Nuclear Physics

Question paper 6

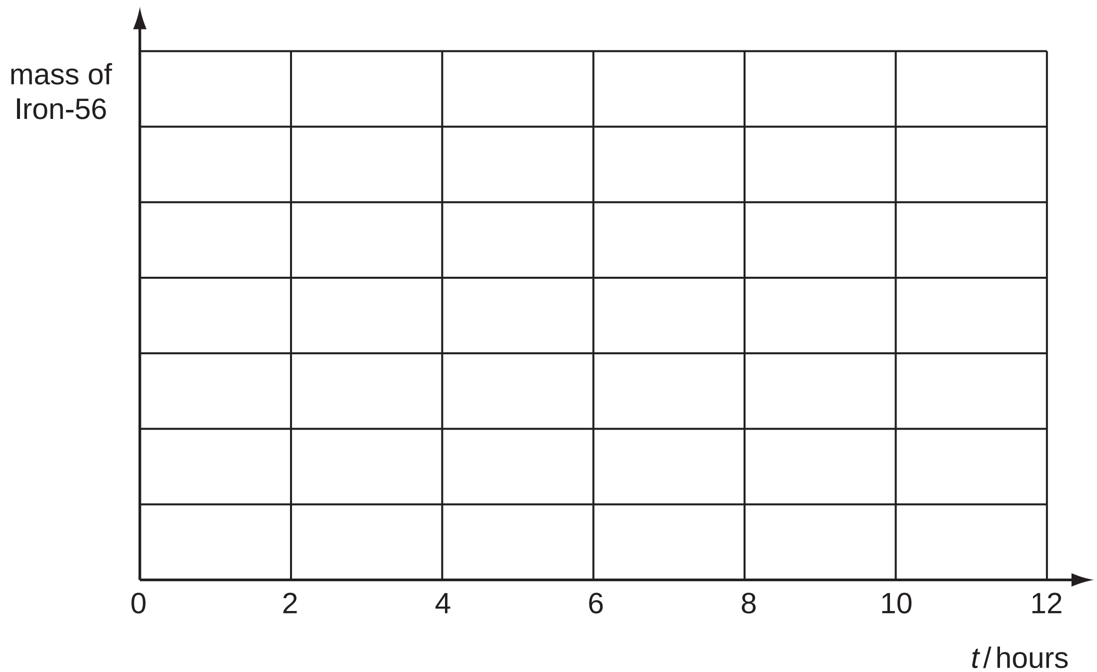
Level	International A Level
Subject	Physics
Exam Board	CIE
Topic	Particle & Nuclear Physics
Sub Topic	Nuclear Physics
Paper Type	Theory
Booklet	Question paper 6

Time Allowed:	**87 minutes**
Score:	**/72**
Percentage:	**/100**

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

1 The isotope Manganese-56 decays and undergoes β- particle emission to form the stable isotope Iron-56. The half-life for this decay is 2.6 hours.
Initially, at time t = 0, a sample of Manganese-56 has a mass of 1.4 μg and there is no Iron-56.

(a) Complete Fig. 7.1 to show the variation with time t of the mass of Iron-56 in the sample for time t = 0 to time t = 11 hours.



[2]

Fig. 7.1

(b) For the sample of Manganese-56, determine

(i) the initial number of Manganese-56 atoms in the sample,

number = ...[2]

(ii) the initial activity.

activity = ... Bq [3]

(c) Determine the time at which the ratio

$$\frac{\text{mass of Iron-56}}{\text{mass of Manganese-56}}$$

is equal to 9.0.

time = ... hours [2]

2 The isotopes Radium-224 ($^{224}_{88}Ra$) and Radium-226 ($^{226}_{88}Ra$) both undergo spontaneous α-particle decay. The energy of the α-particles emitted from Radium-224 is 5.68 MeV and from Radium-226, 4.78 MeV.

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

....

....

....[2]

(ii) Suggest, with a reason, which of the two isotopes has the larger decay constant.

....

....

....

....[3]

(b) Radium-224 has a half-life of 3.6 days.

(i) Calculate the decay constant of Radium-224, stating the unit in which it is measured.

decay constant = ...[2]

(ii) Determine the activity of a sample of Radium-224 of mass 2.24 mg .

activity = ... Bq [4]

(c) Calculate the number of half-lives that must elapse before the activity of a sample of a radioactive isotope is reduced to one tenth of its initial value.

number of half-lives = ...[2]

