Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
TOTAL	

General Certificate of Education
Advanced Level Examination
January 2013

Physics (B): Physics in Context PHYB5

Unit 5 Energy under the microscope

Module 1 Matter Under the Microscope
Module 2 Breaking Matter Down
Module 3 Energy from the Nucleus

Wednesday 23 January 2013 1.30 pm to 3.15 pm

For this paper you must have:
- a pencil and a ruler
- a calculator
- a Data and Formulae Booklet.

Time allowed
- 1 hour 45 minutes

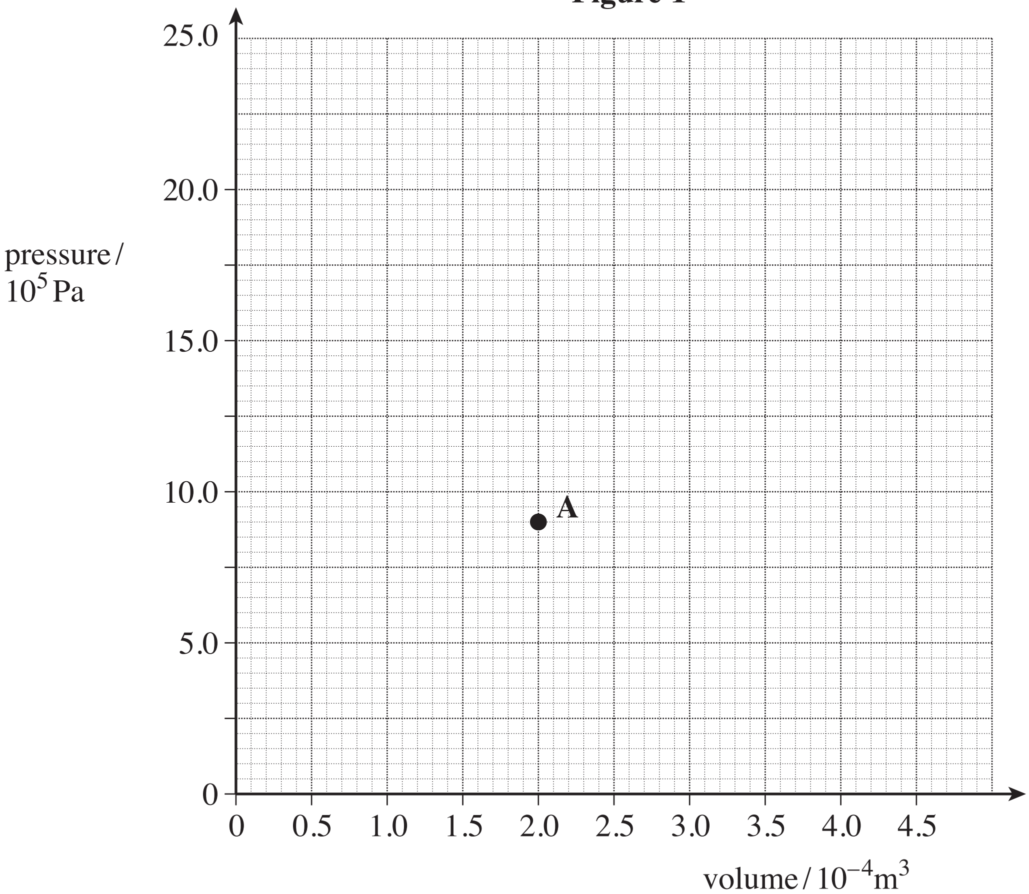
Instructions
- Use black ink or black ball-point pen. Use pencil only for drawing.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show all your working.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator where appropriate.
- A *Data and Formulae Booklet* is provided as a loose insert.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use specialist vocabulary where appropriate.

Answer **all** the questions.

1 In the design of an internal combustion engine, engineers must consider the thermodynamic processes that take place in gases. **Figure 1** is a grid to show the variation of pressure and volume of a fixed mass of gas in a cylinder. **A** is one point in the cycle undergone by the gas.

