Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

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

General Certificate of Education
Advanced Level Examination
June 2011

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

Monday 27 June 2011 9.00 am to 10.45 am

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

Time allowed
- 1 hour 45 minutes

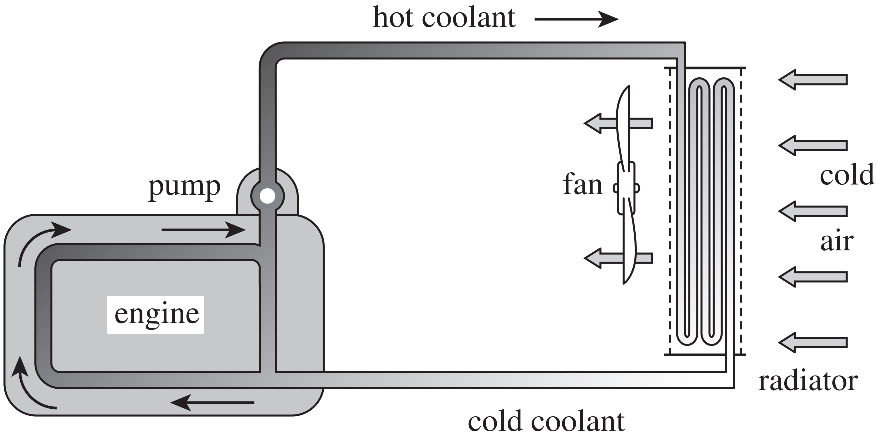
Instructions
- Use black ink or black ball-point pen. Use pencil only for drawing.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- Do all rough work in this 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** questions.

1 Overheating of a car's engine can seriously damage it. To prevent this from happening coolant is circulated around the engine.
Figure 1 shows a simplified cooling system for a car.

Figure 1



1 (a) Consider the coolant in the system to be a thermodynamic system.
Explain how the first law of thermodynamics applies to this system.

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(4 marks)

1 (b) A volume of 9.6×10^{-3} m^3 of coolant passes through a car radiator in each cycle.
As the coolant passes through the radiator its temperature falls from 115 °C to 107 °C.
8.1 m^3 of coolant flows through the radiator per hour.

specific heat capacity of coolant = 3.62×10^3 J kg^{-1} K^{-1}
density of coolant = 1.06×10^3 kg m^{-3}

1 (b) (i) Show that the heat extracted from the coolant in one cycle is about 300 kJ.

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(4 marks)

1 (b) (ii) Calculate the power lost to the surroundings by the radiator.

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power .... W

(3 marks)

Question 1 continues on the next page

1 (b) (iii) The coolant is at an average temperature of 111 ^{o}C as it passes through the radiator. The air surrounding the radiator is at a temperature of 15 ^{o}C.

Calculate the entropy change in the coolant-air system due to loss of heat from the coolant to the air during one cycle of the coolant through the radiator.

Give a suitable unit for your answer.

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entropy change .... unit ....

(4 marks)

1 (b) (iv) Explain whether the overall entropy change is an increase or a decrease.

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(2 marks)

17

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2 Technetium-99m (^{99m}Tc) is a *metastable* radioactive nuclide. It is a gamma ray emitter used in medical testing including radioactive tracing. It emits 140 keV gamma ray photons and has a half-life of 6.01 hours. The short half-life of the isotope allows for scanning procedures which collect data rapidly, but ensures that the total radiation absorbed by the patient is kept to a low level. Technetium-99m decays to technetium-99 (^{99}Tc) which is a less excited state of the same isotope. Technetium-99 is a β^- emitter, having a proton number of 43. Technetium-99 decays into ruthenium (Ru) with a half-life of 2.12×10^5 years.

2 (a) Explain why ^{99m}Tc is said to be metastable.

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(2 marks)

2 (b) (i) Show that after a period of 20 hours approximately 90% of a freshly prepared sample of technetium-99m will have decayed.

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(4 marks)

Question 2 continues on the next page

Turn over ▶

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2 (b) (ii) Calculate the wavelength of a gamma ray which has a photon energy of 140 keV.

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wavelength .... m

(3 marks)

2 (b) (iii) Explain why gamma emission for technetium-99m may be considered to be easily detectable.

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(2 marks)

2 (b) (iv) Considering that technetium-99m decays to technetium-99, explain why technetium-99m allows for scanning data to be collected rapidly but at the same time means that patients do not absorb large quantities of radiation.

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(3 marks)

2 (c) Using nuclear notation, write down the equation by which ^{99}Tc decays into Ru.

