Nuclear Physics

Question paper 3

Level	International A Level
Subject	Physics
Exam Board	CIE
Topic	Particle & Nuclear Physics
Sub Topic	Nuclear Physics
Paper Type	Theory
Booklet	Question paper 3

Time Allowed: **81 minutes**

Score: **/67**

Percentage: **/100**

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

1 One possible nuclear fission reaction is

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

Barium-141 ($^{141}_{56}$Ba) and krypton-92 ($^{92}_{36}$Kr) are both β-emitters.
Barium-141 has a half-life of 18 minutes and a decay constant of $6.4 \times 10^{-4}\,\text{s}^{-1}$.
The half-life of krypton-92 is 3.0 seconds.

(a) State what is meant by *decay constant*.

....

....

.... [2]

(b) A mass of 1.2 g of uranium-235 undergoes this nuclear reaction in a very short time (a few nanoseconds).

(i) Calculate the number of barium-141 nuclei that are present immediately after the reaction has been completed.

number = ... [2]

(ii) Using your answer in **(b)(i)**, calculate the total activity of the barium-141 and the krypton-92 a time of 1.0 hours after the fission reaction has taken place.

activity = ... Bq [4]

2 **(a)** State what is meant by a *nuclear fusion reaction*.

....

....

.... [2]

(b) One nuclear reaction that takes place in the core of the Sun is represented by the equation

$$^{2}_{1}\text{H} + ^{1}_{1}\text{H} \rightarrow ^{3}_{2}\text{He} + \text{energy.}$$

Data for the nuclei are given in Fig. 8.1.

	mass / u
proton $^{1}_{1}\text{H}$	1.00728
deuterium $^{2}_{1}\text{H}$	2.01410
helium $^{3}_{2}\text{He}$	3.01605

Fig. 8.1

(i) Calculate the energy, in joules, released in this reaction.

energy = ... J [3]

(ii) The temperature in the core of the Sun is approximately 1.6×10^{7} K.
Suggest why such a high temperature is necessary for this reaction to take place.

....

....

.... [2]

3 **(a)** Explain why the mass of an α-particle is less than the total mass of two individual protons and two individual neutrons.

....

....

.... [2]

(b) An equation for one possible nuclear reaction is

$$^{4}_{2}He + ^{14}_{7}N \rightarrow ^{17}_{8}O + ^{1}_{1}p.$$

Data for the masses of the nuclei are given in Fig. 8.1.

		mass / u
proton	$^{1}_{1}p$	1.00728
helium-4	$^{4}_{2}He$	4.00260
nitrogen-14	$^{14}_{7}N$	14.00307
oxygen-17	$^{17}_{8}O$	16.99913

Fig. 8.1

(i) Calculate the mass change, in u, associated with this reaction.

mass change = ... u [2]

(ii) Calculate the energy, in J, associated with the mass change in **(i)**.

energy = ... J [2]

(iii) Suggest and explain why, for this reaction to occur, the helium-4 nucleus must have a minimum speed.

....

....

.... [2]

4 When a neutron is captured by a uranium-235 nucleus, the outcome may be represented by the nuclear equation shown below.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{95}_{42}\mathrm{Mo} + {}^{139}_{57}\mathrm{La} + x\,{}^{1}_{0}\mathrm{n} + 7\,{}^{0}_{-1}\mathrm{e}$$

(a) **(i)** Use the equation to determine the value of *x*.

x = ... [1]

(ii) State the name of the particle represented by the symbol ${}^{0}_{-1}\mathrm{e}$.

.... [1]

(b) Some data for the nuclei in the reaction are given in Fig. 8.1.

	mass / u	binding energy per nucleon / MeV
uranium-235 (${}^{235}_{92}\mathrm{U}$)	235.123	
molybdenum-95 (${}^{95}_{42}\mathrm{Mo}$)	94.945	8.09
lanthanum-139 (${}^{139}_{57}\mathrm{La}$)	138.955	7.92
proton (${}^{1}_{1}\mathrm{p}$)	1.007	
neutron (${}^{1}_{0}\mathrm{n}$)	1.009	

Fig. 8.1

Use data from Fig. 8.1 to

(i) determine the binding energy, in u, of a nucleus of uranium-235,

binding energy = ... u [3]

(ii) show that the binding energy per nucleon of a nucleus of uranium-235 is 7.18 MeV.

[3]

(c) The kinetic energy of the neutron before the reaction is negligible.
Use data from **(b)** to calculate the total energy, in MeV, released in this reaction.

energy = ... MeV [2]

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

....

....

