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
January 2010

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 3 February 2010 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

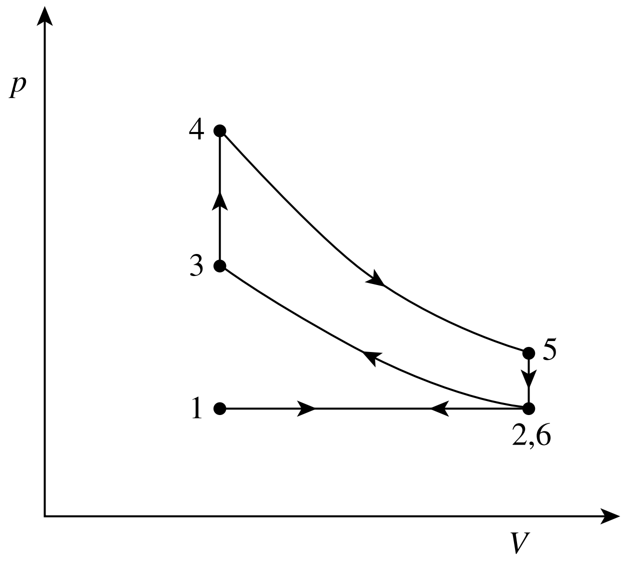
Instructions
- Use black ink or black ball-point pen. Use pencil only for drawing.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Answers written in margins or on blank pages will not be marked.
- Do all rough work in this 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 (a) **Figure 1** shows a p-V graph of the Otto cycle that takes place in each cylinder of a petrol engine. The sequence of the cycle is $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 6$ then back to 1.

Figure 1



1 (a) (i) Describe the change that is taking place during stage $3 \rightarrow 4$ of the cycle.

....

....

....

(2 marks)

1 (a) (ii) What causes this change to take place?

....

....

(1 mark)

1 (a) (iii) State the stage of the cycle in which power is delivered by a cylinder.

....

....

(1 mark)

1 (b) The first law of thermodynamics may be written as

$$\Delta U = Q + W$$

1 (b) (i) What is represented by the term ΔU?

....

(1 mark)

1 (b) (ii) Stage 2→3 is an adiabatic change.
Which **one** of the terms in the first law equation is zero (0) when an adiabatic change occurs?

....

(1 mark)

1 (b) (iii) Explain why stage 2→3 in the Otto cycle can be considered to be an adiabatic change.

....

....

....

....

(2 marks)

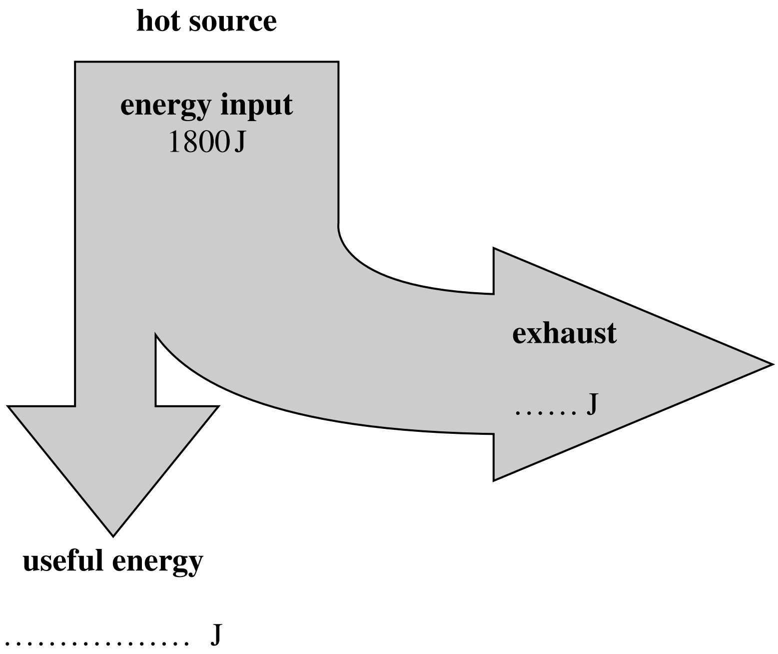
Question 1 continues on the next page

1 (c) During each cycle of a cylinder the input energy is 1800 J.

1 (c) (i) **Figure 2** shows an incomplete Sankey diagram for a cylinder for one cycle.
The diagram is not to scale.
The engine has a thermal efficiency of 27%.
Make appropriate calculations and insert the missing energies on the diagram.

Figure 2

Space for calculations



(2 marks)

1 (c) (ii) The engine operates with a heat sink at a temperature of 313 K.
Calculate the minimum source temperature required for the engine to operate with an efficiency of 27%.

....

....

....

