1

Carbon-14 is a radioactive isotope of carbon which decays by β^-emission with a *half life* of 5700 years.

(a) **(i)** Explain the meaning of the term *half life*.

....

....[1]

(ii) What is the composition of a $^{14}_{6}C$ nucleus?

....[2]

(b) $^{14}_{6}C$ is produced when a nitrogen nucleus $^{14}_{7}N$ first absorbs a neutron in the atmosphere and then the resulting nuclide emits a proton.

(i) State the nuclear reaction equation for the production of $^{14}_{6}C$ from $^{14}_{7}N$.

....[2]

(ii) Write down the stable nuclide into which $^{14}_{6}C$ decays by β^-emission.

....[2]

(c) Living plants absorb carbon dioxide from the atmosphere, a small quantity of which contains $^{14}_{6}C$. The β^-activity A_o from a living plant remains constant but once the plant dies, the activity decays according to the expression

$$A = A_o \, e^{-\lambda t}$$

where A is the activity at time t.

Calculate

(i) the decay constant λ for $^{14}_{6}C$

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

(ii) the quantity $f = \dfrac{\text{the activity after 40 000 years}}{\text{the initial activity } A_o}$

f = ... [2]

2 The radius r of a nucleus consisting of A nucleons is given by the equation

$$r = r_0 A^{1/3}.$$

(a) What does r_0 represent?

....[1]

(b) Fig. 1.1 illustrates this relationship.

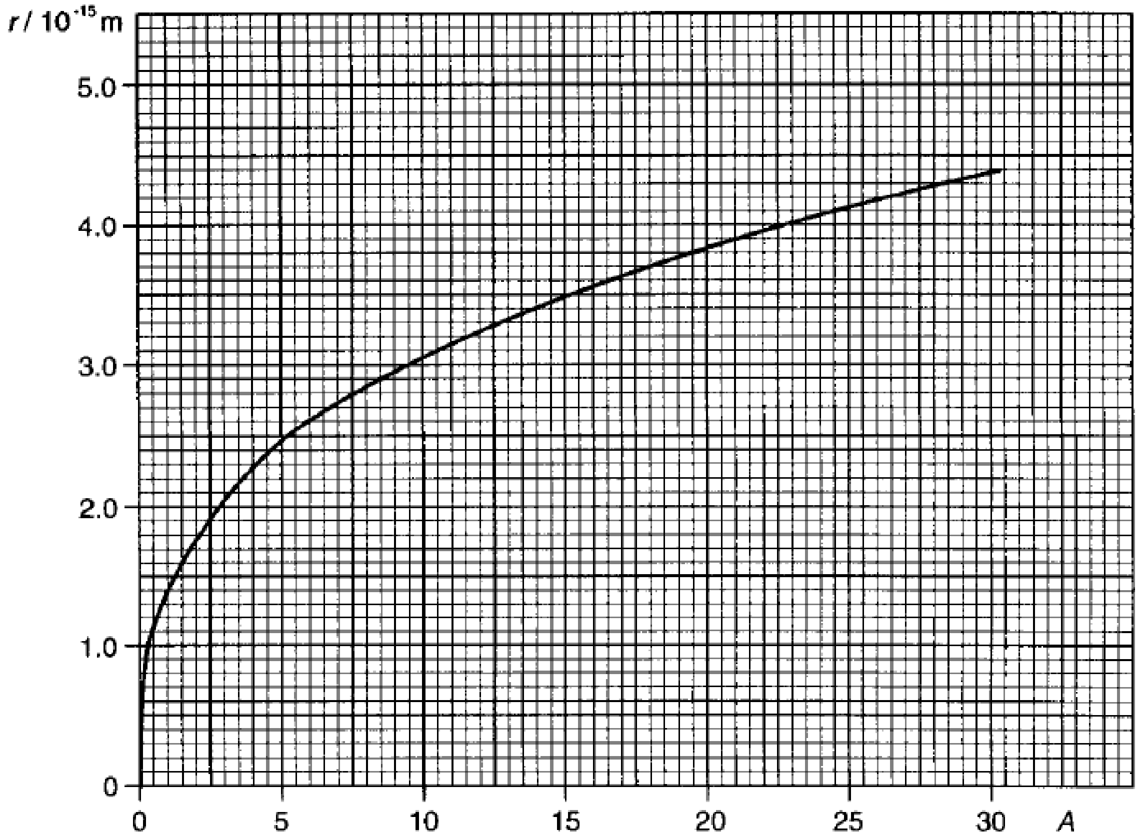

Fig. 1.1

(i) Use Fig. 1.1 to find the value of r when A = 20.

r = ... m

(ii) Use your answer to **(i)** to show that r_0 is equal to 1.4×10^{-15} m.

