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

AQA

General Certificate of Education
Advanced Level Examination
June 2013

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 20 June 2013 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.

Do not write outside the box

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

1 (a) Neutrons can be generated by irradiating beryllium-9 nuclei ($^{9}_{4}Be$) with alpha particles. Each interaction produces a carbon (C) nucleus and a fast neutron. The equation for the reaction is given below.

1 (a) (i) Complete the equation to show the nucleon and proton numbers of the particles and nuclei involved.

$$^{9}_{4}\mathrm{Be} + ^{\dots}_{\dots}\alpha \rightarrow ^{\dots}_{\dots}\mathrm{C} + ^{\dots}_{\dots}\mathrm{n}$$

(3 marks)

1 (a) (ii) Neutrons sustain the chain reaction in a nuclear reactor. Describe how they are produced and used in the fission process.

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(2 marks)

1 (b) It is important for reactor designers to know the *absorption cross-section* of the materials they use.

1 (b) (i) State what is meant by absorption cross-section.

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(1 mark)

1 (b) (ii) State the unit for absorption cross-section. ....

(1 mark)

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1 (c) When selecting a *moderator* to use in a reactor both absorption cross-section and nucleon number are important considerations.

1 (c) (i) Explain the purpose of the moderator in a nuclear reactor.

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(2 marks)

1 (c) (ii) Explain why the moderator's absorption cross-section is an important consideration.

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(1 mark)

1 (c) (iii) Explain why the moderator's nucleon number is an important consideration.

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(1 mark)

11

Turn over for the next question

2 (a) Describe how a beam of fast moving electrons is produced in the cathode ray tube of an oscilloscope.

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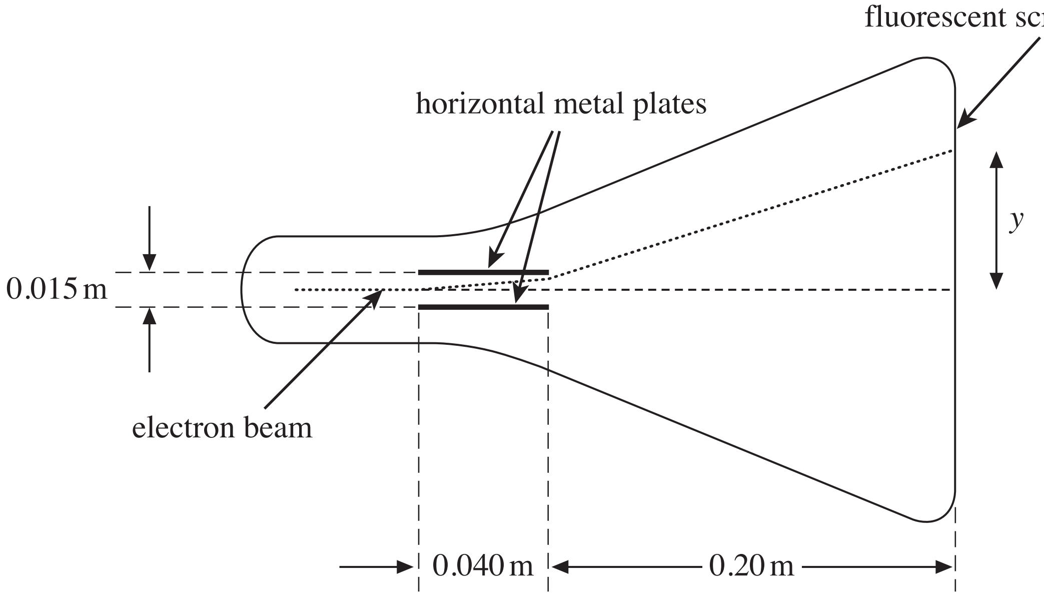
(3 marks)

2 (b) **Figure 1** shows the cathode ray tube of an oscilloscope. The details of how the beam of electrons is produced are not shown.

Figure 1



The electron beam passes between two horizontal metal plates and goes on to strike a fluorescent screen at the end of the tube. The plates are 0.040 m long and are separated by a gap of 0.015 m. A potential difference of 270 V is maintained between the plates. An individual electron takes 1.5×10^{-9} s to pass between the plates. The distance between the right-hand edge of the plates and the fluorescent screen is 0.20 m.

