

Δm = (22.9945 – 22.9898) = 0.0047 u

$\therefore$ Q = (0.0047 u) (931.5 MeV/u)

= 4.4 MeV

Hence, the energy of beta particles can range from 0 to 4.4 MeV

Example: 11 A gamma ray photon creates an electron-positron pair. If the rest mass energy of an electron is 0.5 MeV and the total kinetic energy of the electron-positron pair is 0.78 MeV, then what will be the energy of the gamma ray photon ?

(1) 0.78 MeV (2) 1.78 MeV (3) 1.28 MeV (4) 0.28 MeV

7. NUCLEAR FORCE

- Strong nuclear force is created between necleons by exchange of particles called mesons.
- It is strongest force within nuclear dimensions
- It is short range force (acts only inside the nucleus)
- It is not due to mass or charge of the particle
- It is not due to interaction of paticles with field.
- Nuclear force is not a central force. It does not act along the line joining the particle.
- It is non-conservation in nature.
- If distance between nucleons is smaller than 1fm then nuclear force is repulsive.
- Strong nuclear force is responsible for binding of nucleus.
- Nuclear force is same for all nucleons at same distance, $F_{PP} = F_{NN} = F_{NP}$.
- The nuclear force is stronger if spins of nucleons are parallel (i.e both nucleons ms = + 1/2 or – 1/2) and is weaker if the spins are anti-parallel.

Conservation Laws in nucleus

(1) Conservation of mass & energy : In nuclear reaction, mass and energy are not conserved separately.

Mass is a form of energy. Total mass and energy will be conserved.

mass + energy $\rightarrow$ conserved

(2) Conservation of linear momentum : In any nuclear reaction, total linear momentum is always conserved.

(3) Conservation of angular momentum: In any nuclear reaction, total angular momentum remains conserved.

(4) Conservation of charge : In any nuclear reaction, total charge is always conserved.

(5) Conservation of mass no. : In any nuclear reaction, sum of no. of neutrons and protons remains conserved.

(6) Conservation of lepton no. (L) : When one particle transfer to the other then lepton no. remains conserved.

For electron L = 1

Positron L = –1

Neutrino L = 1

Anti Nutrino L = –1

8. NUCLEAR FISSION & FUSION

(i) NUCLEAR FISSION:

The splitting of heavy nucleus into two or more fragments of comparable masses, with an enormous release of energy is called nuclear fission.

- When slow neutrons are bombarded on ${}_{92}U^{235}$, the fission takes place according to reaction

${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3({}_{0}n^{1}) + 200$ MeV

(a) In nuclear fission the sum of masses before reaction is greater than the sum of masses after reaction, the difference in mass being releases in the form fission energy.

(b) The phenomenon of nuclear fission was discovered by Otto Hans and F. Strassmann in 1939 and was explained by N. Bohr and J.A. Wheeler on the basis of liquid drop model of nucleus.

(c) It may be pointed out that it is not necessary that in each fission we get same daughter nuclides. if uranium breaks in two fragments Ba^{141} and Kr^{92} are formed but they may be any stable isotopes of middle weight atoms. The most probable division is into two fragments containing about 40% and 60% of the original nucleus with the emission of 2 or 3 neutrons per fission. So, average number of neutrons produced per fission is 2.5.

(d) Most of energy released appears in the kinetic energy of fission fragments.

(e) The fission of U^{238} takes place by fast neutrons.

Chain Reaction :

If on average more than one of the neutrons produced in each fission are capable of causing further fission, the number of fissions taking placed at successive stages goes increasesing at a rapid rate, giving rise to self sustained sequence of fission known as chain reaction. the chain reaction takes place only if the size of the fissionable material is greater than a certain size the critical size.

Uncontrolled Chain Reaction :

In this process the number of fissions in a given interval on the average goes on increasing and the system will have the explosive tendency. This forms the principle of atom bomb. If a nuclear reaction is uncontrolled then in about 1 μs, energy of order of 2×10^{13} J is released.

Controlled Chain Reaction :

In this process the number of fissions in a given interval is maintained constant by absorbing a desired number of neutrons. This forms the principle of nuclear reatort, consisting of the following parts :

(a) **Fuel :** The fuel is U^{235} or U^{233} or Pu^{239}

(b) **Moderator :** A moderator is a suitable material to slow down neutrons produced in the fission. The best choice as moderator are heavy water (D_2O) and graphite (C).

(c) **Controller :** To maintain the steady rate of fission, the neutron absorbing material known as controller is used. The control rods are made of cadmium or Boron-steel.

(d) **Coolant :** To remove the considerable amount of heat produced in the fission process, siutable cooling fluids known as coolants, are used. The usual coolants are water, carbon-dioxode, air etc.

