Teacher Resource Bank

GCE Physics B: Physics in Context
Additional Sample Questions (Specification A)
PHYB5 – Energy Under the Microscope

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Dr Michael Cresswell, Director General.

ADDITIONAL SAMPLE QUESTIONS

This document provides a directory of past questions from the legacy AQA GCE Physics Specification A; these questions may prove relevant/useful to both the teaching of the new AQA GCE Physics B: Physics in Context specification and the preparation of candidates for examined units. It is advisable when using these questions that teachers consider how these questions could relate to the new specification. Teachers should be aware of the different treatment of the Quality of Written Communication between the specifications.

For specific examples of the style and flavour of the questions which may appear in the operational exams, teachers should also refer to the Specimen Assessment Materials which accompany the specification.

A mark scheme has been produced which accompanies this document.

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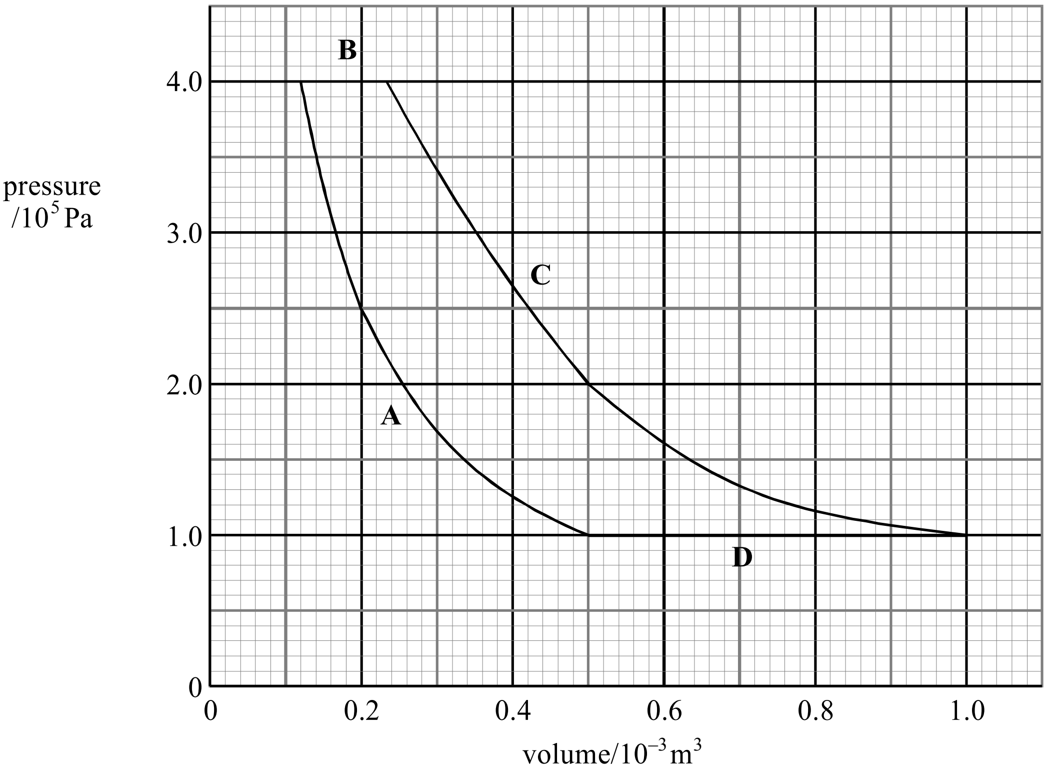
1. The diagram shows the theoretical pressure-volume diagram of an engine in which a fixed mass of gas is taken through a closed cycle of changes. The cycle consists of two isothermal processes **A** and **C**, separated by two constant pressure processes **B** and **D**. Process **A** occurs at a temperature of 300 K.



(a) (i) In which two processes is work done by the gas?

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(ii) In which two processes is the gas supplied with energy from a heat source?

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(2)

(b) Calculate the number of moles of gas contained in the cylinder.

$R = 8.3$ J mo1^{-1} K^{-1}

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(3)

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(c) Calculate the temperature of process **C**.

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(2)

(d) Use the diagram to show that the net work done by the gas in one complete cycle is 70 J.

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(3)

(Total 10 marks)

2. (a) The first law of thermodynamics can be written $\Delta Q = \Delta U + \Delta W$.

(i) State the meaning of each term in this equation.

ΔQ ....

ΔU ....

ΔW ....

(ii) Explain why, for an isothermal expansion, the first law can be written $\Delta W = \Delta Q$.

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(5)

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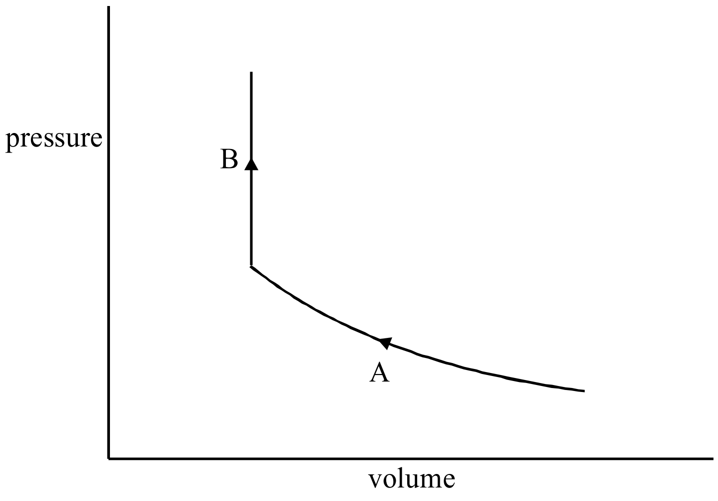
(b)



The diagram shows part of an ideal heat engine cycle in which a fixed mass of gas is taken through the following processes:

process A: isothermal compression at low temperature with an input of work of 83 J

process B: constant volume increase in pressure with an energy input by heating of 200 J

process C: isothermal expansion at high temperature with work output of 139 J

process D: constant volume cooling to the original pressure, volume and temperature

In this cycle, the energy input in process B is the same as the energy rejected in process D.

(i) On the diagram, draw in processes C and D to complete the whole cycle.

(ii) Complete the table by applying the first law of thermodynamics to each process and to the whole cycle.

process	**ΔQ / J**	**ΔU / J**	**ΔW / J**
A		0	–83
B	+200	+200	
C			+139
D			0
whole cycle			

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(iii) The highest and lowest temperatures of the air during the cycle are 500 K and 300 K. Show that the thermal efficiency of the ideal cycle is equal to the maximum possible efficiency for any heat engine working between these temperature limits.

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(9)

(Total 14 marks)

3. (a) When a gas which is heated expands, the first law of thermodynamics can be represented by the equation

$$\Delta Q = \Delta W + \Delta U.$$

Explain the meaning of each term in the equation:

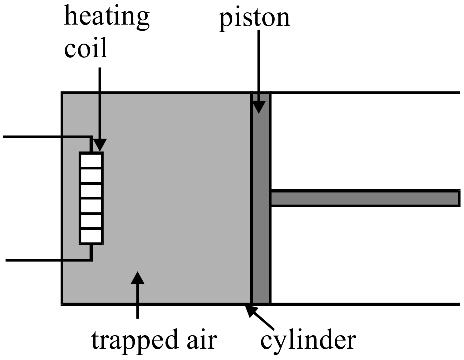
ΔQ ....

ΔW ....

ΔU ....

(3)

(b) A cylinder contains air trapped by a piston. The air can be heated using a heating coil, and the piston moves without friction.



The coil supplies 100J of energy to the air and the piston moves so that the air inside the cylinder is at a constant pressure of 1.5×10^5 Pa. The air expands by 20cm^3. If the cylinder is surrounded by perfect insulation, and no heat can pass through the piston, calculate for the air

(i) ΔQ...