[2]

(c) Hence estimate the density of the hydrogen (^1_1H) nucleus.
State an appropriate unit for your answer.

density = ... [3]

(d) Liquid hydrogen has a density of approximately $70\,kg\,m^{-3}$. Compare this with your answer to **(c)** and discuss what these values imply about the structure of the hydrogen atom.

....

....

....

....

....

....

....[4]

(e) **(i)** Assuming that the nuclei are spherical, deduce the relationship between the volume of the nucleus and the number of nucleons (A).

....

....

(ii) Suggest what your answer to **(i)** implies about the separation of the nucleons inside different nuclei.

....

....

[2]

[Total : 12]

3 This question is about collisions between protons and antiprotons.

(a) State the mass and charge of an antiproton.

mass = ... kg

charge = ... C
[2]

(c) In a particular interaction, the rest masses of a proton and an antiproton are annihilated and two γ-photons are created.

(i) Show that the total rest mass of the proton and antiproton is equivalent to 3.0×10^{-10} J of energy.

[3]

(ii) Calculate the minimum frequency of each γ-photon.

frequency = ... Hz [2]

(iii) State the circumstance in which this minimum frequency would occur.

....

....[1]

[Total : 12]

4 This question is about the neutron.

(a) By putting ticks in the table of Fig. 4.1, indicate the classes of particle of which the neutron is a member.

	baryon	hadron	lepton	neutrino
neutron				

[1]

Fig. 4.1

(b) Complete Fig. 4.2 by entering appropriate values. The first row of the table has already been completed.

	baryon number	charge	strangeness
proton	1	+1	0
neutron			
up quark			
down quark			

[3]

Fig. 4.2

(c) (i) State the composition of the neutron in terms of its constituent quarks.

....

....[1]

(ii) Write a numerical equation which shows that the total baryon number for these quarks is equal to the baryon number of the neutron.

Write equivalent equations for the charge and strangeness of the neutron.

charge ....

strangeness ....

[3]

(d) **(i)** The free neutron can decay, producing a proton, a β-particle and an anti-neutrino. Write an equation representing this decay process.

(ii) Describe this process in terms of the quarks in the neutron.

....

....

....

[4]

5 Natural uranium is a mixture of Uranium-235 and Uranium-238. Both isotopes are present in the fuel rods of a nuclear power station. The $^{235}_{92}U$ nuclei undergo *neutron-induced fission* when they absorb a *thermal neutron*. Absorption of neutrons by a $^{238}_{92}U$ nucleus eventually produces $^{239}_{94}Pu$ which does not undergo fission.

(a) Explain what is meant by

(i) *neutron-induced fission*,

....

....

....

(ii) *thermal neutron*.

....

....
[3]

(b) **(i)** State the name and symbol of the nucleus which is formed when a $^{235}_{92}U$ nucleus absorbs a neutron.

....

(ii) This nucleus then splits into two much less massive nuclei. By referring to the neutron/proton ratio of stable nuclei, discuss why the product nuclei are likely to be radioactive.

....

....

....

....
[3]

(c) (i) Write an equation to represent the decay of a $^{239}_{94}Pu$ nucleus.

....

....

(ii) The half-life of this decay process is 24 000 years. Calculate the percentage of Plutonium-239 which decays in 1000 years.

percentage = ... %

[6]

[Total : 12]

6 (a) Complete the table below for the three types of ionising radiations.

radiation	nature	range in air	penetration ability
α			0.2 mm paper
β	electron		
γ		several km	

[3]

(b) Describe briefly with the aid of a sketch an absorption experiment to distinguish between the three radiations listed above.

....

....

....

....

....

