Physics

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NUCLEAR PHYSICS

The nucleus
Isotopes
Mass defect and nuclear binding energy
Nuclear processes
Radioactive decay
Biological effect of radiation

Objective

- The nucleus
- Isotopes
- Mass defect and nuclear binding energy
- Nuclear processes
- Radioactive decay
- Biological effect of radiation

The Nucleus

Nucleus is core of the atom consists of proton and neutron

One of the conclusion from Rutherford's-Alpha experiment is that atom contains mostly of empty space. Nucleus contains 99.59% of the mass of the atom but only made up a tenth-billionth part of its volume.

Isotopes

Isotopes: are atoms with the same proton number, but different nucleon number

Mass defect and nuclear binding energy

$$\boxed{E = mc^2 \quad \text{and} \quad \Delta E = (\Delta m)c^2}$$

E = Energy equivalent to mass(J),

m = mass (kg),

c = speed of light in vacuum (3.0×10^8 m/s)

Mass defect and nuclear binding energy

- **Binding Energy** is the energy needed to separate the nucleus into individual nucleons
- **Mass Defect** is the difference between the mass of the nucleus and the total mass of each individual nucleons

$$\text{Binding Energy} = \text{Mass Defect} \times c^2$$

Mass defect and nuclear binding energy

Example

Deutorium ($^{2}_{1}H$) atom has a mass of 2.008032 u, calculate the mass defect and the binding energy per nucleon if:

Mass of proton: 1.0073u, Mass of neutron:1.0087u

Mass defect and nuclear binding energy

Answer

Total mass of one proton and one neutron without being joined into one nucleus (Mass final): 1.0073u + 1.0087u = 2.016u

Mass defect: 2.016u – 2.008032u = 0.007968u

Mass defect and nuclear binding energy

Energy equivalent of 1u = mc^2 = $1.66 \times 10^{-27} \times (3 \times 10^8)^2$

Binding energy per nucleon = $mc^2/2$ = $(0.007968 \times 1.66 \times 10^{-27} \times (3 \times 10^8)^2)/2$ = 5.95×10^{-13} J

5.95×10^{-13} J = $(5.95 \times 10^{-13})/(1.6 \times 10^{-19} \times 10^6)$ = 3.72 eV

Nuclear Processes

In Nuclear process nucleon number, proton number and energy plus mass are all conserved

Nuclear Processes

Example

$^{238}_{92}U$ decay though a series of transformation involving the particle below which was emitted by the atom to become stable nuclei:

$\alpha \ \beta \ \beta \ \alpha \ \alpha$

Nuclear Processes

Example (cont)

Which nuclide is not produced during the process?

- $^{228}_{88}Ra$
- $^{230}_{90}Th$
- $^{234}_{91}Pa$
- $^{234}_{92}U$

Nuclear Processes

$$
\begin{tikzcd}
{}^{238}_{92}U \arrow[r, "\alpha"] & {}^{234}_{90}A \arrow[r, "\beta"] & {}^{234}_{91}B \arrow[d, "\beta"] \\
{}^{226}_{88}Pb & {}^{230}_{90}D \arrow[l, "\alpha"'] & {}^{234}_{92}C \arrow[l, "\alpha"']
\end{tikzcd}
$$

Answer: ${}^{228}_{88}Ra$ is not produced

Radioactive Decay

Radioactivity is
the spontaneous and random decay of an unstable nucleus, often accompanied with the emission of an alpha or beta particle, and is usually accompanied by the emission of a gamma ray photon.

Radioactive Decay

$$A = \lambda N$$

A = Activity (Bq (becquerel)),

λ = decay constant (s^{-1}),

N = number of undecayed radioactive nuclei (no unit),

Radioactive Decay

$N = No(\frac{1}{2})^n$, $A = A_o(\frac{1}{2})^n$, $m = m_o(\frac{1}{2})^n$, $C = C_o(\frac{1}{2})^n$,

N,A,m,C = number of undecayed nuclei, Activity, mass, count rate, respectively,

N_o,A_o,m_o,C_o = initial number of undecayed nuclei, initial Activity, initial mass, initial count rate, respectively, BBMerlion

Radioactive Decay

A = - dN/dt, or $\lambda N = -dN/dt$,

By solving the equation above

$N = N_0 \exp(-\lambda t)$,

$X = X_0 \exp(-\lambda t)$,

X can be Activity, mass, and Count rate

Radioactive Decay

$t_{1/2} = (\ln 2) / \lambda$ or $t_{1/2} = 0.693 / \lambda$,

$t_{1/2}$ = half time (s),

λ = decay constant (s^{-1}),

$A = - dN/dt$, or $\lambda N = - dN/dt$

Radioactive Decay

Example

A radioactive isotope sample has a half-life of 32 years. Determine the fraction of the sample that would after 16 years

$\lambda = 0.693/\ t_{½} = 0.693/32$ years^{-1}

By using $N = N_0 \exp(-\lambda t)$

$N/N_0 = \exp(-0.3465) = 0.71$

Biological Effect of Radiation

Radiation damage divided into 2 categories

Somatic damage: the damage occur of any part of the body except reproductive organ, this include radiation sickness (nausea, fatigue, and loss of body hair) and burns, reddening of the skin, ulceration, cataracts in the eye, skin cancer, leukaemia, reduction of white blood cells, death etc

Biological Effect of Radiation

Genetic damage: the damage occur in reproductive organ and hence affecting future generation

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References

A level complete guide, Themis Publisher,

www.xtremepapers.com,

Physics MCQ with helps (topical).