(ii) ΔW...

(iii) ΔU ....

(3)

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(c) If the piston is fixed in its original position, so that the volume of the gas cannot change, what would be the corresponding values?

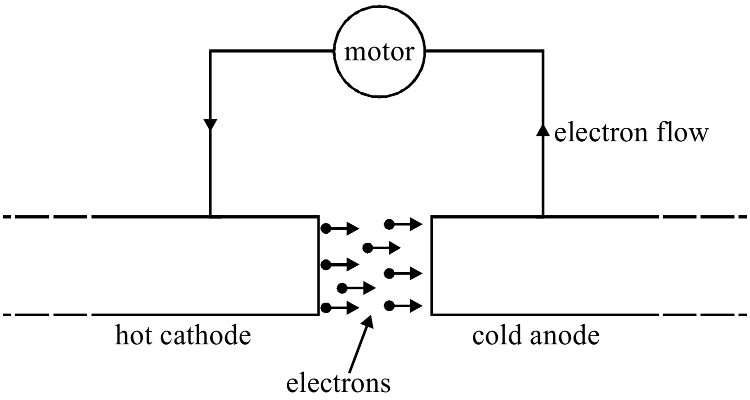
(i) ΔQ ....

(ii) ΔW ....

(iii) ΔU ....

(1)
(Total 7 marks)

4. The diagram shows a heat engine in which energy from a heat source is used to produce the electric current to drive a motor.



Electrons are emitted from the surface of the hot cathode and cross the gap to the cold anode.
The electrons return to the cathode via the motor, resulting in current flow through the motor.
To maintain the cathode and anode at constant temperatures, the cathode is supplied with heat from a high temperature heat source and the anode is cooled by rejecting heat to a low temperature sink.

The following data were obtained from measurements on an experimental engine:

temperature of heat source supplying cathode = 830 °C

temperature of cooling system for anode = 17 °C

heat energy supplied per second to cathode = 78 J

power output of electric motor = 1.5 W

(a) (i) Calculate the maximum possible efficiency of the engine.

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....

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(ii) Show that the actual efficiency of the experimental engine is much lower than the theoretical maximum.

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(4)

(b) Electrons at the surface of the cathode may be emitted only if they acquire sufficient thermal energy from the heat source. The minimum energy needed for an electron to be emitted is called the *work function* of the material of the source. The performance of a heat engine of this type depends greatly on the material properties of the cathode.

(i) Select the most suitable material for the cathode from the table below.

material	**work function**	**melting point**	**electrical resistivity**
A	low	low	low
B	high	high	high
C	low	high	low
D	high	low	high
E	low	high	high
F	high	low	low

The most suitable material is................

(ii) Explain briefly the reasons for your choice of properties.

Work function...

....

....

melting point...

....

....

electrical resistivity ....

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(4)

(Total 8 marks)

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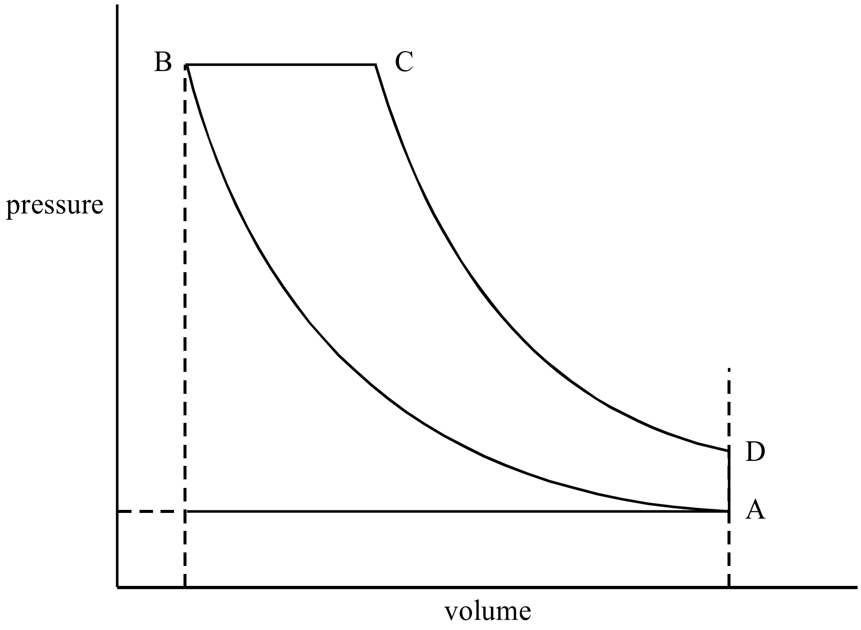
5. The *p*-*V* diagram shown is that of an ideal four-stroke diesel engine cycle.



(a) Use the diagram to describe the processes occurring

(i) between the points marked A and B,

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(ii) between B and C,

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(iii) between C and D,

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(iv) between D and A.

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(6)

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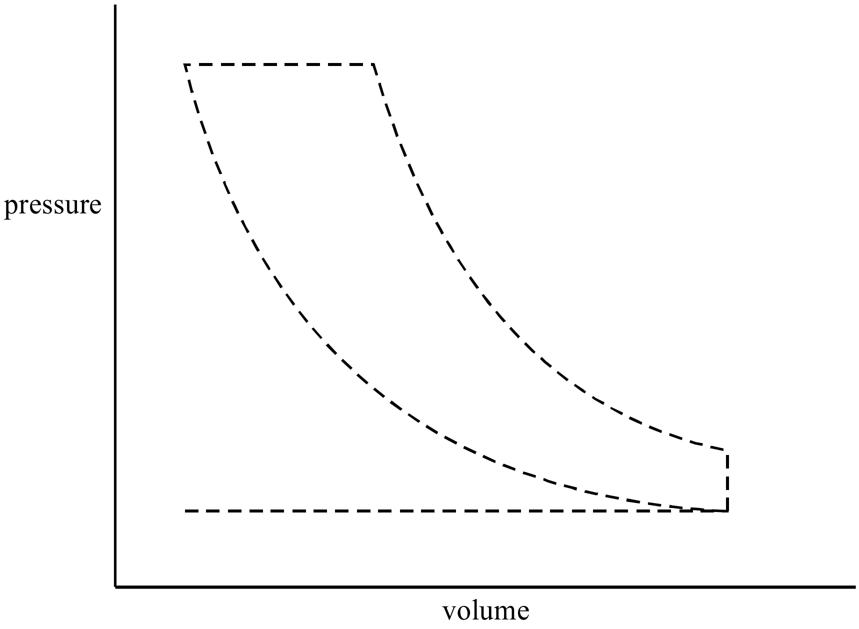
(b) (i) Show, on the axes below, how the diagram might be expected to appear if measurements of pressure and volume were made simultaneously on a real engine under operating conditions. The ideal cycle is shown in dashed lines as a guide.



(ii) State and explain **one** difference between the cycle you have drawn and that of an ideal engine.

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(4)
(Total 10 marks)

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6. **Figure 1** shows the energy transfers in an ideal heat engine operating between a source of heat at a temperature of 640°C and a cold heat-sink at a temperature of 20°C.

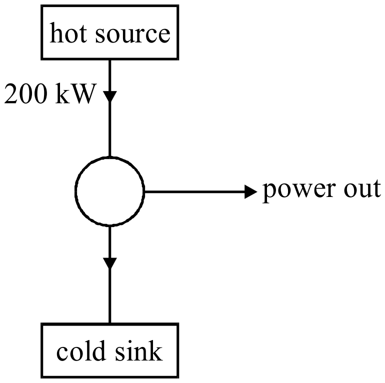

Figure 1

(a) Calculate

(i) the maximum possible efficiency,

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(ii) the maximum power output corresponding to this efficiency if the rate of energy supply from the hot source is 200 kW.