Figure 1



1 (a) The gas in the cylinder is compressed isothermally to a volume that is half of what it was when at point **A**.
Draw a line representing this isothermal compression. Plot **two** points in addition to **A** so that you can draw the line accurately. Label the new end of the line, **B**.

Space for calculations:

(3 marks)

Do not write outside the box

1 (b) The gas undergoes an *adiabatic* expansion so that it returns to its original volume.

1 (b) (i) State what is meant by adiabatic.

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(1 mark)

1 (b) (ii) Without attempting further calculations, sketch the adiabatic expansion on the graph in **Figure 1**.

(1 mark)

1 (b) (iii) Explain why the expansion of the gas in the power stroke of an internal combustion engine can be considered to be adiabatic.

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(1 mark)

1 (b) (iv) State and explain what happens to the temperature of a gas when it is allowed to expand adiabatically.

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(2 marks)

1 (c) At point **A** on **Figure 1**, the temperature of the gas is 1100 °C.
Calculate the number of moles of gas present in the cylinder.

number of moles ....

(2 marks)

10

Turn over ▶

2 The equations below describe what happens in the *carbon cycle* in some stars.

Reaction 1 $\,^{12}_{6}C + \,^{1}_{1}H \rightarrow \,^{13}_{7}X + \gamma + 1.95\,\text{MeV}$

Reaction 2 $\,^{13}_{7}X \rightarrow \,^{13}_{6}C + \,^{0}_{1}e^{+} + A + 2.22\,\text{MeV}$

Reaction 3 $\,^{13}_{6}C + \,^{1}_{1}H \rightarrow \,^{14}_{7}X + \gamma + 7.54\,\text{MeV}$

Reaction 4 $\,^{14}_{7}X + \,^{1}_{1}H \rightarrow \,^{--}_{--}O + \gamma + 7.35\,\text{MeV}$

Reaction 5 $\,^{--}_{--}O \rightarrow \,^{15}_{7}X + \,^{0}_{1}e^{+} + A + 2.75\,\text{MeV}$

Reaction 6 $\,^{15}_{7}X + \,^{1}_{1}H \rightarrow \,^{12}_{6}C + \,^{4}_{2}He + 4.96\,\text{MeV}$

2 (a) (i) Explain why it is referred to as a cycle.

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(1 mark)

2 (a) (ii) Identify the element X. ....

(1 mark)

2 (a) (iii) State below the proton and nucleon numbers for oxygen, O, in reactions 4 and 5.

proton number .... nucleon number ....

(1 mark)

2 (a) (iv) Identify the particle **A** in reactions 2 and 5. ....

(1 mark)

Do not write outside the box

2 (a) (v) State the likely fate of the positrons emitted in reactions 2 and 5.

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(1 mark)

2 (b) The carbon cycle produces only a small proportion of the Sun's energy. It plays a more significant part in other stars.
State **two** physical differences between these stars and the Sun.

physical difference 1 ....

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physical difference 2 ....

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(2 marks)

7

Turn over for the next question

3 (a) A cyclotron is used to accelerate protons. The cyclotron frequency, f, is 23 MHz.

3 (a) (i) Explain how a proton is accelerated in the cyclotron.

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(3 marks)

3 (a) (ii) Show that the cyclotron frequency is given by:

$$f = \frac{BQ}{2\pi m}$$

where m is the mass of a proton, B is the magnetic flux density in the Dees and Q is the proton charge.

(2 marks)

3 (a) (iii) Calculate the magnetic flux density in the Dees of the cyclotron.