....[3]

(c) Rutherford suggested that the isotopes of uranium had equal numbers of atoms, when the Earth was formed. The half lives of two isotopes of uranium are shown in the table below.

isotope	$^{235}_{92}U$	$^{238}_{92}U$
half life / 10^9 years	0.75	4.5

(i) Assuming Rutherford's suggestion is correct, calculate the ratio

$$\frac{\text{number of } ^{235}_{92}\text{U atoms}}{\text{number of } ^{238}_{92}\text{U atoms}}$$

at a time 4.5×10^9 years after the Earth was formed.

ratio = ...[3]

(ii) The present day value for this ratio is 0.0072. Suggest without detailed calculation why this theory therefore puts the age of the Earth between 6.0×10^9 and 7.5×10^9 years.

....

....

....

....

....

....[2]

[Total : 11]

7 (You will be awarded marks for the quality of written communication in your answer to question 7.)

(a) Describe briefly one scattering experiment to investigate the size of the nucleus of the atom. Include a description of the properties of the incident radiation which makes it suitable for this experiment.

....

....

....

....

....

....

....

....

....

....

....

....[6]

(b) **(i)** Give one difference and one similarity between a fusion reaction and a fission reaction.

difference ....

....

similarity..

....[2]

(ii) Describe the process of the fission of a $^{235}_{92}U$ nucleus, induced by a neutron.

....

....

....

....

....

....

....

....[4]

[Total : 12]

Quality of written communication [4]

8 Two adjacent protons, situated inside a certain nucleus, are acted upon by three forces. These are electrostatic, gravitational and strong interaction (i.e. strong force).

(a) State whether each of these forces is attractive or repulsive.

1 electrostatic ....

2 gravitational ....

3 strong interaction ....
[1]

(b) The average separation of the nucleons in this nucleus is 0.80×10^{-15} m.
Calculate, giving an appropriate unit in each case, the magnitude of

(i) the electrostatic force

force = ...

(ii) the gravitational force.

force = ...
[6]

(c) Use your answers to **(b)** to comment on the relative importance of electrostatic and gravitational forces inside the nucleus.

....

....

....[2]

(d) Fig. 1.1 shows the variation with nucleon-nucleon separation of the strong interaction between two nucleons.