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(3)

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(b) A designer states that the two-stage ideal heat engine shown in **Figure 2**, below, would operate at a greater overall efficiency, and hence provide a greater total power output, than the engine of Figure 1. The same heat source and sink are to be used, but the energy rejected from the first stage enters a reservoir which acts as a source of energy for the second stage. The temperature of the reservoir is such that the maximum possible efficiency of the first stage is 34% and that of the second stage is 52%.

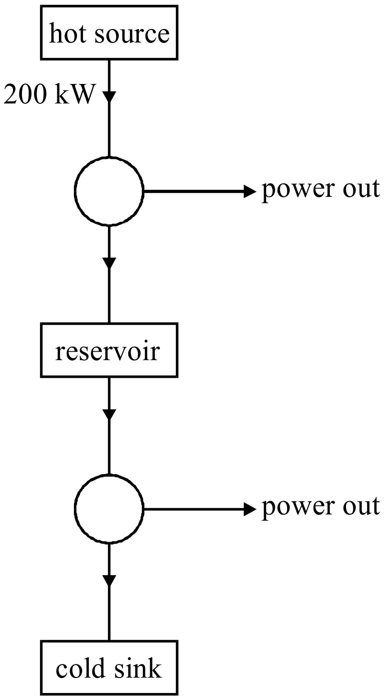

Figure 2

For the two-stage engine, operating at its maximum theoretical efficiency, calculate

(i) the power output of the first stage,

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(ii) the power delivered to the reservoir from the first stage,

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(iii) the power output of the second stage,

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(iv) the overall efficiency of the two-stage engine.

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(4)

(c) Comment on the validity of the designer's statement.

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(3)
(Total 10 marks)

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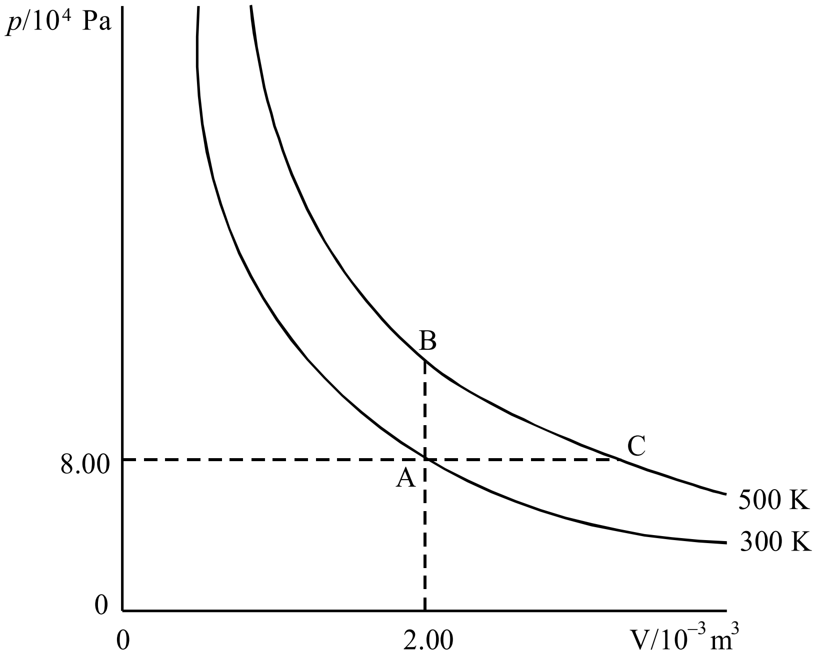
7. (a) The diagram shows curves (not to scale) relating pressure p, and volume, V, for a fixed mass of an ideal monatomic gas at 300 K and 500 K. The gas is in a container which is closed by a piston which can move with negligible friction.

molar gas constant, R, = 8.31 J mol^{-1} K^{-1}



(i) Show that the number of moles of gas in the container is 6.4×10^{-2}

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(ii) Calculate the volume of the gas at point C on the graph.

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(3)

(b) (i) Give an expression for the total kinetic energy of the molecules in one mole of an ideal gas at kelvin temperature T.

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(ii) Calculate the total kinetic energy of the molecules of the gas in the container at point A on the graph.

Explain why this equals the total internal energy for an ideal gas.

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(4)

(c) Defining the terms used, explain how the first law of thermodynamics, $\Delta Q = \Delta U + \Delta W$,
applies to the changes on the graph

(i) at constant volume from A to B,

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(ii) at constant pressure from A to C.

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(5)

(d) Calculate the heat energy absorbed by the gas in the change

(i) from A to B,

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(ii) from A to C

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(3)
(Total 15 marks)

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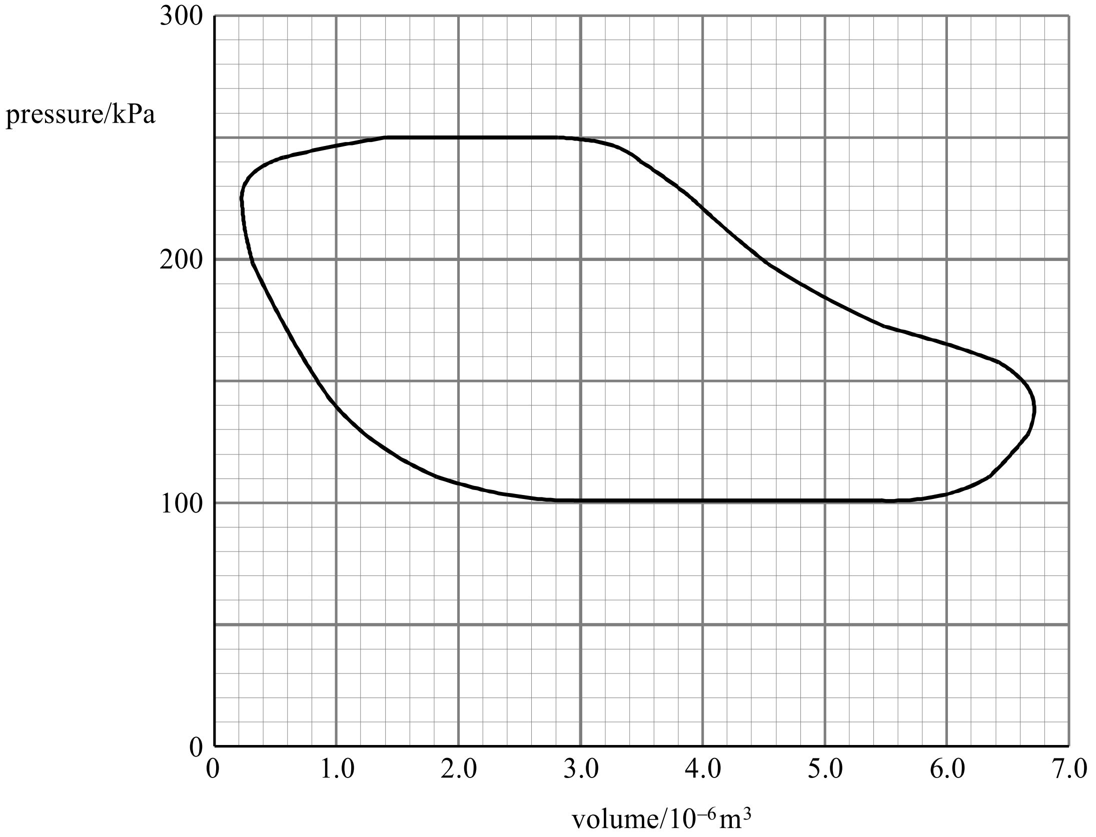
8. A small steam engine used for demonstrating energy transfers is fitted with sensors for monitoring the pressure and volume of the steam in its cylinder. The indicator diagram shows one cycle of pressure and volume changes taken when the engine was used to lift a load at a steady rate.



