Centre Number						Candidate Number				
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For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
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TOTAL	

General Certificate of Education
Advanced Level Examination
June 2015

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

Thursday 18 June 2015 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 (enclosed).

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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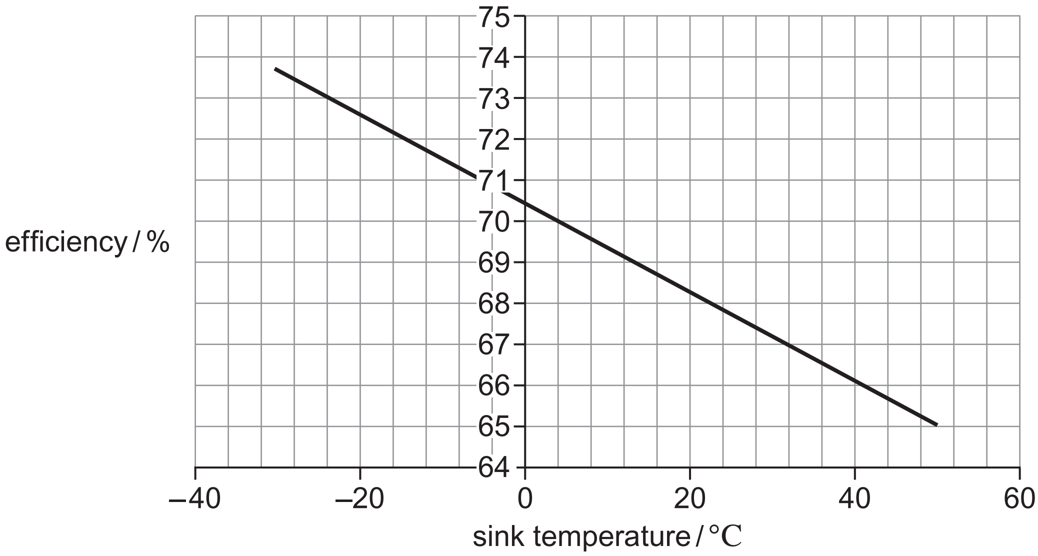
Answer **all** the questions in the spaces provided.

1 (a) An engine runs from a hot energy source which is at a constant temperature. The graph in **Figure 1** shows how the maximum thermal efficiency of the engine varies as the sink temperature changes.

Figure 1



1 (a) (i) Show that the temperature of the hot energy source for this engine is about 920 K.

[4 marks]

1 (a) (ii) Explain why a practical engine does **not** achieve the maximum thermal efficiency possible for its source and sink temperatures.

[2 marks]

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1 (b) In a practical engine the temperature of the hot energy source is $920\ \mathrm{K}$ and the sink temperature is $310\ \mathrm{K}$. The engine has an efficiency of 44% and provides a useful output of $35\ \mathrm{kW}$.
Calculate the entropy change that occurs in one second when the engine is running.
Give the unit for entropy change.
State whether the entropy change is positive or negative.

[5 marks]

entropy change .... unit ....

positive or negative ....

1 (c) Entropy changes can be illustrated by using similar balls of two different colours shaken in a glass container.
A and **B** in **Figure 2** show the glass container at different times.

Figure 2

A **B**

State whether **A** or **B** is likely to have occurred first and explain how consideration of the entropy of the system supports your answer.

[3 marks]