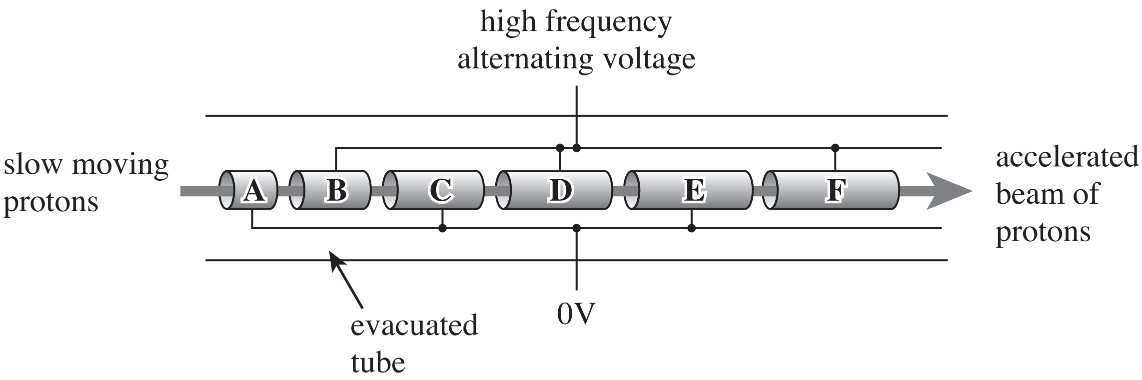
magnetic flux density .... T

(2 marks)

Do not write outside the box

3 (b) **Figure 2** shows the arrangement of drift tubes in a linear accelerator (LINAC).

Figure 2



3 (b) (i) Explain why the length of the drift tubes increases along the direction of travel of the protons.

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(2 marks)

3 (b) (ii) Explain why the increase in length between successive drift tubes gets smaller towards the high-energy end of the LINAC.

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(3 marks)

Turn over ▶

Do not write outside the box

3 (b) (iii) Physicists often use LINACs to produce proton-proton collisions.
State what the physicists expect to observe as a result of such collisions and why it is advantageous to use two beams of moving protons instead of one beam aimed at a stationary target.

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(3 marks)

15

4 (a) (i) Explain how a heart pacemaker helps to keep the patient's heart beating at appropriate rates without any external connections.

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(3 marks)

4 (a) (ii) Explain the importance of knowing the electrical resistivity of heart tissue when designing a pacemaker.

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(2 marks)