(a) Using information from the indicator diagram, together with the measured speed of the engine, the indicated power of the engine during the lifting operation was estimated to be 5.0 W. Show that this corresponds to an engine speed of about 450 cycles min^{-1}.

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(5)

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(b) During the lifting operation, a load of 42 N was lifted through a height of 1.2 m in a time of 12 s.

(i) Estimate the mechanical efficiency of the engine.

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(ii) Explain why the mechanical efficiency is not equal to 1.

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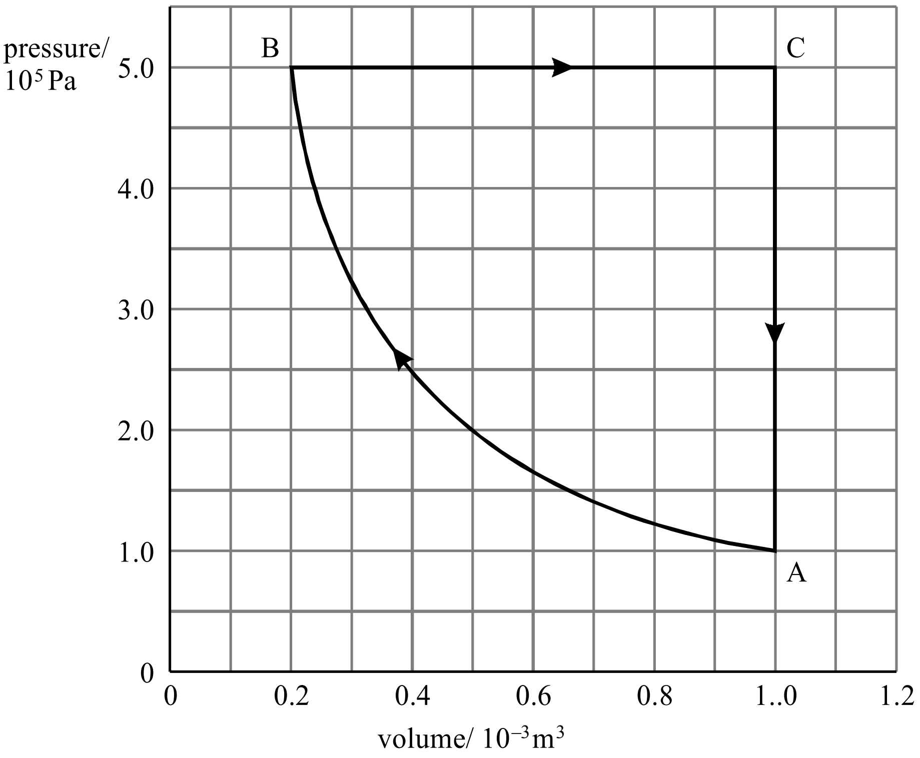
(4)
(Total 9 marks)

9. The *p V* diagram shows a cycle in which a fixed mass of an ideal gas is taken through the following processes: A ➔ B isothermal compression, B ➔ C expansion at constant pressure, C ➔ A reduction in pressure at constant volume.



(a) Show that the compression in process A → B is isothermal.

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(2)

(b) In which **two** of the three processes must heat be removed from the gas?

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(1)

(c) Calculate the work done by the gas during process B → C.

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(2)

(d) The cycle shown in the diagram involves 6.9×10^{-2} mol of gas.

(i) At which point in the cycle is the temperature of the gas greatest?

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(ii) Calculate the temperature of the gas at this point.

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(4)
(Total 9 marks)

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10. Use the following data to answer the question below.

specific latent heat of fusion of lead = 23 kJ kg^{-1}
molar mass of lead = 0.21 kg mol^{-1}

(i) Estimate the mass of a lead atom.

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(ii) Estimate the energy supplied to an atom of lead when solid lead melts.

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(iii) Calculate the speed of a lead atom with the same kinetic energy as the energy supplied in part (ii).

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(Total 5 marks)

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11. A single cylinder steam engine has an idealised indicator diagram as shown in **Figure 1**. Between **A** and **B** the cylinder is connected directly to a source of high pressure steam. Between **C** and **D** the cylinder is connected to the atmosphere.

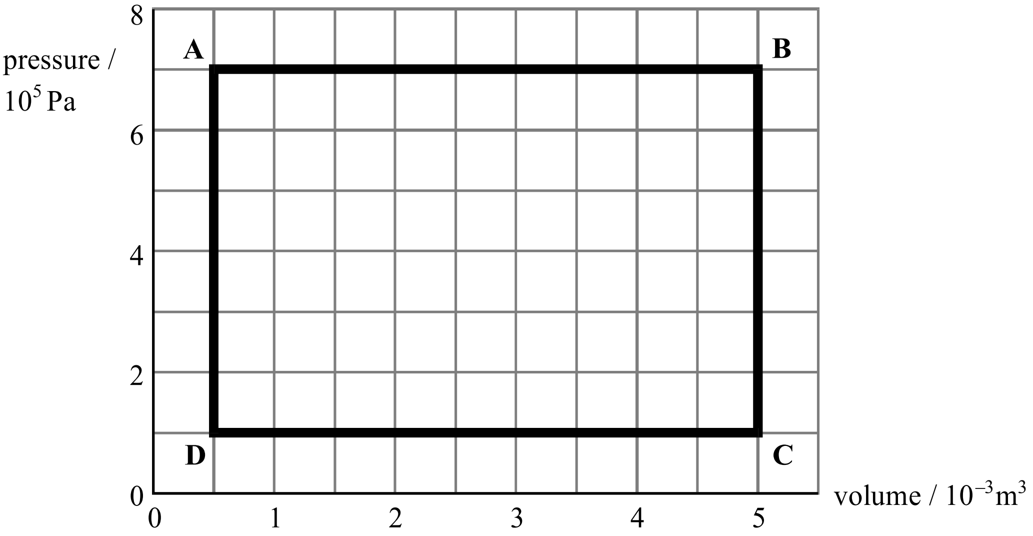

Figure 1

(a) Calculate the indicated power output of the engine when it is working at a rate such that one cycle takes 0.20 s.

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(2)

(b) In a modified version of the engine, the steam input is cut off when the piston is part way along its stroke. The new indicator diagram is shown in **Figure 2**.

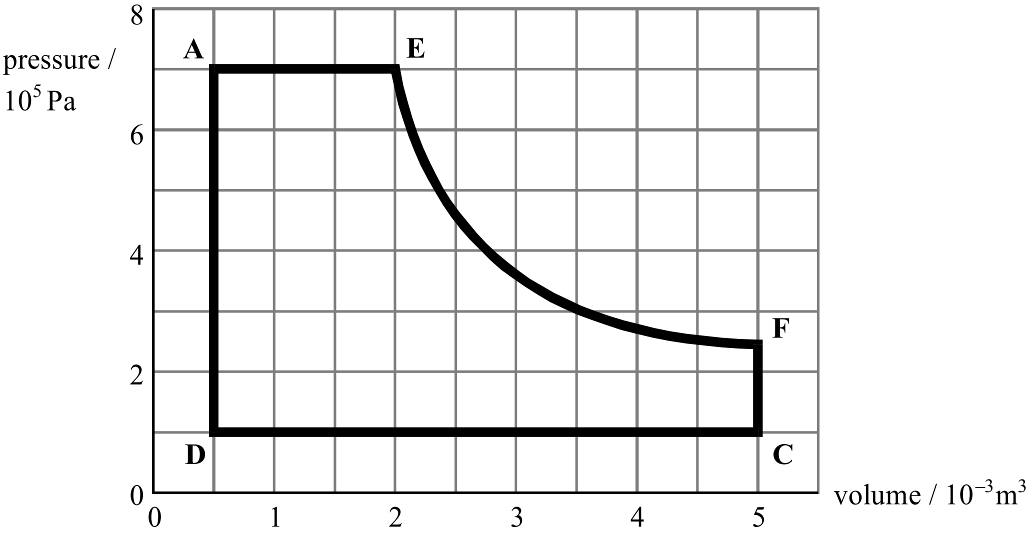

Figure 2

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Use **Figures 1** and **2** to compare the performance of an engine based on the modified cycle with that of the original engine when both engines are making the same number of cycles per second. In your comparison you should consider the steam supplied to the engines, their power outputs and their efficiencies.

