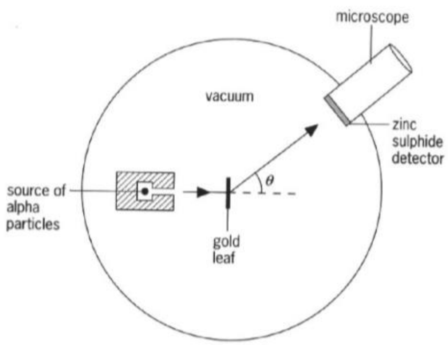
NUCLEAR PHYSICS

α-particle scattering experiment



In all nuclear reactions, the following are conserved.

- Nucleon number
- Proton number
- Mass-energy
- Momentum

- Most α-particles were hardly deflected: atom is largely empty space. Nucleus is small.
- A few were scattered through large angles of more than 90°, even deflecting backwards.
- Nucleus massive and positively charged.

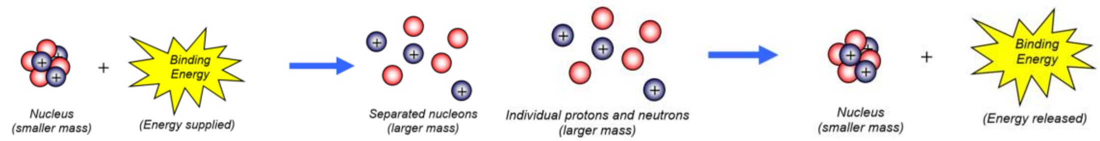
Definitions

- A nucleon is a constituent of the nucleus i.e. a proton or a neutron.
- A nuclide is a species of atomic characterized by the constitution of its nucleus and hence by the no. of protons and neutrons.
- Nuclide notation: A - Nucleon number. Z - Proton number.

$$^{A}_{Z}X$$

- Isotopes are atoms with the same no. of protons but different number of neutrons.
- One unified atomic mass unit (U) is one-twelfth the mass of the carbon-12 atom. U - 1.66x10^{-27}kg.

Energy from Nuclear Reactions



Mass Defect, Binding Energy and Nuclear Stability:

Mass defect of nucleus:

$$\Delta M = Zm_p + (A - Z)m_n - M_{nucleus}$$

Mass defect of atom:

$$\Delta M = Zm_p + (A - Z)m_n + Zm_e - M_{atom}$$

Binding energy of a nucleus: Energy needed to separate the nucleus into its constituents.

Binding energy of atom: Energy needed to separate the atom into its constituents.

Mass-Energy equivalence: E= mc^2, where E is the Binding Energy, m is the mass defect and c is the speed of light.

Binding energy per nucleon: Average energy needed to remove a nucleon from the nucleus: BE of nucleus divided by no. of nucleons.

Nuclear Stability: The higher the binding energy per nucleon, the more stable the nucleus is.

Very small nuclei tend to form stable nuclei through <u>Fusion</u>: two smaller nuclei join together to make a larger nucleus.

Very large nuclei can split to form a more stable nuclei through <u>Fission</u>: a large nucleus splits into smaller nuclei, usually of comparable size.

Calculating Energy Released:

i) Energy released = (mass of reactants - mass of products) x c^2
ii) Energy released = binding energy of products - binding energy of reacts
iii) Energy absorbed = (mass of product - mass of reactants) x c^2
iv) Energy absorbed = binding energies of reactants = binding energies of products

Note that the mass difference in (i) and (iii), the mass difference should be called mass difference and not mass defect.

Mathematics of Radioactive Decay

Activity, A, (s^{-1} or Bq), rate of decay of number of disintegrations (of undecayed nuclei, N) per unit time.

$$A = -\frac{dN}{dt}$$

Decay constant, λ: Activity divided by number of undecayed nuclei. It is the probability per unit time that a nucleus will decay.

$$\lambda = \frac{A}{N}$$

Variation of Activity A, no. of undecayed nuclei N and count rate C with time:

$$A = A_0 e^{-\lambda t}$$

$$N = N_0 e^{-\lambda t}$$

$$C = C_0 e^{-\lambda t}$$

Half life, $t_{1/2}$: average time taken for half of the original no. of nuclei in a sample of radioactive nuclide to decay, or average time taken for the activity of a sample of radioactive nuclide to half.

$$t_{\frac{1}{2}} = \frac{ln2}{\lambda}$$

Variation of Activity A, number of undecayed nuclei N and count rate C with number of half-lives:

$$\frac{A}{A_0} = (1/2)^{No.of\ half-lives}$$

$$\frac{N}{N_0} = (1/2)^{No.of\ half-lives}$$

$$\frac{C}{C_0} = (1/2)^{No.of\ half-lives}$$

Radioactive Decay:

a **spontaneous** (not triggered by external factors or influences) and **random** (Unable to predict which nucleus or when a particular nucleus will decay) process where an unstable nucleus changes into a different nuclide, emitting radiation as it does so.

Types of radioactive decay:

Alpha Decay (an α-particle is a helium nucleus)

$${}^{A}_{Z}A \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

Beta Decay (an β-particle is an electron)

$${}^{A}_{Z}A \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}e$$

$${}^{A}_{Z}A \rightarrow {}_{Z-1}^{A}Y + {}_{1}^{0}e$$

An unstable neutron in nucleus turns into proton and electron and emits the electron.

Gamma Decay: (emission of high energy photon)

$${}^{A}_{Z}A * \rightarrow {}^{A}_{Z}X + \gamma$$

More on Beta Decay: the existence of **neutrinos.**

$${}^{A}_{Z}A \rightarrow {}_{Z+1}^{A}Y + {}_{-1}^{0}e + \bar{v}$$

The energy emitted in each reaction is shared between the β-particle and the neutrino (or antineutrino in the case of beta-minus decay). This allows the β particles to be emitted from the nucleus with a range of energies and momenta, ensuring that the principles of conservation of mass-energy and of linear momentum are obeyed.

The neutrino and antineutrino are: 1) neutrally charged. 2)seen to have negligible mass. 3) interacts only very weakly with other matter and hence eluded detection for many years.

Biological Effects of Radiation:

Ionizing radiation with sufficient energy so that during an interaction with an atom, it can remove electron from the atom, causing it to be charged or ionized.

Direct effects of ionizing radiation on cells

- Radiation interacts directly with DNA molecules, or some other cellular component critical to the survival or the cell. DNA might be broken or have sections removed.

Indirect effects of ionizing radiation on cells

- Radiation interacts with other molecules, e.g. water, producing ions and radicals (H^+, OH^- ,$H^·$,$OH^·$) which can then attack cells and DNA. They can also combine to form toxic substances like H_2O_2.

Consequence of cell damage

1. Cell dies: (which is if not too many cells die)
2. Cell repairs itself (which is good)
3. Cell survives but mutates (which is bad because it may cause cancer)

- Acute effects (high doses of radiation over short time): Symptoms include vomiting, burns, blood count change, hair loss, sterility and death.
- Chronic (low doses of radiation over long time)" Development of cancer, genetic mutation, developmental abnormalities and growth disorders.