Nuclear Physics

Question paper 5

Level	International A Level
Subject	Physics
Exam Board	CIE
Topic	Particle & Nuclear Physics
Sub Topic	Nuclear Physics
Paper Type	Theory
Booklet	Question paper 5

Time Allowed: **78 minutes**

Score: **/65**

Percentage: **/100**

A*	A	B	C	D	E	U
>85%	'77.5%	70%	62.5%	57.5%	45%	<45%

1 **(a)** State what is meant by the *decay constant* of a radioactive isotope.

....

....

.... [2]

(b) Show that the decay constant λ is related to the half-life $t_{\frac{1}{2}}$ by the expression

$$\lambda t_{\frac{1}{2}} = 0.693.$$

[3]

(c) Cobalt-60 is a radioactive isotope with a half-life of 5.26 years (1.66×10^8 s).

A cobalt-60 source for use in a school laboratory has an activity of 1.8×10^5 Bq.

Calculate the mass of cobalt-60 in the source.

mass = ... g [3]

2 **(a)** A sample of a radioactive isotope contains N nuclei at time t. At time $(t + \Delta t)$, it contains $(N - \Delta N)$ nuclei of the isotope.

For the period Δt, state, in terms of N, ΔN and Δt,

(i) the mean activity of the sample,

activity = ... [1]

(ii) the probability of decay of a nucleus.

probability = ... [1]

(b) A cobalt-60 source having a half-life of 5.27 years is calibrated and found to have an activity of 3.50×10^5 Bq. The uncertainty in the calibration is ±2%.

Calculate the length of time, in days, after the calibration has been made, for the stated activity of 3.50×10^5 Bq to have a maximum possible error of 10%.

time = ... days [4]

3 Two deuterium (^2_1H) nuclei are travelling directly towards one another. When their separation is large compared with their diameters, they each have speed *v* as illustrated in Fig. 5.1.

Fig. 5.1

The diameter of a deuterium nucleus is 1.1×10^{-14} m.

(a) Use energy considerations to show that the initial speed *v* of the deuterium nuclei must be approximately 2.5×10^6 m s^{-1} in order that they may come into contact. Explain your working.

[3]

(b) For a fusion reaction to occur, the deuterium nuclei must come into contact. Assuming that deuterium behaves as an ideal gas, deduce a value for the temperature of the deuterium such that the nuclei have an r.m.s. speed equal to the speed calculated in **(a)**.

temperature = ... K [4]

(c) Comment on your answer to **(b)**.

....

....[1]

4 A positron ($^{0}_{+1}e$) is a particle that has the same mass as an electron and has a charge of $+1.6 \times 10^{-19}$ C.
A positron will interact with an electron to form two γ-ray photons.

$$^{0}_{+1}e + ^{0}_{-1}e \rightarrow 2\gamma$$

Assuming that the kinetic energy of the positron and the electron is negligible when they interact,

(a) suggest why the two photons will move off in opposite directions with equal energies,

....

....

....

....

....

....[3]

(b) calculate the energy, in MeV, of one of the γ-ray photons.

energy = ... MeV [3]

5 **(a)** Explain what is meant by the *binding energy* of a nucleus.

....

.... [1]

(b) Fig. 7.1 shows the variation with nucleon number (mass number) A of the binding energy per nucleon E_B of nuclei.

Fig. 7.1

One particular fission reaction may be represented by the nuclear equation

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3^{1}_{0}\text{n}.$$

(i) On Fig. 7.1, label the approximate positions of

1. the uranium ($^{235}_{92}$U) nucleus with the symbol U,

2. the barium ($^{141}_{56}$Ba) nucleus with the symbol Ba,

3. the krypton ($^{92}_{36}$Kr) nucleus with the symbol Kr. [2]

(ii) The neutron that is absorbed by the uranium nucleus has very little kinetic energy. Explain why this fission reaction is energetically possible.

....

....

.... [2]

(c) Barium-141 has a half-life of 18 minutes. The half-life of Krypton-92 is 3.0 s.
In the fission reaction of a mass of Uranium-235, equal numbers of barium and krypton nuclei are produced.
Estimate the time taken after the fission of the sample of uranium for the ratio

$$\frac{\text{number of Barium-141 nuclei}}{\text{number of Krypton-92 nuclei}}$$

to be approximately equal to 8.

time = ... s [3]

6 **(a)** Define the *decay constant* of a radioactive isotope.