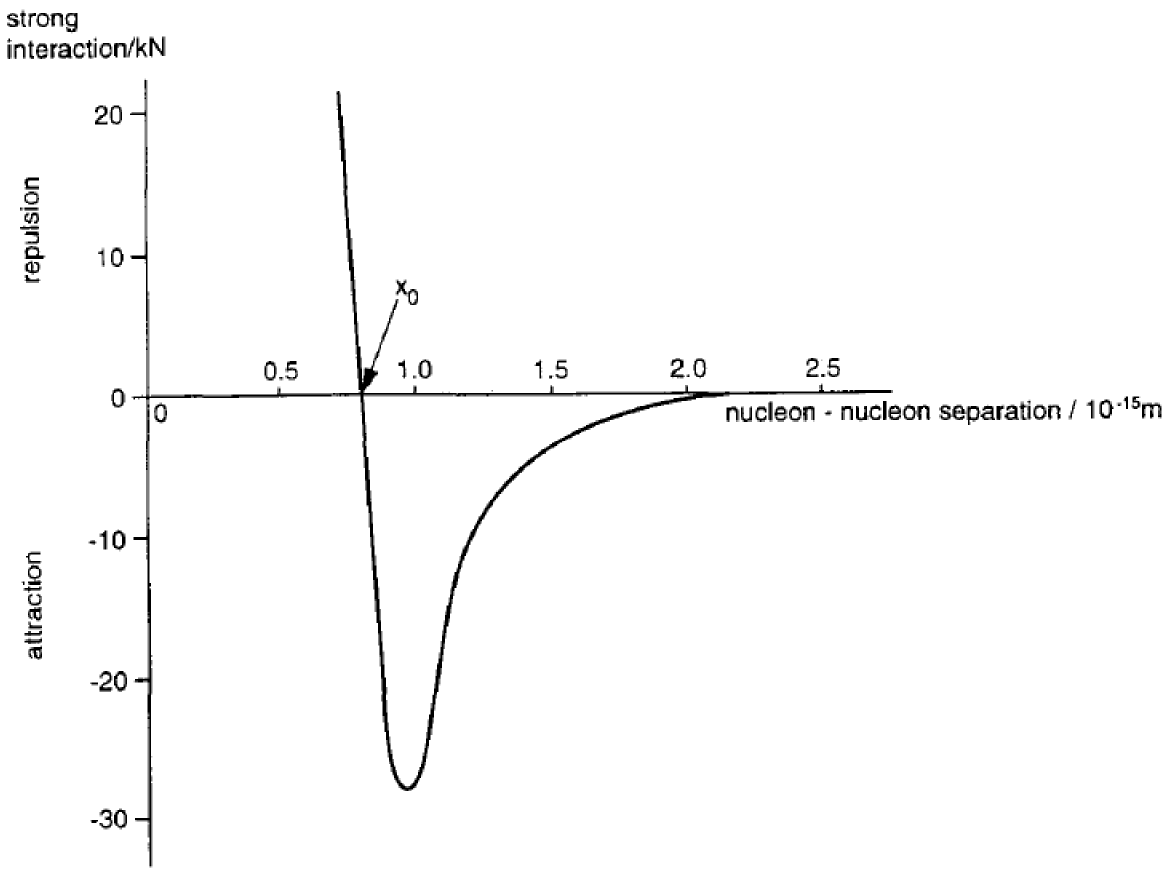

Fig. 1.1

When both nucleons are *neutrons*, the equilibrium separation is x_0. Explain whether the equilibrium separation between two *protons* will be greater, less than or equal to x_0.

....

....

....

....[3]

[Total : 12]

