(iii) Calculate this constant number of $^{239}_{93}Np$ nuclei.

half-life of $^{239}_{93}Np = 2.04 \times 10^5$ s

number = ... [3]

(iv) Sketch a graph on Fig. 2.1 to show how the number of $^{239}_{93}Np$ nuclei present varies with time. Label this graph Y. [1]

(d) (i) What is the half-life of plutonium-239 in seconds?

1 year = 3.16×10^7 s

half-life = ... s [2]

(ii) On Fig. 2.1, sketch a graph to show how the number of $^{239}_{94}Pu$ nuclei varies with time. Label this graph Z. [2]

[Total: 14]

58

This question is about the possibility of fusion between a tritium nucleus and a deuterium nucleus.

A tritium nucleus ^3_1H and a deuterium nucleus ^2_1H approach each other along the same line with the **same** speed *u*.

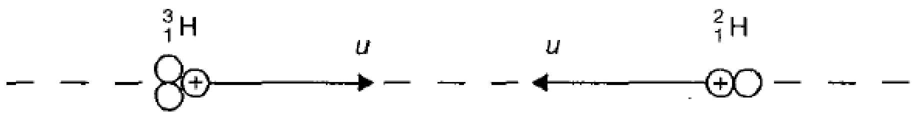

Fig. 3.1

Each nucleus decelerates, comes to rest and then accelerates in the reverse direction.

(a) (i) By considering conservation of momentum, explain why both nuclei cannot come to rest at the same time.

....

....

....

.... [1]

(ii) When the nuclei are closest together they have the same **velocity**. Show that this velocity is $u/5$.

[2]

(b) (i) Energy is conserved during the interaction.

Write a word equation relating the initial energy of the two nuclei when they are far apart, to their energy when they are closest together. Your equation should make clear the kind(s) of energy involved.

....

.... [1]

(ii) Show that the total **initial** kinetic energy of the two nuclei is equal to $4.18 \times 10^{-27} u^2$ joule where u is in $m\,s^{-1}$.

[3]

(iii) The potential energy E of two charges Q_1 and Q_2, separated by a distance r is given by

$$E = \frac{Q_1 Q_2}{4\pi \epsilon_0 r}. \qquad \epsilon_0 = \text{permittivity of free space}$$

For ${}^{3}_{1}H$ and ${}^{2}_{1}H$ to fuse, their separation must be no more than 1.50×10^{-15} m.

Calculate the minimum value of u for fusion to take place.

minimum value of u = ... $m s^{-1}$ [4]

[Total: 11]

59

A uranium-236 nucleus, ${}^{236}_{92}U$, undergoes fission, producing nuclei of zirconium-100, ${}^{100}_{40}Zr$, and tellurium-131, ${}^{131}_{52}Te$.

(a) Write a nuclear equation to represent this fission reaction.

.... [1]

(b) Each of the product nuclei is a β^- emitter.

(i) State the change, if any, in the nucleon number and the proton number caused by a β^- emission.

nucleon number ....

proton number .... [1]

(ii) The β^- decay of zirconium-100 is followed by three more β^- decays before the product nucleus is stable.

State the nucleon number and the proton number of the resulting stable nucleus.

nucleon number ....

proton number .... [1]

(iii) On Fig. 6.1, use crosses to represent each of the nuclei involved in the series of decays by which zirconium-100 changes to a stable nucleus. Add arrows to show the direction of each reaction. [2]

