| 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 | |

General Certificate of Education
Advanced Level Examination
June 2014

# 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 19 June 2014 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.

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

**1 (a) (i)** Fuel is ignited in the combustion stage of a cylinder in a four-stroke engine. This raises the temperature and pressure of the gas in the cylinder. The combustion stage is followed by the power stroke in which the expanding hot gas does work on the piston.

Describe, in the correct sequence, what occurs in the two strokes of the engine cycle that follow the power stroke.

**[2 marks]**

.............................................................................................................................................

.............................................................................................................................................

.............................................................................................................................................

.............................................................................................................................................

**1 (a) (ii)** In a petrol engine a spark is used so that the fuel reaches its combustion temperature. Explain why, in a diesel engine, it is possible to ignite the mixture of fuel and air by first compressing air and then injecting fuel.

**[2 marks]**

.............................................................................................................................................

.............................................................................................................................................

.............................................................................................................................................

.............................................................................................................................................

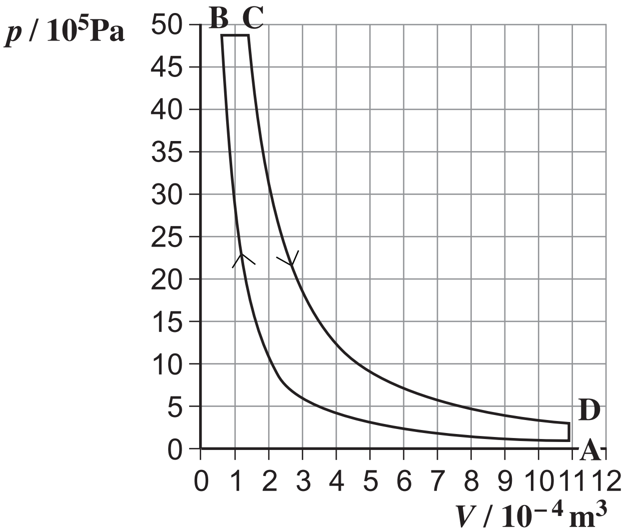
Do not write outside the box

**1 (b)** **Figure 1** shows changes in pressure and volume that take place during one cycle of a gas in a cylinder that has a movable piston.
**Table 1** shows data for the points **A**, **B**, **C** and **D** in the cycle.
Use the data from this table when answering questions from part **(b)**, **(c)** and **(d)**.

**Table 1**

| | $p / 10^5$ Pa | $V / 10^{-4}$ m$^3$ | $T$ / K |
|---|---|---|---|
| **A** | 1.01 | 10.90 | 290 |
| **B** | 49.00 | 0.68 | 880 |
| **C** | 49.00 | 1.50 | 1940 |
| **D** | 3.02 | 10.90 | |

**Figure 1**




Calculate the temperature of the gas at point **D** in the cycle.

**[3 marks]**

temperature at **D** ................................................ K

**1 (c)** Assume that the gas in the cylinder behaves as an ideal monatomic gas.

**1 (c) (i)** Calculate the number of moles of gas in the cylinder.

**[3 marks]**

number of moles ....................................................

**Question 1 continues on the next page**

**Turn over ▶**

**1 (c) (ii)** The mass of a molecule of the gas is $4.8 \times 10^{-26}$ kg.
Calculate the mean square speed of a gas molecule when the gas is at point **A** in the cycle.
Give an appropriate unit for your answer.

**[4 marks]**

mean square speed ................................................ unit ..................................

**1 (d)** Calculate the work done on the piston by the gas during the stage **BC**.

**[3 marks]**

work done ................................................ J

**1 (e)** State whether each of the quantities in the first law of thermodynamics is positive, negative or zero for the gas during the change from **D** to **A**.

**[2 marks]**

| | |
|---|---|
| $\Delta U$ | |
| $W$ | |
| $Q$ | |

19

Do not write outside the box

**2 (a)** A velocity selector is an essential part of a mass spectrometer. Describe and explain the operation of a velocity selector.
You may draw a diagram in the space provided to help you.