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(4 marks)

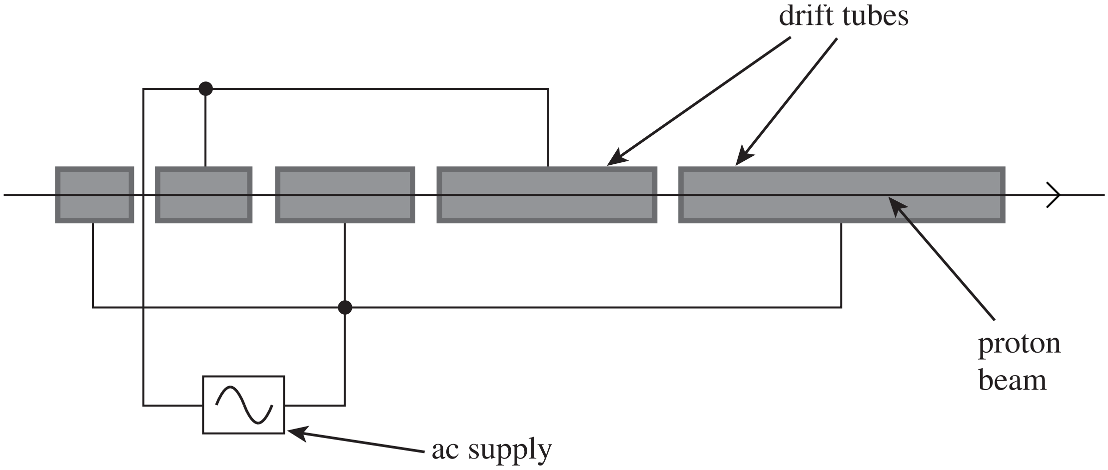
18

Turn over for the next question

Do not write outside the box

3 **Figure 2** shows the main features of a linear accelerator (LINAC) used to accelerate protons.

Figure 2



3 (a) (i) Explain where and how the protons are accelerated and where they move at constant speed.

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(3 marks)

3 (a) (ii) Explain why the drift tubes are of increasing length.

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(2 marks)

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3 (b) A particular LINAC has 25 drift tubes.

3 (b) (i) Consider the protons to have negligible speed as they enter the first drift tube of the LINAC. The potential difference between each drift tube is 35 kV.
Show that the maximum speed of the protons as they emerge from the LINAC is $1.3 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

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(4 marks)

3 (b) (ii) By performing a suitable calculation, state and explain whether or not relativistic corrections need to be made for protons of this speed.

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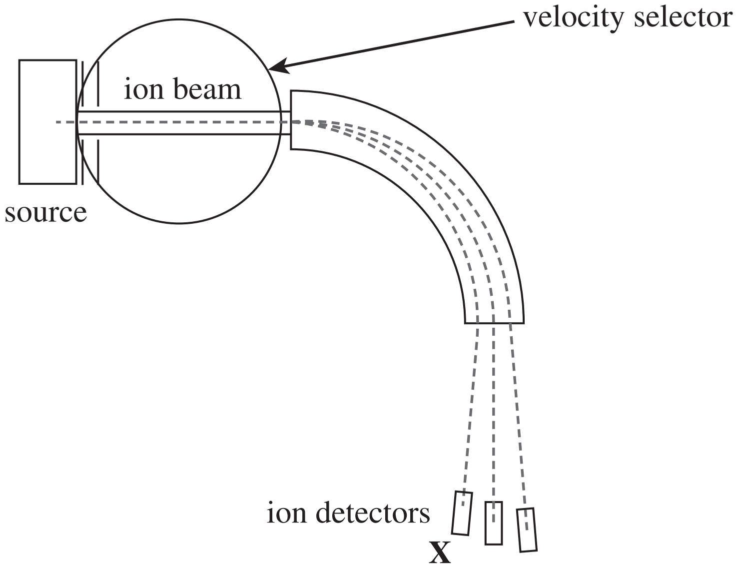
(3 marks)

12

Turn over ▶

4 **Figure 3** shows one version of a mass spectrometer in which positive ions are deflected through different amounts by a magnetic field.

Figure 3



4 (a) (i) On **Figure 3** shade the region over which the deflecting magnetic field acts to produce the deflection shown.

(1 mark)

4 (a) (ii) State the direction of the deflecting magnetic field.

