

Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
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5	
6	
7	
TOTAL	



General Certificate of Education
Advanced Level Examination
June 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

Tuesday 29 June 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. 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.



J U N 1 0 P H Y B 5 0 1

Answer **all** questions.

1 (a) Explain what is meant by the term *specific heat capacity*.

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(2 marks)

1 (b) The energy wasted each second when a car engine is operating is 280 kJ. A coolant circulating in a car engine removes 20% of this energy.

1 (b) (i) The coolant enters the engine at a temperature of 81 °C and leaves at a temperature of 88 °C. The rate of flow of the coolant through the engine is 2.5 kg s⁻¹.

Calculate the specific heat capacity of the coolant used.
Give an appropriate unit for your answer.

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specific heat capacity

unit

(4 marks)



1 (b) (ii) The overall efficiency of the engine is 25% .
Calculate the useful energy delivered by the engine each second.

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useful energy per second kJ
(2 marks)

1 (b) (iii) Explain why it is not possible to make an engine with a thermal efficiency of 100%
even if all frictional forces could be eliminated.

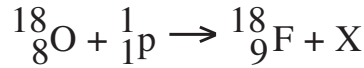
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(3 marks)



2 Fluorine-18 is an isotope that is used in PET scanners. It is a positron emitter with a half-life of 110 minutes. It is made by bombarding oxygen-18 atoms with high energy protons which are produced using a cyclotron.

2 (a) (i) The equation below shows the nuclear equation for the production of the fluorine-18.



State the proton number, nucleon number and name of the particle represented by X in the above equation.

proton number

nucleon number

name of particle

(3 marks)

2 (a) (ii) Explain why it is necessary to use protons that have a high energy to produce the radioactive fluorine.

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(2 marks)

2 (a) (iii) A hospital that does not have its own cyclotron uses fluorine-18 that is produced some distance away.

The hospital requires a source with an activity of 20 GBq. The total time between production of the isotope and its arrival at the hospital is 3.0 hours.

Calculate the initial activity of the source that has to be produced by the cyclotron.

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initial activity GBq
(3 marks)



2 (a) (iv) Calculate the number of radioactive atoms of fluorine-18 present in the 20 GBq source that arrives at the hospital.

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number of atoms
(2 marks)

2 (b) Many hospitals now have cyclotrons on site to produce the radioactive material that is necessary in investigative and diagnostic medicine. In one cyclotron the protons have a final orbit of diameter 1.8 m and leave the cyclotron with a kinetic energy of 2.4×10^{-12} J.

2 (b) (i) Show that the kinetic energy E_k of a proton when it leaves the cyclotron is given by

$$E_k = \frac{B^2 r^2 q^2}{2m}$$

where B is the flux density of the magnetic field in the cyclotron
 r is the radius of the cyclotron
 q is the proton charge
and m is the mass of a proton.

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(3 marks)

Turn over ►



2 (b) (ii) Calculate the flux density of the magnetic field in the cyclotron.
Give an appropriate unit for your answer.