9 Fig. 2.1 shows the variation with nucleon number (mass number) of the binding energy per nucleon for various nuclides.

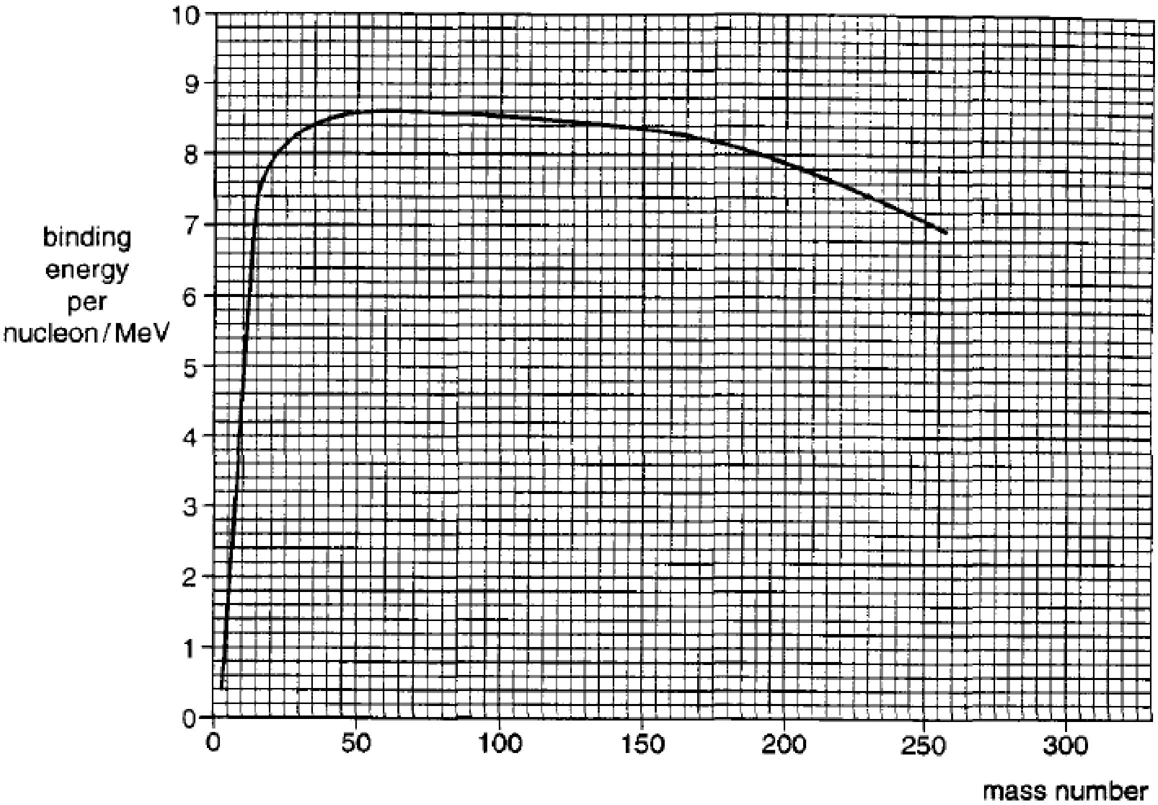

Fig. 2.1

(a) State the number of nucleons in the nucleus of

$^{94}_{37}Rb$ ....

$^{142}_{55}Cs$ ....

$^{235}_{92}U$ ....

[2]

(b) Use Fig. 2.1 to calculate the energy released when a $^{235}_{92}U$ nucleus undergoes fission, producing nuclei of $^{94}_{37}Rb$ and $^{142}_{55}Cs$.

energy = ... MeV [6]

(c) **(i)** On Fig. 2.2, sketch a graph which shows the variation with nucleon number of the *relative yield of fission products for a fissile material such as Uranium-235.* [2]

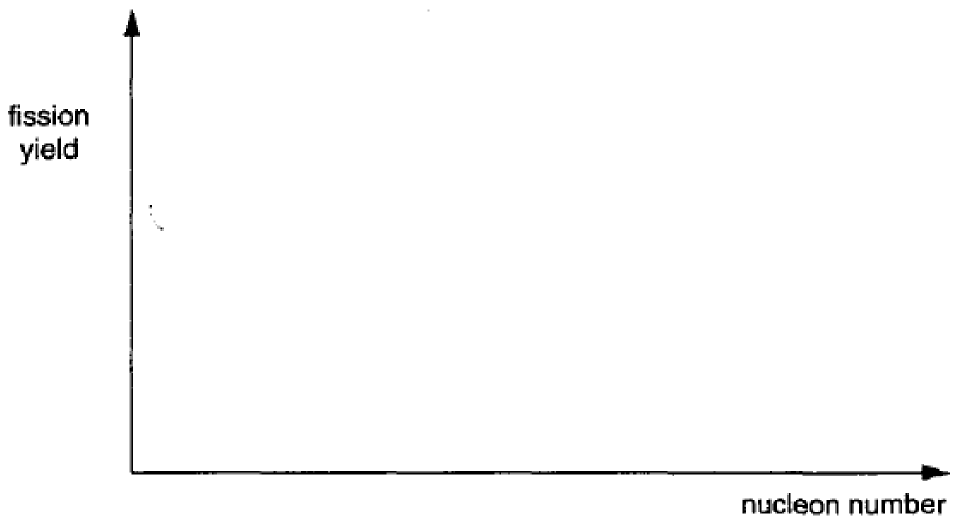

Fig. 2.2

(ii) Mark possible positions for $^{94}_{37}Rb$ and $^{142}_{55}Cs$ on your graph and label them. [2]

[Total : 12]

10 **(a) (i)** Explain what is meant by a *plasma*.

....

....

....[2]

(ii) Explain why the material in the interior of the Sun is in the form of a plasma.

....

....

....[2]

(b) (i) Explain how the high temperature inside the Sun aids the process of nuclear fusion.

....

....

(ii) State **one** other condition inside the Sun which increases the likelihood of fusion.

....

....
[2]

(c) Fig. 3.1 is a flow diagram illustrating the stages in the carbon cycle, which occurs inside the Sun.