....

temperature .... K
(2 marks)

1 (c) (iii) The calorific value of the fuel used is 34 MJ per litre.
Calculate the volume of fuel injected into one cylinder during each cycle.

1 litre = 1000 cm^3

....

....

....

....

volume .... cm^3
(2 marks)

1 (c) (iv) A car engine has 4 cylinders. Each cylinder completes a cycle 15 times each second when the car is travelling at a constant speed of 85 km h^{-1}.
Calculate the time for which the engine can run on one litre of fuel.

....

....

....

....

time .... s
(2 marks)

1 (c) (v) Calculate the distance the car can travel on one litre of fuel when travelling at a constant speed of 85 km h^{-1}.

....

....

....

....

distance .... km
(2 marks)

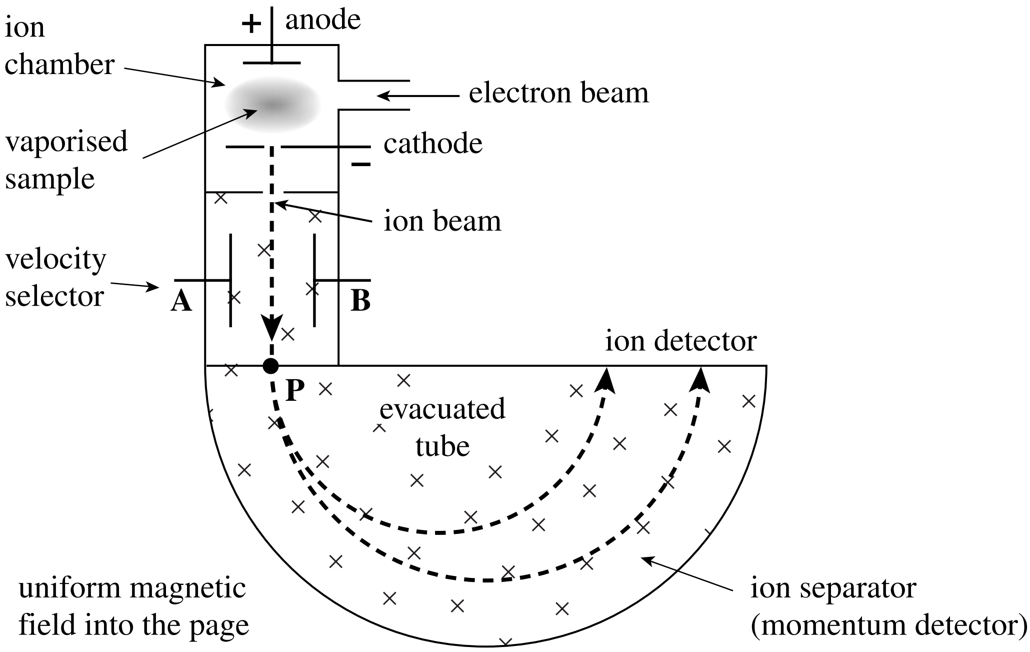
18

Turn over ▶

Areas outside the box will not be scanned for marking

2 **Figure 3** shows the structure of a Bainbridge mass spectrometer.

Figure 3



2 (a) The magnetic flux density in the velocity selector is 0.25 T. Positively charged ions travelling at $1.2 \times 10^5\,\text{m s}^{-1}$ and carrying a charge of magnitude $1.6 \times 10^{-19}\,\text{C}$ pass through the velocity selector and enter the ion separator (momentum detector).

2 (a) (i) State the direction of the force on a positive ion due to the magnetic field as the ion passes through the velocity selector.

....

(1 mark)

2 (a) (ii) Show that the magnitude of the force on the ion due to the magnetic field in the velocity selector is about $5 \times 10^{-15}\,\text{N}$.

....

....

....

....

....

(3 marks)

2 (a) (iii) The plates of the velocity selector are 18 mm apart.
Ions that travel at $1.2 \times 10^5\,\mathrm{m\,s^{-1}}$ are selected and enter the ion separator.
Calculate the potential difference between the plates of the velocity selector.

....

....

....

....

....

....

potential difference V
(3 marks)

2 (a) (iv) State and explain which plate of the velocity selector, **A** or **B**, would be connected to the positive terminal of the supply.

....

....

....
(2 marks)

2 (b) (i) The magnetic flux density in the ion separator is also 0.25 T. The ions enter the separator at point **P**.
How far from **P** will ions of mass 22.9 u be detected?

....

....

....

....

....

....

....

distance from **P** .... m
(4 marks)

Question 2 continues on the next page

Turn over ▶

2 (b) (ii) Using his mass spectrometer, Bainbridge could differentiate between masses that were different by 1 part in 1000.
Explain whether Bainbridge's spectrometer could differentiate between oxygen-15 ions of mass 15.003 u and nitrogen-15 ions of mass 15.000 u.