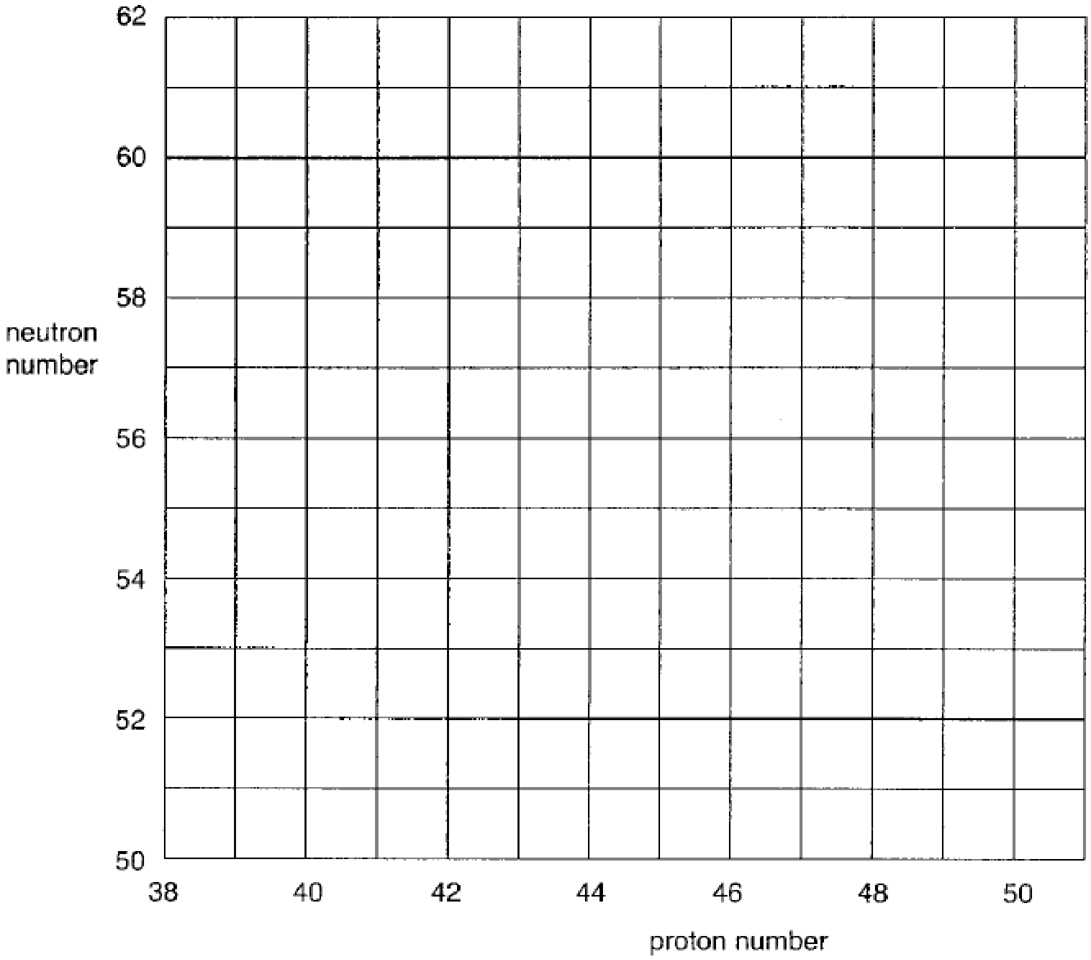

Fig. 6.1

(iv) On a graph of neutron number against proton number, stable nuclei all lie close to a line. On Fig. 6.1, sketch this line. [1]

(c) Zirconium-100 decays initially to niobium-100.

data:	nuclear masses:	zirconium-100	99.895 808 u
		niobium-100	99.891 679 u
		electron mass	0.000 549 u

(i) Calculate the mass defect for this decay reaction.

mass defect = ... u [2]

(ii) Show that this mass defect is equivalent to about 5×10^{-13} J.

[2]

(iii) When a particular zirconium-100 nucleus decays, the emitted β^- particle has only about 2×10^{-13} J. Suggest why this is less than the energy calculated in **(ii)**.

....

....

....

.... [2]

[Total: 12]

60

(a) The activity A of a sample of a radioactive nuclide is given by the equation

$$A = \lambda N$$

Define each of the terms in the equation.

A ....

....

λ ....

....

N ....

....[3]

(b) A 1000 MW coal-fired power station burns 7.0×10^6 kg of coal in one day. Two parts per million of the mass of the coal is $^{238}_{92}U$. The uranium remains in the residue left after the coal is burnt. The uranium nuclide $^{238}_{92}U$ decays by α-particle emission with a half-life of 4.5×10^9 years to an isotope of thorium.

(i) Write down

1 the proton number Z of thorium ....

2 the nucleon number A for this isotope of thorium ....[1]

(ii) Calculate the mass of uranium produced in the residue in one day.

mass = ... kg [1]

(iii) Hence show that the number of uranium atoms in this mass of uranium is 3.5×10^{25}.

[1]

(iv) Calculate the activity of this mass of uranium. Give a suitable unit with your answer.

1 year $= 3.2 \times 10^7$ s

activity = ... unit .... [3]

(c) To drive the turbines in the power station superheated steam at 450 K is required. Cold water enters the boilers at 290 K. Suggest and explain **two** reasons why it is **not** possible to use the formula

$$\Delta Q = mc\Delta\theta$$

to calculate the total energy used to transform the cold water into superheated steam. In the formula ΔQ is the energy absorbed by a mass m of water, c is the specific heat capacity of water and $\Delta\theta$ is its change in temperature.

....

....

....

....

....

....[3]

[Total: 12]

61

This question is about nuclear density.

(a) Fig. 1.1 shows the relationship between the cube of the radius r of atomic nuclei and nucleon number A.

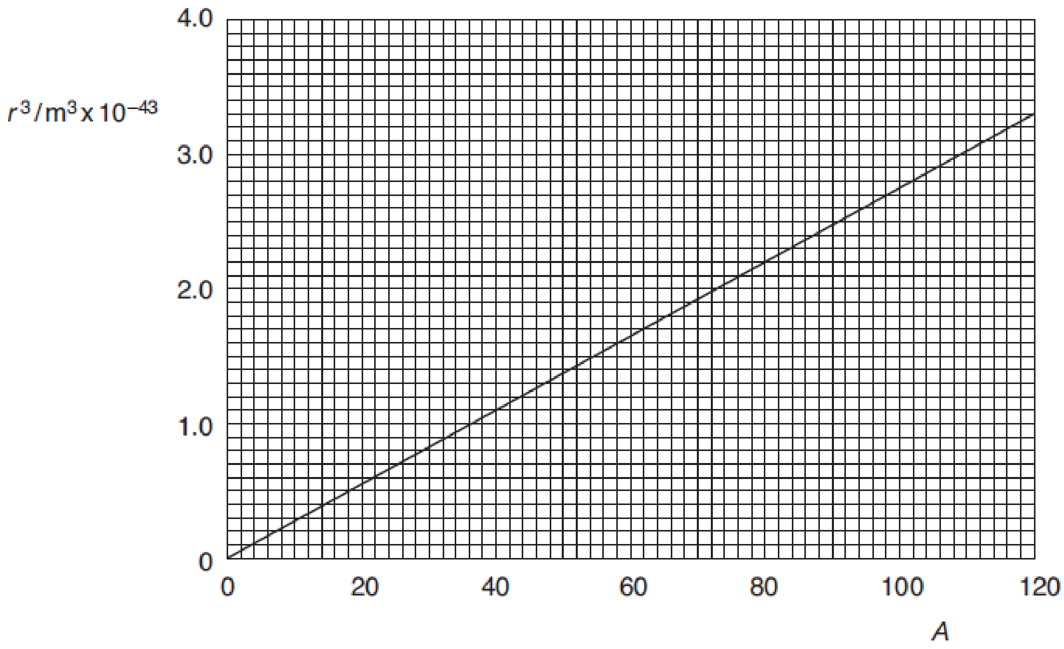

Fig. 1.1

(i) Deduce the gradient of this graph.

gradient = ... [1]

(ii) Use your answer to **(i)** to calculate the radius r_0 of a single nucleon.

radius = ... m [3]

(b) Calculate the density of a carbon-12 nucleus $^{12}_{6}C$.

density = ... $kg\,m^{-3}$ [3]

(c) Diamond is formed from carbon-12 atoms. The density of diamond is $3530\,kg\,m^{-3}$.

(i) Calculate the ratio $\frac{\text{density of a carbon-12 nucleus}}{\text{density of diamond}}$.

ratio = ... [1]

(ii) Explain why this ratio is so large.

....

....

....

.... [2]

[Total: 10]

62

This question is about nuclear fission of uranium-235.

(a) (i) State what is meant by a *thermal neutron*.

....

.... [1]

(ii) State the importance of thermal neutrons in relation to the fission of uranium-235.

....

....

.... [1]

(b) A uranium-235 nucleus $^{235}_{92}U$ undergoes fission, producing nuclei of lanthanum-146 $^{146}_{57}La$ and bromine-87 $^{87}_{35}Br$. The binding energies per nucleon of these nuclides are shown below.

nuclide	binding energy per nucleon/MeV
$^{235}_{92}U$	7.6
$^{146}_{57}La$	8.2
$^{87}_{35}Br$	8.6

(i) Plot these values on the grid of Fig. 2.1. [1]

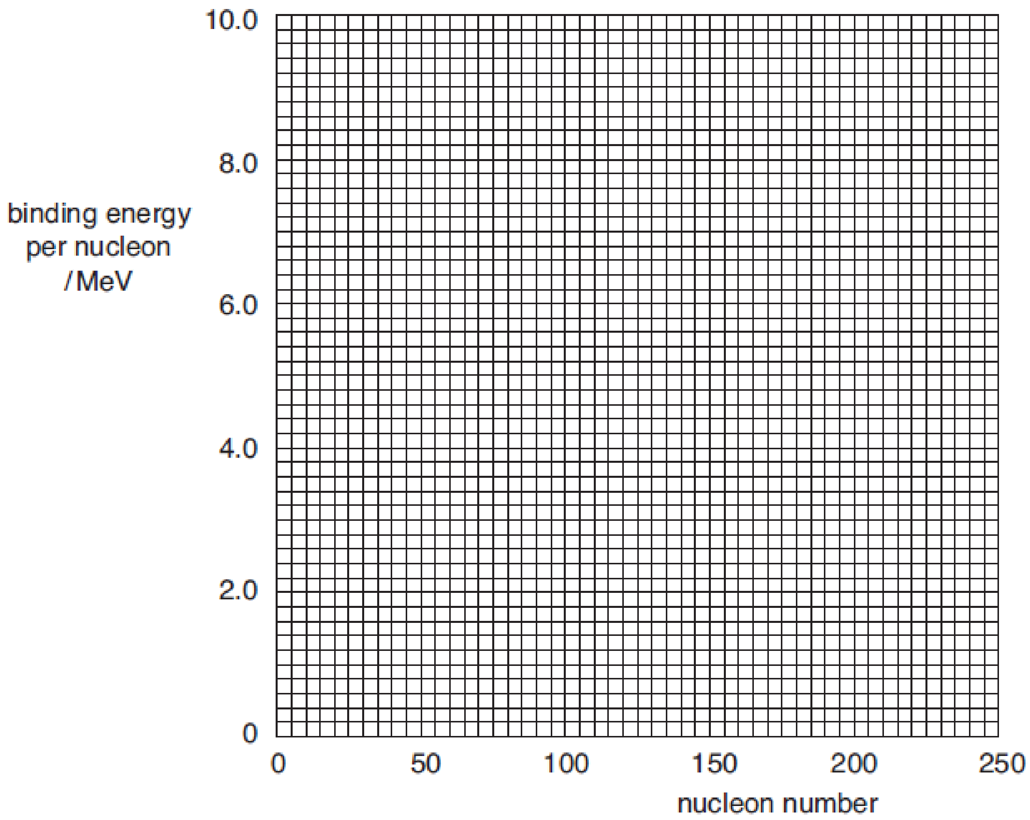

Fig. 2.1

(ii) Sketch a graph on Fig. 2.1, to show how the binding energy per nucleon varies with nucleon number for **all** nuclei. [2]