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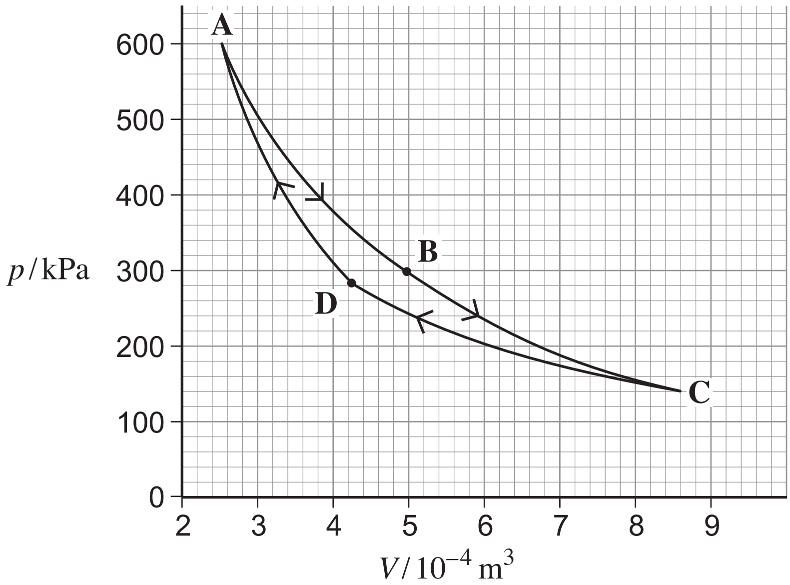
2 The Carnot cycle is the most efficient theoretical cycle of changes for a fixed mass of gas in a heat engine.
Figure 3 shows the pressure–volume (p–V) diagram for a gas undergoing a Carnot cycle of changes **ABCDA**.

Figure 3



2 (a) (i) Show that during the change **AB** the gas undergoes an isothermal change.

[3 marks]

2 (a) (ii) Explain how the first law of thermodynamics applies to the gas in the change **BC**.

[3 marks]

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2 (a) (iii) Determine the ratio $\frac{T_A}{T_C}$,
where T_A is the temperature of the gas at **A** and T_C is the temperature of the gas at **C**.

[3 marks]

ratio ....

2 (b) Show that the work done during the change **AB** is about 110 J.

[2 marks]

2 (c) When running at a constant temperature, one practical engine goes through 2400 cycles every minute. In one complete cycle of this engine, 114 J of energy has to be removed by a coolant so that the engine runs at a constant temperature. The temperature of the coolant rises by 18 °C as it passes through the engine.

Calculate the volume of the coolant that flows through the engine in one second.

specific heat capacity of coolant = 3.8×10^3 J kg^{-1} K^{-1}
density of coolant = 1.1×10^3 kg m^{-3}

[3 marks]

volume flowing in one second .... m^3

14

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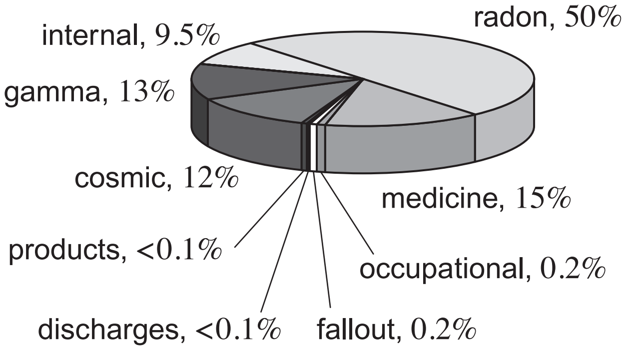
3 The pie chart in **Figure 4** shows that radon contributes 50% of the average UK annual radiation dose for a person in the UK.

Figure 4



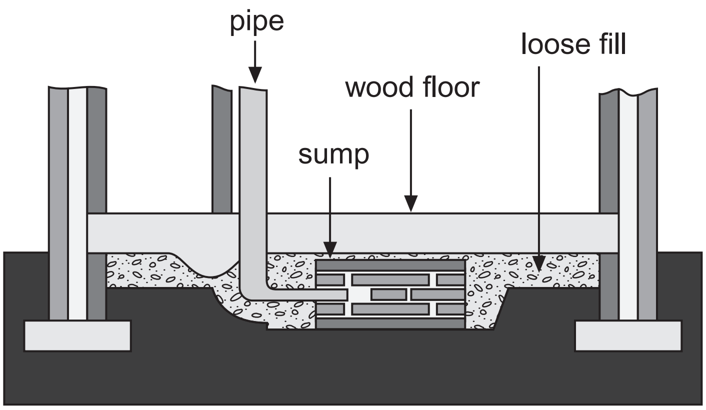
The contribution from radon is due to a radioactive gas, radon-222 ($^{222}_{86}Rn$). A nucleus of radon-222 decays by emitting an alpha particle of energy 5.5 MeV. Radon is produced in the decay chain of uranium-238 ($^{238}_{92}U$), which exists naturally in granite rock. People living in buildings built on granite are at risk from the effects of radiation. Radon gas seeps up through the ground and into buildings through cracks in the floor.