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2 (b) (i) Show that the vertical acceleration of an electron as it passes between the horizontal metal plates is approximately 3.2×10^{15} m s^{-2}.

(3 marks)

2 (b) (ii) Show that the vertical distance travelled by an electron as it passes between the horizontal metal plates is approximately 3.6 mm.

(2 marks)

2 (b) (iii) Show that the vertical component of velocity achieved by an electron in the beam by the time it reaches the end of the plates is approximately 4.7×10^{6} m s^{-1}.

(2 marks)

2 (b) (iv) Calculate the vertical displacement, *y*, of the electron beam from the centre of the screen. Give your answer in m.

vertical displacement .... m

(3 marks)

13

Turn over ▶

Do not write outside the box

3 (a) The Joint European Torus (JET) is an experimental fusion reactor that uses deuterium-tritium fusion. The reaction is shown below.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.59\,MeV$$

3 (a) (i) Describe the energy changes that occur when fusion takes place.

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(3 marks)

3 (a) (ii) Use the energy released in the reaction to calculate the change in mass between the reactants and their products and hence deduce the mass of a tritium nucleus, giving your answer in u.

mass of deuterium nucleus	=	2.013553 u
mass of helium nucleus	=	4.002602 u
mass of a neutron	=	1.008665 u

mass of tritium .... u

(5 marks)

Do not write outside the box

3 (b) The deuterium and tritium used in JET is in the form of a *plasma*. When the plasma is heated to a temperature of 7.4×10^9 K, deuterium and tritium nuclei are able to get sufficiently close to undergo fusion. At this temperature, the kinetic energy of the nuclei is enough to overcome their mutual electrostatic repulsion.

3 (b) (i) State what is meant by a plasma and explain how one may be produced.

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(2 marks)

3 (b) (ii) Show that the average kinetic energy of the nuclei in the plasma is approximately 8×10^{-14} J when the plasma temperature is 3.7×10^9 K.

(2 marks)

3 (b) (iii) Estimate the separation of a deuterium nucleus and a tritium nucleus when they are close enough for fusion to occur. Give your answer in m.

separation of nuclei .... m

(4 marks)

Do not write outside the box

3 (c) Explain why it is difficult to contain a plasma and how containment is managed in a nuclear fusion reactor of this type. As part of your answer you should state what is meant by superconductivity and explain why it is important to use superconducting devices.

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

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(6 marks)

22

Turn over for the next question

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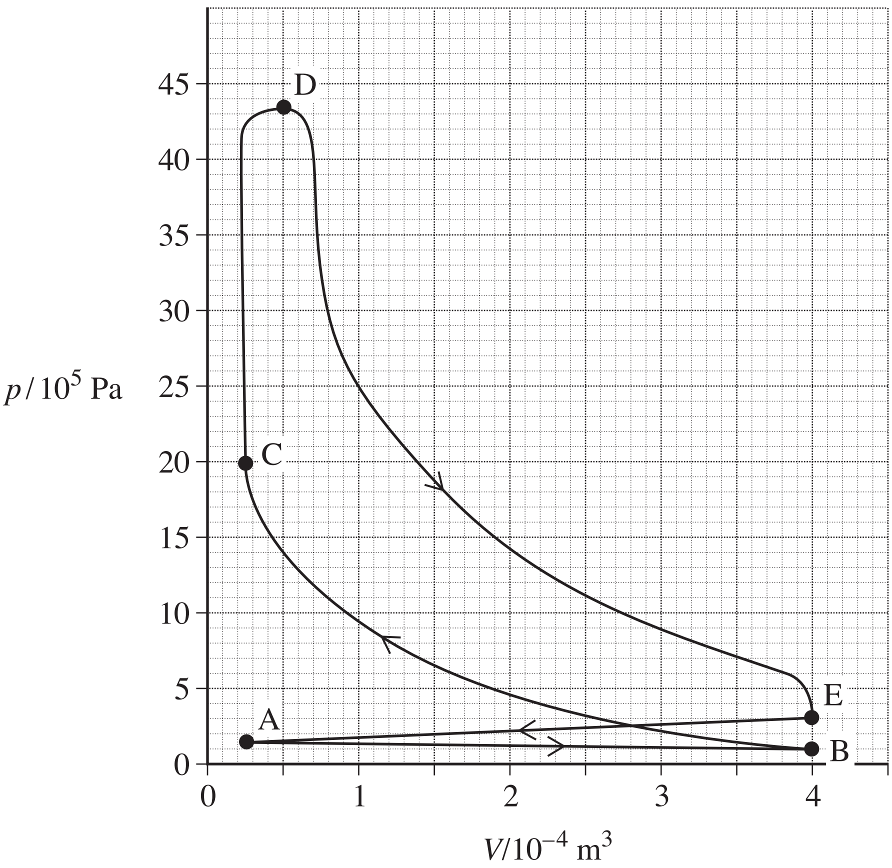
4 The p-V diagram for the gases in one cylinder of an internal combustion engine is shown in **Figure 2**. It shows the changes in pressure and volume for the gases during the four strokes of one complete cycle.

