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	

AQA

General Certificate of Education
Advanced Level Examination
January 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

Wednesday 2 February 2011 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.

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Answer **all** questions.

1 (a) A particular heart pacemaker uses a capacitor which has a capacitance of $4.2\,\mu F$.
Explain what is meant by *a capacitance of* $4.2\,\mu F$.

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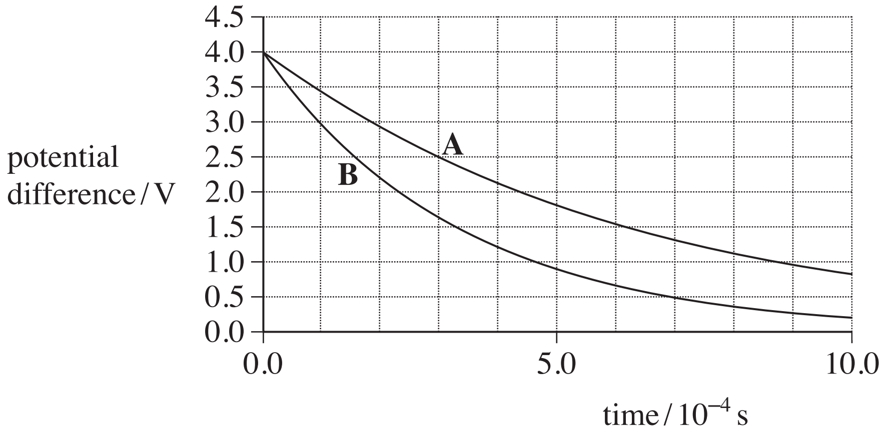
(2 marks)

1 (b) Capacitor **A**, of capacitance $4.2\,\mu F$, is charged to 4.0 V and then discharged through a sample of heart tissue. This capacitor is replaced by capacitor **B** and the charge and discharge process repeated through the same sample of tissue.
The discharge curves are shown in **Figure 1**.

Figure 1



1 (b) (i) By considering the discharge curve for capacitor **A**, show that the resistance of the sample of heart tissue through which the discharge occurs is approximately 150 Ω.

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(4 marks)

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1 (b) (ii) State and explain whether capacitor **B** has a larger or smaller capacitance than that of capacitor **A**.

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(2 marks)

1 (c) Capacitor **A** was charged to a potential difference of 4.0 V before discharging through the sample of heart tissue.
Determine how much energy it passed to the sample of heart tissue in the first 0.90 ms of the discharge.

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energy .... J

(3 marks)

11

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2 (a) Explain what is meant by the entropy of a thermodynamic system.

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(1 mark)

2 (b) Explain why the **total** entropy of a thermodynamic system and its surroundings cannot decrease.

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(2 marks)

2 (c) A piece of lead of mass 2.5 kg and at a temperature of 50.0°C, is immersed in a tank containing 25 kg of water at a temperature of 15.0°C. The lead and the water eventually reach the same temperature.

specific heat capacity of lead $= 1.27 \times 10^{2}\,\mathrm{J\,kg^{-1}\,K^{-1}}$
specific heat capacity of water $= 4.18 \times 10^{3}\,\mathrm{J\,kg^{-1}\,K^{-1}}$

2 (c) (i) Show that the rise in temperature of the water is less than 0.2 K.

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(4 marks)

2 (c) (ii) Calculate the magnitude of the change in entropy of the lead.
You should use the average temperature of the lead in your calculation.
State the appropriate unit.

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entropy change .... unit ....

(5 marks)

2 (c) (iii) Calculate the magnitude of the change in entropy of the water.
You should assume that the water is at 15°C.

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entropy change .... unit ....

(2 marks)

2 (c) (iv) For each of the quantities in part (c)(ii) and part (c)(iii) state and explain whether the sign of the change in entropy is positive or negative.

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(2 marks)

16

Turn over ▶

3 (a) (i) The ideal gas equation is $pV = nRT$.
State the meaning of each of the terms in the equation. Give a consistent set of units for these quantities.

p ....