The radiation from radon is not, however, the main risk to health. The risk to health comes from the next two nuclides in the decay chain, polonium-218 and a radioactive form of lead, lead-214. These nuclides are solid and can become attached to dust and water particles in the air. When breathed in, these nuclides can remain in the lungs and the alpha particle radiation they emit can cause cancer.

It is recommended that buildings are tested regularly to check radon levels. In work places or in schools the maximum acceptable level of activity is $400\ \mathrm{Bq\ m^{-3}}$. In homes action is needed if the activity exceeds $200\ \mathrm{Bq\ m^{-3}}$.

Designing new buildings with a radon sump can reduce radiation levels. A sump is a cavity within the ground beneath a building, as shown in **Figure 5**. Radon gas is sucked from the ground into the sump due to the reduced pressure in the sump. This is then pumped through a pipe into the air outside the building, where it disperses safely.

Figure 5



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3 (a) (i) The pie chart in **Figure 4** shows contributions from **fallout** and **cosmic**.

Explain the meaning of each of these terms.

[2 marks]

fallout ....

....

cosmic ....

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3 (a) (ii) Give **two** examples of how medicine contributes to the average dose received.

[2 marks]

1 ....

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2 ....

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3 (b) (i) The alpha particle emitted when a nucleus of radon-222 decays has an energy of $5.5\ \mathrm{MeV}$.

Estimate the change in mass that takes place when the nucleus of radon-222 decays.

[2 marks]

change in mass .... kg

3 (b) (ii) Explain whether the actual change in mass is greater or smaller than your answer to part **(b)(i)**.

[1 mark]

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3 (c) (i) Circle the number of alpha particles that are emitted as $^{238}_{92}U$ decays to $^{222}_{86}Rn$.

[1 mark]

16 8 4 2

3 (c) (ii) Circle the number of beta-minus particles that are emitted as $^{238}_{92}U$ decays to $^{222}_{86}Rn$.

[1 mark]

8 6 4 2

3 (d) (i) Suggest why radon is less of a risk to health than the products of its decay.

[2 marks]

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3 (d) (ii) Suggest why the acceptable activity in the home is 200 Bq m^{-3} whilst that in workplaces and schools is 400 Bq m^{-3}.

[1 mark]

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3 (e) A test discovered that the radon activity in a schoolroom was 600 Bq m^{-3}. The half-life of radon-222 is 3.8 days.

3 (e) (i) Calculate the time, in hours, that it takes before the risk of using the room is at an acceptable level.
Assume that the room could be sealed to prevent radon entering or leaving.

[3 marks]

time .... hours

Do not write outside the box

3 (e) (ii) Calculate the maximum number of radon atoms in one cubic metre that is acceptable in schools.

[3 marks]

number of radon atoms ....

3 (e) (iii) Use your answer to part **(e)(ii)** to calculate the pressure due to the radon gas in a room when the temperature is 17 ºC.
Give an appropriate unit for your answer.

[4 marks]

pressure due to radon gas.................................. unit ....

3 (f) Suggest **two** ways of keeping activity to a safe level in homes affected by radon, where it is not possible to install a sump system.

[2 marks]

1 ....

2 ....

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4 (a) Explain what is meant by a **thermal** neutron.