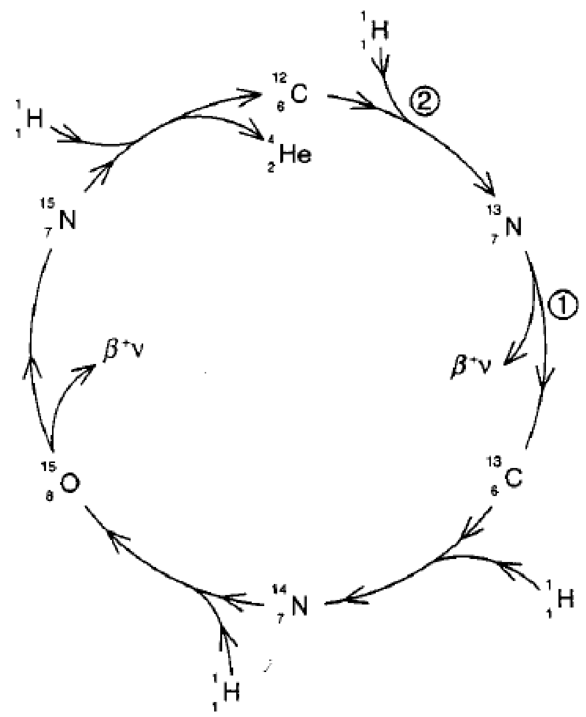

Fig. 3.1

(i) For the stages labelled '1' and '2', write a nuclear equation for the reaction and state in words what change is taking place.

1 ....

....

....

2 ....

....

....

[4]

(ii) Write an equation which summarises the overall reaction of the carbon cycle. Describe in words the process which this equation represents.

....

....

....[2]

[Total : 12]

11 **(a)** State the names of the classes of particles (one in each case) which include

(i) positrons and neutrinos ....

(ii) protons and neutrons. ....

[2]

(b) An unstable nucleus may decay by emitting a positron and a neutrino. This can be due to a proton decaying to a neutron. Write an equation to represent this proton decay.

[2]

(c) (i) State the composition of the proton and neutron in terms of their constituent quarks.

proton ....

neutron ....

[2]

(ii) Hence write an equation for the process described in **(b)**, in terms of changes in quark composition.

[1]

(iii) State the baryon number and charge of each particle in the equation of **(c)(ii)**. Hence show that baryon number and charge are conserved.

....

....

....

....

....

....

....

....

....

....[5]

[Total : 12]

12 Strontium-90 is one of the radioactive by-products of the fission of uranium. Values of the activity of a sample of Strontium-90 at various times after its formation are recorded in Fig. 6.1.

Activity / 10^6 Bq	79.5	62.1	48.5	37.8	29.5	23.1	18.0
Time / year	5.0	15.0	25.0	35.0	45.0	55.0	65.0

Fig. 6.1

(a) On Fig. 6.2 below, plot a graph to show the variation with time of the activity of this sample. [3]