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

**[6 marks]**

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

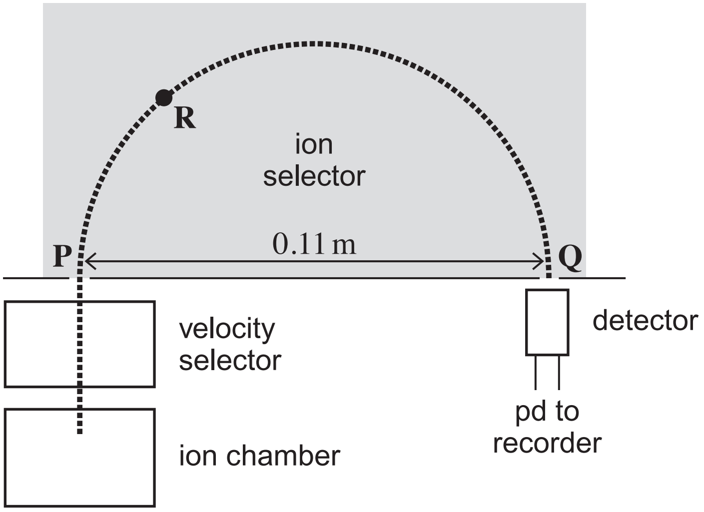
........................................................................................................................................

........................................................................................................................................

**Turn over ▶**

**2 (b)** **Figure 2** shows the component parts of a mass spectrometer used to measure the mass of ions.

**Figure 2**




Ions of a single element are produced at a steady rate in the ion chamber. The ions are accelerated by an electric field that produces a steady beam current. The ions, all carrying a double positive charge, then enter the velocity selector that selects ions that travel at a constant speed of $15\,000\,\mathrm{m\,s^{-1}}$. They enter the ion selector region at **P** and a magnetic field causes the ions to move in a circular path. Ions that pass through the hole at **Q** are detected. The separation between **P** and **Q** is fixed at $0.11\,\mathrm{m}$.

To analyse the sample, the magnetic flux density in the ion selector is increased linearly with time, as shown in **Figure 3**. This causes ions of different mass to enter the detector at different times. The voltages produced by the recorder represent the relative amounts of ions of different masses in the sample. **Figure 4** shows how the voltage $V$ varied with time for a sample of an element that contained isotopes **W**, **X** and **Y**.

**Figure 3**

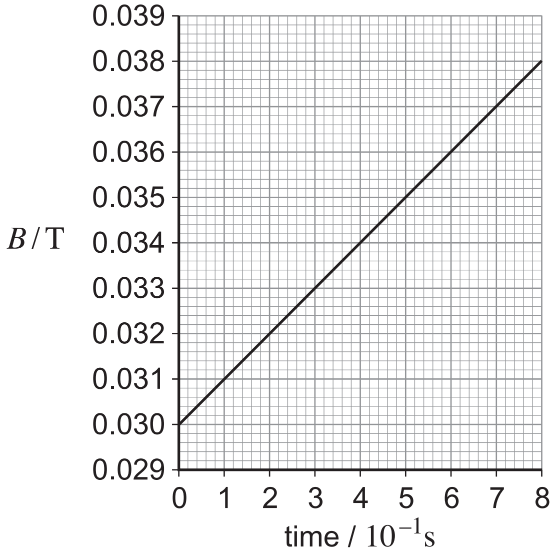
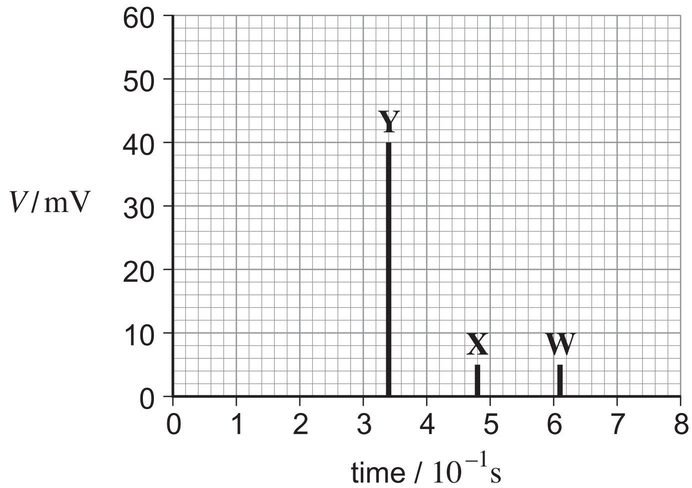



**Figure 4**



Do not write outside the box

**2 (b) (i)** Show in **Figure 2** the direction of the force that is exerted on an ion by the magnetic field when at the point labelled **R**.

