Nuclear Physics

Question paper 2

Level	International A Level
Subject	Physics
Exam Board	CIE
Topic	Particle & Nuclear Physics
Sub Topic	Nuclear Physics
Paper Type	Theory
Booklet	Question paper 2

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)** An isotope of an element is radioactive. Explain what is meant by *radioactive decay*.

....

....

....

.... [3]

(b) At time t, a sample of a radioactive isotope contains N nuclei. In a short time Δt, the number of nuclei that decay is ΔN.

State expressions, in terms of the symbols t, Δt, N and ΔN for

(i) the number of undecayed nuclei at time $(t + \Delta t)$,

number = ... [1]

(ii) the mean activity of the sample during the time interval Δt,

mean activity = ... [1]

(iii) the probability of decay of a nucleus during the time interval Δt,

probability = ... [1]

(iv) the decay constant.

decay constant = ... [1]

(c) The variation with time t of the activity A of a sample of a radioactive isotope is shown in Fig. 9.1.

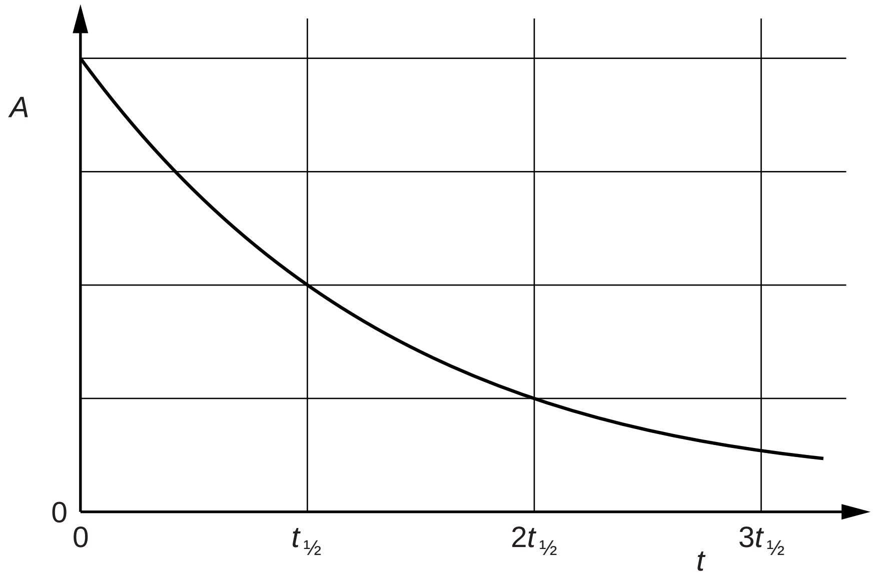

Fig. 9.1

The radioactive isotope decays to form a stable isotope S. At time $t = 0$, there are no nuclei of S in the sample.

On the axes of Fig. 9.2, sketch a graph to show the variation with time t of the number n of nuclei of S in the sample.

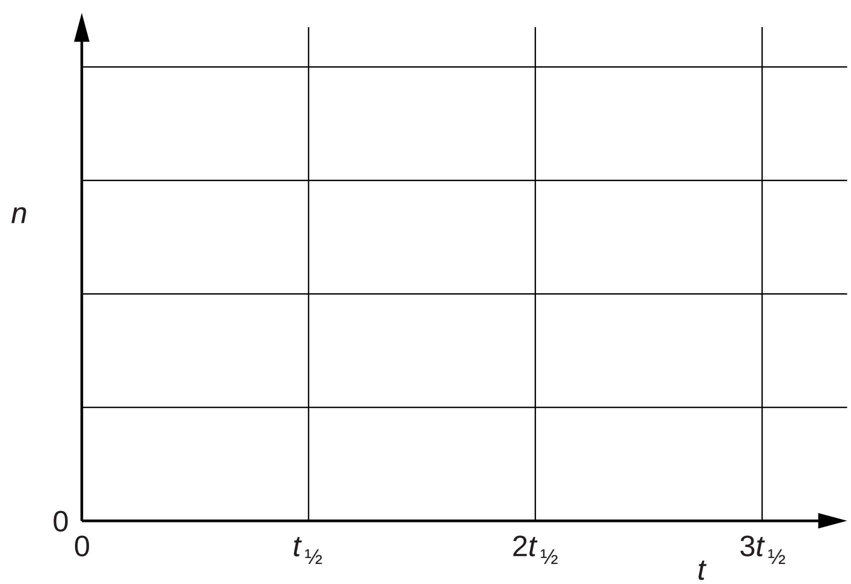

Fig. 9.2

[2]