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flux density

unit

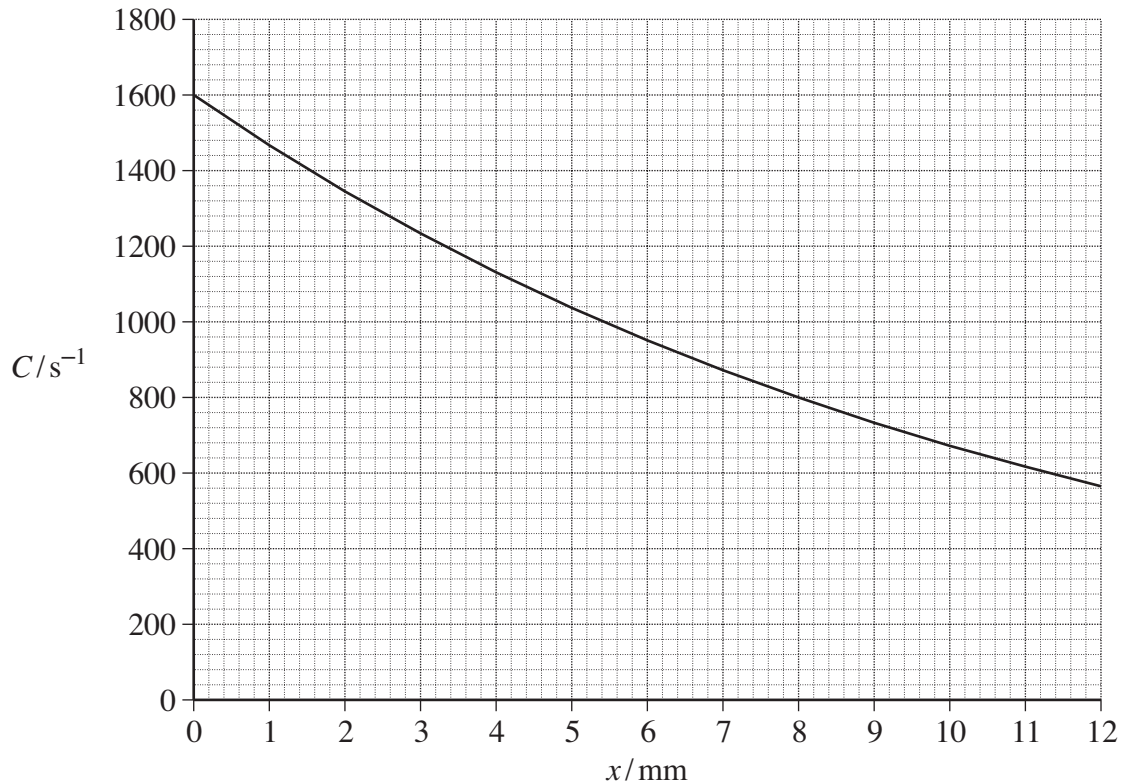
(3 marks)

16



- 3 **Figure 1** shows how the count rate C recorded by a gamma radiation detector varies when different thicknesses x of a metal absorber are inserted between a gamma source and the detector.

Figure 1



- 3 (a) (i) Use data from **Figure 1** to show that the count rate C decreases exponentially with absorber thickness x .

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(3 marks)

- 3 (a) (ii) Explain what is meant by the half-thickness of an absorber.

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(2 marks)

Question 3 continues on the next page

Turn over ►



3 (a) (iii) State the factors on which the half-thickness depends.

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(2 marks)

3 (a) (iv) The count rate C is proportional to the intensity I of the radiation reaching the detector. The intensity I varies according to the equation

$$I = I_0 e^{-\mu x}$$

where I_0 is the intensity of the radiation incident on the surface of the absorber and μ is the attenuation coefficient.

Use data from **Figure 1** to calculate the value of μ for the metal absorber. Give an appropriate unit for μ .

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attenuation coefficient

unit

(3 marks)



3 (b) In air, the intensity of gamma radiation falls with distance according to an inverse square law. Explain how increasing the distance between the user and the source and appropriate use of absorbers of known half-thickness can minimise the risks involved when conducting experiments with isotopes that emit gamma radiation.

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(4 marks)

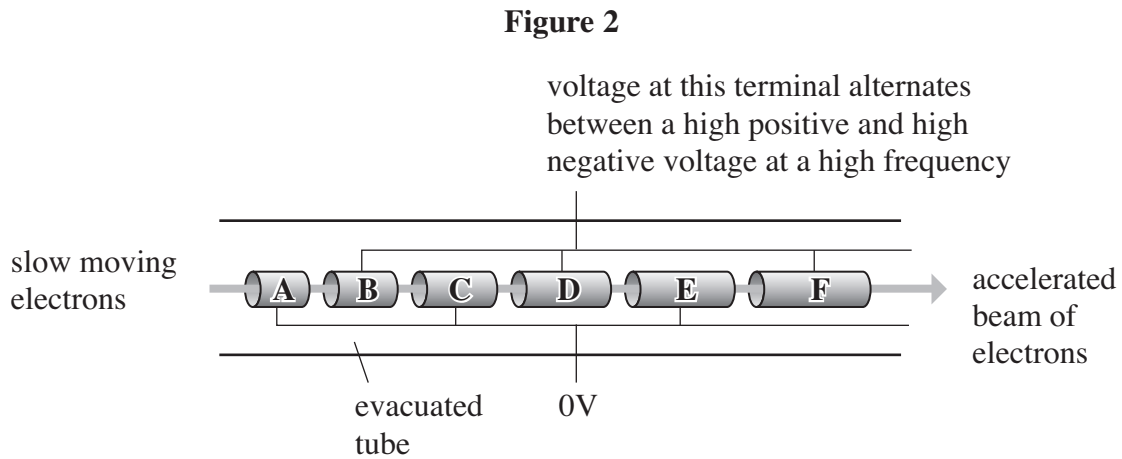
14

Turn over for the next question

Turn over ►



4 **Figure 2** shows a linear accelerator.