....

....

....

....

(2 marks)

2 (c) The speed of the ions in a mass spectrometer is low enough for relativistic corrections to be unnecessary in calculations.
Calculate the speed relative to a stationary observer at which the mass of ions of rest mass 22.9 u would increase to 23.0 u.
Give your answer correct to 3 significant figures.

....

....

....

....

....

....

....

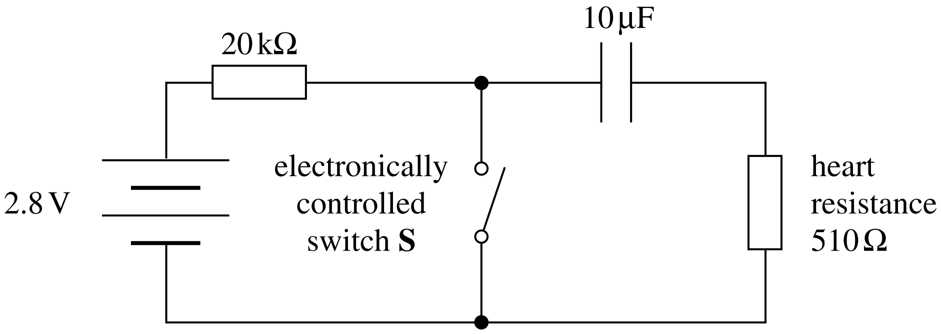
speed .... $m\,s^{-1}$

(3 marks)

18

3 **Figure 4** shows a simplified model of a circuit that is used in a heart pacemaker.

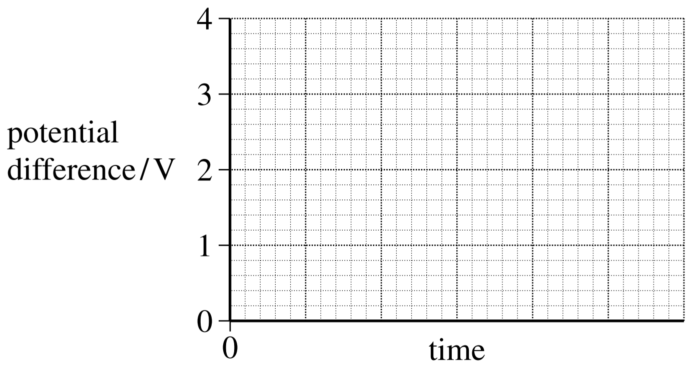
Figure 4



The pacemaker delivers 60 pulses per minute to the heart. The pulse rate is controlled by the electronically controlled switch **S**.

3 (a) The capacitor is initially uncharged. When **S** is open the 2.8 V battery charges the capacitor.
Sketch, on the axes below, a graph showing how the potential difference across the capacitor varies with time as it charges up to 2.8 V. A time scale is not required.

(2 marks)



Question 3 continues on the next page

Turn over ▶

3 (b) (i) To deliver a short pulse of charge from the fully charged capacitor to the heart, **S** is closed for 550 μs.
Show that the potential difference across the capacitor at the end of each pulse is about 2.5 V.

....

....

....

....

....

(3 marks)

3 (b) (ii) Calculate the charge that flows through the heart during each pulse.

....

....

....

....

....

....

charge C

(3 marks)

3 (b) (iii) A battery has a charge capacity of 0.35 Ah.
Calculate the time, in years, for which this battery can operate the pacemaker at the constant rate of 60 pulses per minute.

....

....

....

....

....

time .... years

(3 marks)

3 (c) One purpose of a capacitor used in a pacemaker is to deliver stored charge to stimulate the heart.
Describe briefly **one** other use of capacitors in pacemaker circuits.

....

....

....

(2 marks)

13

Turn over for the next question

4 Technetium-99m (Tc-99m) is used widely in medical applications. The Tc-99m nuclei decay by gamma emission with a half-life of 6.0 hours.

Tc-99m is produced from the decay of molybdenum-99 ($^{99}_{42}\text{Mo}$) which is a β^- emitter.

4 (a) (i) One use of technetium-99m is for producing images of the brain.
State **one** use other than imaging for which technetium can be used in medicine.

....

....

(1 mark)

4 (a) (ii) The symbol 'm' indicates that the technetium isotope is *metastable*.
Explain what is meant by metastable in this context.

....

....

....

(2 marks)

4 (a) (iii) Write down the complete nuclear equation for the production of technetium-99m from molybdenum-99.

(3 marks)

4 (b) In one case a typical dose injected into a patient has an initial activity of 350 MBq.

4 (b) (i) Calculate the number of atoms of Tc-99m that are injected to provide this initial activity.

....

....

....

....

....

number of atoms ....