2 The power for a space probe is to be supplied by the energy released when plutonium-236 decays by the emission of α-particles.

The α-particles, each of energy 5.75 MeV, are captured and their energy is converted into electrical energy with an efficiency of 24%.

(a) Calculate

(i) the energy, in joules, equal to 5.75 MeV,

energy = ... J [1]

(ii) the number of α-particles per second required to generate 1.9 kW of electrical power.

number per second = ... s^{-1} [2]

(b) Each plutonium-236 nucleus, on disintegration, produces one α-particle.
Plutonium-236 has a half-life of 2.8 years.

(i) Calculate the decay constant, in s^{-1}, of plutonium-236.

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

(ii) Use your answers in **(a)(ii)** and **(b)(i)** to determine the mass of plutonium-236 required for the generation of 1.9 kW of electrical power.

mass = ... g [4]

(c) The minimum electrical power required for the space probe is 0.84 kW.

Calculate the time, in years, for which the sample of plutonium-236 in **(b)(ii)** will provide sufficient power.

time = ... years [2]

3 One likely means by which nuclear fusion may be achieved on a practical scale is the D-T

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

....

.... [1]

(b) In the D-T reaction, a deuterium ($^{2}_{1}H$) nucleus fuses with a tritium ($^{3}_{1}H$) nucleus to form a helium-4 ($^{4}_{2}He$) nucleus. The nuclear equation for the reaction is

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

Some data for this reaction are given in Fig. 9.1.

	mass / u
deuterium ($^{2}_{1}H$)	2.01356
tritium ($^{3}_{1}H$)	3.01551
helium-4 ($^{4}_{2}He$)	4.00151
neutron ($^{1}_{0}n$)	1.00867

Fig. 9.1

(i) Calculate the energy, in MeV, equivalent to 1.00 u. Explain your working.

energy = ... MeV [3]

(ii) Use data from Fig. 9.1 and your answer in **(i)** to determine the energy released in this D-T reaction.

energy = ... MeV [2]

(iii) Suggest why, for the D-T reaction to take place, the temperature of the deuterium and the tritium must be high.

....

....

.... [2]

4 During the de-commissioning of a nuclear reactor, a mass of 2.5×10^6 kg of steel is found to be contaminated with radioactive nickel-63 ($^{63}_{28}Ni$).
The total activity of the steel due to the nickel-63 contamination is 1.7×10^{14} Bq.

(a) Calculate the activity per unit mass of the steel.

activity per unit mass = ... Bq kg^{-1} [1]

(b) Special storage precautions need to be taken when the activity per unit mass due to contamination exceeds 400 Bq kg^{-1}.
Nickel-63 is a β-emitter with a half-life of 92 years.
The maximum energy of an emitted β-particle is 0.067 MeV.

(i) Use your answer in **(a)** to calculate the energy, in J, released per second in a mass of 1.0 kg of steel due to the radioactive decay of the nickel.

energy = ... J [1]

(ii) Use your answer in **(i)** to suggest, with a reason, whether the steel will be at a high temperature.

....

....

.... [1]

(iii) Use your answer in **(a)** to determine the time interval before special storage precautions for the steel are not required.

time = ... years [3]

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

....

....

.... [2]

(b) Data for the masses of some particles are given in Fig. 10.1.

	mass / u
proton	1.00728
neutron	1.00867
tritium ($^{3}_{1}H$) nucleus	3.01551
polonium ($^{210}_{84}Po$) nucleus	209.93722

Fig. 10.1

The energy equivalent of 1.0 u is 930 MeV.