(iii) Use information from the table to calculate how much energy in MeV is released when a $^{235}_{92}U$ nucleus undergoes fission.

energy = ... MeV [3]

(iv) Sketch a graph on Fig. 2.2, to show how the relative yield of fission products for uranium-235 varies with nucleon number. [2]

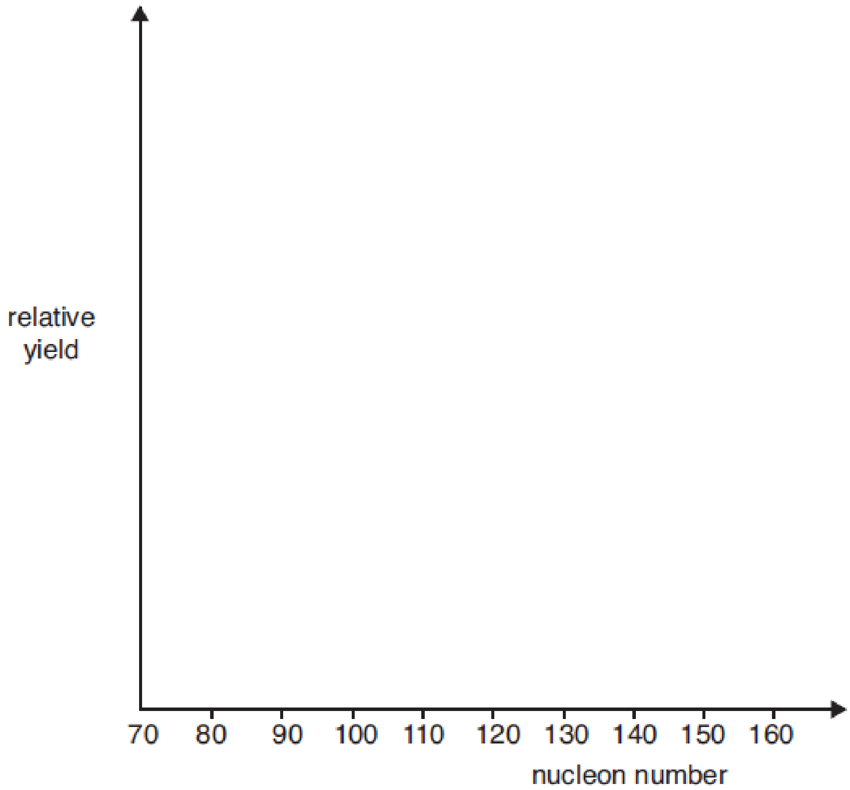

Fig. 2.2

(v) Use information from Fig. 2.2 to mark **on Fig. 2.1** the regions of the graph where **most** of the fission products lie. Label these regions 'F'. [2]

(c) (i) Neutrons emitted from a fission reaction may be slowed down by colliding with carbon-12 nuclei $^{12}_{6}C$. The initial speed of a neutron is $1.5 \times 10^7 \, m\,s^{-1}$. On average the neutron's speed after each collision is equal to 0.93 of its speed before the collision. Show that after 120 collisions its speed has been reduced to about $2.5 \times 10^3 \, m\,s^{-1}$.

[2]

(ii) When a neutron collides head-on with a $^{12}_{6}C$ nucleus, as shown in Fig. 2.3, its speed is reduced by about 15%.

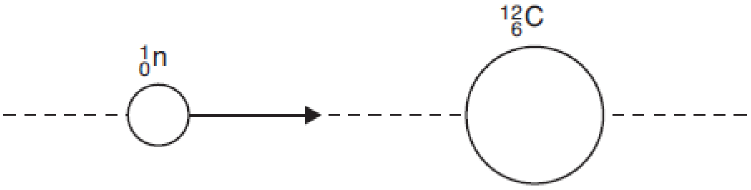

Fig. 2.3

Suggest why this speed reduction is different from the reduction stated in **(i)**.

....

....

.... [1]

[Total: 15]

63

This question is about nuclear fusion reactions inside the Sun.

(a) Explain the importance of gravity in making fusion reactions possible inside the Sun.

....

....

....

....

....

.... [3]

(b) Two hydrogen nuclei ^1_1H, which are initially a long way apart, approach each other along the same straight line.

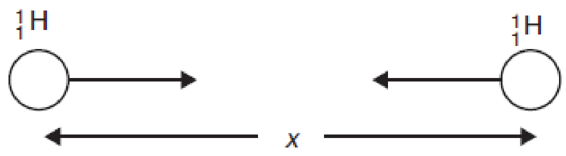

Fig. 3.1

The repulsive force F_e between them varies with their separation x as shown in Fig. 3.2.

