Centre Number						Candidate Number				
Surname										
Other Names										
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For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
TOTAL	

General Certificate of Education
Advanced Level Examination
January 2012

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

Friday 27 January 2012 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.

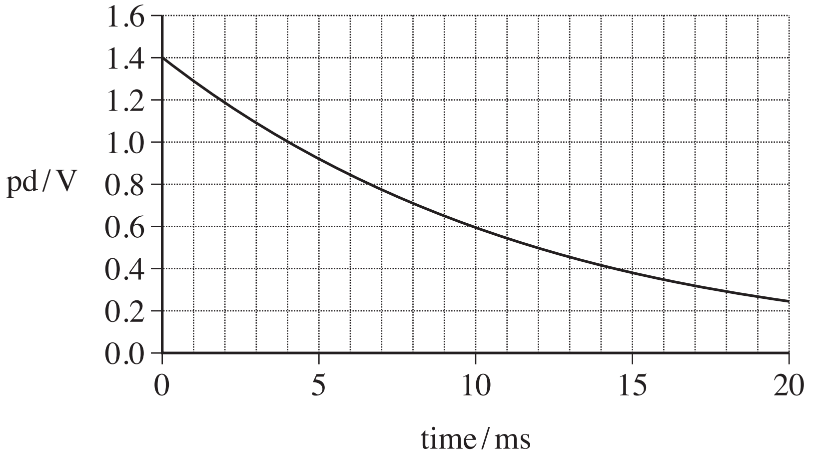
Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator where appropriate.
- A *Data and Formulae Booklet* is provided as a loose insert.
- You will be marked on your ability to:
  – use good English
  – organise information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

Do not write outside the box

Answer **all** questions.

1 **Figure 1** shows part of the discharge curve for a capacitor that a manufacturer tested for use in a heart pacemaker.

Figure 1



The capacitor was initially charged to a potential difference (pd) of 1.4 V and then discharged through a 150 Ω resistor.

1 (a) Show that the capacitance of the capacitor used is about 80 μF.

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(3 marks)

1 (b) Explain why the rate of change of the potential difference decreases as the capacitor discharges.

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(3 marks)

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1 (c) Calculate the percentage of the initial energy stored by the capacitor that is lost by the capacitor in the first 0.015 s of the discharge.

energy lost ....%

(3 marks)

1 (d) The charge leaving the capacitor in 0.015 s is the charge used by the pacemaker to provide a single pulse to stimulate the heart.

1 (d) (i) Calculate the charge delivered to the heart in a single pulse.

charge C

(1 mark)

1 (d) (ii) The manufacturer of the pacemaker wants it to operate for a minimum of 5 years working at a constant pulse rate of 60 per minute.
Calculate the minimum charge capacity of the power supply that the manufacturer should specify so that it will operate for this time.
Give your answer in amp-hours (Ah).

minimum capacity ....Ah

(2 marks)

12

2 The table shows the binding energy per nucleon for two nuclei.

nucleus	**binding energy per nucleon/10^{-12} J**
helium-4	1.1332417
beryllium-8	1.1314027

2 (a) (i) Explain what is meant by the total binding energy of a nucleus.

....

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(1 mark)

2 (a) (ii) It is more usual to quote binding energies of nucleons in MeV rather than J.
Calculate the total binding energy, in MeV, of a beryllium-8 nucleus.

binding energy ....MeV

(3 marks)

2 (b) (i) Calculate the change in mass that occurs when two helium-4 nuclei fuse to form a beryllium-8 nucleus.

mass change ....kg

(2 marks)

Do not write outside the box

2 (b) (ii) Two helium-4 nuclei are initially separated by a large distance and are travelling toward one another. The helium nuclei become influenced by the strong force when their centres are separated by a distance of 3.82×10^{-15} m.
Calculate the total initial kinetic energy of the nuclei needed for them to reach this separation.

kinetic energy ....J
(3 marks)

2 (b) (iii) Explain why the kinetic energy calculated in part (b)(ii) will not enable the helium nuclei to fuse and produce a beryllium-8 nucleus.

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(3 marks)

12

Do not write outside the box

3 (a) In a diesel engine the air in a cylinder is compressed quickly before injecting the fuel. This increases the pressure inside the cylinder and raises the air temperature to the ignition temperature of the fuel.
Explain **in terms of the kinetic theory of gases** why the temperature and pressure of the air changes as it is compressed.

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

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(6 marks)

Do not write outside the box

3 (b) In one engine a cylinder has a volume of 3.1×10^{-4} m^3. The air taken into the cylinder is initially at atmospheric pressure, 1.0×10^5 Pa, and has a temperature of 35 ºC. The air just reaches the fuel ignition temperature of 210 ºC when it is compressed to $\frac{1}{18}$ of its initial volume.