4 (a) Suggest **one** advantage and **one** disadvantage of constructing a linear accelerator compared with an accelerator such as a synchrotron to produce electrons with the same high energy.

Advantage

Disadvantage

(2 marks)

4 (b) (i) The accelerating potential difference at each gap is 4.8 kV. The electrons have negligible speed when arriving at the gap between **A** and **B**. Show that in the gap between **A** and **B**, the electrons are accelerated to a speed of about $4 \times 10^7 \text{ m s}^{-1}$.

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(3 marks)



4 (b) (ii) In order to be accelerated at the next gap the time taken to travel through tube **B** needs to be 1.8 ns.
Calculate the length of tube **B**.

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length of tube **B** m
(1 mark)

4 (b) (iii) Because of the high speed of the electrons relative to the stationary accelerator, a relativistic correction is necessary.
The rest mass of an electron is 9.110×10^{-31} kg.
Calculate the relativistic increase in mass that occurs when an electron accelerates from rest to a speed of 4.0×10^7 m s⁻¹.

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mass increase kg
(3 marks)

4 (b) (iv) Explain whether the relativistic change in mass would increase or decrease the required length for tube **B**.

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(2 marks)



5 A uranium-235 ($^{235}_{92}\text{U}$) nucleus undergoes spontaneous decay producing a nucleus of thorium-231 ($^{231}_{90}\text{Th}$) by emitting an alpha particle. The energy released appears as kinetic energy of the particles.

The masses of the nuclei involved are given in the table below.

Nucleus	Mass / u
uranium-235	235.0439299
thorium-231	231.0363043
alpha particle	4.0015062

5 (a) (i) Explain what is meant by spontaneous decay.

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(2 marks)

5 (a) (ii) Calculate the energy, in J, released when **one** uranium-235 nucleus decays.

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energy J

(3 marks)



5 (a) (iii) The energy released by alpha sources can be used to power electrical components and could be used to power heart pacemakers.

Explain briefly how energy released in alpha decay can be converted to electrical energy.

Go on to discuss the risks involved with the use of such supplies to power heart pacemakers.

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

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(6 marks)

Question 5 continues on the next page

Turn over ►



5 (b) When the separation of the centres of the alpha particle and the thorium nucleus is 5.1×10^{-14} m, the only force acting on each particle is that due to the charges on the particles.

5 (b) (i) Calculate the repulsive force on each particle at this separation.

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repulsive force N
(4 marks)

5 (b) (ii) Calculate the acceleration of the alpha particle at this separation.

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acceleration m s^{-2}
(3 marks)



5 (c) Each atom of uranium-235 can be made to yield a greater energy than that produced by alpha decay. This is achieved by neutron-induced fission.

5 (c) (i) Describe the process that occurs in the neutron-induced fission of uranium-235.

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(3 marks)

5 (c) (ii) The energy released by the induced fission of each uranium nucleus is 2.7×10^{-11} J. Calculate the energy, in J, released by the fission of 0.50 kg of uranium-235.

molar mass of uranium-235 = 0.235 kg

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energy released J

(3 marks)

24

Turn over ►



6 **Figure 3** shows a circuit that is used in a defibrillator in which a short pulse of charge is used to revive a patient who suffers a cardiac arrest in which their heart stops beating.

Figure 4 shows how the charge on the capacitor varies with time when the capacitor is charging.