[2 marks]

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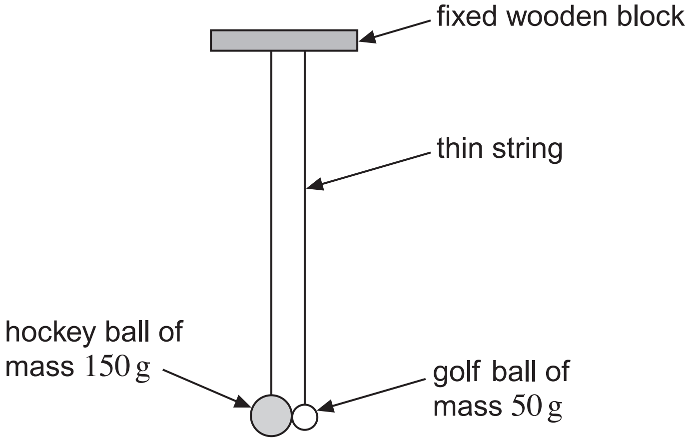
4 (b) A student sets up the arrangement in **Figure 6** to demonstrate the principle of moderation in a nuclear reactor.

Figure 6



A golf ball of mass 50 g is initially hanging vertically and just touching a hockey ball of mass 150 g. The golf ball is pulled up to the side and released. It has a speed of $1.3\ \text{m s}^{-1}$ when it collides head-on with the hockey ball. After the collision the balls move in opposite directions with equal speeds of $0.65\ \text{m s}^{-1}$.

4 (b) (i) Calculate the height above its initial position from which the golf ball is released. Assume that there is no air resistance.

[2 marks]

height .... m

Do not write outside the box

4 (b) (ii) Show that momentum is conserved in the collision and that the collision is perfectly elastic.

[4 marks]

4 (b) (iii) Calculate the percentage of the kinetic energy of the golf ball transferred to the hockey ball during the collision.

[2 marks]

percentage transferred .... %

4 (b) (iv) Explain how this demonstration relates to the moderation process in a reactor and state **one** way in which the collisions in a reactor differ from the collision in the demonstration.

[2 marks]

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4 (b) (v) Name the substance used as the moderator in a pressurised water reactor (PWR).

[1 mark]

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Question 4 continues on the next page

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4 (c) Describe how useful energy is produced by nuclear fission and go on to explain how this energy is used to generate electricity in a nuclear power station that uses a PWR.
You may draw diagrams in the space provided to help you.

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

[6 marks]

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5 In stars, helium-3 and helium-4 are formed by the fusion of hydrogen nuclei. As the temperature rises, a helium-3 nucleus and a helium-4 nucleus can fuse to produce beryllium-7 with the release of energy in the form of gamma radiation.

Table 1 shows the masses of these nuclei.

Table 1

Nucleus	**Mass / u**
Helium-3	3.01493
Helium-4	4.00151
Beryllium-7	7.01473

5 (a) (i) Calculate the energy released, in J, when a helium-3 nucleus fuses with a helium-4 nucleus.

[4 marks]

energy released .... J

5 (a) (ii) Assume that in each interaction the energy is released as a single gamma-ray photon.

Calculate the wavelength of the gamma radiation.

[3 marks]

wavelength .... m

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5 (b) For a helium-3 nucleus and a helium-4 nucleus to fuse they need to be separated by no more than 3.5×10^{-15} m.

5 (b) (i) Calculate the minimum total kinetic energy of the nuclei required for them to reach a separation of 3.5×10^{-15} m.

[3 marks]

total kinetic energy .... J

5 (b) (ii) Calculate the temperature at which two nuclei with the average kinetic energy for that temperature would be able to fuse.
Assume that the two nuclei have equal kinetic energy.

[3 marks]

temperature .... K

5 (b) (iii) Suggest a star type in which this reaction is most likely to occur.

[1 mark]

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Question 5 continues on the next page

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5 (c) Scientists continue to try to produce a viable fusion reactor to generate energy on Earth using reactors like the Joint European Torus (JET). The method requires a plasma that has to be raised to a suitable temperature for fusion to take place.