.... [2]

(ii) Show that the decay constant λ and the half-life $t_{\frac{1}{2}}$ of an isotope are related by the expression

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

[3]

(b) In order to determine the half-life of a sample of a radioactive isotope, a student measures the count rate near to the sample, as illustrated in Fig. 9.1.

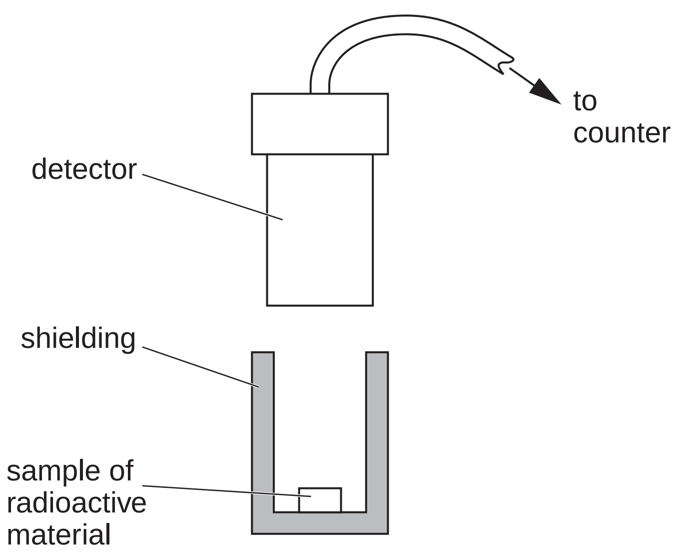

Fig. 9.1

Initially, the measured count rate is 538 per minute. After a time of 8.0 hours, the measured count rate is 228 per minute.

Use these data to estimate the half-life of the isotope.

half-life = ... hours [3]

(c) The accepted value of the half-life of the isotope in **(b)** is 5.8 hours.
The difference between this value for the half-life and that calculated in **(b)** cannot be explained by reference to faulty equipment.

Suggest two possible reasons for this difference.

1. ....

....

2. ....

....
[2]

6 The element strontium has at least 16 isotopes. One of these isotopes is strontium-89. This isotope has a half-life of 52 days.

(a) State what is meant by *isotopes*.

....

....

....[2]

(b) Calculate the probability per second of decay of a nucleus of strontium-89.

probability = ... s^{-1} [3]

(c) A laboratory prepares a strontium-89 source.
The activity of this source is measured 21 days after preparation of the source and is found to be 7.4×10^6 Bq.

Determine, for the strontium-89 source at the time that it was prepared,

(i) the activity,

activity = ... Bq [2]

(ii) the mass of strontium-89.

mass = ...g [2]

7 The isotope phosphorus-33 ($^{33}_{15}P$) undergoes β-decay to form sulfur-33 ($^{33}_{16}S$), which is stable.
The half-life of phosphorus-33 is 24.8 days.

(a) **(i)** Define radioactive *half-life*.

....

....

....[2]

(ii) Show that the decay constant of phosphorus-33 is $3.23 \times 10^{-7}\,s^{-1}$.

[1]

(b) A pure sample of phosphorus-33 has an initial activity of 3.7×10^{6} Bq.

Calculate

(i) the initial number of phosphorus-33 nuclei in the sample,

number = ...[2]

(ii) the number of phosphorus-33 nuclei remaining in the sample after 30 days.

number = ...[2]

(c) After 30 days, the sample in **(b)** will contain phosphorus-33 and sulfur-33 nuclei.
Use your answers in **(b)** to calculate the ratio

$$\frac{\text{number of phosphorus-33 nuclei after 30 days}}{\text{number of sulfur-33 nuclei after 30 days}}.$$

ratio = ... [2]

8 Radon-222 is a radioactive element having a half-life of 3.82 days.

Radon-222, when found in atmospheric air, can present a health hazard. Safety measures should be taken when the activity of radon-222 exceeds 200 Bq per cubic metre of air.

(a) (i) Define radioactive *decay constant*.

....

....

.... [2]

(ii) Show that the decay constant of radon-222 is $2.1 \times 10^{-6}\,s^{-1}$.

[1]

(b) A volume of $1.0\,m^3$ of atmospheric air contains 2.5×10^{25} molecules.

Calculate the ratio

$$\frac{\text{number of air molecules in } 1.0\,m^3 \text{ of atmospheric air}}{\text{number of radon-222 atoms in } 1.0\,m^3 \text{ of atmospheric air}}$$

for the minimum activity of radon-222 at which safety measures should be taken.

ratio = ... [3]