(e) **Reactor shiled :** The intense neutrons and gamma radiation produced in nuclear reactors are hermful for human body. To protect the workers from such radiations, the reactor core is surrounded by concerate wall, called the reactor shiled.

(f) U^{238} is non - fissile, it can not support a chain reaction.

Critical mass : If the amount of uranium is too small, then the liberated neutrons have large scope to escape from the surface and the chain reaction may stop before enough energy is released for explosion. Therefore, in order for explosion to occur, the mass uranium has to be greater than some minimum value, called the **critical mass**.

Multiplication Factor :

It is the ratio of the rate of neutron production and the rate at which the neutrons disappear. Whether a mass of active material will sustain a chain reaction or not is determined by the multiplication factor (K). If

K = 1, the chain reaction will be sustained. If K = 1, the mass is said to be critical size and rector is called critical reactor.

(ii) NUCLEAR FUSION :

The phenomenon of combination of two or more light nuclei to form a heavy nucleus with release of enormous amount of energy is called the nuclear fusion. The sum of masses before fusion must be greater than the sum of masses after fusion, the difference in mass appearing as fusion energy. The fusion of two deuterium nuclei into helium is expressed as

$_1H^2 + {}_1H^2 \to {}_2He^4 + 23.8$ MeV

It may be pointed out that fusion reaction does not actually occur. Due to huge quantity of energy release, the helium nucleus $_2He^4$ has got such a large value of excitation energy that it breaks up by the emission of a proton or a neutron as soon as it is formed, giving rise to the following reactions.

$_1H^2 + {}_1H^2 \to {}_2He^3 + {}_0n^1 + Q(= 3.26\text{ MeV})$

$_1H^2 + {}_1H^2 \to {}_1H^3 + {}_1H^1 + Q(= 4.04\text{ MeV})$

The fusion process occurs at extremely high temperature and high pressure just as it takes place at sun where temperature is 10^7K. So, fusion reactions are also called Thermo-nuclear reactions.

- Nuclear fusion has the possibility of being a much better source of energy than fission due to the following reasons.
  (a) In fusion there is no radiation hazard as no radioactive material is used.
  (b) The fuel needed for fission (U-235 etc.) is not available easily whereas hydrogen needed for fusion can be obtained in huge quantity.
  (c) The energy released per nucleon is much more in fusion than in fission.

However, the very high temperature and pressure required for fusion cannot be easily created and maintained and as such it has not been possible as yet to use fusion for power generation.

Uses of Radioactive isotopes :

(i) In Medicine :

- Co^{60} for treatment of cancer
- Na^{24} for circulation of blood
- I^{131} for thyroid
- Sr^{90} for treatement of skin & eye
- Fe^{59} for location of brain tumor
- radiographs of castings and teeth

(ii) In Industries :

For detecting leakage in water and oil pipe lines for investigation of wear & tear, study of plastics & alloys, thickness measurement.

(iii) In Agriculture :

C^{14} to study kinetics of plant photosynthesis.

P^{32} to find nature of phosphate which is best for given soil & crop

Co^{60} for protecting potato crop from earth worm.

Sterilization of insects for pest control.

(iv) In Scientific research :

- K^{40} to find age of meteorites
- S^{35} in factories

(v) Carbon dating :

- It is used to find age of earth and fossils
- The age of earth is found by Uranium disintegration and fossil age by disintegration of C^{14}.
- The estimated ege of earth is about 5×10^9 years.
- The half life of C^{14} is 7500 years.

(vi) As Tracers:

- A very small quantity of radio isotope present in any specimen is called tracer.
- This technique is used to study complex biochemical reactions, in detection of cracks, blockage etc., tracing sewage or silt in sea

(vii) In Geology :

- For dating geological specimens like ancient rocks, lunar rocks using Uranium
- For dating archaeological specimens, biological specimens using C^{14}.

SOLVED EXAMPLES

Example: 12 In a nuclear reactor, fission is produced in 1 g for U^{235} (235.0439) in 24 hours by slow neutrons (1.0087 u). Assume that ${}_{35}Kr^{92}$ (91.8973 u) and ${}_{56}Ba^{141}$ (140.9139 amu) are produced in all reactions and no energy is lost.

(i) Write the complete reaction

(1) ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1$

(2) ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 2{}_0n^1$

(3) ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + {}_0n^1$

(4) ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 4{}_0n^1$

(ii) Calculate the total energy produced in kilowatt hour.

Given 1 u = 931 MeV.