You may be awarded marks for the quality of written communication in your answer.

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(4)
(Total 6 marks)

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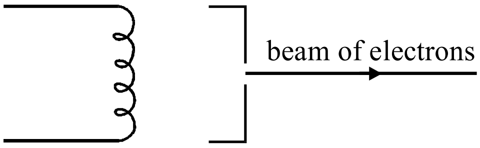
12. (a) The diagram shows a narrow beam of electrons produced by attracting electrons emitted from a filament wire to a metal plate which has a small hole in it.



(i) Why does an electric current through the filament wire cause the wire to emit electrons?

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(ii) Why must the filament wire and the metal plate be in an evacuated tube?

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(3)

(b) The voltage between the filament wire and the plate is 3600 V. For each electron emerging through the hole in the plate, calculate

(i) the kinetic energy, in J,

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(ii) the speed.

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(4)
(Total 7 marks)

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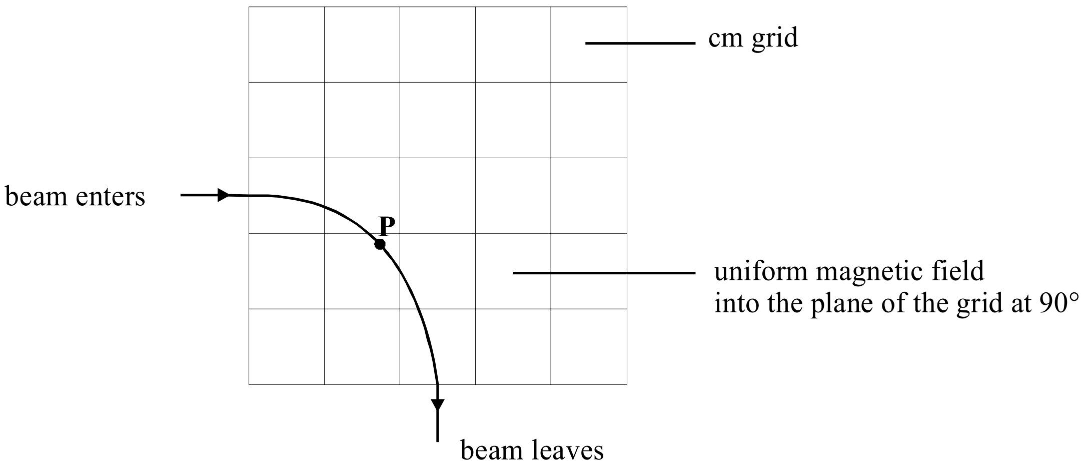
13. (a) An electron beam enters a uniform magnetic field and leaves at right angles, as shown in the diagram which is drawn to full-scale.



(i) Draw an arrow at P to show the direction of the force on an electron in the beam.

(ii) Explain why the kinetic energy of the electrons in the beam is constant.

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(3)

(b) (i) Measure the radius of curvature of the electron beam in the diagram.

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(ii) The electron beam was produced by means of an electron gun in which each electron was accelerated through a potential difference of 3.2 kV The magnetic flux density was 7.6 mT. Use these data and your measured value of the radius of curvature of the electron beam to determine the specific charge of the electron, *e/m*.

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(6)
(Total 9 marks)

14. **Figure 1** shows an electron gun that produces electrons with a kinetic energy of 6.0 × 10^{-16}J.

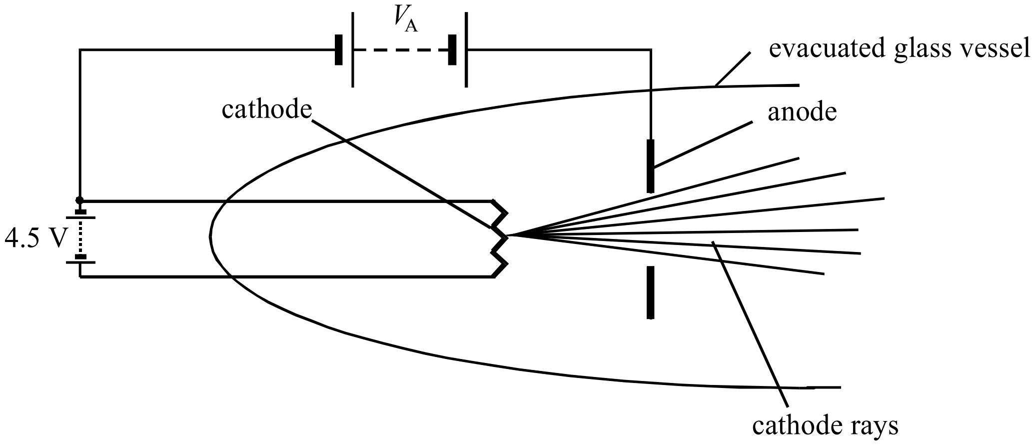

Figure 1

(a) (i) Calculate the cathode-anode potential, V_A.

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(ii) What part does the 4.5 V power supply play in producing electrons?

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(4)

(b) After leaving an electron gun, a narrow beam of electrons of speed 3.6×10^7 m s^{-1} enters a uniform electric field at right angles to the field. The electric field is due to two oppositely charged parallel plates of length 60 mm, separated by a distance of 25 mm. as shown in Figure 2. The potential difference between the plates is adjusted to 1250 V so that the beam just emerges from the field at P without touching the positive plate.

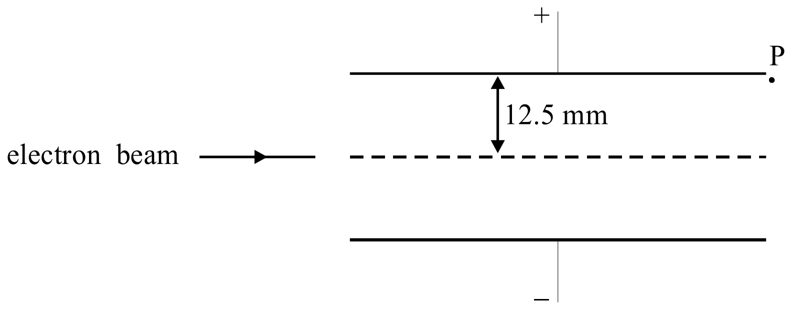

Figure 2

(i) On **Figure 2**, sketch the path of the beam in the field and beyond.

(ii) Calculate the time for which each electron is between the plates.

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(iii) Use the data above to calculate the specific charge of the electron, *e/m*

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(8)
(Total 12 marks)

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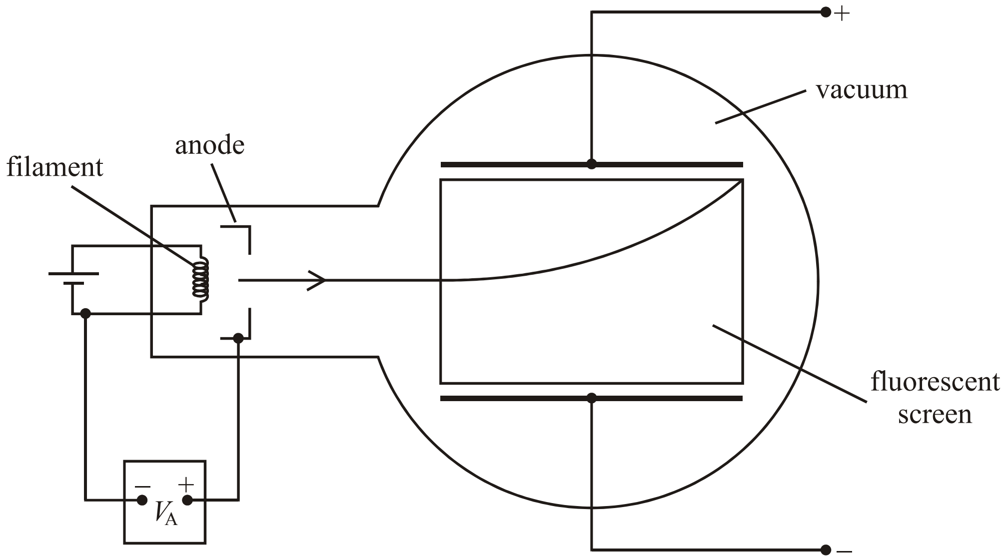
15. A narrow beam of electrons is directed into a uniform electric field created by two oppositely charged parallel horizontal plates, as shown in the figure below. The initial direction of the beam is perpendicular to the direction of the electric field. The beam makes a visible trace on a vertical fluorescent screen.