Calculate the pressure of the air in the cylinder when it reaches the ignition temperature.

pressure ....Pa

(3 marks)

3 (c) (i) State the name for the type of thermodynamic process that takes place in the gas in the cylinder during the compression stroke.

....

(1 mark)

3 (c) (ii) Which of the terms in the first law of thermodynamics is zero (0) for this change?

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(1 mark)

3 (d) Explain how a steady driving force is produced by a diesel engine.

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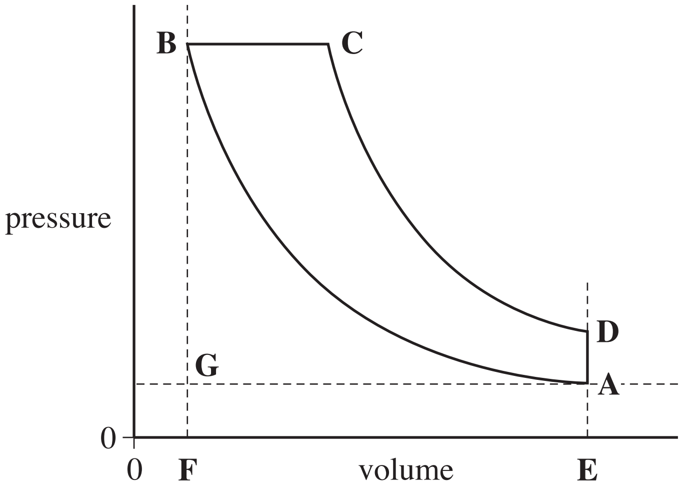
(2 marks)

Turn over ▶

3 (e) **Figure 2** show an idealised *p*-*V* diagram for one cycle of a diesel engine.

Figure 2



The table below shows different areas of the diagram. Indicate in the second column the area that corresponds to

P, the work done when the fuel-air mixture expands

and **N,** the net work output of the cylinder over one complete cycle.

area	
BCDAB	
BCDEFB	
BCDAGB	
BAEFB	

(2 marks)

3 (f) Explain how the thermodynamic efficiency of an ideal engine, operating at a constant air temperature, can be increased.

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(2 marks)

17

4 In a nuclear reactor the mean energy produced by each uranium-235 nucleus that undergoes induced fission is 3.0×10^{-11} J. In one pressurised water reactor, PWR, the fuel rods in the reactor contain 2.0×10^{4} kg of uranium-235 and 40% of the energy produced per second is converted to 500 MW of electrical output power. It is assumed that all the energy produced in the reactor core is removed by pressurised water in the coolant system. The pressure of the water is approximately 150 times greater than normal atmospheric pressure. The water enters the reactor at a temperature of 275 ºC and leaves at a temperature of 315 ºC. Under the operational conditions of the reactor the mean density of water in the coolant circuit is 730 kg m^{-3} and the specific heat capacity of water is approximately 5000 J kg^{-1} K^{-1}.

normal atmospheric pressure = 1.0×10^{5} Pa
molar mass of uranium-235 = 0.235 kg

4 (a) The equation below gives one induced fission reaction that takes place in a reactor.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathbf{X} \Rightarrow {}^{n}_{56}\mathrm{Br} + {}^{90}_{p}\mathrm{Kr} + 2\,{}^{1}_{0}\mathbf{X}$$

4 (a) (i) State the name of the particle represented by **X**.

....

(1 mark)

4 (a) (ii) State the proton and nucleon numbers represented by p and n.

p ....

n ....

(2 marks)

4 (b) (i) Calculate the number of fission reactions that occur in the reactor each second.

number of fission reactions per second ....

(2 marks)

Question 4 continues on the next page

Turn over ▶

4 (b) (ii) The reactor fuel rods contain 2.0×10^4 kg of uranium-235. Assume that all this uranium-235 could be used.
Calculate the maximum time, in years, for which the reactor could operate.

time ....years
(4 marks)

4 (b) (iii) Suggest why it is not possible to use all the uranium-235 in the reactor fuel rods.

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(2 marks)

4 (c) Calculate the force exerted by the pressurised water on each square centimetre of the wall of the reactor.

force ....N
(2 marks)

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4 (d) Calculate, in $m^3\ s^{-1}$, the flow rate of the water through the PWR reactor.
You will need to use data from the passage on page 9 at the beginning of Question 4.

flow rate .... $m^3\ s^{-1}$
(4 marks)

4 (e) In a PWR the cooling water also acts as the moderator in the reactor and boron rods are used to control the power output. Describe the physical processes that take place in the moderator and control rods.

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(4 marks)

21

Turn over for the next question

5 Radioactive nuclides are often injected into patients for either diagnosis or treatment of diseases. Following preparation the nuclide has a *physical half-life* and after injection a *biological half-life*.

5 (a) (i) Explain what is meant by half-life.