**[1 mark]**

**2 (b) (ii)** Explain why it is important that there is a high vacuum in the ion selector.

**[2 marks]**

............................................................................................................................

............................................................................................................................

............................................................................................................................

**2 (b) (iii)** Determine the percentage of ions detected that give rise to the peak labelled **Y** in **Figure 4**.

**[2 marks]**

percentage of ions ..................................................

**2 (b) (iv)** Show that the approximate mass, $m$, of an ion that is detected is given by the equation

$$m = 1.2 \times 10^{-24}\ B$$

where $m$ is in kg
and $B$ is the flux density, in tesla (T), of the magnetic field in the ion detector.

**[3 marks]**

**Question 2 continues on the next page**

**Turn over ▶**

Do not write outside the box

**2 (b) (v)** Use the equation in **(b)(iv)** to determine the mass, $m_A$, of each ion that gives rise to the peak labelled $\mathbf{X}$ in **Figure 4**.

**[2 marks]**

mass of an ion ............................................. kg

**2 (b) (vi)** The ions that give rise to the peak labelled $\mathbf{Y}$ have a mass of $4.01 \times 10^{-26}$ kg and have a proton number of 12. How many electrons and neutrons are there in the **ions** that give rise to the peak at $\mathbf{Y}$?
Show your reasoning clearly.

**[4 marks]**

number of electrons .........................................................................................

number of neutrons ..........................................................................................

20

**Turn over for the next question**

**DO NOT WRITE ON THIS PAGE**
**ANSWER IN THE SPACES PROVIDED**

**3** A defibrillator is used to stimulate the heart in a patient who is suffering from a heart attack. In a biphasor defibrillator a capacitor $\mathbf{C_1}$ discharges for a short time interval through the patient, using electrodes placed on the patient's chest as shown in **Figure 5**. Then, almost immediately, a second capacitor $\mathbf{C_2}$ discharges so that charge flows for a shorter time interval, in the opposite direction to that produced when $\mathbf{C_1}$ discharges. Whatever the resistance of the patient, the total energy delivered to the patient in one attempt to stimulate the heart has to be $150\,\mathrm{J}$.
In one defibrillator $\mathbf{C_1}$ and $\mathbf{C_2}$ both have a capacitance of $100\,\mu\mathrm{F}$. **Figure 6** shows how the potential difference across each capacitor varies with time in one attempt to stimulate a patient's heart.

**Figure 5**

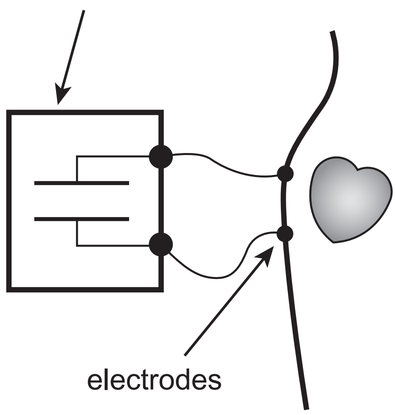
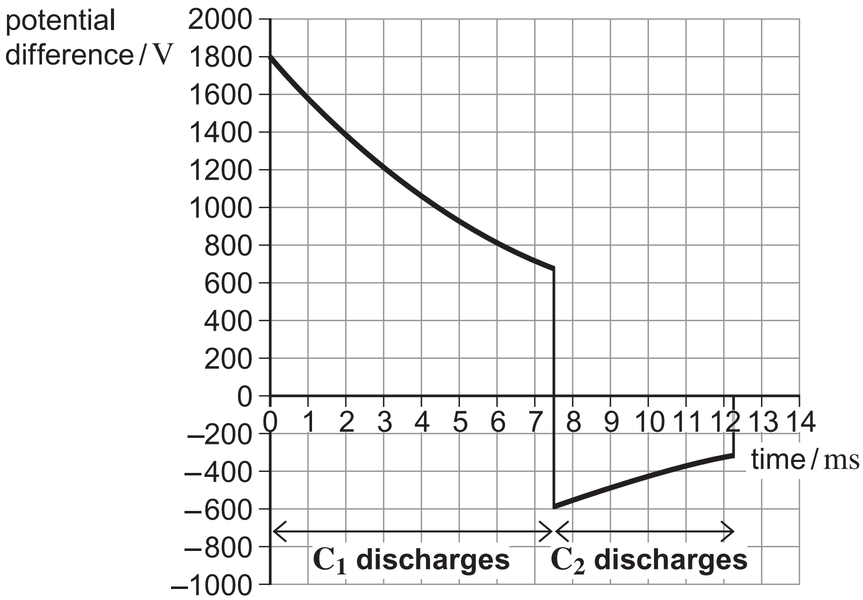



