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NUCLEI AND RADIOACTIVITY

Atom is the smallest entity that acts as the building block of all matter.

It consists of an extremely small central core, called the nucleus, around which electrons revolve in certain specified orbits. Though nucleus is very tiny, it is amazingly complex and

THE ATOMIC NUCLEUS

Charge and Mass

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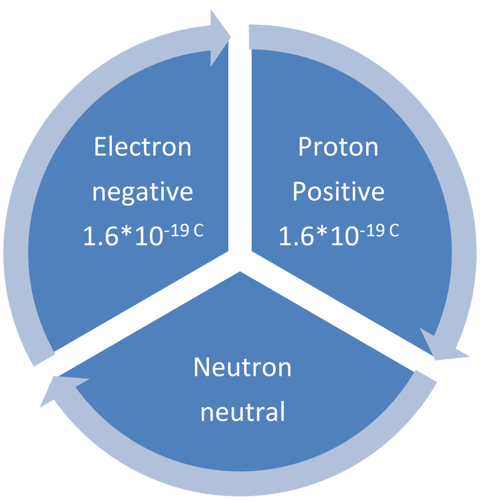


The number of neutrons in a nucleus is usually denoted by N = A – Z. Usually N > Z. The difference (N–Z) increases as A increases.

Size

The sizes of atomic nuclei are usually quoted in terms of their radii. Many nuclei are nearly spherical in shape and the radius R is given approximately by the formula $R = r_0 A^{1/3}$

Here r_0 is the unit nuclear radius and its numerical value is taken as 1.2 fermi, a unit of length in honour of famous physicist Enrico Fermi

Notation

The nucleus of an atom is represented by the chemical symbol of the element, with the A value as its superscript and Z value as its subscript; both on the left hand side of the chemical symbol. Thus if the chemical symbol of an element is, say, X, its nucleus is represented by ${}^{A}_{Z}X$

Unified Atomic Mass

The unit of atomic mass, abbreviated as u, is defined as (1/12)th of the actual mass of ${}^{12}_{6}C$. We know that the value of the mass of a carbon atom is 1.99267×10^{-26} kg. Hence

$$1u = (1/12) \times \text{mass of one carbon atom with } A = 12$$
$$= (1/12) \times (1.99267 \times 10^{-26} kg)$$
$$= 1.660565 \times 10^{-27} kg$$
$$= 1.66 \times 10^{-27} kg$$

Mass Defect and Binding Energy

The mass of the nucleus of an atom of any element is always found to be less than the sum of the masses of its constitutent nucleons. This difference in mass is called mass-defect

Sum of the masses of the nucleons $= Zm_p + (A-Z)m_n$

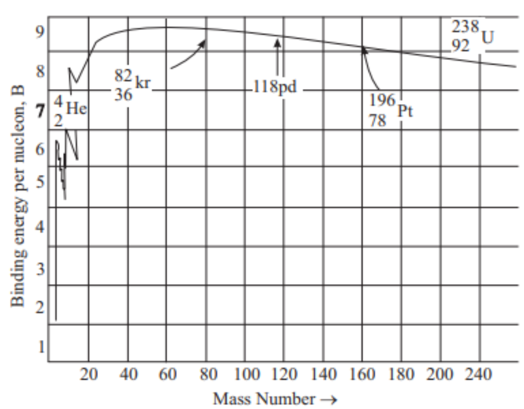
$\therefore \quad \Delta m = [Z.m_p + (A-Z)m_n] - M$

where M is actual mass of nucleius.

mass defect appears as energy which binds the nucleons together.

Binding Energy per nucleon, B= $\Delta m\, c^2/A$

or $$B = \frac{[Zm_p + (A-Z)m_n - M]c^2}{A}$$



HOW DO NUCLEONS CLING TOGETHER : NUCLEAR FORCE

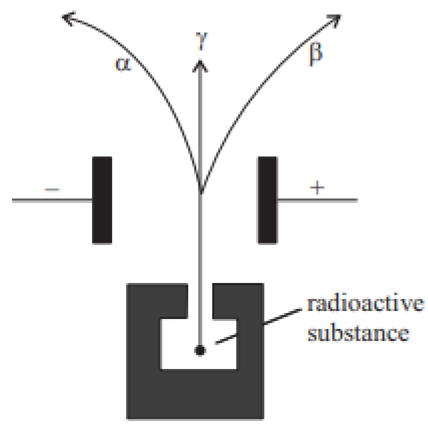
Characteristic Properties

- the gravitational as well as electrostatic forces obey inverse square law
- These nuclear forces must account for the attractive force between : – a proton and a neutron; – two protons; and – two neutrons.
- nuclear force is charge independent.

RADIOACTIVITY

a natural phenomenon in which atoms emit radiations to attain stability

Nature of Radiations



- Lord Rutherford established the existence of two distinct components : α-particles and β-rays. The existence of third radiation – gamma rays – was established by P. Villard
- The emitted radiation is called the radioactive radiation and the process of disintegration (break-up) of atomic nuclei (by emitting α, β and γ-rays) is called radioactive decay
- Sometimes, the break-up can be induced by bombarding stable nuclei with other light particles (like neutron and protons). It is then called artificial radio-activity.