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(1 mark)

5 (a) (ii) Explain how a nuclide has a biological half-life.

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(1 mark)

5 (a) (iii) Explain why the physical half-life of a radioactive nuclide is constant whilst its biological half-life varies.

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(2 marks)

5 (b) Technetium-99m emits gamma radiation of photon energy 2.24×10^{-14} J. It has a physical half-life of 2.2×10^{4} s and a biological decay constant of 8.0×10^{-6} s^{-1}.

5 (b) (i) Calculate the frequency of the gamma ray photon.

frequency ....Hz

(2 marks)

Do not write outside the box

5 (b) (ii) Calculate the physical decay constant of technetium-99m.

decay constant ....s^{-1}
(2 marks)

5 (b) (iii) A sample of technetium-99m is injected into a patient.
Calculate the time taken for the activity of the sample that remains in the patient to fall to 10% of the initial activity.
Give your answer in seconds to a number of significant figures that is consistent with the data used.

time taken .... s
(4 marks)

5 (c) There are risks involved when using radioactive materials to diagnose disease or to treat patients.

5 (c) (i) What is meant by risk?

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(1 mark)

5 (c) (ii) State the property of radiation that makes it useful in the treatment of a disease such as cancer and explain why there are risks associated with the treatment.

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(3 marks)

5 (c) (iii) State the criterion that a doctor would use to decide whether or not to use radiation to treat a patient.

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(1 mark)

17

Turn to page 16 for the next question.

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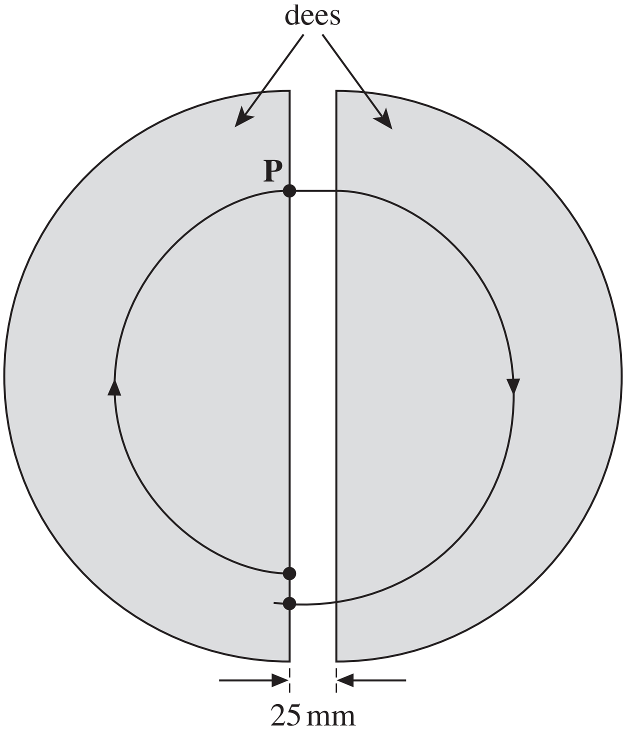
6 **Figure 3** shows part of the path of a proton in a cyclotron. The proton is moving in a circular path of radius 0.20 m when it reaches the gap between the two 'dees' at **P**. The gap is 25 mm wide. At **P**, the proton is travelling at 726 km s^{-1} and its kinetic energy is 2750 eV. On reaching the gap the proton is accelerated by a uniform electric field, produced by a potential difference of 370 V between the dees.

Figure 3



6 (a) (i) Calculate the acceleration of the proton that is produced by the electric field in the gap.

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

(3 marks)

Do not write outside the box

6 (a) (ii) Show that the energy of the proton after crossing the gap is about 5×10^{-16} J and go on to calculate the speed of the proton after being accelerated across the gap.

proton speed ....m s^{-1}

(4 marks)

6 (a) (iii) Calculate the time taken for the proton to cross the gap.

time to cross the gap ....s

(2 marks)

6 (b) Protons travelling at a speed v within a dee are moving in a magnetic field and follow a semicircular path of radius r.

6 (b) (i) Show that $r = kv$, where k is a constant.

(3 marks)

Turn over ▶

Do not write outside the box

6 (b) (ii) Calculate the magnetic flux density in the dees.
Give an appropriate unit for your answer.

flux density .... unit ....

(3 marks)

6 (c) In a cyclotron, the magnetic flux density and the frequency of the accelerating potential difference remain constant as the particle energy increases. In the synchrotron, they both have to change. Explain these differences in the operation of the accelerators.

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(4 marks)

6 (d) Although originally used as research tools in universities, some hospitals now have their own cyclotrons. State what use a hospital might make of its cyclotron and give one advantage of the hospital having its own cyclotron on site rather than making use of a cyclotron that is some distance away.

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(2 marks)

21

END OF QUESTIONS

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