(a) Explain why the beam curves upwards at an increasing angle to the horizontal.

You may be awarded marks for the quality of written communication in your answer.

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(4)

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(b) When a uniform magnetic field of a certain flux density is applied perpendicular to the screen, the beam passes between the plates undeflected.

(i) Show that the beam is undeflected when the magnetic flux density

$B = \frac{E}{v}$, where E is the electric field strength between the plates and v is the speed of the electrons.

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(ii) Hence show that the specific charge, *e/m*, of the electron can be calculated using

$$\frac{e}{m} = \frac{E^2}{2B^2V_A}$$

where V_A is the anode voltage and B is the magnetic flux density needed for zero deflection.

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(iii) Determine the specific charge of the electron using the following data:

anode voltage = 4500 V
potential difference between the plates = 3800 V
plate separation = 50 mm
magnetic flux density = 1.9 mT

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(7)
(Total 11 marks)

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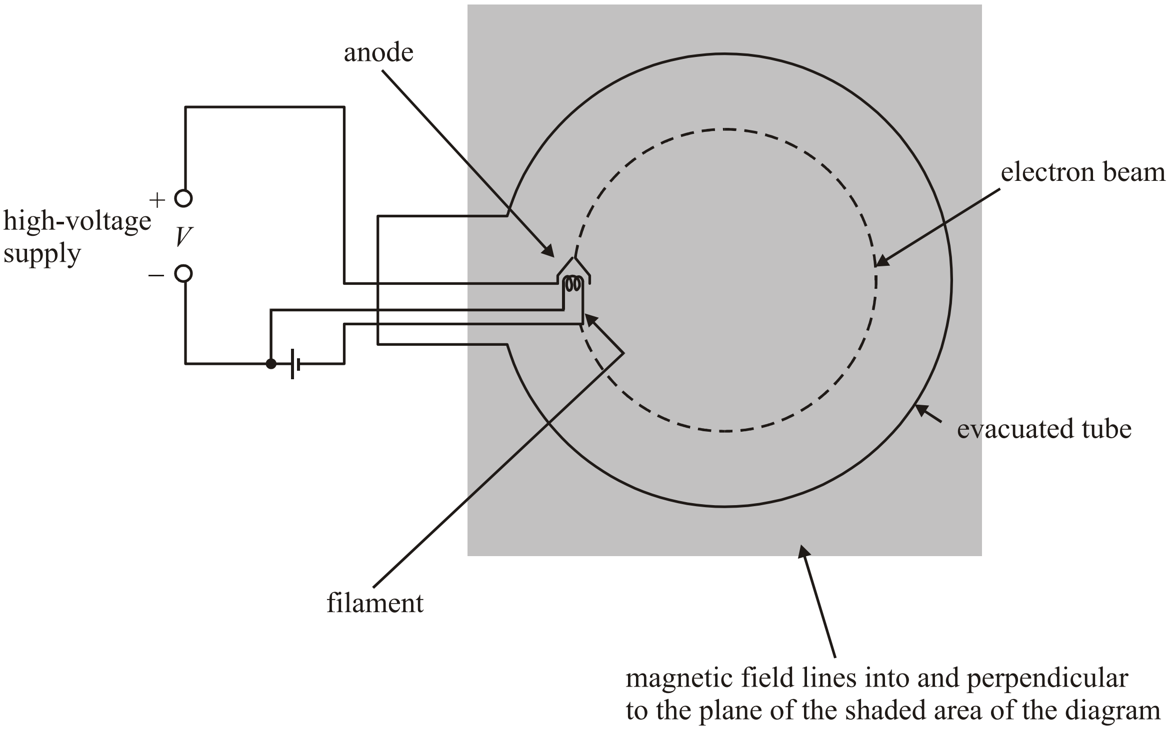
16. The figure below shows an electron gun in an evacuated tube. Electrons emitted by *thermionic emission* from the metal filament are attracted to the metal anode which is at a fixed potential, V, relative to the filament. Some of the electrons pass though a small hole in the anode to form a beam which is directed into a uniform magnetic field.



(a) (i) Explain what is meant by thermionic emission.

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(ii) Show that the speed, v, of the electrons in the beam is given by

$$v = \left(\frac{2eV}{m}\right)^{\frac{1}{2}},$$

where m is the mass of the electron and e is the charge of the electron.

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(3)

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(b) The beam of electrons travels through the field in a circular path at constant speed.

(i) Explain why the electrons travel at constant speed in the magnetic field.

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(ii) Show that the radius, *r*, of the circular path of the beam in the field is given by

$$r = \left(\frac{2mV}{B^2 e}\right)^{\frac{1}{2}}$$

where *B* is the magnetic flux density and *V* is the pd between the anode and the filament.

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(iii) The arrangement described above was used to measure the specific charge of the electron, *e/m*. Use the following data to calculate *e/m*.

$B = 3.1$ mT
$r = 25$ mm
$V = 530$ V

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(7)
(Total 10 marks)

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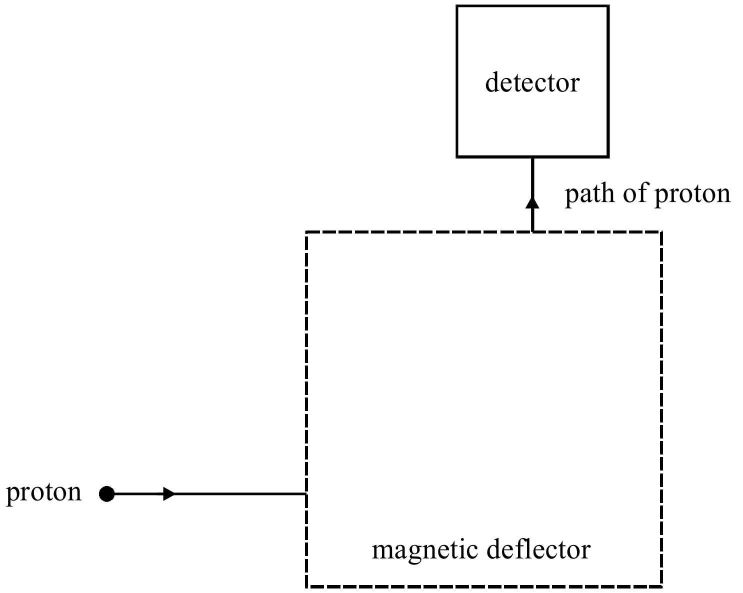
17. The diagram shows an arrangement in a vacuum to deflect protons into a detector using a magnetic field, which can be assumed to be uniform within the square shown and zero outside it.
The motion of the protons is in the plane of the paper.



(a) Sketch the path of a proton through the magnetic deflector. At any point on this path draw an arrow to represent the magnetic force on the proton. Label this arrow F.

(2)

(b) State the direction of the uniform magnetic field causing this motion.