α-particles

- Alpha particles are helium nuclei (^4_2He) and consist of two protons and two neutrons. Being charged particles, they get deflected in electric and magnetic fields.
- They produce fluorescence in substances like zinc sulphide and barium platino cyanide, affect a photographic plate, can induce radioactivity in certain elements and produce nuclear reactions.
- They have great ionizing power. A single particle in its journey through a gas can ionize thousands of gas atoms before being absorbed.
- They have little penetration power through solid substances, and get scattered by thin foils of metals.
- They can be stopped by 0.02 mm thick aluminum sheet.
- The energies of α particles emitted from a radioactive substance is a characteristic of the emitting nucleus. This corresponds to a variation in their velocity from 1.4×10^7 m s–1 to 2.05×10^7 m s–1.

β-particles

- β-Particles can be both positively and negatively charged.
- They originate in the nucleus in the process of conversion of a neutron into a proton, and vice versa. Further studies of β-particles have revealed the following properties.
- Being charged particles, they get deflected by electric and magnetic fields.
- They produce fluorescence in materials like zinc-sulphide and barium plationcynide; and affect photographic plates.
- They can ionize gas atoms but to a much smaller extent than the α-particles.
- Negatively charged β-particles can pass through a few mm of aluminium sheets. They are about 100 times more penetrating than α-particles.
- Average energies of negative β-particles vary between 2 MeV and 3MeV. Due to their small mass, their velocities vary in range from 0.33c to 0.988c, where c is velocity of light.

(iii) γ-rays

γ-rays are electromagnetic waves of high frequency, and as such highly energetic. They are characterized with the following properties :

- They do not get deflected by electric or magnetic fields. They travel with velocity of light in free space.
- Their penetration power is more than that of α and β-particles; γ-rays can penetrate through several centimeters of iron and lead sheets.
- They have ionizing power that is smaller compared to that of α and β-particles.
- They can produce fluorescence in materials and affect a photographic plate.

Radioactive Decay

In any radioactive decay,

- spontaneous emission consists of either a single αparticle or a β-particle.
- The emission of an α-particle from a radioactive nucleus (called parent nucleus) changes it into a new nucleus (new element is called daughter nucleus) with its atomic

number decreased by two and its mass number decreased by four.

- Similarly, emission of a β particle changes the parent nucleus into a daughter nucleus with its atomic number increased by unity (if it is β– emission) but its mass number remains unchanged.
- The emission of γ-rays does not change the atomic number or the mass number of the parent nucleus and hence no new nucleus is formed.

$$ {}^{A}_{Z}X \xrightarrow{\alpha-\text{decay}} {}^{4}_{2}He + {}^{A-4}_{Z-2}Y $$
(α-particle)

$$ {}^{A}_{Z}X \xrightarrow{\beta-\text{decay}} {}^{0}_{-1}e + {}^{A}_{Z-1}Y $$
(β-particle)

$$ ({}^{A}_{Z}X)^{*} \xrightarrow{\gamma-\text{decay}} {}^{A}_{Z}X + \gamma $$

Law of Radioactive Decay

The number of radioactive atoms disintegrating per second is proportional to the number of radioactive atoms present at that instant of time. This is called law of radioactive decay.

$$ \frac{dN(t)}{dt} \propto N, $$

$$ \frac{dN(t)}{dt} = -\lambda N(t) $$

$$ \lambda = -\frac{1}{N(t)} \frac{dN(t)}{dt} $$

Thus, decay constant (λ) may be defined as the ratio of the instantaneous rate of disintegration to the number of radioactive atoms present at that instant.

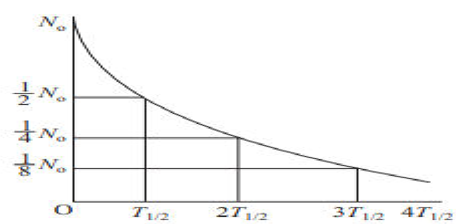
Half time

The half life (T1/2) of any radioactive element is defined as the time in which the number of parent radioactive atoms decreases to half of the initial number. By definition, at t = T1/2, N = N0 /2

$$ N_0/2 = N_0 \exp(-\lambda T_{1/2}) $$

or $\lambda T_{1/2} = \log_e 2$

or
$$ T_{1/2} = \frac{\log_e 2}{\lambda} = \frac{2.303 \times \log_{10} 2}{\lambda} = \frac{2.303 \times 0.3010}{\lambda} = \frac{0.693}{\lambda} $$



CheckYourself

1. Radioactive substance do not emit
   A. Neutrons
   B. Alpha rays
   C. Beta rays
   D. Gamma rays

2. The half life of a radioactive elements depend on
   - A. Temperature
   - B. Pressure
   - C. Nature of element
   - D. Quantity of radioactive element
3. Which of the following statement istrue
   - A. Radioactivity is a statistical process
   - B. Radioactivity is a spontaneous process
   - C. Radioactivity is a neutral characteristic of some element
   - D. Radioactive elements cannot be produced in the laboratory
4. The half life of a radioactive decay is n times its mean life, n is equal to
   - A. 0.6930
   - B. 0.06930
   - C. 1/0.6930
   - D. 0.3070
5. The life of a radioactive substances 30 days. The substance will disintegrate completely in
   - A. 30days
   - B. 300 days
   - C. 3000 days
   - D. Infinite time

Stretch Yourself

1. Define the following terms: (i) Atomic number; (ii) Mass number; (iii) Mass defect; (iv) Binding energy of nucleons; (v) Half-life; (vi) Average life; (vii) Decay constant.
2. If the activity of a redioactive sample drops to 1/16 th of its initial value in 1 hour and 20 minutes, Calculate the half-life
3. State the law of radioactive decay
4. Write the characteristics of alpha decay

Hint to Check Yourself

1 A 2 C 3 D 4 A 5D