Chapter 20

NUCLEAR PHYSICS

25

Name: ______________________________ CT: ___________

Duration: 30 minutes

Data and Formulae

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
elementary charge	e	=	1.60×10^{-19} C
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
radioactive decay	x	=	$x_o \exp(-\lambda t)$
decay constant	λ	=	$\ln 2 / t_{1/2}$

Section A: Multiple Choice Questions (2 marks each)
Fill in the answers in the boxes below.

1	2	3	4	5	6
D	C	D	C	D	C

1 The deviation of α-particles by thin metal foils through angles that range from 0° to 180° can be explained by

A scattering from free electrons.

B diffuse reflection from the metal surface.

C diffraction from the crystal lattice.

D scattering from small but heavy regions of positive charge.

Ans: D

2 A nucleus has a nucleon number *A*, a proton number *Z* and a binding energy *B*. The masses of the neutron and proton are m_n and m_p respectively, and *c* is the speed of light.

The mass of the nucleus is given by the expression

A $Am_n + Zm_p - \frac{B}{c^2}$

B $Am_n + Zm_p + \frac{B}{c^2}$

C $(A-Z)m_n + Zm_p - \frac{B}{c^2}$

D $(A-Z)m_n + Zm_p + \frac{B}{c^2}$

Ans: C

3 The rest mass of the deuteron, ${}^2_1\text{H}$, is equivalent to an energy of 1876 MeV. The rest mass of a proton is equivalent to 939 MeV and the rest mass of a neutron is equivalent to 940 MeV.

A deuteron may disintegrate to a proton and a neutron if it

A emits a γ -ray photon of energy 1 MeV.

B captures a γ -ray photon of energy 1 MeV.

C emits a γ -ray photon of energy 3 MeV.

D captures a γ -ray photon of energy 3 MeV.

Ans: D

Since $\Sigma M_{\text{Reactants}} < \Sigma M_{\text{Products}}$, a photon must be absorbed whose energy is equal to the difference $(\Sigma M_{\text{Products}} - \Sigma M_{\text{Reactants}})c^2$.

4 At time *t*, a sample of radioactive substance contains *N* atoms of a particular nuclide. At time (*t* + Δ*t*), where Δ*t* is a short period of time, the number of atoms of the nuclide is (*N* – Δ*N*).

Which expression is equal to the decay constant of the nuclide?

A $\frac{\Delta N}{N}$ **B** $\frac{\Delta N}{\Delta t}$ **C** $\frac{\Delta N}{N\Delta t}$ **D** $\frac{N\Delta N}{\Delta t}$

Ans: **C**

Decay constant λ = probability of decay per unit time

Probability of decay = $\frac{\Delta N}{N}$

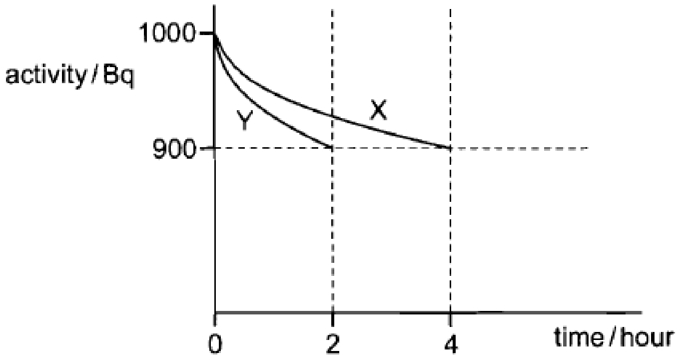
Hence $\lambda = \frac{\Delta N}{N\Delta t}$

OR Activity *A* = rate of decay = $\frac{\Delta N}{\Delta t}$

Since $A = \lambda N$

=> $\lambda = \frac{A}{N} = \frac{\Delta N}{N\Delta t}$

5 The graph shows how the activities of two isotopes X and Y vary with time.



What will be the ratio $\dfrac{\text{activity of X}}{\text{activity of Y}}$ after each has decayed for 8 hours?

