1. 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.

✎ In your answer, you should make clear how evidence for the size of the nucleus follows from your description.

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[Total 8 marks]

2. (a) Complete the table below for the **three** types of ionising radiation.

radiation	nature	range in air	penetration ability
α			0.2 mm of 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.

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[3]

[Total 6 marks]

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

A method of producing helium nuclei is shown by the following nuclear equation.

$$4\,{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2\,{}^{0}_{1}\text{e}$$

Describe this process of fusion giving as much detail as you can.
Compare the energy release in this process with the energy released in alpha-particle decay.

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[5]

Quality of Written Communication [2]

[Total 7 marks]

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

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

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]

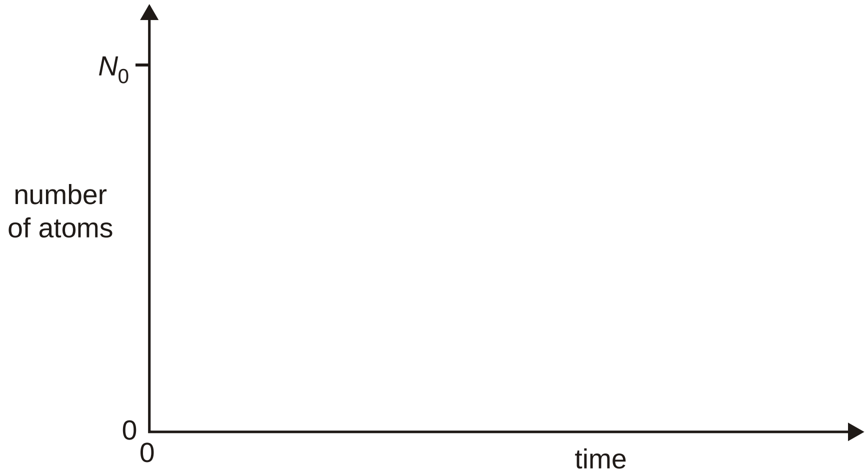
(c) The rock sample initially contained 5.00 g of uranium-238. Calculate the initial number N_0 of atoms of uranium-238 in this sample.

number = ...

[2]

(d) On the figure below, 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.

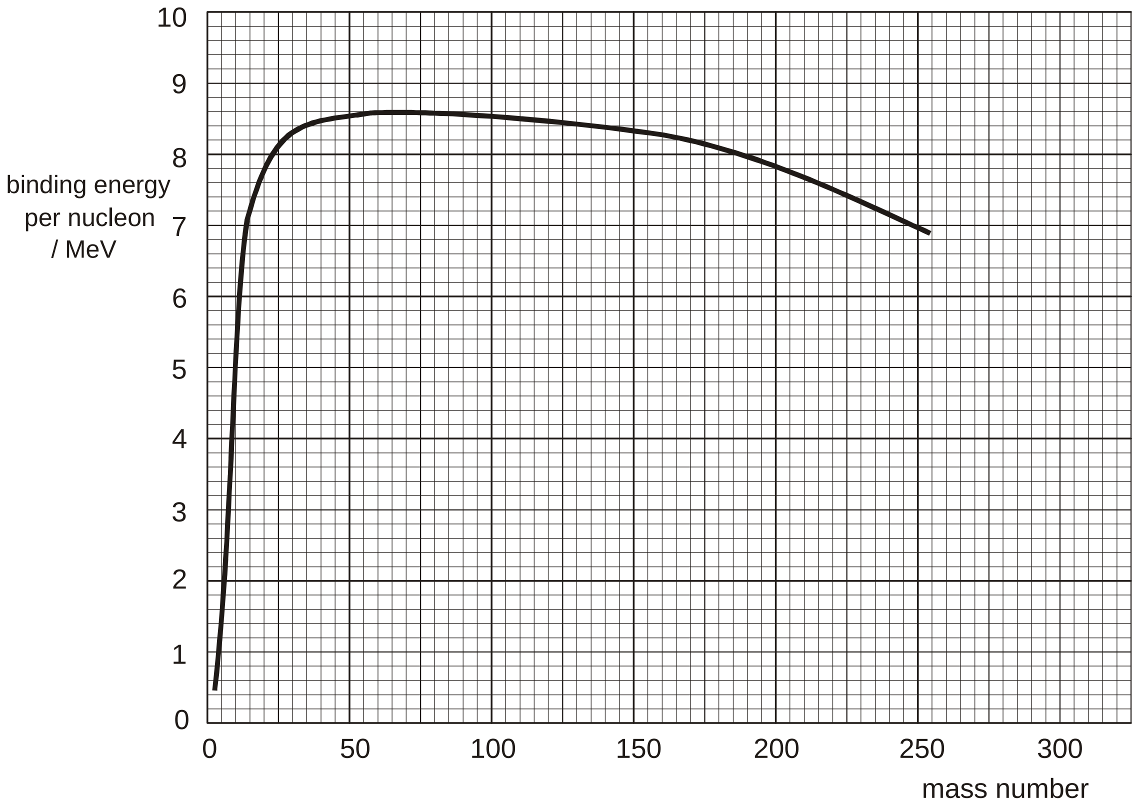
Label your graphs ‘U’ and ‘Pb’ respectively.