Figure 2



4 (a) (i) State the names of the 4 strokes of the cycle.

A → B ....

B → C ....

D → E ....

E → A ....

(1 mark)

4 (a) (ii) State what is happening to the gases in the cylinder between the points labelled **B** and **C** on **Figure 2**.

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(1 mark)

4 (a) (iii) Explain how the engine supplies the energy necessary for this process when the engine is running steadily.

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(1 mark)

4 (a) (iv) State what is happening to the gases in the cylinder between the points labelled **E** and **A** in **Figure 2**.

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(1 mark)

4 (a) (v) Explain the significance of the area of the triangle **EAB**.

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(1 mark)

4 (b) **EAB** may be neglected when determining the net work done on the piston for one cylinder over one cycle. Calculate the work done for one cylinder over one cycle.

work done for one cylinder .... J

(3 marks)

Do not write outside the box

4 (c) A recent adaptation of an engine adds two extra strokes to the cycle. In the first additional stroke, water is injected into the cylinder and almost instantaneously vaporises to high-pressure steam. This forces the piston downwards in another power stroke. It may be assumed that this power stroke is adiabatic. After the additional power stroke, the piston moves upwards, ejecting the used steam from the cylinder. The normal cycle then begins again.

In this way, some of the energy stored in the engine block is extracted, making the engine more efficient.

The water that is injected into the cylinder has a mass of 5.0 g. It is injected into the cylinder at 20 ºC. It is heated, vaporised, and the steam produced is then heated to 450 ºC.

4 (c) (i) Calculate the energy required to produce the 5.0 g of steam at 450 ºC.

specific heat capacity of water	=	4.2×10^3 J kg^{-1} K^{-1}
mean specific heat capacity of steam	=	5.0×10^3 J kg^{-1} K^{-1}
energy required to vaporise 1 kg of water at 100 ºC	=	2.26×10^6 J

energy .... J

(4 marks)

4 (c) (ii) The steam is ejected from the cylinder at a temperature of 150 ºC.
Calculate the thermal efficiency of the extraction of the energy from the steam.

efficiency ....

(3 marks)

Do not write outside the box

4 (c) (iii) Explain how the use of the water increases the overall efficiency of the engine.

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(2 marks)

4 (c) (iv) Describe how the first law of thermodynamics applies to the gas in the cylinder during the additional power stroke.

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(4 marks)

21

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5 Cyclotrons, LINACs and synchrotrons are used to accelerate charged particles to high energies in order to discover new particles or to investigate their properties.

5 (a) Explain why scientists and engineers continue to design particle accelerators that produce particles with increasing maximum energies.

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(2 marks)

5 (b) (i) In synchrotrons, the particle beam is controlled using magnetic fields that vary in magnitude during the acceleration of the charged particles. Explain the purpose of the magnetic fields and why they must vary in magnitude.

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(3 marks)

5 (b) (ii) Synchrotrons also use alternating electric fields that vary in frequency during the acceleration of the charged particles. Explain the purpose of the alternating electric fields and why their frequency must vary.

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(2 marks)

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5 (c) A particle accelerator accelerates protons to a speed of $2.9 \times 10^8\ \text{m s}^{-1}$ which is close to the speed of electromagnetic radiation in a vacuum.
Calculate the kinetic energy of the protons. Give your answer in GeV.

kinetic energy .... GeV

(5 marks)

5 (d) (i) State **two** advantages of LINACs compared with synchrotrons.

advantage 1 ....

....

advantage 2 ....

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(2 marks)

5 (d) (ii) Cyclotrons can only achieve relatively low particle energies, yet they continue to be useful. State **two** current uses for cyclotrons.

first use ....

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second use ....

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(2 marks)

16

Turn over ▶

Do not write outside the box

6 Technetium-99m (Tc-99m) is used in many diagnostic imaging procedures in hospitals. It is usually produced in a generator by the decay of molybdenum-99 (Mo-99). Mo-99 has a decay constant of $2.92 \times 10^{-6}\,\mathrm{s}^{-1}$ and each decay produces a beta particle, an electron antineutrino, and a Tc-99m nucleus.
One freshly prepared generator has an activity of 1.3×10^{11} Bq. Each Tc-99m nucleus that is formed decays, producing a 140 keV gamma ray and a Tc-99 nucleus. The Tc-99 that remains in the body following diagnosis is also radioactive with a half-life of 2.1×10^{5} y. When it decays, it emits a low-energy beta particle.

6 (a) (i) State and explain the meaning of 99m when used to describe the technetium nucleus.

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(3 marks)

6 (a) (ii) Explain why Tc-99m is considered to be a suitable choice for use as a tracer in diagnostic medicine.

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(4 marks)

Do not write outside the box

6 (b) (i) Calculate the mass of Mo-99 contained in the freshly prepared Tc-99m generator.

mass of Mo-99 .... g

(3 marks)

6 (b) (ii) The Tc-99m generator may be considered to be useful until the activity of the Mo-99 has fallen to 1.7×10^{10} Bq.

Calculate the maximum useful life of the Tc-99m generator.

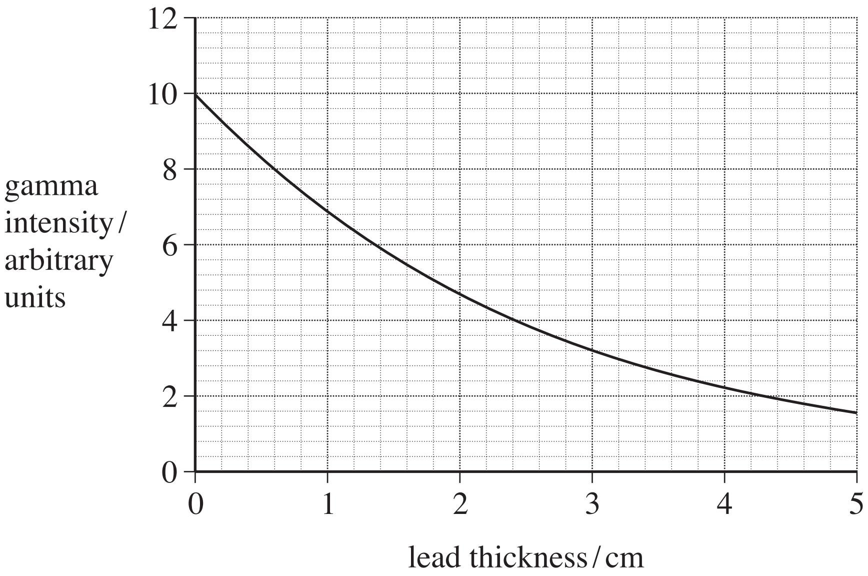
maximum useful life ....

(3 marks)

Turn over ▶

6 (c) A Tc-99m generator is usually enclosed in a lead box to protect users against exposure to gamma rays. **Figure 3** below shows the variation of gamma intensity with lead thickness for gamma rays of energy 140 keV.

Figure 3



Use **Figure 3** to find a reliable value for the half-thickness of lead for this energy of gamma rays and go on to calculate μ, the absorption coefficient of lead. Give your answer in cm^{-1}.

absorption coefficient .... cm^{-1}

(4 marks)

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END OF QUESTIONS

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