Question 4 continues on the next page

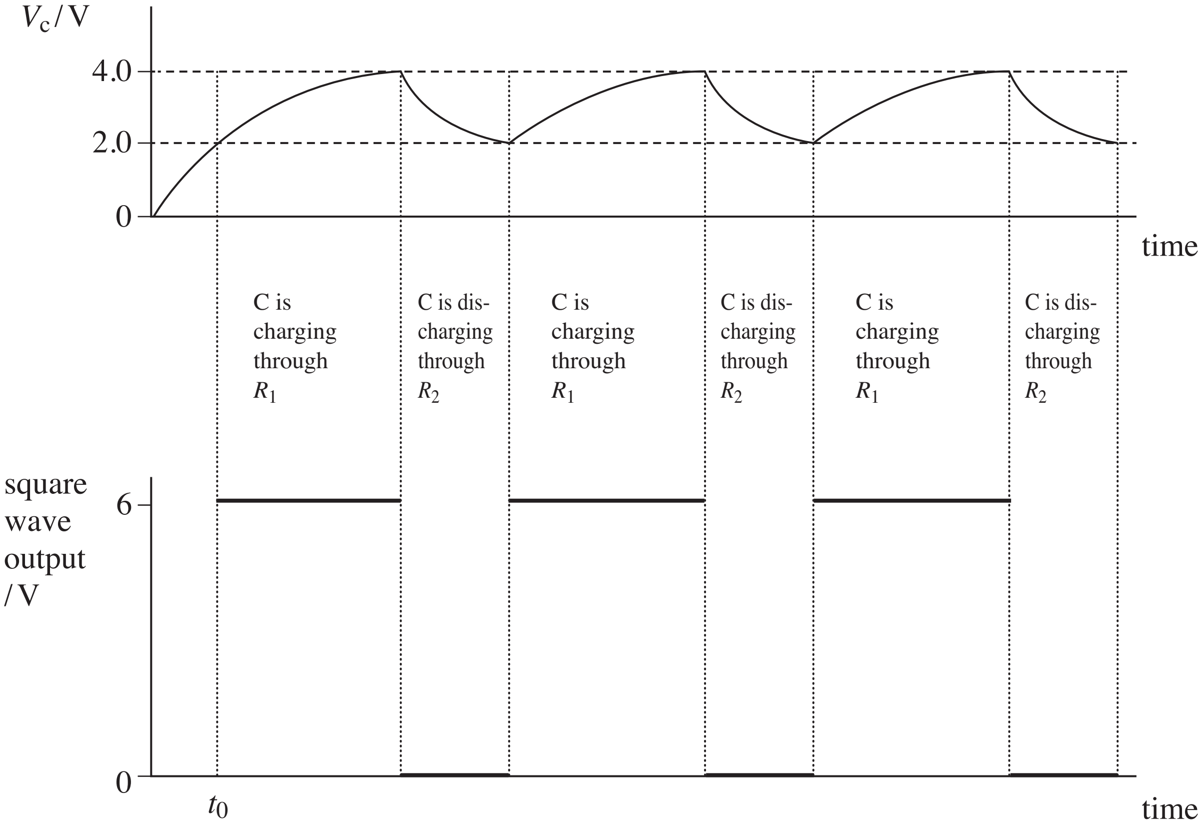
Turn over ▶

4 (b) A designer requires a timing circuit to drive a pacemaker. The circuit uses the charging and discharging of a capacitor, C, to generate a square wave as shown in **Figure 3**. A 6.0 V supply is used for both the capacitor and the timing circuit.

In the first part of the cycle, the capacitor charges through a resistor of resistance R_1. The timing circuit senses the potential difference, V_c , across the capacitor and produces a 6 V output when it detects that V_c is greater than 2.0 V.

When V_c reaches 4.0 V, the timing circuit causes the capacitor to begin discharging through a resistor of resistance R_2 and automatically sets the square wave to 0 V. As soon as the capacitor has discharged so that V_c is down to 2.0 V, charging begins again and the timing circuit output changes back to 6 V.

Figure 3



The square wave required by the pacemaker has a frequency of 0.85 Hz. The duration of time for which the wave has a value of 6 V is twice that for which it has a value of 0 V.

4 (b) (i) Show that, for each charge – discharge cycle, the time for which the output is 0 V is approximately 400 ms.

(1 mark)

4 (b) (ii) R_2 has a resistance of 2.5 kΩ. Calculate the capacitance of the capacitor C, such that V_c decays from 4.0 V to 2.0 V in 400 ms.

capacitance .... F

(3 marks)

4 (b) (iii) Suggest a value of the resistor R_1 that would produce a charging curve as shown in **Figure 3**. Explain your choice.

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(2 marks)

4 (b) (iv) On the grid below, sketch a graph of charging and discharging current against time for two charge – discharge cycles of the capacitor, C, starting from the time shown as t_o on **Figure 3**. Label your axes with appropriate values.

(4 marks)

15

Turn over ▶

5 Antibodies in the human body can be used in Targeted Alpha Therapy in the treatment of very small cancers. Antibodies are microscopic structures that are produced by the body to protect against bacteria or unusual cells. In Targeted Alpha Therapy, an alpha emitter such as bismuth-213 is attached to an appropriate antibody. When the bismuth decays, the alpha particle emitted is likely to hit and destroy the cancer cell. The range of the alpha particle is approximately the same as the size of a cell so damage is limited to the cell to which the antibody is attached.