(3 marks)

4 (b) (ii) Calculate the mass of technetium-99m that is injected.

mass of 1 mol of Tc-99m = 99 g

....

....

....

....

....

mass .... g

(2 marks)

4 (b) (iii) Suggest why injecting technetium-99m can provide a rapid sequence of images to show movement in the body for only about 10 minutes after being injected, whilst images of stationary body parts can be produced for a further 3 hours.

....

....

....

....

....

....

....

....

(3 marks)

14

5 Deuterons can generate energy by means of the following reactions.
Initially, two deuterons fuse to form tritium and a proton. Then another deuteron fuses with the tritium nucleus to form helium-5. Helium-5 is unstable and disintegrates to form helium-4 and a neutron.

$$^{2}_{1}H + ^{2}_{1}H \Rightarrow ^{3}_{1}H + ^{1}_{1}p$$

$$^{2}_{1}H + ^{3}_{1}H \Rightarrow ^{5}_{2}He$$

$$^{5}_{2}He \Rightarrow ^{4}_{2}He + ^{1}_{0}n$$

The table shows the binding energy per nucleon for some of the particles that are involved in these reactions.

particle	**binding energy per nucleon /MeV**
$^{1}_{1}p$ and $^{1}_{0}n$	0
$^{2}_{1}H$	1.113
$^{3}_{1}H$	2.828
$^{4}_{2}He$	7.073

5 (a) (i) How many neutrons are there in a tritium nucleus?

number of neutrons ....
(1 mark)

5 (a) (ii) Calculate the total binding energy of a helium-4 nucleus.

....

....

total binding energy .... MeV
(1 mark)

5 (a) (iii) Calculate the energy released in the production of one helium-4 nucleus by these reactions. Show clearly how you arrive at the result. Give your answer in MeV and in J.

....

....

....

....

....

....

....

....

energy released .... MeV

energy released .... J

(4 marks)

5 (b) (i) Explain why high temperatures are necessary to produce the reactions involving deuterium and tritium.

....

....

....

....

....

....

....

....

(4 marks)

Question 5 continues on the next page

Turn over ▶

5 (b) (ii) Explain why a viable fusion reactor may be considered to be preferable to the fission reactors that are currently in use.

....

....

....

....

....

....

....

....

....

....

....

....

(4 marks)

14

6 Some accelerators in CERN's Large Hadron Collider (LHC) are synchrotrons. In the LHC, protons are accelerated to speeds of 0.9999*c*, very close to the speed of light. The protons travel around the accelerator in bunches of 1.2×10^{11} particles, each proton having a final energy of 7×10^{12} eV. In the most energetic experiments, two such proton beams collide head on.

Techniques for producing low temperatures are vitally important in the design and operation of the LHC. The low temperatures provide the conditions for the coils in over 9000 magnets to become superconducting. These magnets control the beam and ensure that the particles follow the correct 27 km long path inside the collider. In order that particles are not lost from the beam and to reduce energy loss, the LHC has to be evacuated and cooled so that the pressure is very low. When operating, there will be only about 400 million molecules in each cubic centimetre of the chamber. The temperature inside the collider will be only 1.9 K so that the mean kinetic energy and therefore average speed of the gas molecules that remain in the collider will also be low. In these conditions the internal pressure in the LHC will be about 1×10^{-8} Pa which is 10 times lower than the pressure produced by the small amount of gas present on the Moon.

6 (a) (i) Calculate the total energy of each bunch of protons in the LHC.

....

....

....

....

....

total energy .... J

(3 marks)

6 (a) (ii) A proton travels around the 27 km path in the LHC at 0.9999*c*. Show that in the proton's frame of reference it will take about 6 ms to travel around the LHC.

....

....

....

....

....

....

(3 marks)

Question 6 continues on the next page

Turn over ▶

6 (b) In some experiments accelerated protons collide with protons in a stationary target. Explain briefly the advantage of using two beams of protons that collide head on.

....

....

....

....

....

(2 marks)

6 (c) (i) Show that the value of 400 million molecules per cubic centimetre is consistent with the other data in lines 11-17 of the passage.

....

....

....

....

....

....

....

(3 marks)

6 (c) (ii) Assuming the mass of a gas molecule that remains in the LHC to be 4.8×10^{-26} kg, calculate the root mean square speed of the gas molecules.

....

....

....

....

....

....

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

(3 marks)

Areas outside the box will not be scanned for marking

6 (d) A superconducting material is initially at room temperature. Describe how the electrical resistance of the material changes as its temperature is lowered.

....

....

....

....

....

(3 marks)

6 (e) Explain in terms of the behaviour of molecules why evacuation and cooling lower the pressure inside the LHC.

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

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(6 marks)

END OF QUESTIONS

23

There are no questions printed on this page

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED