Q1.

6 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]

Q2.

use

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

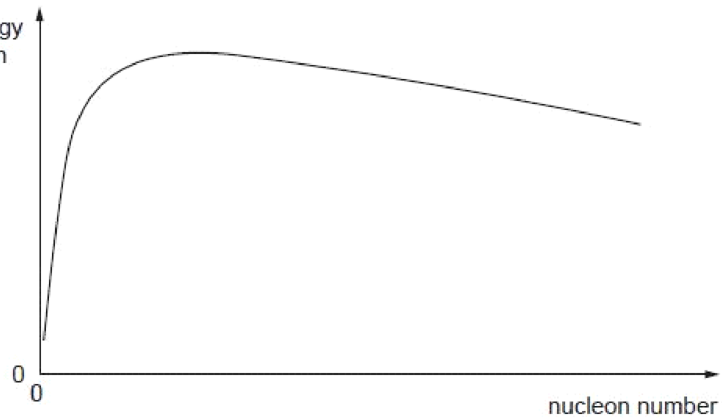


Fig. 8.1

(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

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

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

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

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

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

$^{235}_{92}U$: 1.2191×10^{-12} J

$^{144}_{56}Ba$: 1.3341×10^{-12} J

$^{90}_{36}Kr$: 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)**.

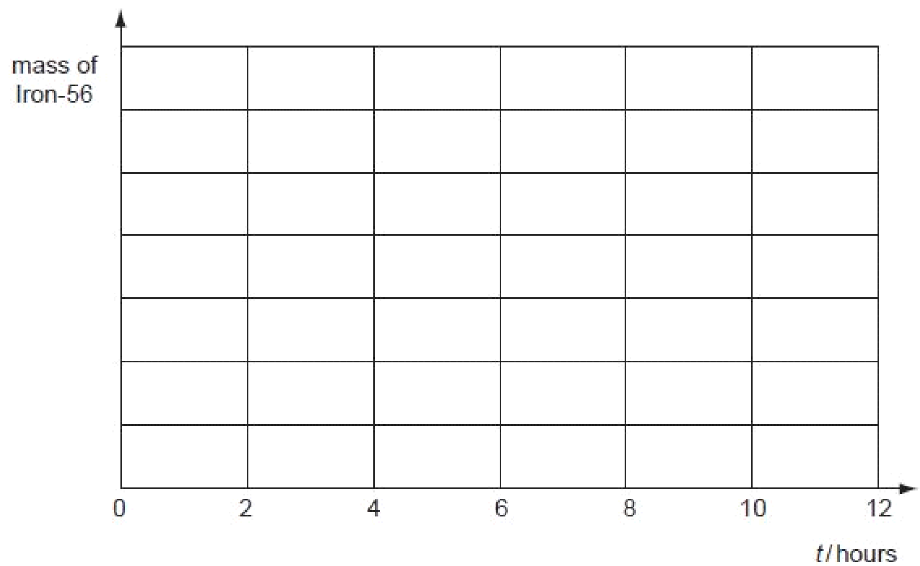
....

.... [1]

Q3.

7 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]

Q4.

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]

Q5.

8 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]

Exa

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

energy = ... MeV [3]

Q6.

9 **(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]

Q7.

8 A π^0 meson is a sub-atomic particle.
A stationary π^0 meson, which has mass 2.4×10^{-28} kg, decays to form two γ-ray photons.
The nuclear equation for this decay is

$$\pi^0 \longrightarrow \gamma + \gamma.$$

(a) Explain why the two γ-ray photons have the same energy.

....

....

....[2]

(b) Determine, for each γ-ray photon,

(i) the energy, in joule,

energy = ... J [2]

(ii) the wavelength,

wavelength = ... m [2]

For Examiner's Use

(iii) the momentum.

Ex

momentum = ... N s [2]

Q8.

8 Americium-241 is an artificially produced radioactive element that emits α-particles.
A sample of americium-241 of mass 5.1 μg is found to have an activity of 5.9×10^5 Bq.

For Examiner's Use

(a) Determine, for this sample of americium-241,

(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) Another radioactive element has a half-life of approximately 4 hours.
Suggest why measurement of the mass and activity of a sample of this element is not appropriate for the determination of its half-life.

....

.... [1]

Q9.