Alpha particles have a very high Linear Energy Transfer (LET) which indicates the amount of energy lost per unit length due to ionisations of material in its path. The LET for the 8.0 MeV alpha particle from bismuth-213 is 580 keV per μm in human tissue. In 25 % of emissions, bismuth also emits a 440-keV gamma ray. This allows the distribution of the bismuth to be monitored outside the body and for the dose rate for different parts of the body to be assessed. In initial tests, doses of 24 MBq kg^{-1} of body mass were used.

The half-life of Bi-213 is 46 minutes.

5 (a) (i) Show that the decay constant of Bi-213 is approximately $2.5 \times 10^{-4}\ s^{-1}$.

(2 marks)

5 (a) (ii) Calculate the mass of Bi-213 that would be used for treating a patient with a body mass of 65 kg. Give your answer in g.

mass .... g

(4 marks)

Do not write outside the box

5 (b) (i) Calculate the wavelength of the gamma ray that accompanies some of the alpha emissions from bismuth-213.

wavelength .... m
(3 marks)

5 (b) (ii) The absorption coefficient for 440 keV gamma rays in human tissue is 0.23 cm^{-1}.
Calculate the percentage of the gamma activity that is detectable from outside the body due to an emission 8.0 cm below the skin.

percentage of activity detectable .... %
(2 marks)

5 (c) Use data from the passage to estimate the size of cells being targeted by the alpha emissions.
Give your answer in m.

cell size .... m
(2 marks)

Turn over ▶

Do not write outside the box

5 (d) Compare the risks associated with Targeted Alpha Therapy with those associated with the use of external radioactive sources for cancer treatment. Include a description of the effects of radioactivity on living tissue.

The quality of your written communication will be assessed in your answer.

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(6 marks)

19

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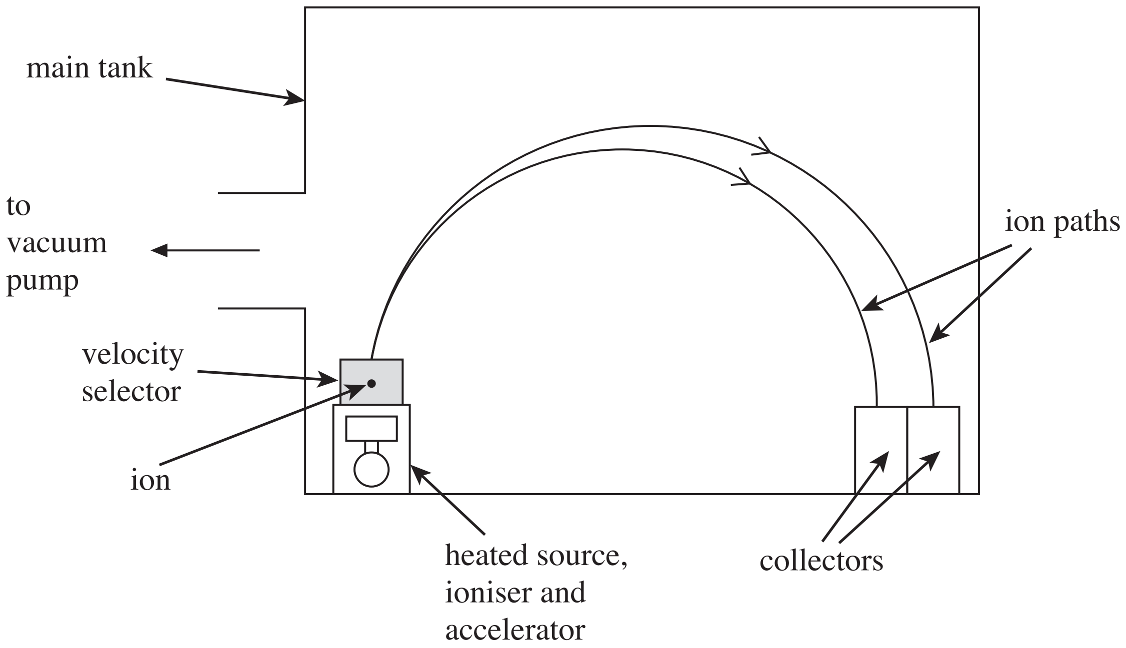
6 **Figure 4** shows a calutron which is a device used for separating uranium-235 and uranium-238 ions. The calutron works in a manner similar to a mass spectrometer. Ions of both isotopes are produced and accelerated in the heated source, ioniser, and accelerator. In order that ions follow predictable paths in the main tank, it is necessary that they are all travelling at the same speed. This is achieved by the velocity selector. A magnetic field in the main tank causes the ions to move in the semicircular paths shown.