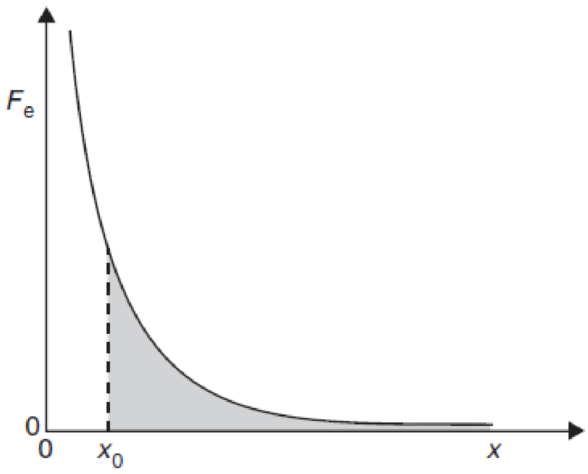

Fig. 3.2

The nuclei fuse if their separation becomes equal to or less than a critical separation x_0. What is the physical significance of the shaded area?

....

....

....

.... [2]

(c) The average kinetic energy E_k in joule, of ^1_1H nuclei inside a star is given by the equation

$$E_k = 2.07 \times 10^{-23} T.$$

The temperature T of the Sun's interior is 15×10^6 K.

Calculate the combined average kinetic energy of **two** ^1_1H nuclei inside the Sun.

kinetic energy = ... J [1]

(d) The interior of the Sun is mainly composed of ${}^1_1H$ nuclei and these nuclei collide continually. Two nuclei will fuse if their combined energy exceeds 1.1×10^{-12} J. Use your answer from **(c)** to explain why only a very small proportion of the head-on collisions between ${}^1_1H$ nuclei result in a fusion reaction.

....

....

....

.... [3]

(e) The hydrogen cycle of fusion reactions is responsible for most of the energy generated inside the Sun. In one of these reactions two ${}^1_1H$ nuclei fuse to make a deuterium nucleus ${}^2_1H$ thus:

$${}^1_1H + {}^1_1H \rightarrow {}^2_1H + {}^0_1e + {}^0_0\upsilon$$

(i) Calculate the energy in joule generated by this reaction.

	mass / u
${}^1_1H$ nucleus	1.007276
${}^2_1H$ nucleus	2.013553
${}^0_1e$	0.000549

energy = ... J [3]

(ii) State how the positron ${}^0_1e$ created in the reaction will result in **further** generation of energy.

....

....

.... [1]

[Total: 13]

64

Uranium-238 ${}^{238}_{92}U$ decays to lead-206 ${}^{206}_{82}Pb$ by means of a series of decays.

One nucleus of ${}^{238}_{92}U$ decays eventually to one nucleus of ${}^{206}_{82}Pb$.

This means that, over time, the ratio of lead-206 atoms to uranium-238 atoms increases. This ratio may be used to determine the age of a sample of rock.

In a particular sample of rock, the ratio

$$\frac{\text{number of lead-206 atoms}}{\text{number of uranium-238 atoms}} = \frac{1}{2}.$$

(a) Show that the ratio

$$\frac{\text{number of uranium-238 atoms left}}{\text{number of uranium-238 atoms initially}} = \frac{2}{3}.$$

Assume that the sample initially contained only uranium-238 atoms and subsequently it contained only uranium-238 atoms and lead-206 atoms.

[2]

(b) Calculate the age of the rock sample.

The half-life of ${}^{238}_{92}U$ is 4.47×10^9 years.

age = ... years [3]

(c) The rock sample initially contained 5.00 g of uranium-238. Calculate the initial number N_0 of atoms of uranium-238 in this sample.

number = ... [2]

(d) On Fig. 5.1, sketch graphs to show how the number of atoms of uranium-238 and the number of atoms of lead-206 vary with time over a period of several half-lives.

Label your graphs 'U' and 'Pb' respectively. [3]

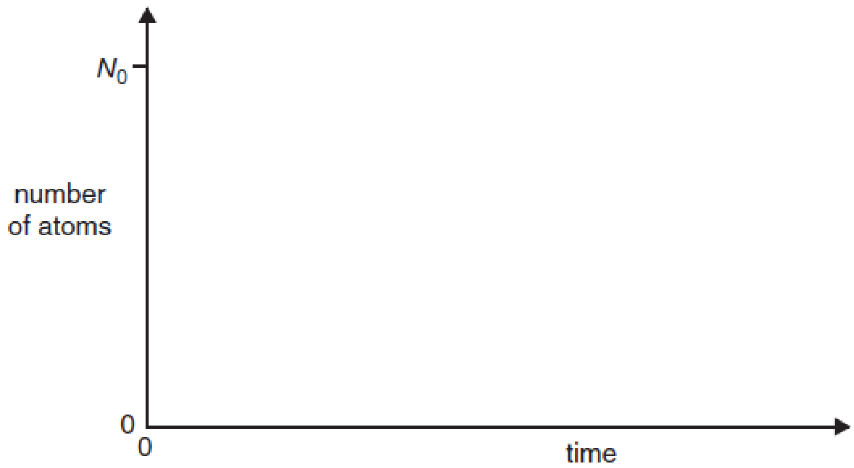

Fig. 5.1

[Total: 10]

65

(a) (i) Name the group of particles of which the electron and the positron are members.