[3]

[Total 10 marks]

5. The figure below shows the variation with nucleon number (mass number) of the binding energy per nucleon for various nuclides.



(a) (i) State the number of nucleons in the nucleus of $^{94}_{37}Rb$. ....

(ii) State the number of protons in the nucleus of $^{142}_{55}Cs$. ....

(iii) State the number of neutrons in the nucleus of $^{235}_{92}U$. ....

[2]

(b) Use the figure above 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

[4]

[Total 6 marks]

6. This question is about nuclear fusion reactions inside the Sun.

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

....

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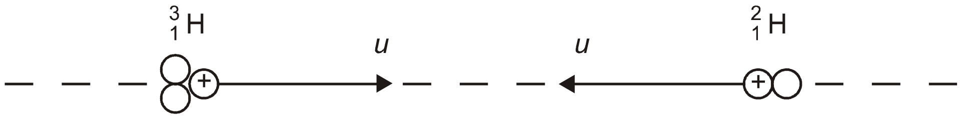
....

[Total 3 marks]

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

A tritium nucleus $^{3}_{1}H$ and a deuterium nucleus $^{2}_{1}H$ approach each other along the same line with the **same** speed *u*.



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

$$E = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r} \qquad \varepsilon_0 = \text{permittivity of free space}$$

For ${}^{3}_{1}\text{H}$ and ${}^{2}_{1}\text{H}$ 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 marks]

8. A fuel rod inside a nuclear reactor contains uranium-238. When a ${}^{238}_{92}\text{U}$ nucleus is exposed to free neutrons it can absorb a neutron. The resulting nucleus decays, first to neptunium-239 ${}^{239}_{93}\text{Np}$ (**decay 1**) and then to plutonium-239 ${}^{239}_{94}\text{Pu}$ (**decay 2**).

(a) Write nuclear equations for these two decay reactions.

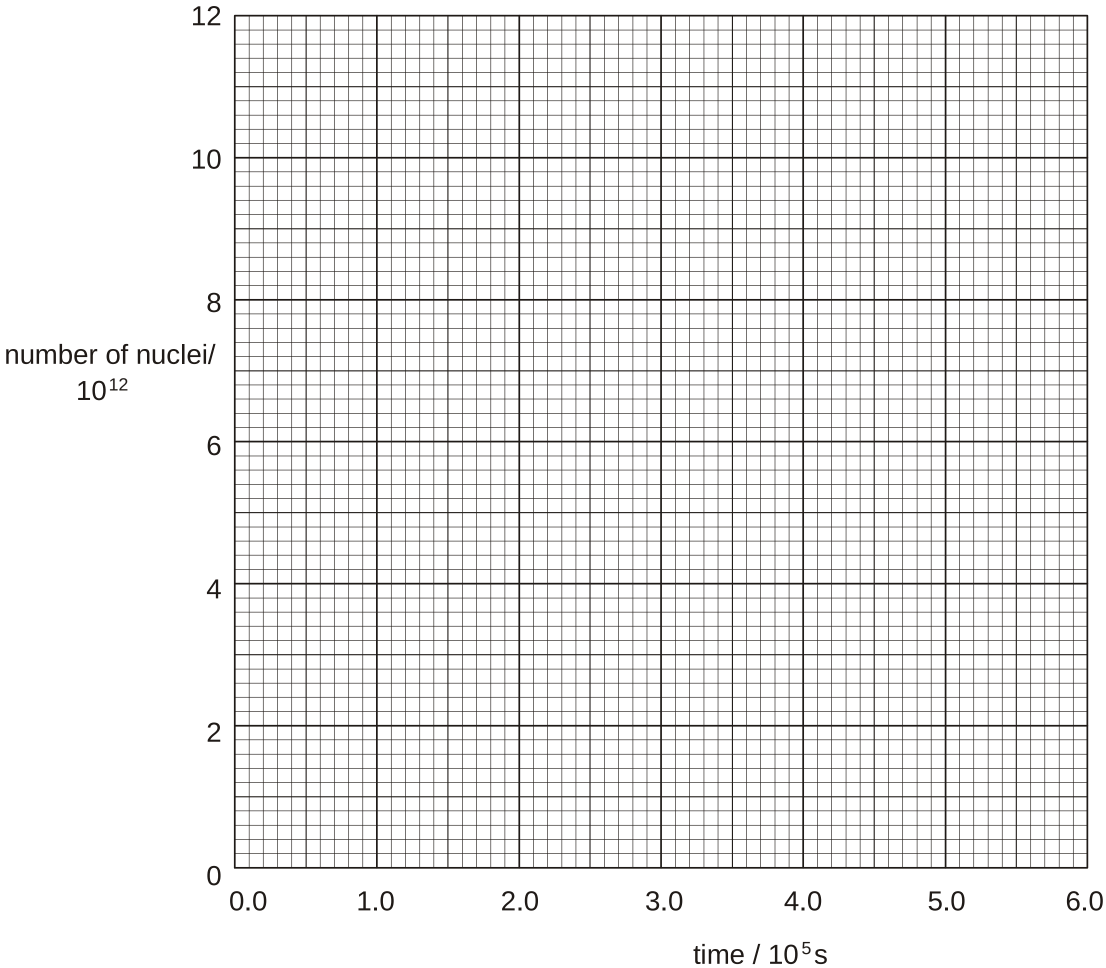
decay 1 ....