....

(1)

(c) The speed of a proton as it enters the deflector is $5.0 \times 10^6 \text{ms}^{-1}$. If the flux density of the magnetic field is 0.50T, calculate the magnitude of the magnetic force on the proton.

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(2)

(d) If the path were that of an electron with the same velocity, what **two** changes would need to be made to the magnetic field for the electron to enter the detector along the same path?

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(2)
(Total 7 marks)

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18. (a) (i) State **two** differences between a proton and a positron.

difference 1 ....

....

difference 2 ....

....

(ii) A narrow beam of protons and positrons travelling at the same speed enters a uniform magnetic field. The path of the positrons through the field is shown in **Figure 1**.

Sketch on **Figure 1** the path you would expect the protons to take.

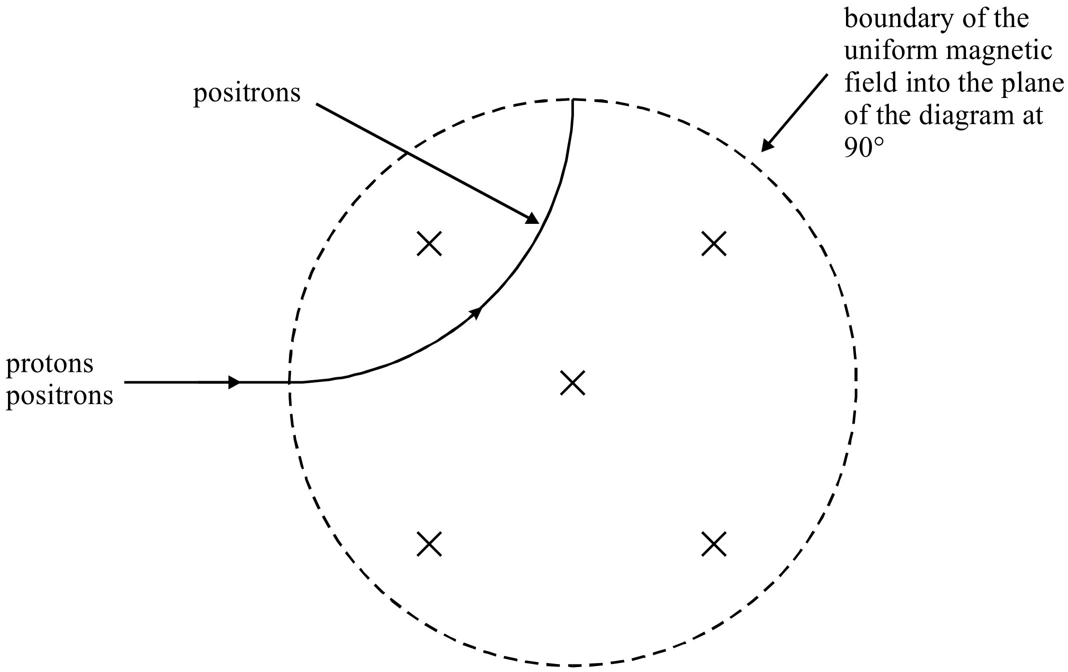

Figure 1

(iii) Explain why protons take a different path to that of the positrons.

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(5)

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(b) **Figure 2** shows five isotopes of carbon plotted on a grid in which the vertical axis represents the neutron number *N* and the horizontal axis represents the proton number Z. Two of the isotopes are stable, one is a beta minus emitter and two are positron emitters.

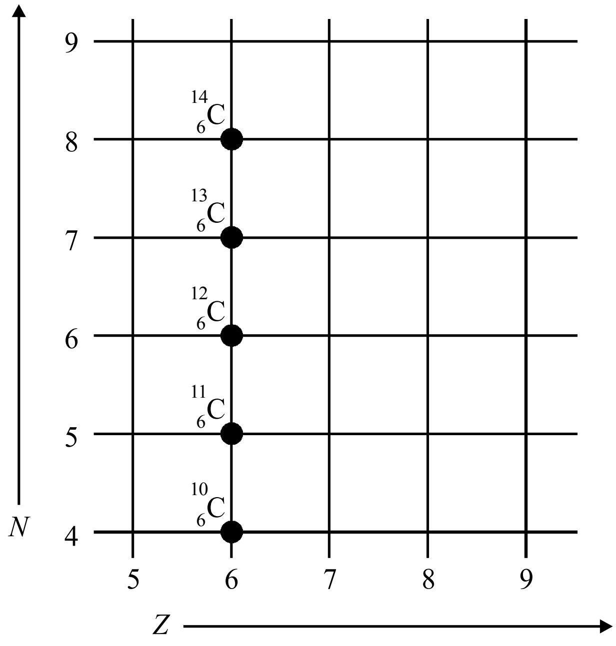

Figure 2

(i) Which isotope is a beta minus emitter?

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(ii) Which of the two positron emitters has the shorter half-life? Give a reason for your choice.

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(3)

(c) A positron with kinetic energy 2.2 MeV and an electron at rest annihilate each other.
Calculate the average energy of each of the two gamma photons produced as a result of this annihilation.

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(2)
(Total 10 marks)

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19. An electron travelling at constant speed enters a uniform electric field at right angles to the field. While the electron is in the field it accelerates in a direction which is

A in the same direction as the electric field.
B in the opposite direction to the electric field.
C in the same direction as the motion of the electron.
D in the opposite direction to the motion of the electron.

(Total 1 mark)

20. (a) One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space is invariant.

(i) Explain what is meant by this statement.

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(ii) What is the other postulate?

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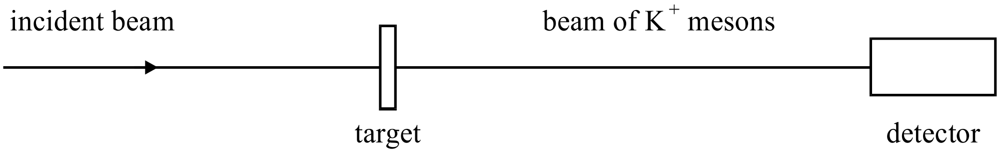
(3)

(b) K^+ mesons are sub-atomic particles of half life 86ns when at rest. In an accelerator experiment, a beam of K^+ mesons travelling at a speed of 0.95*c* is created, where c is the speed of light.



(i) Calculate the half-life of the K^+ mesons in the beam measured in the laboratory frame of reference.

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(ii) What is the greatest distance that a detector could be sited from the point of production of the K^+ mesons to detect at least 25% of the K^+ mesons produced?

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(6)
(Total 9 marks)

21. (a) In a cathode ray tube, electrons emitted from a cathode are attracted towards an anode by means of a large potential difference. If the anode-cathode potential difference is 2200 V, calculate the kinetic energy, in J, and speed of each electron just before impact at the anode.

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(2)

(b) (i) If an electron of this energy was to impinge on a fluorescent screen, calculate the shortest wavelength of the electromagnetic radiation subsequently emitted and explain why this is a minimum value.

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(ii) Calculate the de Broglie wavelength of an electron with the same energy as that hitting the screen previously.

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(7)
(Total 9 marks)

22. (a) One of the two postulates of Einstein’s theory of special relativity is that the speed of light in free space is invariant.

(i) Explain what is meant by this postulate.

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(ii) State and explain the other postulate.

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(4)

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(b) A stationary muon has a rest mass of 1.88×10^{-28} kg and a half-life of 2.2×10^{-6}s.

Calculate

(i) the mass of a muon travelling at 0.996 *c*, where *c* is the speed of light in a vacuum,

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(ii) the distance, in a laboratory frame of reference, travelled in one half-life by a muon moving at 0.996 *c*.