.... [1]

(ii) Name another member of this group.

.... [1]

(b) (i) State the quark composition of the neutron.

.... [1]

(ii) Complete the table to show the charge *Q*, baryon number *B* and strangeness *S* for the quarks in the neutron. [2]

quark	*Q*	*B*	*S*

(iii) Hence deduce the values of *Q*, *B* and *S* for the neutron.

Q .... *B* .... *S* .... [1]

(c) It is suggested that a proton p^+ can react with a pi particle π^- to form a kaon K^0 and a neutron, thus

$$p^+ + \pi^- \rightarrow K^0 + n^0$$

data

particle	quark composition
π^-	$\bar{u}$ d
K^0	d $\bar{s}$

Deduce whether the reaction is possible.

[4]

[Total: 10]

66

Two radioactive isotopes which are serious health hazards to human beings are strontium-90 and caesium-137. Both decay by β^--emission.

(a) The nuclear equations for each of the decays are shown below with letters substituted for some of the numbers.

$$^{90}_{38}\text{Sr} \rightarrow {}^{90}_{Z}\text{Y} + \beta^-$$

$$^{137}_{55}\text{Cs} \rightarrow {}^{A}_{A-N}\text{Ba} + \beta^-$$

Write down the numerical values of the two letters Z and N. State what each represents.

Z ....

....[2]

N ....

....[2]

(b) The radioactive decay law can be written in the form

$$A = \lambda N$$

where A is the activity, λ is the decay constant and N is the number of undecayed nuclei.

(i) Define the term *activity*.

....

....[1]

(ii) Caesium-137 has a half-life of 30 years. Calculate the decay constant.

1 year = 3.15×10^7 s

λ = ... s^{-1} [2]

(c) The radioactive dust cloud from the Chernobyl explosion in 1986 contained caesium-137. Fig. 6.1 shows the graph of the number of undecayed nuclei of caesium-137 remaining in a dust particle against time after the explosion.

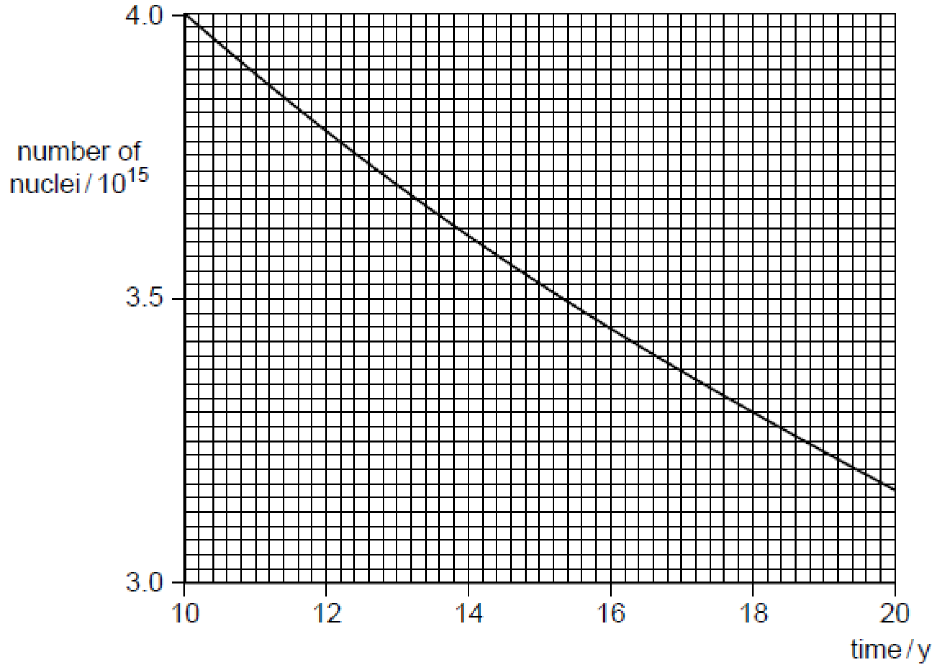

Fig. 6.1

(i) Use Fig. 6.1 to calculate the activity of the caesium dust particle after 15 years.

activity = ... Bq [2]

(ii) Use data from the graph to show that the initial number of nuclei of caesium-137 in the dust particle is about 5.0×10^{15}.

[3]

(iii) Hence show that the original mass of caesium-137 in the dust particle is about 1 µg.

[2]

[Total: 14]

67

State the relative sizes of atoms and nuclei.
Electrons can be used to give evidence for the radius and structure of the nucleus but X-rays cannot. Explain why this is so.

....

....

....

....

....

....

....

....

....

....

....

....

....

....[4]

Quality of Written Communication [4]

[Total: 15]

68

This question is about the forces between nucleons.
The graph of Fig. 1.1 shows the variation of the strong force between two nucleons with the separation of the centres of the nucleons. Over the range shown this graph is a straight line.