Figure 4



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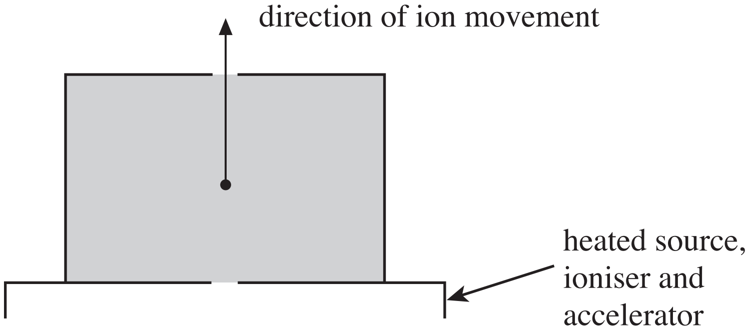
6 (a) **Figure 5** is an enlarged diagram of the velocity selector.

Figure 5



6 (a) (i) Explain how the velocity selector works.

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(4 marks)

6 (a) (ii) Draw and label onto **Figure 5**, the type and direction of the fields that would ensure that the velocity selector functions correctly.

(2 marks)

6 (b) In one calutron, uranium ions with a single charge travel at a speed of $3.5 \times 10^4\ \mathrm{m\,s^{-1}}$. The magnetic flux density is 0.15 T.

6 (b) (i) Show that the separation of beams of U-235 and U-238 is approximately 1.5 cm when they reach the collectors.

(4 marks)

6 (b) (ii) Calculate the potential difference that would be required in the accelerator to produce U-235 ions of this speed.

potential difference V

(2 marks)

6 (c) It was initially considered that the ions within a beam would repel each other as they travelled through the main tank. This repulsion force might have the effect of significantly widening the beams and causing them to overlap. You will now perform calculations to assess whether or not the beam widening effect is significant.
For the purpose of these calculations, assume that the magnetic field in the main tank has been turned off.
Ions take 5.4×10^{-5} s to move through the tank.

6 (c) (i) As they leave the velocity selector, two singly charged U-235 ions experience a mutual repulsion force of 2.3×10^{-16} N
Calculate the initial separation of the ions.

initial ion separation .... m

(2 marks)

Turn over ▶

Do not write outside the box

6 (c) (ii) Calculate the initial acceleration of the ions, caused by the repulsion force.

initial acceleration .... $m\,s^{-2}$

(2 marks)

6 (c) (iii) Estimate the separation of the ions after 5.4×10^{-5} s, assuming that the initial acceleration caused by the electrostatic repulsion remains constant.

ion separation .... m

(3 marks)

6 (c) (iv) State and explain whether your estimate of the final separation of the ions is an overestimate or an underestimate.

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(2 marks)

21

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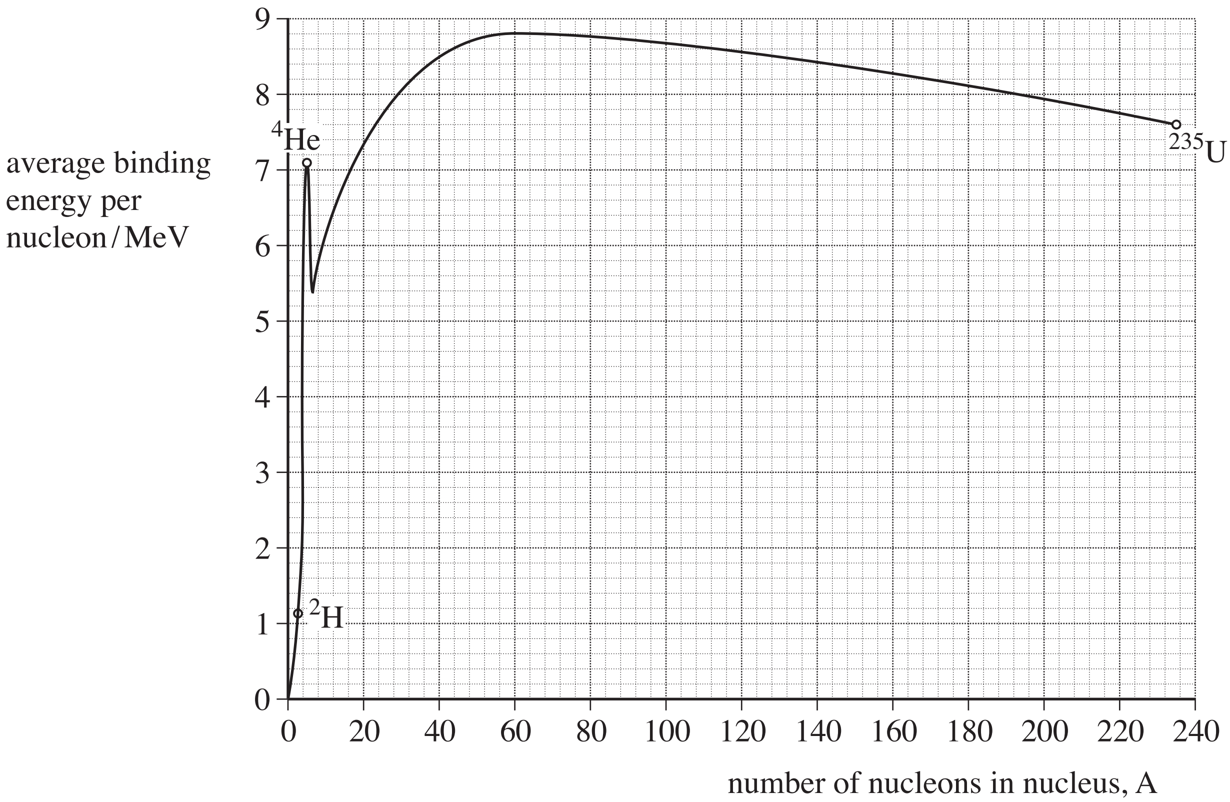
7 **Figure 6** shows the variation in binding energy per nucleon with nucleon number.

Figure 6



7 (a) A uranium-235, ^{235}U, nucleus fissions into two approximately equally sized products.
Use data from the graph to show that the energy released as a result of the fission is approximately 4×10^{-11} J.
Show on the graph how you have used the data.

(4 marks)

Do not write outside the box

7 (b) Using the data below, show that the energy available from the fusion of two hydrogen-2, ^{2}H, nuclei to make a helium-4, ^{4}He, nucleus is approximately 3.7×10^{-12} J.

mass of ^{2}H = 2.0135 u
mass of ^{4}He = 4.0026 u

(4 marks)

7 (c) Compare the energy available from the complete fission of 1 kg of uranium-235 with the energy available from the fusion of 1 kg of hydrogen-2.

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(3 marks)

7 (d) Fission and fusion reactions release different amounts of energy. Discuss other reasons why it would be preferable to use fusion rather than fission for the production of electricity, assuming that the technical problems associated with fusion could be overcome.

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(2 marks)

END OF QUESTIONS

13