3 Fig. 8.1 shows the variation with nucleon number of the binding energy per nucleon of a nucleus.

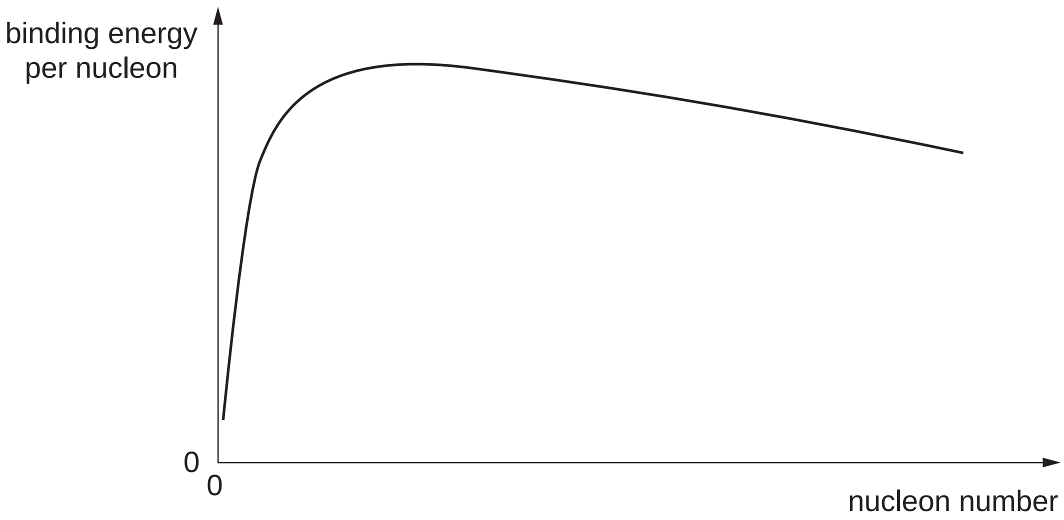


Fig. 8.1

(a) On Fig. 8.1, mark with the letter S the position of the nucleus with the greatest stability. [1]

(b) One possible fission reaction is

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{144}_{56}\text{Ba} + {}^{90}_{36}\text{Kr} + 2{}^{1}_{0}\text{n}.$$

(i) On Fig. 8.1, mark possible positions for

1. the Uranium-235 ($^{235}_{92}\text{U}$) nucleus (label this position U),

2. the Krypton-90 ($^{90}_{36}\text{Kr}$) nucleus (label this position Kr). [1]

(ii) The binding energy per nucleon of each nucleus is as follows.

$^{235}_{92}\text{U}$: 1.2191×10^{-12} J

$^{144}_{56}\text{Ba}$: 1.3341×10^{-12} J

$^{90}_{36}\text{Kr}$: 1.3864×10^{-12} J

Use these data to calculate

1. the energy release in this fission reaction (give your answer to three significant figures),

energy = ... J [3]

2. the mass equivalent of this energy.

mass = ... kg [2]

(iii) Suggest why the neutrons were not included in your calculation in **(ii)**.

....

.... [1]

4 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) Suggest, with a reason, which nucleus, $^{90}_{38}\text{Sr}$ or $^{90}_{39}\text{Y}$, has the greater binding energy.

....

....

.... [2]

(b) Explain what is meant by the decay constant.

....

....

.... [2]

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

(i) Calculate, for this sample of strontium,

1. the initial number of atoms,

number = ... [3]

2. the initial mass.

mass = ... kg [2]

(ii) Determine the activity A of the sample 5.0 years after purchase, expressing the answer as a fraction of the initial activity A_0. That is, calculate the ratio $\frac{A}{A_0}$.

ratio = ………………………………….. [2]

5 **(a)** Define the term radioactive *decay constant*.

....

....

....[2]

(b) State the relation between the activity A of a sample of a radioactive isotope containing N atoms and the decay constant λ of the isotope.

....[1]

(c) Radon is a radioactive gas with half-life 56 s. For health reasons, the maximum permissible level of radon in air in a building is set at 1 radon atom for every 1.5×10^{21} molecules of air. 1 mol of air in the building is contained in $0.024\,m^3$.

Calculate, for this building,

(i) the number of molecules of air in $1.0\,m^3$,

number = ...

(ii) the maximum permissible number of radon atoms in $1.0\,m^3$ of air,

number = ...

(iii) the maximum permissible activity of radon per cubic metre of air.

activity = ... Bq
[5]

6 **(a)** The radioactive decay of some nuclei gives rise to the emission of α-particles.
State

(i) what is meant by an α-particle,

....[1]

(ii) two properties of α-particles.

1. ....

....

2. ....

....
[2]

(b) One possible nuclear reaction involves the bombardment of a stationary nitrogen-14 nucleus by an α-particle to form oxygen-17 and another particle.

(i) Complete the nuclear equation for this reaction.

$${}^{14}_{7}\text{N} + {}^{\cdots\cdots}_{\cdots\cdots}\alpha \rightarrow {}^{17}_{8}\text{O} + \ldots\ldots\ldots\ldots\ldots\ldots$$ [2]

(ii) The total mass-energy of the nitrogen-14 nucleus and the α-particle is less than that of the particles resulting from the reaction. This mass-energy difference is 1.1 MeV.

1. Suggest how it is possible for mass-energy to be conserved in this reaction.

....

....[1]

2. Calculate the speed of an α-particle having kinetic energy of 1.1 MeV.

speed = ... m s^{-1} [4]

7 **(a)** State the basic assumptions of the kinetic theory of gases.

....

....

....

....

....

.... [4]

(b) Use equations for the pressure of an ideal gas to deduce that the average translational kinetic energy $<E_K>$ of a molecule of an ideal gas is given by the expression

$$<E_K> = \frac{3}{2} \frac{R}{N_A} T$$

where R is the molar gas constant, N_A is the Avogadro constant and T is the thermodynamic temperature of the gas.

[3]

(c) A deuterium nucleus $^{2}_{1}H$ and a proton collide. A nuclear reaction occurs, represented by the equation

$$^{2}_{1}H + ^{1}_{1}p \longrightarrow ^{3}_{2}He + \gamma.$$

(i) State and explain whether the reaction represents nuclear fission or nuclear fusion.

....

....

.... [2]

(ii) For the reaction to occur, the minimum total kinetic energy of the deuterium nucleus and the proton is 2.4×10^{-14} J.
Assuming that a sample of a mixture of deuterium nuclei and protons behaves as an ideal gas, calculate the temperature of the sample for this reaction to occur.

temperature = ... K [3]

(iii) Suggest why the assumption made in **(ii)** may not be valid.

....

....[1]