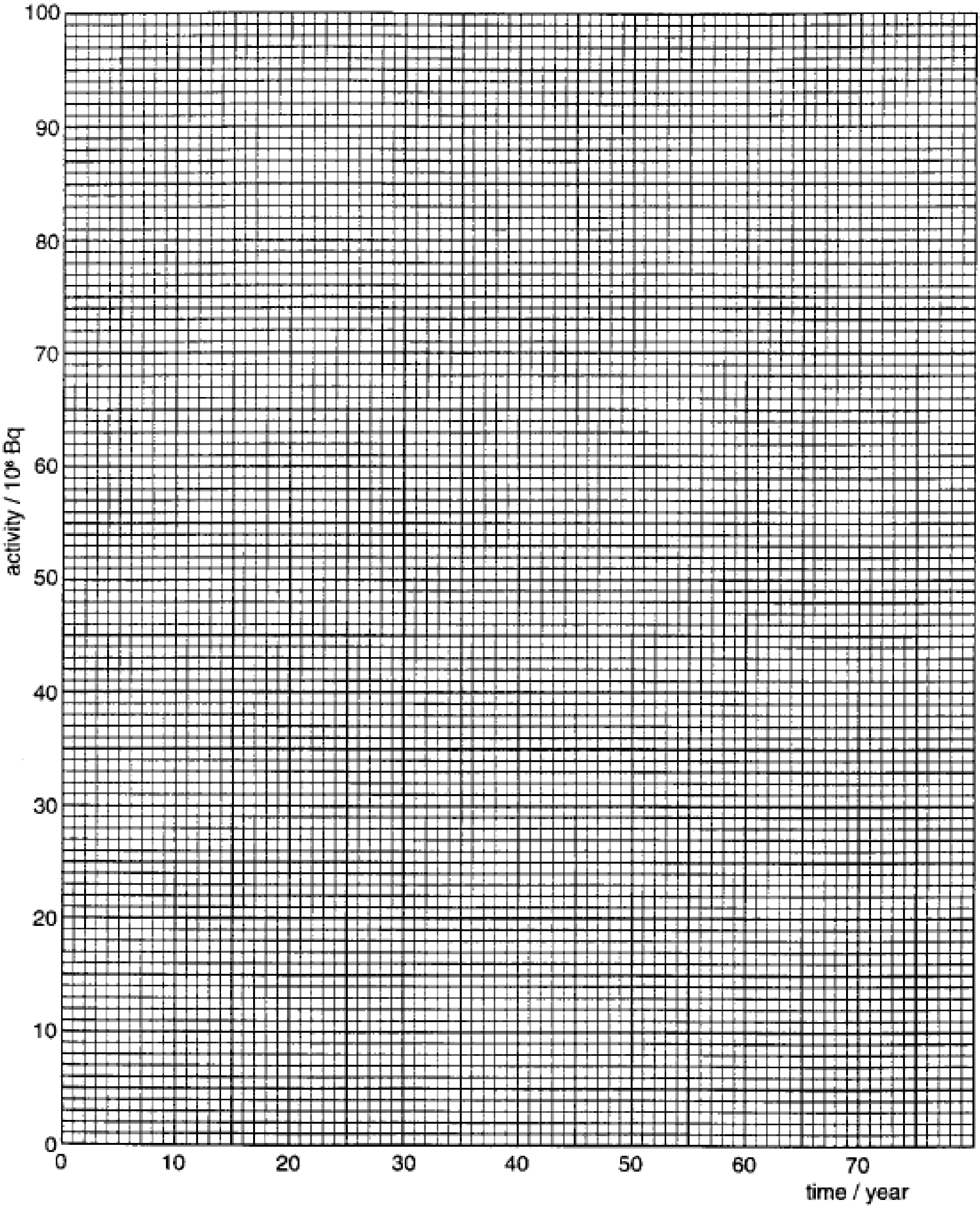
activity / 10^8 Bq
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
time / year

Fig. 6.2

(b) Activity A is related to time t by the equation

$$A = A_0 e^{-\lambda t}.$$

Use your graph to find values of

(i) A_0 (give an appropriate unit for your answer)

A_0 = ...

(ii) the half-life, $t_{½}$, of the isotope.

half-life = ... year [3]

(c) Use your answer to **(b)(ii)** to show that the value of λ for this material is 2.5×10^{-2} year^{-1}.

[1]

(d) This sample, in a suitable containment, is considered safe when its activity has fallen to 1% of its initial value. Calculate the time t when this occurs.

time = ... years [3]

[Total : 10]

13 The radioactive nuclide of plutonium, $^{239}_{94}Pu$, decays by alpha-particle emission with a half-life of 2.4×10^4 years. The alpha-particle energy is 8.2×10^{-13} J.

(a) **(i)** For a $^{239}_{94}Pu$ nucleus, state the number of

protons ....

neutrons .... [1]

(ii) For the nucleus produced as the result of the decay, state the number of

protons ....

neutrons .... [2]

(b) Calculate the decay constant of the plutonium nuclide.

1 year = 3.2×10^7 s

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

(c) A small power source to generate 2.5 W is to be made from the plutonium isotope.

(i) Show that the rate of decay of the plutonium must be at least 3×10^{12} Bq.

[2]

(ii) Calculate the number of plutonium atoms needed to provide this activity.

number = ... [2]

(iii) Calculate the mass of plutonium in the source.

mass = ... kg [2]

(d) Another isotope of plutonium, $^{238}_{94}Pu$, also decays by alpha-particle emission but with a half-life of 86 y. The alpha-particle energy is 8.8×10^{-13} J.

State **one** advantage and **one** disadvantage of using ^{238}Pu instead of ^{239}Pu in the power source.

advantage ....

....

.... [1]

disadvantage ....

....

.... [1]

[Total: 12]

14

In this question, four marks are available for the quality of written communication.

(a) Describe the structure of the atom and the nature of its constituents.

....

....

....

....

....

....

....

....

....

....

....

.... [4]

15

The graphs shown in Fig. 1.1 show the variation with separation r of **(i)** the electrostatic force F_E and **(ii)** the gravitational force F_G between two protons.