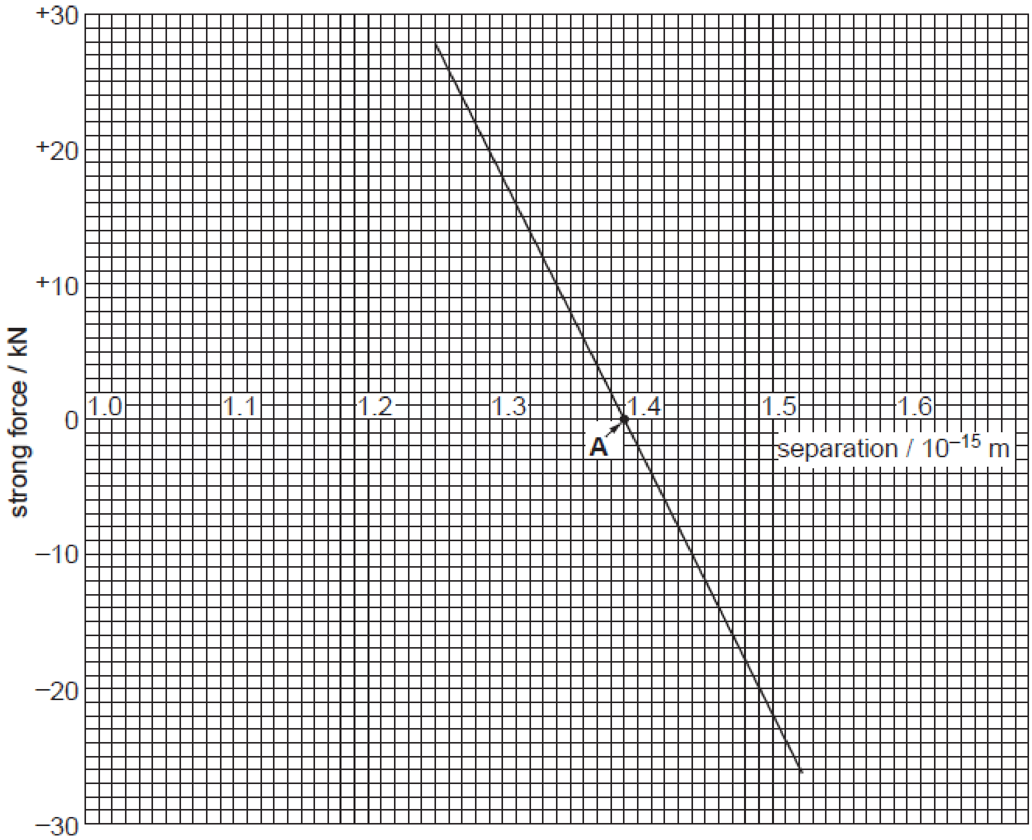

Fig. 1.1

(a) State and explain the significance of the point **A** in relation to two **neutrons**.

....

....

....

....

....[2]

(b) Find the gradient of the graph.

gradient = ...[2]

(c) Calculate the electrostatic force between two **protons** if their separation is equal to 1.40×10^{-15} m.

force = ... N [2]

(d) **(i)** State what must be true of the strong force and the electrostatic force for two adjacent protons to be in equilibrium.

....

....

....[1]

(ii) When two protons are at equilibrium their centres are at a separation **B**. Point **B** is very close to **A** but is **not** shown on Fig. 1.1.
Use the results from **(b)** and **(c)** to calculate the position of **B** in relation to **A**.
Explain your answer.

....

....

....

....

....[3]

[Total: 10]

69

This question is about the formation and decay of plutonium-239, $^{239}_{94}Pu$.
Natural uranium is a mixture of the nuclides $^{235}_{92}U$ and $^{238}_{92}U$. When this natural uranium is exposed to neutrons, the heavier nuclei absorb a neutron. The resulting nucleus then undergoes two decay reactions, resulting in the formation of a $^{239}_{94}Pu$ nucleus.

(a) Write nuclear equations to represent these three reactions.
The nuclide formed in reaction 2 is an isotope of neptunium (Np).

reaction 1 ....

reaction 2 ....

reaction 3 ....
[4]

(b) A physicist prepares a sample of the neptunium isotope which decays to plutonium-239. She measures the activity of the sample over a period of 5.0 days. She then plots the graph shown in Fig. 2.1 of the variation with time of the activity of the sample.