decay 2 ....

[2]

(b) In the fuel rod, $^{239}_{93}Np$ nuclei are produced at a constant rate of $1.80 \times 10^7\ s^{-1}$.

On the figure below, draw a graph to show how the number of $^{239}_{93}Np$ nuclei **produced** varies with time.
Label this graph X. Assume that initially there are no $^{239}_{93}Np$ nuclei.



[1]

(c) (i) State and explain, without calculation, how the number of $^{239}_{93}Np$ nuclei **decaying** per second varies with time.

....

....

....

[2]

(ii) State why the number of $^{239}_{93}Np$ nuclei **present** eventually becomes constant.

....

....

[1]

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

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

number = ...

[3]

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

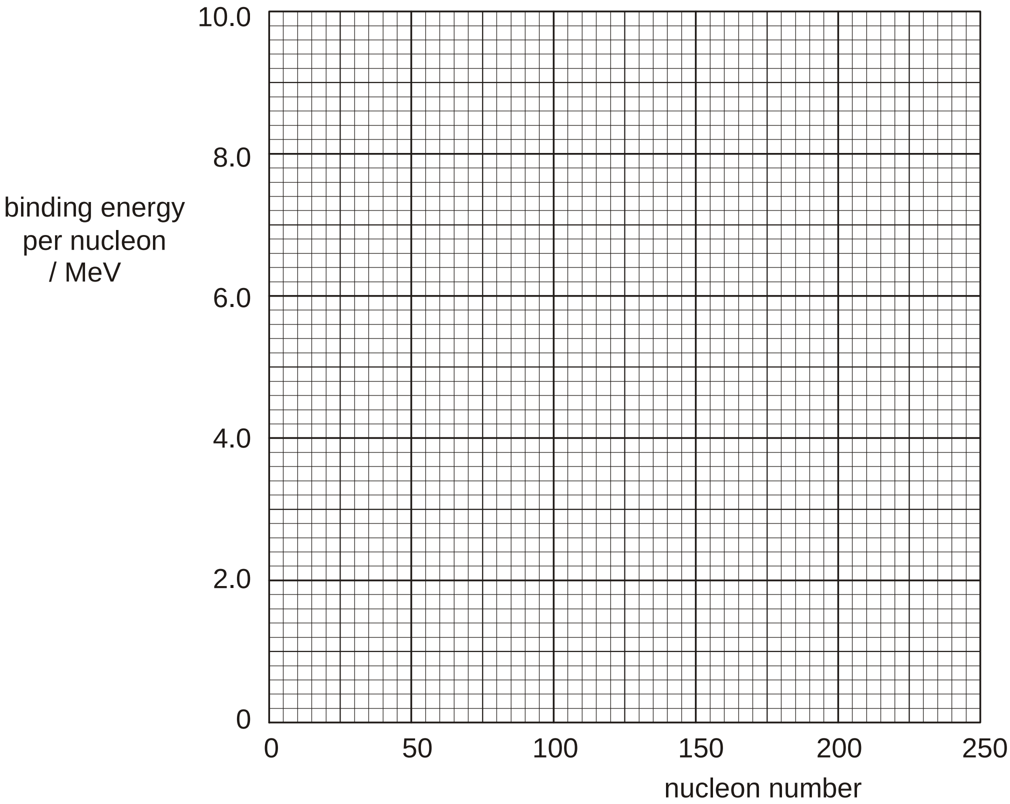
[1]

[Total 10 marks]

9. 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 below.



[1]

(ii) Sketch a graph on the grid above, 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]

[Total 6 marks]