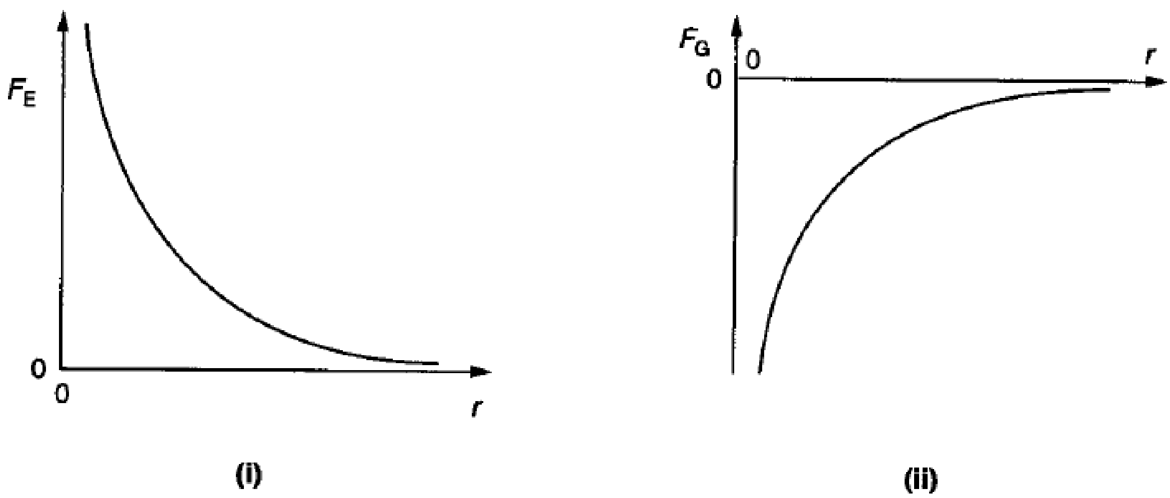

Fig. 1.1

(a) State the relation between

(i) F_E and r

....

....

(ii) F_G and r.

....

....

[2]

(b) Why is F_E positive, whereas F_G is negative?

....

....

....[1]

(c) The range of values of r represented by each graph is the same.
State with a reason whether the F_E and F_G scales cover the same range of values.

....

....

....[2]

(d) Fig. 1.2 shows how the strong force F_S varies with the separation r of two neutrons.

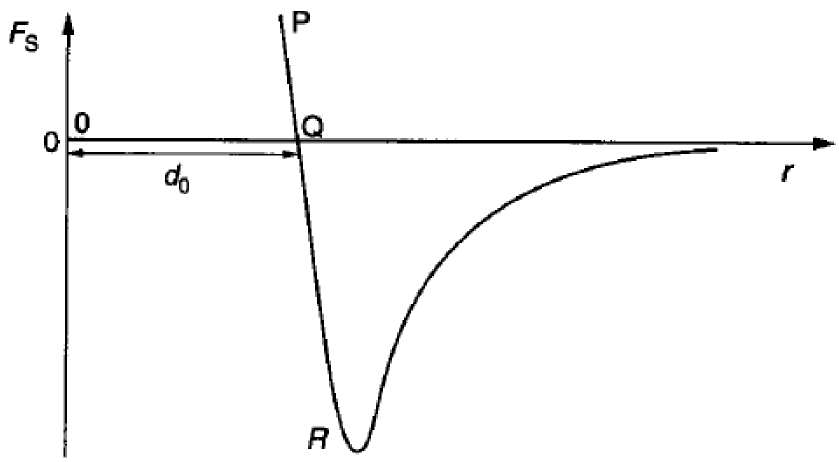

Fig.1.2

(i) State the significance of the separation d_0.

....

....[1]

(ii) State whether F_S is attractive or repulsive in regions PQ and QR.

PQ ....

QR ....

[1]

(iii) Explain how your answers to **(i)** and **(ii)** are related.

....

....

....[2]

(e) Calculate the density of a neutron. Assume that $d_0 = 1.4 \times 10^{-15}$ m and that the difference in mass between a proton and a neutron is negligible.
Give an appropriate unit for your answer.

density = ... unit ....[3]

[Total: 12]