(1) 1.14×10^4 kWh (2) 4.04×10^4 kWh (3) 2.28×10^4 kWh (4) 3.28×10^4 kWh

Solution: The nuclear fission reaction is ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_0n^1$

Mass defect $\Delta m = [(m_u + m_n) - (m_{Ba} + m_{Kr} + 3\, m_n)] = 236.0526 - 235.8373 = 0.2153$ u

Energy released Q = 0.2153 × 931 = 200 MeV. Number of atoms in 1 g

$= \dfrac{6.02\times10^{23}}{235} = 2.56\times10^{21}$

Energy released in fission of 1 g of U^{235} is $E = 200 \times 2.56 \times 10^{21} = 5.12 \times 10^{23}$ MeV

$= 5.12 \times 10^{23} \times 1.6 \times 10^{-13} = 8.2 \times 10^{10}$ J

$= \dfrac{8.2\times10^{10}}{3.6\times10^{6}}\text{kWh} = 2.28\times10^{4}\text{ kWh}$

Example: 13 What is the power output of ${}_{92}U^{235}$ reactor if it takes 30 days to use up 2 kg of fuel and if each fission gives 185 MeV of usable energy? Avogadro's number = 6.02×10^{26} per kilomole.

(1) 45 megawatt (2) 58.46 megawatt (3) 72 megawatt (4) 92 megawatt

Solution : Number of atoms in 2 kg fuel

$\frac{2}{235} \times 6.02\times10^{26} = 5.12\times10^{24}$

Fission rate = Number of atoms fissioned in one second

$= \frac{5.12\times10^{24}}{30\times24\times60\times60}$

$= 1.975\times10^{18} s^{-1}$

Each fission gives 185 MeV. Hence, energy obtained in one second.

$P = 185\times1.975\times10^{18} MeV\ s^{-1}$

$= 185\times1.975\times10^{18} \times1.6\times10^{-19}\ Js^{-1} = 58.46\ MW$

Example: 14 The energy released per fission of uranium 235 is about 200MeV. Areactor using U-235 as fuel is producing 1000 kilowatts power. The number of U-235 nuclei undergoing fission per sec is, approximately-

(A) 10^6 (B) 2×10^8 (C) 3×10^{16} (D) 931

Solution: The energy produced per second is

$= 1000 \times 10^3\ J = \frac{10^5}{1.6\times10^{-19}}\ eV = 6.25 \times 10^{24}\ eV$

The number of fissions should be, thus :

$\text{number} = \frac{6.25\times10^{24}}{200\times10^6} = 3.125 \times 10^{16}$

QUICK FOLLOW UP

NUCLEAR PHYSICS

Size of Nucleus

Radius of a Nucleus

$R = R_0 A^{1/3}$

Mass Defect

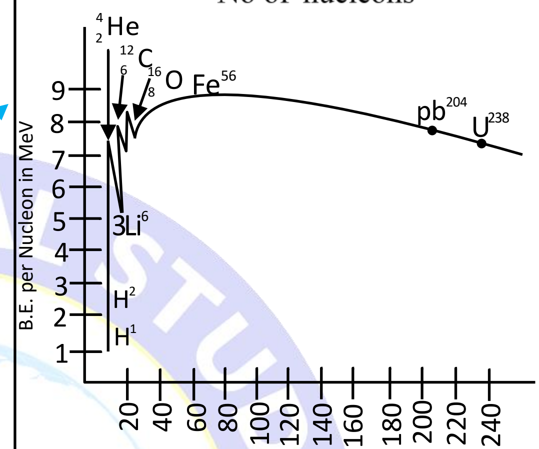
$\Delta M = [Zm_p + (A-Z)\, m_n] - M$

Binding Energy of Nucleus

$B.E. = \Delta Mc^2 = [Zm_p + (A-Z)\, m_n - M] \times c^2$

Binding Energy of Nucleus

$$\text{per Nucleon} = \frac{B.E.}{\text{No of nucleons}}$$

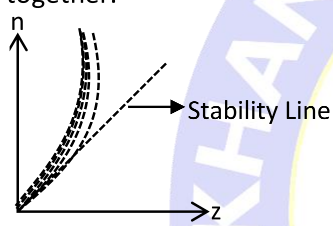


Density of Nucleus

$$\frac{\text{Mass}}{\text{Volume}} = \frac{\text{Mass of Nuclues(A)}}{\frac{4}{3}\pi R^3}$$

Nuclear Force Theory

Nuclear force is a force which hold the Nucleon together.



For atomic number < 20, most Stable Nuclei have n : p ratio nearly 1 : 1

For n/p ratio > 1.52, Nucleus is unstable.

For atomic number > 83,

Nuclear Fusion and Fission

Fusion

$^4_2He + ^6_3Li \rightarrow ^{10}_5B$

Fission

$^{235}_{92}He + ^1_0n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^1_0n$