V ....

n ....

R ....

T ....

(2 marks)

3 (a) (ii) List **four** assumptions used in the kinetic theory of gases.

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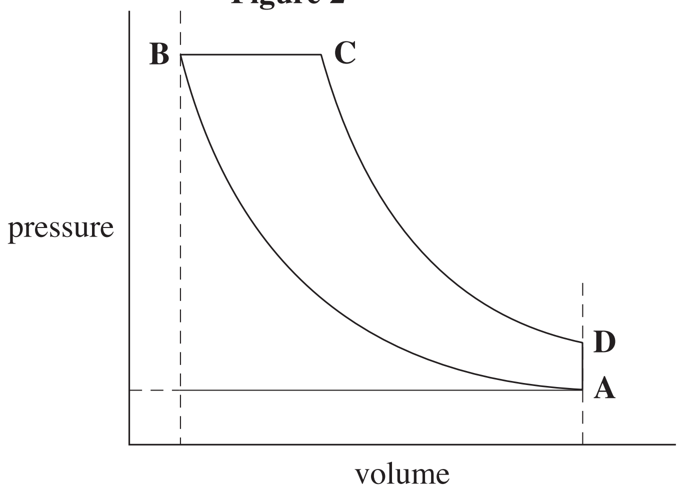
(4 marks)

3 (b) **Figure 2** is an idealised p–V diagram for a four-stroke engine in which air is compressed before fuel is injected into the cylinder. The fuel combusts when it comes into contact with the hot air. **AB** and **CD** are both adiabatic processes.
The fuel is injected during stage **BC**.

Figure 2



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3 (b) By referring to **Figure 2** describe and explain what is happening to the gases in the cylinder between

3 (b) (i) **A** and **B**

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(2 marks)

3 (b) (ii) **B** and **C**

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(2 marks)

3 (b) (iii) **C** and **D**

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(2 marks)

3 (b) (iv) **D** and **A**.

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(2 marks)

Question 3 continues on the next page

Turn over ▶

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3 (c) The table shows the values of some thermodynamic properties of a diesel cycle.

Heat input from combustion of gases (Q_i) / MJ	**Heat output via exhaust gases / MJ**	**Work done on fuel–air mixture gases (W_i) / MJ**	**Work done by fuel–air mixture gases (W_o) / MJ**
1.800	0.737	0.450	

3 (c) (i) Calculate the value of W_o in MJ.

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(1 mark)

3 (c) (ii) The thermal efficiency of any heat engine is defined as the net work done by the working substance ($W_o - W_i$) divided by the total heat input (Q_i).
Calculate the thermal efficiency of the cycle.
Give your answer to an appropriate number of significant figures.

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thermal efficiency ....

(2 marks)

3 (c) (iii) The calorific value of diesel fuel is $45.3\,\text{MJ kg}^{-1}$.
Calculate the mass of diesel fuel that is used in **one** cycle.

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mass .... kg

(2 marks)

19

4 When a cyclotron is operating, charged particles move in circular arcs of increasing radius.

4 (a) Describe and explain how a cyclotron works.

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

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(6 marks)

Question 4 continues on the next page

Turn over ▶

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4 (b) (i) Show that the time, T, taken for a proton to travel one complete circle in a cyclotron is given by

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

where the symbols have their usual meaning.
Ensure that each of your steps is clearly shown.

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(4 marks)

4 (b) (ii) Explain why this implies that T is independent of the speed of the protons and the radius of the circle in which they move.

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(1 mark)

Do not write outside the box

4 (c) In the earliest cyclotrons protons were accelerated to energies of 80 keV.

4 (c) (i) Show that the speed of 80 keV protons is about $4 \times 10^{6}\ \mathrm{m\,s^{-1}}$. Assume that relativistic effects can be neglected.

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(3 marks)

4 (c) (ii) Show that the assumption in part (c)(i) is valid.