**Figure 6**




**3 (a) (i)** Calculate the initial charge on $\mathbf{C_1}$.

**[2 marks]**

initial charge ................................................ C

**3 (a) (ii)** Show that the resistance between the electrodes when the waveform has the shape in **Figure 6** is about $75\,\Omega$.

**[3 marks]**

**3 (b) (i)** Show that the energy dissipated when $C_1$ discharges through the patient is about 140 J.
**[3 marks]**

energy dissipated in $C_1$ ................................................ J

**3 (b) (ii)** Use the energy value given in **(b)(i)** and information from the passage to calculate the energy dissipated in the patient by capacitor $C_2$.
**[1 mark]**

energy dissipated in $C_2$ ................................................ J

**3 (b) (iii)** Calculate the average current through the patient during the discharge of $C_2$.
**[3 marks]**

average current ................................................ A

**3 (c)** This defibrillator uses the same capacitors to stimulate the heart of a patient for whom the resistance between the electrodes is much lower than $75\,\Omega$. The patient still has to receive a total energy of 150 J in an attempt to stimulate the heart. Explain why the lower resistance presents a design problem and how the operation of the defibrillator could be modified so that the patient receives 150 J of energy.
**[3 marks]**

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

15

**4 (a)** When nuclei decay by emitting alpha or beta particles the decays are often followed by the emission of gamma radiation. Explain why the gamma radiation is emitted and what determines the frequency of the gamma radiation emitted by a nucleus.

**[3 marks]**

.............................................................................................................................

.............................................................................................................................

.............................................................................................................................

.............................................................................................................................

.............................................................................................................................

.............................................................................................................................

**4 (b)** Gamma emitters can be used in diagnosis and treatment in medicine.
State **one** use for each.

**[2 marks]**

Use in diagnosis .........................................................................................................

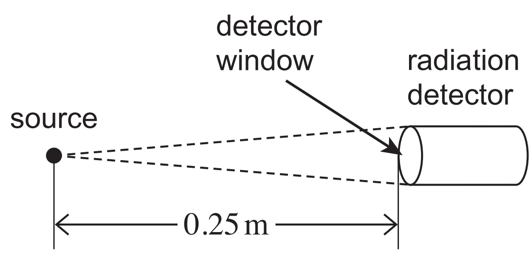
.............................................................................................................................

Use in treatment .........................................................................................................

.............................................................................................................................

**4 (c)** **Figure 7** shows an arrangement used by a student in an experiment to determine the gamma-radiation activity of a source.

**Figure 7**




The detector window has an area of $1.4 \times 10^{-4}\ \text{m}^2$ and the detector records $1.5\%$ of the photons that are incident on the window. When the window is $0.25\ \text{m}$ from the source the recorded count rate, corrected for background radiation, is $880\ \text{min}^{-1}$.

**4 (c) (i)** Calculate the gamma activity of the source giving the correct SI unit for activity.

**[5 marks]**

gamma activity ...................................................... unit ....................

**4 (c) (ii)** When a sheet of lead $3.5\,\text{cm}$ thick is inserted between the source and detector in **Figure 7**, the corrected count rate falls to $115\,\text{min}^{-1}$.
Calculate the absorption coefficient $\mu$ for lead.
Give an appropriate unit for your answer.

**[4 marks]**

absorption coefficient $\mu$ ...................................................... unit ....................