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

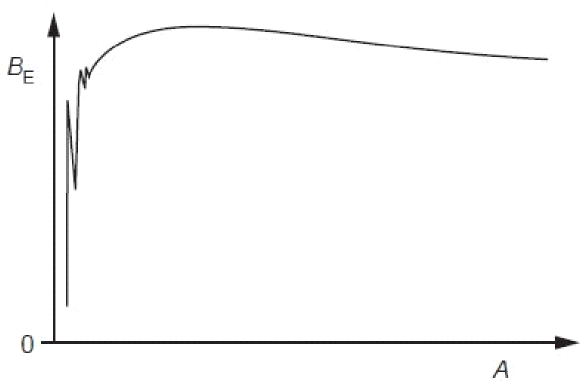


Fig. 8.1

On Fig. 8.1, mark the approximate positions of

(i) iron-56 (label this point Fe), [1]

(ii) zirconium-97 (label this point Zr), [1]

(iii) hydrogen-2 (label this point H). [1]

(b) **(i)** State what is meant by *nuclear fission*.

....

....

....[2]

(ii) By reference to Fig. 8.1, explain how fission is energetically possible.

....

....

....

....[2]

Q10.

8 **(a)** State what is meant by the *binding energy* of a nucleus.

....

....

.... [2]

(b) Show that the energy equivalence of 1.0 u is 930 MeV.

[3]

Exa

(c) Data for the masses of some particles and nuclei are given in Fig. 8.1.

	mass / u
proton	1.0073
neutron	1.0087
deuterium ($^{2}_{1}H$)	2.0141
zirconium ($^{97}_{40}Zr$)	97.0980

Fig. 8.1

Use data from Fig. 8.1 and information from **(b)** to determine, in MeV,

(i) the binding energy of deuterium,

binding energy = ... MeV [2]

(ii) the binding energy **per nucleon** of zirconium.

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

Q11.

9 (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.

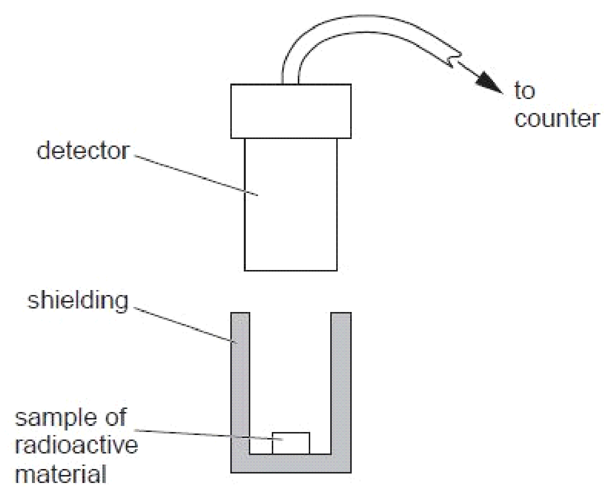


Fig. 9.1

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]

For Examin Use

Q12.

8 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]

Q13.

8 **(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

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

Data for the nuclei are given in Fig. 8.1.

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

Q14.

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

....

....

.... [2]

For Examiner Use

(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]

Q15.

8 (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]

Q16.

6 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]

Use

(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]

Q17.

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

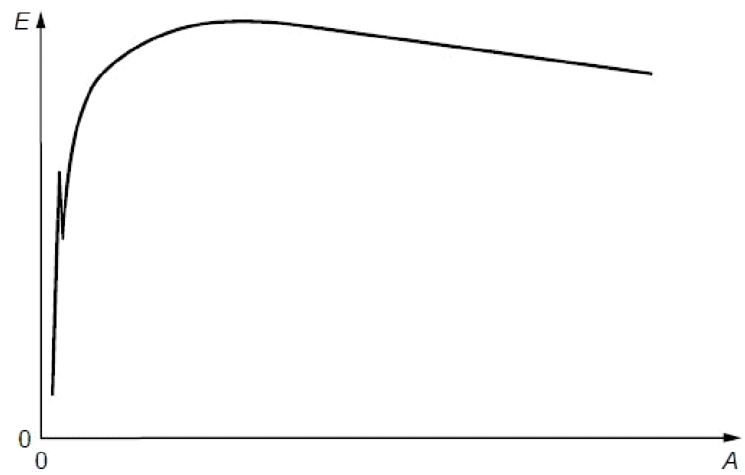


Fig. 7.1

(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.

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

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

number = ... [1]

Use

(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]

Q18.

8 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]

Q19.

7 **(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.