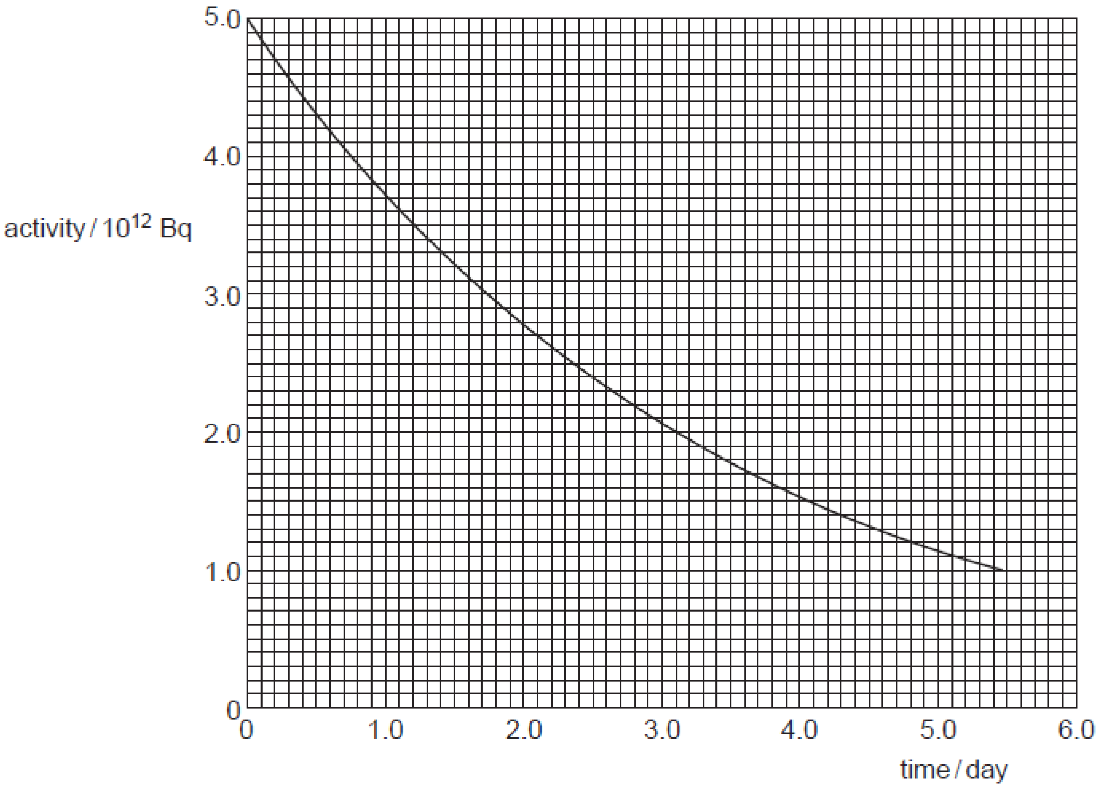

Fig. 2.1

(i) Find the half-life in seconds of the neptunium isotope.

half-life = ... s [2]

(ii) Show that the decay constant of the neptunium isotope is $3.4 \times 10^{-6}\ s^{-1}$.

[1]

(iii) Deduce the number of nuclei of the neptunium isotope which are present after 2.00 days.

number = ...[3]

(c) The physicist then measures the activity of a sample of plutonium-239 over the same period.

(i) State the half-life of plutonium-239.

half-life = ...year [1]

(ii) On Fig. 2.2, sketch the shape of the graph which she might obtain. [1]

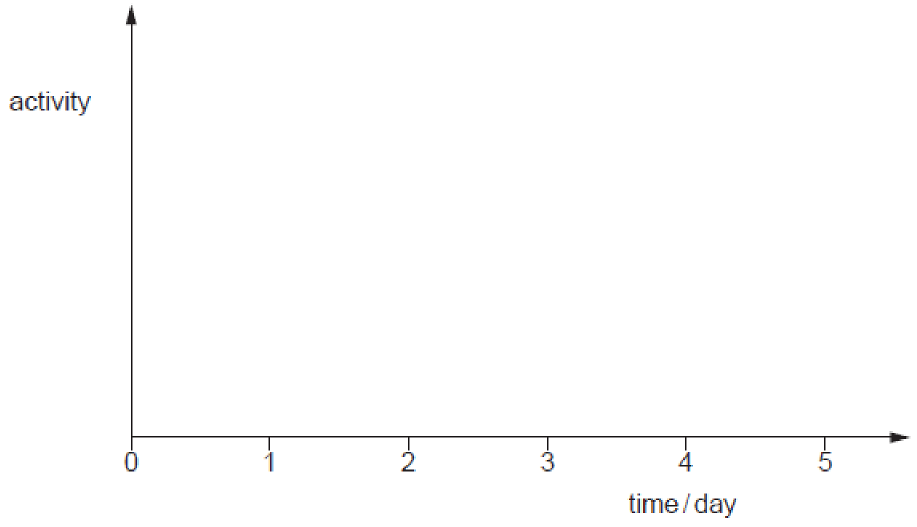

Fig. 2.2

[Total: 12]

70

This question is about particles and their antiparticles.

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

mass = ... kg   charge = ... C [2]

(b) State where an antiproton might be found.

....[1]

(c) When a proton and an antiproton meet, γ-photons are produced.

(i) Describe these photons as fully as you can for a **slow-moving** proton-antiproton collision. No calculation is required.

....

....

....

....

....

....

....

....[3]

(ii) A proton and an antiproton are moving with almost the same high speed and in the same direction. Each possesses 8.00×10^{-11} J of kinetic energy. The two particles meet. Calculate the frequency of the γ-photons produced.

frequency = ... Hz [4]