....

....

.... [2]

(b) Strontium-90 is a radioactive isotope having a half-life of 28.0 years. Strontium-90 has a density of 2.54 g cm^{-3}.

A sample of Strontium-90 has an activity of 6.4 10^9 Bq. Calculate

(i) the decay constant λ, in s^{-1}, of Strontium-90,

λ = ... s^{-1} [2]

(ii) the mass of Strontium-90 in the sample,

mass = ... g [4]

(iii) the volume of the sample.

volume = ... cm^3 [1]

(c) By reference to your answer in **(b)(iii)**, suggest why dust that has been contaminated with Strontium-90 presents a serious health hazard.

....

....

.... [2]

7 Uranium-234 is radioactive and emits α- particles at what appears to be a constant rate.

A sample of Uranium-234 of mass 2.65 μg is found to have an activity of 604 Bq.

(a) Calculate, for this sample of Uranium-234,

(i) the number of nuclei,

number = ... [2]

(ii) the decay constant,

decay constant = ... s^{-1} [2]

(iii) the half-life in years.

half-life = ... years [2]

(b) Suggest why the activity of the Uranium-234 appears to be constant.

....

.... [1]

(c) Suggest why a measurement of the mass and the activity of a radioactive isotope is not an accurate means of determining its half-life if the half-life is approximately one hour.

....

.... [1]

8 Fig. 7.1 illustrates the variation with nucleon number *A* of the binding energy per nucleon *E* of nuclei.

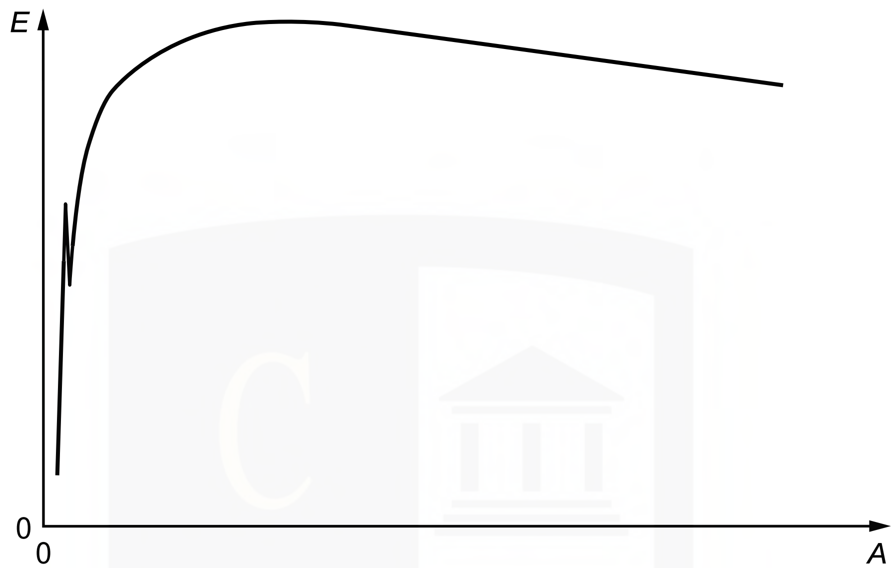

Fig. 7.1

(a) **(i)** Explain what is meant by the *binding energy* of a nucleus.

....

....

.... [2]

(ii) On Fig. 7.1, mark with the letter S the region of the graph representing nuclei having the greatest stability. [1]

(b) Uranium-235 may undergo fission when bombarded by a neutron to produce Xenon-142 and Strontium-90 as shown below.

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{142}_{54}Xe + {}^{90}_{38}Sr + \text{neutrons}$$

(i) Determine the number of neutrons produced in this fission reaction.

number = ………………………….. [1]

(ii) Data for binding energies per nucleon are given in Fig. 7.2.

isotope	binding energy per nucleon / MeV
Uranium-235	7.59
Xenon-142	8.37
Strontium-90	8.72

Fig. 7.2

Calculate

1. the energy, in MeV, released in this fission reaction,

energy = ………………………… MeV [3]

2. the mass equivalent of this energy.

mass = …………………………….. kg [3]