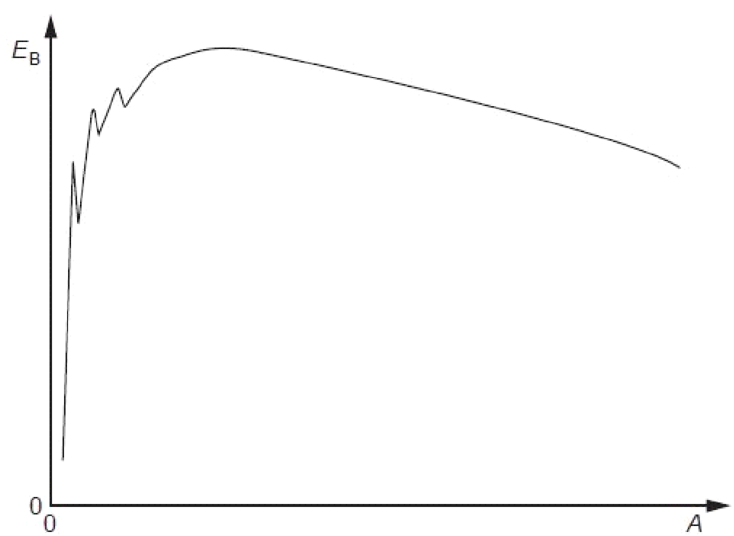


Fig. 7.1

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]

Q20.

8 The controlled reaction between deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) has involved ongoing research for many years. The reaction may be summarised as

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

where Q = 17.7 MeV.

Binding energies per nucleon are shown in Fig. 8.1.

	binding energy per nucleon / MeV
$^{2}_{1}H$	1.12
$^{1}_{0}n$	–
$^{4}_{2}He$	7.07

Fig. 8.1

(a) Suggest why binding energy per nucleon for the neutron is not quoted.

....

.... [1]

(b) Calculate the mass defect, in kg, of a helium $^{4}_{2}He$ nucleus.

mass defect = ... kg [3]

(c) **(i)** State the name of the type of reaction illustrated by this nuclear equation.

.... [1]

(ii) Determine the binding energy per nucleon, in MeV, of tritium ($^{3}_{1}H$).

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

For Examiner's Use

Q21.

8 **(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]

Q22.

8 In some power stations, nuclear fission is used as a source of energy.

For Examiner's Use

(a) State what is meant by *nuclear fission*.

....

....

.... [2]

(b) The nuclear fission reaction produces neutrons. In the power station, the neutrons may be absorbed by rods made of boron-10.
Complete the nuclear equation for the absorption of a single neutron by a boron-10 nucleus with the emission of an α-particle.

$$^{10}_{5}\text{B} + \text{.....................} \rightarrow {}^{\cdots}_{3}\text{Li} + \text{.....................}$$ [3]

(c) Suggest why, when neutrons are absorbed in the boron rods, the rods become hot as a result of this nuclear reaction.

....

....

....

.... [3]

Q23.

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

For Examiner's Use

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

....

....

.... [2]

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

[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]

For Examiner's Use

Q24.

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

For Examiner's Use

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]

Q25.

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

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

For Examiner's Use

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

x = ... [1]

(ii) State the name of the particle represented by the symbol $^{0}_{-1}$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 ($^{235}_{92}$U)	235.123	
molybdenum-95 ($^{95}_{42}$Mo)	94.945	8.09
lanthanum-139 ($^{139}_{57}$La)	138.955	7.92
proton ($^{1}_{1}$p)	1.007	
neutron ($^{1}_{0}$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.

For Examiner's Use

[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]

Q26.

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

For Examiner's Use

....

....

....[2]

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

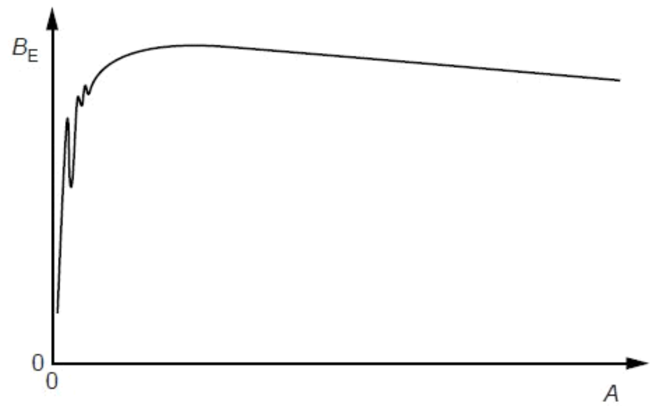


Fig. 8.1

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.

For Examiner's Use

	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]

Q27.

8 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]

Q28.

10 **(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

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

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

....

....

.... [2]

Q29.

9 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]

Q30.

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

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

....

.... [1]

(b) In the D-T reaction, a deuterium (^2_1H) nucleus fuses with a tritium (^3_1H) nucleus to form a helium-4 (^4_2He) nucleus. The nuclear equation for the reaction is

$$^2_1H + ^3_1H \longrightarrow ^4_2He + ^1_0n + \text{energy}$$

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

	mass / u
deuterium (^2_1H)	2.01356
tritium (^3_1H)	3.01551
helium-4 (^4_2He)	4.00151
neutron (^1_0n)	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]

Q31.

9 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]