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(2 marks)

16

Turn over for the next question

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5 In the research into nuclear fusion one of the most promising reactions is between deuterons ($^2_1$H) and tritium nuclei ($^3_1$H) in a gaseous plasma. Although deuterons can be relatively easily extracted from sea water, tritium is difficult to produce. It can, however, be produced by bombarding lithium-6 ($^6_3$Li) with neutrons. The two reactions are summarised as:

$$^2_1\text{H} + ^3_1\text{H} \rightarrow ^4_2\text{He} + ^1_0\text{n} + \text{energy}$$

$$^6_3\text{Li} + ^1_0\text{n} \rightarrow ^3_1\text{H} + ^4_2\text{He} + \text{energy}$$

Masses of reactants:

$^1_0$n = 1.008665u
$^2_1$H = 2.013553u
$^3_1$H = 3.016049u
$^4_2$He = 4.002603u
$^6_3$Li = 6.015122u

1u is equivalent to 1.66×10^{-27} kg or 931 MeV

5 (a) (i) Explain why the atomic mass unit, u, may be quoted in kg or MeV.

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(2 marks)

5 (a) (ii) Calculate the maximum amount of energy, in MeV, released when 1.0 kg of lithium-6 is bombarded by neutrons.

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energy released .... MeV

(5 marks)

Do not write outside the box

5 (a) (iii) Suggest why the lithium-6 reaction could be thought to be self-sustaining once the deuteron-tritium reaction is underway.

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(1 mark)

5 (b) (i) In order to fuse, a deuteron and a tritium nucleus must approach one another to within approximately 1.5×10^{-15} m.
Calculate the minimum total initial kinetic energy that these nuclei must have.

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minimum total kinetic energy of nuclei .... J

(3 marks)

5 (b) (ii) Show that a temperature of approximately 4×10^{9} K would be sufficient to enable this fusion to occur in a gaseous plasma.

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(3 marks)

Question 5 continues on the next page

5 (b) (iii) Explain in terms of the forces acting on nuclei why the deuteron-tritium mixture must be so hot in order to achieve the fusion reaction.

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(4 marks)

18

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6 Radioisotope thermoelectric generators (RTGs) are electrical generators powered by radioactive decay. As a radioisotope decays some of the energy released is converted into electricity by means of devices called thermocouples. In this way RTGs have been used as power sources in satellites, space probes and heart pacemakers.

The Cassini space probe was launched in 1997. It carried three RTGs each containing 11 kg of a nuclear fuel, plutonium oxide (a compound having two oxygen atoms combined with every plutonium-238 atom). In 1997, when the probe was launched, the power released from one gram of plutonium oxide was 500 mW.
Plutonium-238 ($^{238}_{94}\text{Pu}$) is an alpha emitter, decaying into uranium(U).
The half-life of the decay is 87.7 years.

mass of one mol of plutonium-238 = 238 g
mass of one mol of oxygen atoms = 16 g

6 (a) State and explain why environmentalists might have been concerned by the use of such a large quantity of plutonium-238.

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(2 marks)

6 (b) State and explain whether the activity of a given number of atoms of plutonium is affected when they are in the form of plutonium oxide.

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(2 marks)

Question 6 continues on the next page

6 (c) (i) Calculate the decay constant, in s^{-1}, for plutonium-238.

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decay constant .... s^{-1}

(2 marks)

6 (c) (ii) Calculate the number of plutonium-238 atoms in the total mass of the plutonium oxide in the Cassini probe at the beginning of its mission.

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number of plutonium-238 atoms ....

(5 marks)

6 (c) (iii) Calculate the initial activity of the plutonium-238 in the Cassini probe.
Give a suitable unit for your answer.

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initial activity of plutonium-238 .... unit ....

(3 marks)

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6 (d) (i) Write a nuclear equation for the $^{238}_{94}$Pu decay.

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(2 marks)

6 (d) (ii) Assume the power released by the RTGs' fuel originated as the kinetic energy of the alpha particles emitted in the decay of $^{238}_{94}$Pu.
Calculate the maximum kinetic energy of each alpha particle.

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kinetic energy of alpha particle .... J

(4 marks)

20

END OF QUESTIONS

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