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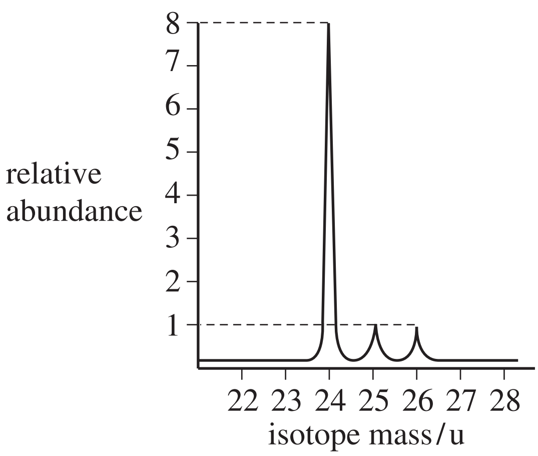
(1 mark)

Figure 4 shows the relative abundance of the three isotopes present in a material being sampled in the mass spectrometer.

Figure 4



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4 (b) Assume that each of the ions has a charge of +e and enters the magnetic field with the same velocity.
State the isotope mass of the ion that is detected at **X** in **Figure 3**.
Explain your reasoning.

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(4 marks)

4 (c) Calculate the mass, in kg, of one mole of the sampled material.

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mass .... kg

(3 marks)

Question 4 continues on the next page

4 (d) Mass spectrometers are designed to ensure that all ions have the same velocity by passing them through a velocity selector. Here an electric field is applied to the ions producing a force which exactly balances the force applied by a magnetic field. In an experiment the electric field strength is $1.00\,\text{kV}\,\text{m}^{-1}$ and the magnetic flux density is 44.7 mT.

4 (d) (i) Calculate the speed of the ions emerging from the velocity selector.

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speed .... $\text{m}\,\text{s}^{-1}$

(2 marks)

4 (d) (ii) Explain whether the speed of an emerging ion would be different if it had a charge of +2e.

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(2 marks)

4 (d) (iii) What effect would this charge increase have on the radius of curvature of the path of the ions in the magnetic field?

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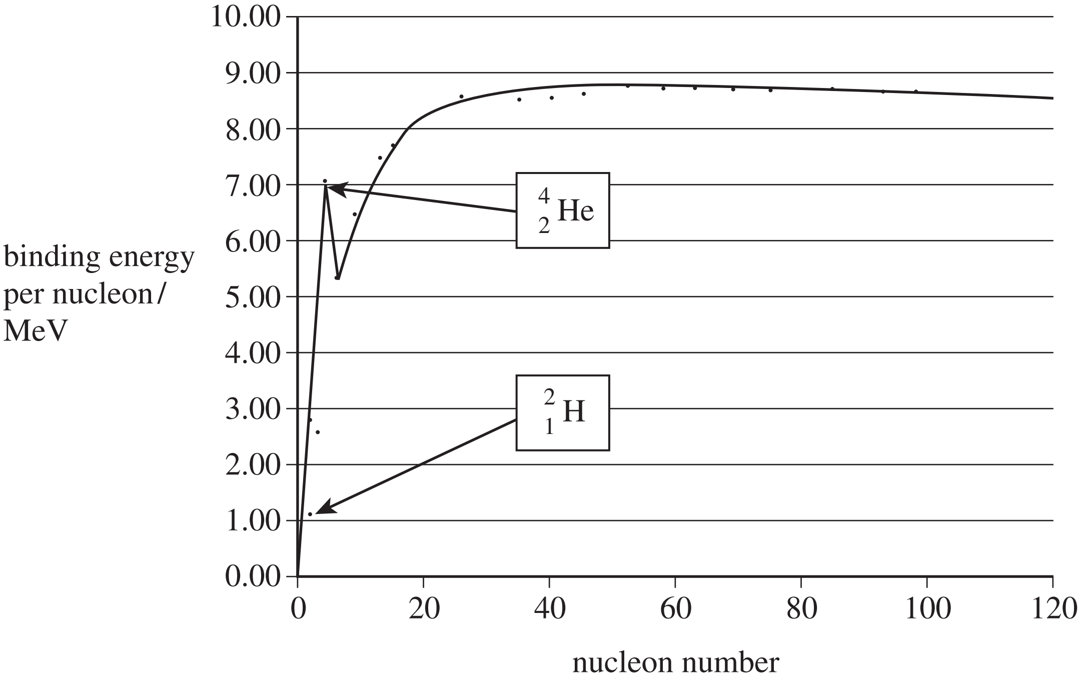
(2 marks)

15

5 **Figure 5** shows the variation of nuclear binding energy per nucleon with nucleon number.

Figure 5



5 (a) (i) Explain the meaning of the term *mass defect* and how it is related to nuclear binding energy.

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(3 marks)

Question 5 continues on the next page

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5 (a) (ii) Using the data on **Figure 5** estimate the energy released in MeV when **two** ${}^{2}_{1}H$ nuclei fuse to make a ${}^{4}_{2}He$ nucleus.

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energy released .... MeV

(3 marks)

5 (a) (iii) Explain why the hydrogen must be at a high temperature for the ${}^{2}_{1}H$ nuclei to be able to fuse.

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(3 marks)

5 (a) (iv) Show that, in order to fuse, a pair of colliding ${}^{2}_{1}H$ nuclei must have a total kinetic energy of approximately 1.5×10^{-13} J.

diameter of ${}^{2}_{1}H$ nucleus = 1.5×10^{-15} m

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(3 marks)

5 (b) Explain what is meant by a plasma. Go on to discuss the problems involved in maintaining fusion reactions in a terrestrial fusion reactor such as the Joint European Torus (JET) project.

The quality of your written communication will be assessed in this question.

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(6 marks)

18

6 (a) Explain what is meant by the capacitance of a capacitor.

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(1 mark)

6 (b) **Figure 6** shows a circuit used for charging a capacitor of capacitance *C* through a resistor of resistance *R*. The battery has an emf *E*.
Figure 7 shows of the variation of potential difference across the capacitor with time from when the switch *S* is closed.

Figure 6

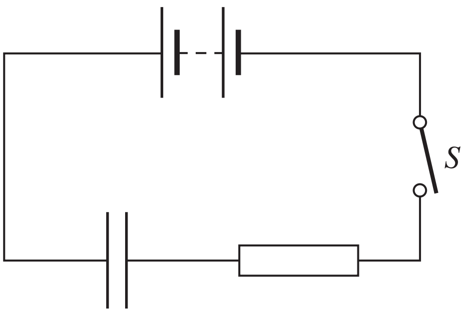
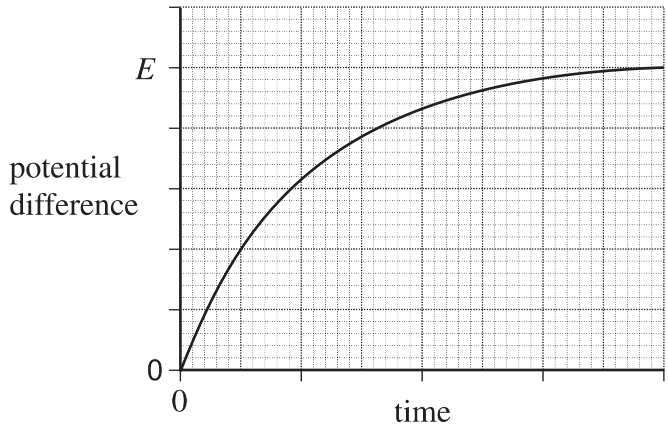


Figure 7



6 (b) (i) Explain the shape of the graph in **Figure 7**.

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(3 marks)

6 (b) (ii) Mark on **Figure 7** the shape of the graph that you would expect when the capacitor is replaced by one of smaller capacitance and the charging process repeated.

(2 marks)

6 (c) Implantable cardioverter defibrillators (ICDs) are increasingly being used to prevent sudden deaths from heart attacks. One ICD consists of a capacitor system which is charged to 650 V and then discharged through the heart. This provides the heart with 32 J of energy. Two identical capacitors are used in the system, each with 325 V across it. The heart has a resistance of approximately 510 Ω.

6 (c) (i) State and explain how the capacitors are connected in the ICD.

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(2 marks)

6 (c) (ii) Show that the combination of the capacitors has a total capacitance of approximately 150 μF.

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(2 marks)

6 (c) (iii) Calculate the time constant for the capacitor/heart combination.
Give a suitable unit for your answer.

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time constant .... unit ....

(2 marks)

Question 6 continues on the next page

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6 (c) (iv) The capacitor system is effectively discharged when 1.0 V remains across it. Calculate the time the capacitor system takes to discharge from 650 V to 1.0 V.

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time .... s

(3 marks)

6 (d) (i) The voltage across each capacitor is limited to 325 V. Each capacitor is marked with a maximum allowable pd of 400 V.
Suggest what might happen if this pd were to be exceeded.
Explain your reasoning.

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(2 marks)

6 (d) (ii) Fitting ICDs in patients is often preferable to alternative treatments. Suggest why ICDs are preferable and go on to state why great care needs to be taken over their design.

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(3 marks)

END OF QUESTIONS

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