A $\dfrac{9}{10}$ **B** $\dfrac{10}{9}$ **C** $\dfrac{81}{100}$ **D** $\dfrac{100}{81}$

Ans: **D**

Isotope X

$$900 = 1000e^{-\lambda_X(4)}$$
$$\lambda_X = 0.0263\ \text{hr}^{-1}$$

After 8 hrs,

$$A_X = 1000e^{-(0.0263)(8)} = 810\ \text{Bq}$$

Isotope Y

$$900 = 1000e^{-\lambda_Y(2)}$$
$$\lambda_Y = 0.0527\ \text{hr}^{-1}$$

After 8 hrs,

$$A_Y = 1000e^{-(0.0527)(8)} = 656\ \text{Bq}$$

Hence $\dfrac{A_X}{A_Y} = 1.23 = \dfrac{100}{81}$

6 A detector of ionising radiation gives a background count rate of 24 per minute. A radioactive source is placed close to the detector and the reading is 532 counts per minute. What will be the reading after two half-lives of the source?

A 127 **B** 133 **C** 151 **D** 157

Ans: **C**

$C = C_o e^{-(\ln 2)\left(\frac{t}{t_{1/2}}\right)}$

$C = (532 - 24)e^{-(\ln 2)(2)} = 127$

Hence detector reading = 127 + 24 = 151

Section B: Structured Questions (13 marks)

7 **(a)** Define *binding energy*. [1]

It is defined as the energy needed just to separate completely the nucleons in the nucleus. / It is also defined as energy released when a nucleus is formed by putting all its constituent nucleons together

(b) A minimum energy Q is required to remove a neutron from a helium-4 nuclide to form a helium-3 nuclide. The following data is given:

Binding energy per nucleon of helium-4 nuclide = 6.8 MeV

Binding energy per nucleon of helium-3 nuclide = 2.3 MeV

Mass of neutron = 1.0087 u

(i) Write the nuclear equation for this reaction. [1]

$^{4}_{2}\text{He} \rightarrow {}^{3}_{2}\text{He} + {}^{1}_{0}n$

(ii) Calculate Q. [2]

$$Q = \Sigma\, B.E._{reactants} - \Sigma\, B.E._{products}$$
$$= 4(6.8) - 3(2.3)$$
$$= 20.3 \text{ MeV}$$

(iii) Hence calculate the difference in mass between the helium-3 and helium-4 nuclides. [2]

By Conservation of Energy,

Mass Energy of Reactants + Q = Mass Energy of Products

$$(\Sigma M_{\text{Products}} - \Sigma M_{\text{Reactants}}) \times c^2 = Q$$

$$m(n) + m(\text{He-3}) - m(\text{He-4}) = \frac{Q}{c^2}$$

$$m(\text{He-4}) - m(\text{He-3}) = 1.0087(1.66 \times 10^{-27}) - \frac{(20.3 \times 10^{6})(1.60 \times 10^{-19})}{(3.00 \times 10^{8})^2}$$

$$= 1.64 \times 10^{-27} \text{ kg}$$

8 Strontium-90 decays with the emission of a β-particle to form Yttrium-90. The reaction is represented by the equation

$$^{90}_{38}\text{Sr} \rightarrow ^{90}_{39}\text{Y} + ^{0}_{-1}\text{e} + 0.55\,\text{MeV}$$

The decay constant is 0.025 year^{-1}.

(a) Explain what is meant by the *decay constant*. [1]

The decay constant λ is the ratio of the number of decays per unit time to the number of remaining radioactive nuclei. (It represents the probability that a radioactive nucleus will decay in a unit time.)

(b) At the time of purchase of a Strontium-90 source, its activity is 3.7 × 10^{6} Bq.

(i) Calculate, for this sample of Strontium-90,

1. the initial number of atoms present, [2]

$$A = \lambda N$$

$$3.7 \times 10^{6} = \frac{0.025}{365 \times 24 \times 3600}(N)$$

$$N = 4.67 \times 10^{15}$$

2. the initial mass. [2]

$$\text{Initial mass} = \frac{4.67 \times 10^{15}}{6.02 \times 10^{23}} \times 90 = 6.98 \times 10^{-7}\ \text{g}$$

(ii) Determine the activity of the sample 5.0 years after purchase, expressing your answer as a fraction of the initial activity A_o. [2]

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

$$\frac{A}{A_o} = e^{-(0.025)(5.0)} = 0.882$$