Figure 3

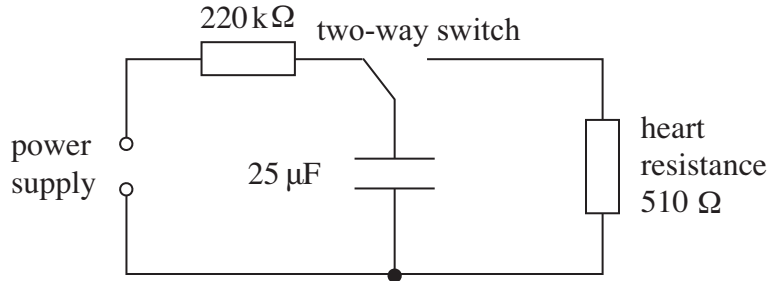
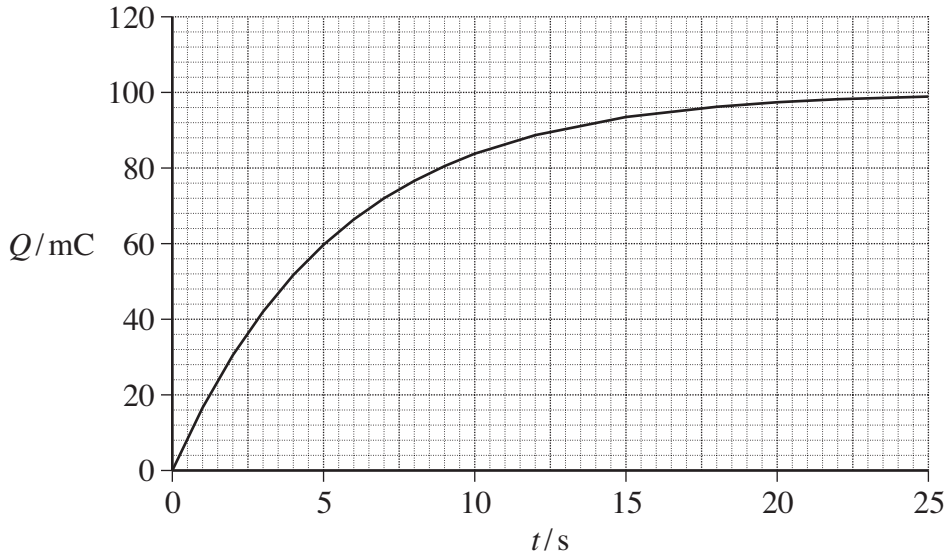


Figure 4



6 (a) (i) Use **Figure 4** to determine the initial charging current.

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initial charging current A
(2 marks)



6 (a) (ii) Calculate the emf of the supply used to charge the capacitor.
Assume that the supply has negligible internal resistance.

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emf of the supply V
(2 marks)

6 (a) (iii) Explain why the current that charges the capacitor falls as the capacitor charges.

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(3 marks)

6 (b) For the system to work successfully, the capacitor has to deliver 140 J of energy to the heart in a pulse that lasts for 10 ms.

6 (b) (i) Show that the charge on the capacitor when it is storing this much energy is about 85 mC.

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(2 marks)

Question 6 continues on the next page

Turn over ►



6 (b) (ii) Calculate the average power supplied during the pulse.

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average power W
(1 mark)

6 (c) The circuit designer suggests that the capacitor can be used successfully after a charging time equal to 1.5 time constants of the charging circuit shown in **Figure 3**. Explain with a calculation whether or not the designer's suggestion is valid.

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(3 marks)

13



7 A knowledge of absorption cross-sections and fission cross-sections of neutrons by different nuclei is important in the design of nuclear reactors. The 1 MeV neutrons that are emitted following the fission of a uranium nucleus have a speed of $1.4 \times 10^7 \text{ m s}^{-1}$. For neutrons with this speed the fission cross-section for the neutrons is small so, in order to produce a sustained chain reaction, the fuel needs to have a high concentration of uranium-235 nuclei. The cross-sections are higher for slow neutrons so in a pressurised water reactor (PWR) the neutrons are slowed down by collisions with the protons that are present in water. The reduced speed enables the use of reactor fuel rods that have not been highly enriched with uranium-235. The collisions with the protons reduce the energies of the neutrons to 0.025 eV so that their speeds are about 2200 m s^{-1} . Neutrons with this speed are called thermal neutrons. A 1 MeV neutron may need 100 collisions to slow down to 2200 m s^{-1} .

7 (a) (i) Give the name for a substance such as water that is used to slow down neutrons in a reactor.

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(1 mark)

7 (a) (ii) Use data from the passage to calculate the average energy lost by a neutron, in eV, when it collides with a proton in the PWR.

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 energy lost eV
(1 mark)

7 (a) (iii) Describe what would happen if a neutron collides head-on with a stationary proton.

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(2 marks)

Question 7 continues on the next page

Turn over ►



7 (b) Calculate the temperature of an ideal gas for which the mean energy of the molecules is 0.025 eV.

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temperature K
(3 marks)

7 (c) (i) Explain what is meant by absorption cross-section.
You may draw a diagram to help your explanation.

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(3 marks)

7 (c) (ii) The unit used to measure absorption cross-sections is equivalent to $1 \times 10^{-28} \text{ m}^2$.
State the name of this unit.

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(1 mark)

END OF QUESTIONS