5 (c) (i) State **two** nuclei that are most likely to be used to form the plasma of a fusion reactor.

[2 marks]

1 ....

2 ....

5 (c) (ii) State **one** method which can be used to raise the temperature of the plasma to a suitable temperature.

[1 mark]

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6 The specification for a pacemaker requires a suitable charge to be delivered in 1.4 ms. A designer uses a circuit with a capacitor of capacitance 3.0 μF and a 2.5 V power supply to deliver the charge. The designer calculates that a suitable charge will be delivered to the heart as the capacitor discharges from a potential difference (pd) of 2.5 V to a pd of 1.2 V in 1.4 ms.

6 (a) (i) Calculate the charge on the capacitor when it is charged to a pd of 2.5 V.

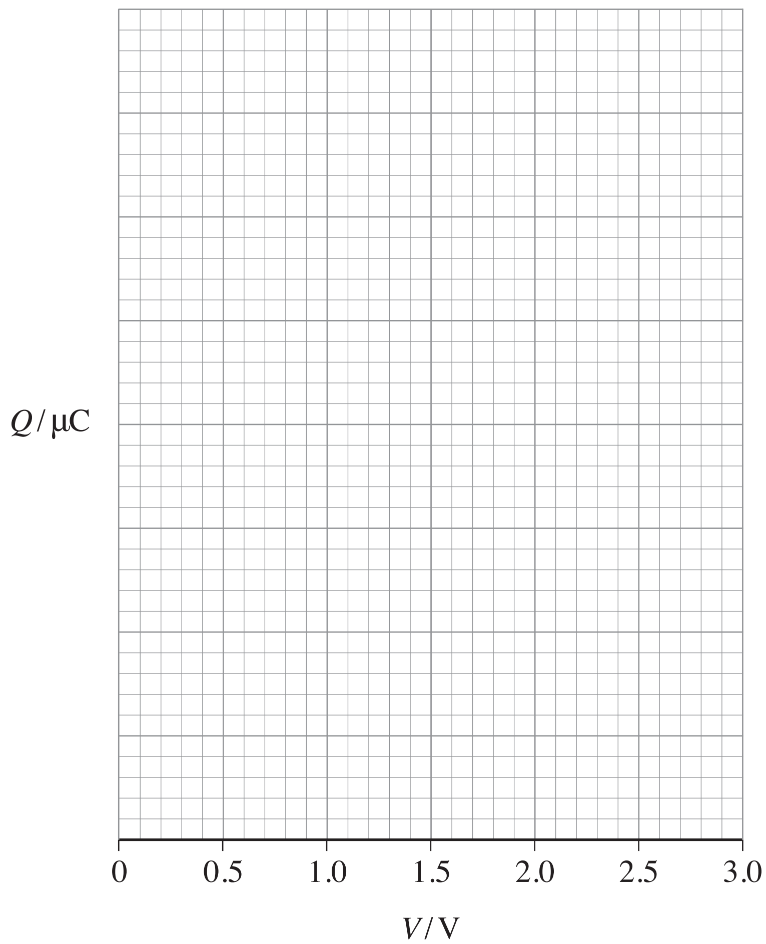
[1 mark]

charge C

6 (a) (ii) Draw, on **Figure 7**, a graph showing how the charge, Q, on the capacitor varies with the pd, V, as it discharges through the heart.
Include an appropriate scale on the charge axis.

[3 marks]

Figure 7



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6 (b) Calculate the energy delivered to the heart in a single pulse from the pacemaker when the capacitor discharges to 1.2 V from 2.5 V.

[3 marks]

energy .... J

6 (c) (i) Calculate the resistance of the heart that has been assumed in the design.

[3 marks]

resistance .... Ω

6 (c) (ii) Explain why the rate of change of pd between the capacitor plates decreases as the capacitor discharges.

[2 marks]

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END OF QUESTIONS

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