(i) Calculate the binding energy, in MeV, of a tritium ($^{3}_{1}H$) nucleus.

binding energy = ... MeV [3]

(ii) The total mass of the separate nucleons that make up a polonium-210 ($^{210}_{84}Po$) nucleus is 211.70394 u.

Calculate the binding energy per nucleon of polonium-210.

binding energy per nucleon = ... MeV [3]

(c) One possible fission reaction is

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

By reference to binding energy, explain, without any calculation, why this fission reaction is energetically possible.

....

....

.... [2]

6 Some water becomes contaminated with radioactive iodine-131 ($^{131}_{53}I$).
The activity of the iodine-131 in 1.0 kg of this water is 460 Bq.
The half-life of iodine-131 is 8.1 days.

(a) Define radioactive *half-life.*

....

....

.... [2]

(b) **(i)** Calculate the number of iodine-131 atoms in 1.0 kg of this water.

number = ... [3]

(ii) An amount of 1.0 mol of water has a mass of 18 g.

Calculate the ratio

$$\frac{\text{number of molecules of water in 1.0 kg of water}}{\text{number of atoms of iodine-131 in 1.0 kg of contaminated water}}.$$

ratio = ... [2]

(c) An acceptable limit for the activity of iodine-131 in water has been set as 170 Bq kg^{-1}.

Calculate the time, in days, for the activity of the contaminated water to be reduced to this acceptable level.

time = ... days [3]

7 **(a)** State what is meant by *nuclear binding energy*.

....

....

.... [2]

(b) The variation with nucleon number A of the binding energy per nucleon B_E is shown in Fig. 8.1.

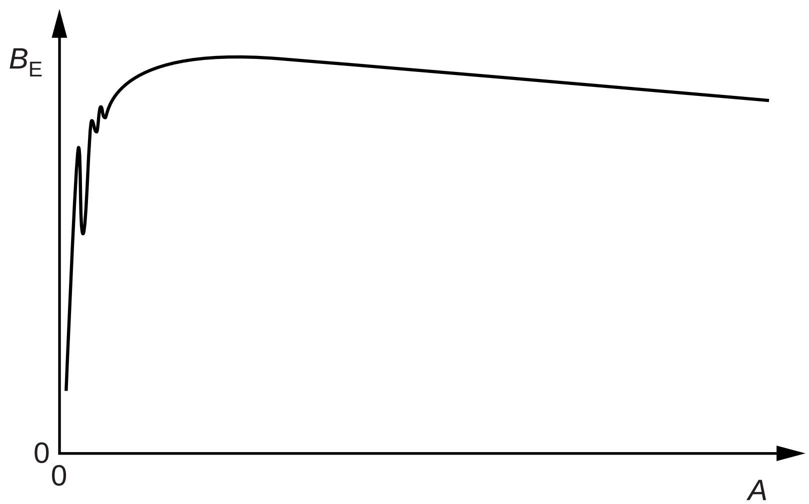

Fig. 8.1

When uranium-235 ($^{235}_{92}U$) absorbs a slow-moving neutron, one possible nuclear reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{95}_{42}Mo + ^{139}_{57}La + 2^{1}_{0}n + 7^{0}_{-1}\beta + \text{energy}.$$

(i) State the name of this type of nuclear reaction.

.... [1]

(ii) On Fig. 8.1, mark the position of

1. the uranium-235 nucleus (label this position U), [1]

2. the molybdenum-95 ($^{95}_{42}Mo$) nucleus (label this position Mo), [1]

3. the lanthanum-139 ($^{139}_{57}La$) nucleus (label this position La). [1]

(iii) The masses of some particles and nuclei are given in Fig. 8.2.

	mass / u
β-particle	5.5×10^{-4}
neutron	1.009
proton	1.007
uranium-235	235.123
molybdenum-95	94.945
lanthanum-139	138.955

Fig. 8.2

Calculate, for this reaction,

1. the change, in u, of the rest mass,

change in mass = ... u [2]

2. the energy released, in MeV, to three significant figures.

energy = ... MeV [3]