**4 (c) (iii)** State **two** precautions that the student should take when setting up the apparatus to reduce the risks involved in carrying out the experiment.

**[2 marks]**

precaution 1 ..............................................................................................................

..............................................................................................................

precaution 2 ..............................................................................................................

..............................................................................................................

16

**5** Plutonium-238 ($^{238}_{94}Pu$) is used as the heat source in radioisotope thermoelectric generators (RTGs) which are used to provide power for the electronic equipment in some spacecraft. Plutonium-238 has a half-life of 88 years and when a plutonium-238 nucleus decays it emits an alpha particle with kinetic energy $8.8 \times 10^{-13}$ J.
At the start of a space mission, one RTG contains $3.79 \times 10^{25}$ atoms of plutonium-238 which have a total mass of 15 kg. Initially, the RTG generates 380 W of electrical power from the heat produced by the plutonium-238.

**5 (a) (i)** From the options below, put the letter in the box that states the proton number and nucleon number for the isotope formed when plutonium-238 decays.

**[1 mark]**

| | proton number | nucleon number |
|---|---|---|
| **A** | 92 | 238 |
| **B** | 92 | 234 |
| **C** | 95 | 238 |
| **D** | 95 | 234 |

**5 (a) (ii)** Explain why nuclei that emit alpha particles are more suitable for this purpose than those that emit beta or gamma radiation.

**[2 marks]**

...................................................................................................................................

...................................................................................................................................

...................................................................................................................................

**5 (b)** The RTG converts the energy from the radioactive decay into electrical energy.

Calculate the initial efficiency of the RTG.

**[4 marks]**

initial efficiency ..................................................

Do not write outside the box

**5 (c)** Calculate the number of atoms of plutonium-238 that would decay during a space mission lasting 12 years.

**[5 marks]**

number of atoms ....................................................

**5 (d)** An isolated solid sphere of plutonium-238 would reach a steady temperature when the energy lost from the surface is equal to the energy produced by the decaying plutonium.

State and explain the effect of doubling the radius on the steady temperature reached by a solid plutonium sphere.

**[3 marks]**

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

15

**Turn over ▶**

**6 (a)** A deuteron consists of a proton and a neutron and has a mass equivalent to 1875.6 MeV. Calculate the mass defect, in kg, for a deuteron.

**[4 marks]**

mass defect ............................................. kg

**6 (b)** The most likely reaction that will be used in fusion reactors is that between a deuteron, D, and a tritium nucleus, T. The reaction is shown below together with the kinetic energies of the particles that result from the fusion reaction.

$$\mathrm{D} + \mathrm{T} \longrightarrow {}^{4}_{2}\mathrm{He}\ (3.56\ \mathrm{MeV}) + {}^{1}_{0}\mathrm{n}\ (14.03\ \mathrm{MeV})$$

**6 (b) (i)** Show that the kinetic energy $E_\mathrm{k}$ of a particle is given by

$$E_\mathrm{k} = \frac{p^2}{2m}$$

where $p$ is the momentum of the particle.

**[2 marks]**

**6 (b) (ii)** Assume that the deuteron and tritium nucleus are stationary when they undergo fusion. Show that the kinetic energies of the particles given in the equation are consistent with there being no change in the total momentum during the fusion process.

**[3 marks]**

**6 (c)** Explain what is meant by induced nuclear fission.

**[2 marks]**

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

**Question 6 continues on the next page**

Do not write outside the box

**6 (d) (i)** The energy available from the induced fission of one nucleus is about $200\,\text{MeV}$ whereas the fusion of a deuteron with a tritium nucleus yields only $17.5\,\text{MeV}$. Explain why it is still considered to be worthwhile continuing to develop a practical fusion reactor.

**[2 marks]**

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

**6 (d) (ii)** Discuss **two** problems that have to be overcome to create a practical fusion reactor.

**[2 marks]**

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

............................................................................................................................................

**15**

**END OF QUESTIONS**

**There are no questions printed on this page**

**DO NOT WRITE ON THIS PAGE**
**ANSWER IN THE SPACES PROVIDED**

**There are no questions printed on this page**

**DO NOT WRITE ON THIS PAGE**
**ANSWER IN THE SPACES PROVIDED**