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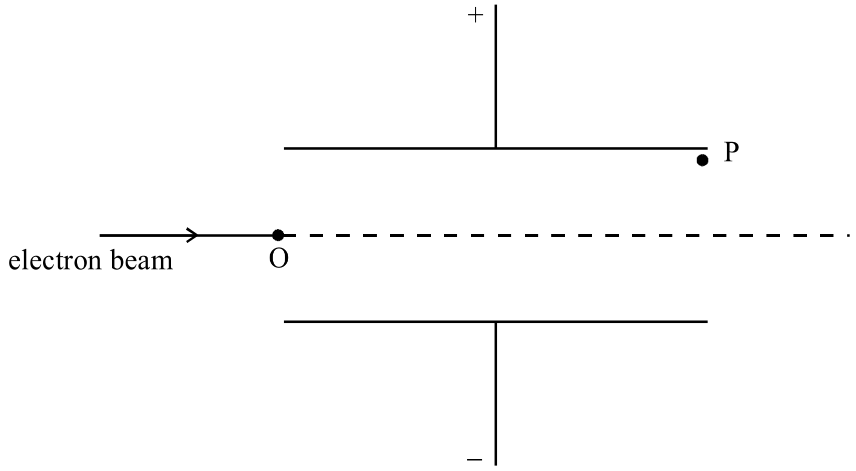
(6)
(Total 10 marks)

23. The diagram shows a narrow beam of electrons directed at right angles into a uniform electric field between two oppositely-charged parallel metal plates at a fixed potential difference.



(a) The electrons enter the field at O and leave it at P. Sketch the path of the beam from O to P and beyond P.

(2)

(b) A uniform magnetic field is applied to the beam perpendicular to the electric field and to the direction of the beam. The magnetic field reduces the deflection of the beam from its initial direction.

(i) Explain why the magnetic field has this effect on the beam.

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(ii) The magnetic flux density is adjusted until the beam passes through the two fields without deflection. Show that the speed v of the electrons when this occurs is given by

$$v = \frac{E}{B}$$

where E is the electric field strength and B is the magnetic flux density.

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(5)

(c) In an experiment to measure the specific charge of the electron, electrons were accelerated from rest through a potential difference of 2900 V to a speed of 3.2×10^7 m s^{-1}. Use this information to calculate the specific charge of the electron.

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(3)

(Total 10 marks)

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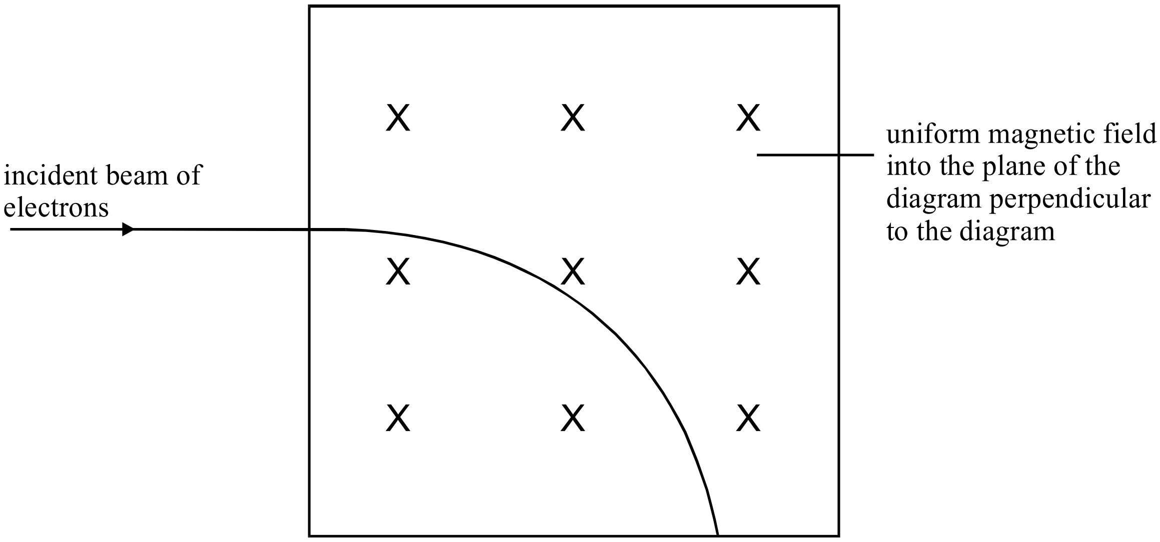
24. A narrow beam of electrons at a speed of 3.2×10^7 m s^{-1} travels along a circular path in a uniform magnetic field of flux density, B, as shown in the diagram.



(a) Explain why the path of the beam in the field is circular.

You may be awarded marks for the quality of written communication in your answer.

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(3)

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(b) (i) Show that the speed, v, of the electrons in the field is given by

$$v = \frac{Ber}{m},$$

where r is the radius of the circular path of the beam in the field.

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(ii) When the flux density was 7.3 mT, the radius of the circular path of the beam in the field was 25 mm. Use the data to calculate the specific charge of the electron.

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(5)
(Total 8 marks)

25. (a) In a science fiction film, a space rocket travels away from the Earth at a speed of 0.994 *c*, where *c* is the speed of light in free space. A radio message of duration
800 s is transmitted by the space rocket.

(i) Calculate the duration of the message when it is received at the Earth.

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(ii) Calculate the distance moved by the rocket in the Earth's frame of reference in the time taken to send the message.

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(4)

(b) A student claims that a twin who travels at a speed close to the speed of light from Earth to a distant star and back would, on return to Earth, be a different age to the twin who stayed on Earth. Discuss whether or not this claim is correct.

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(3)
(Total 7 marks)

26. What is the mass difference of the nucleus ${}^{7}_{3}\text{Li}$?

Use the following data:
mass of a proton = 1.00728 u
mass of a neutron = 1.00867 u
mass of a ${}^{7}_{3}\text{Li}$ nucleus = 7.01436 u

A 0.03912 u

B 0.04051 u

C 0.04077 u

D 0.04216 u

(Total 1 mark)

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27. Nuclei of $^{218}_{84}\text{Po}$ decay by the emission of an α particle to form a stable isotope of an element X. You may assume that no γ emission accompanies the decay.

(a) (i) State the proton number and the nucleon number of X.

proton number ....

nucleon number ....

(ii) Identify the element X.

....

(2)

(b) Each decaying nucleus of Po releases 8.6×10^{-13} J of energy.

(i) State the form in which this energy *initially* appears.

....

(ii) Using **only** the information provided in the question, calculate the difference in mass between the original $^{218}_{84}\text{Po}$ atom and the combined mass of an atom of X and an α particle.

speed of light in vacuum = $3.0 \times 10^{8}\,\text{ms}^{-1}$

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(3)
(Total 5 marks)

28. (a) Nuclear fission can occur when a neutron is absorbed by a nucleus of uranium-235. An incomplete equation for a typical fission reaction is given below.

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{141}_{56}\text{Ba} + \text{X} + 3\,{}^{1}_{0}\text{n}$$

(i) State the nuclear composition of X.

proton number ....

neutron number ....

(ii) Name the element of which X is an isotope.

....

(3)

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(b) In a small nuclear power plant one fifth of the fission energy is converted into a useful output power of 10 MW. If the average energy released per fission is 3.2×10^{-11} J, calculate the number of uranium-235 nuclei which will undergo fission per day.

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(3)
(Total 6 marks)

29. A student attempted to determine the *half-life* of a radioactive substance, which emits α particles, by placing it near a suitable counter. He recorded *C,* the number of counts in 30 s, at various times, *t,* after the start of the experiment.

The results given in the table were obtained.

t/minute	0	10	20	30	40	50	60
number of counts in 30s, *C*	60	42	35	23	18	14	10
In *C*							

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

....

....

(1)

(b) Complete the table.

(1)

(c) On the grid on the next page

(i) plot ln C against *t,*

(ii) draw the best straight line through your points,

(iii) determine the gradient of your graph.

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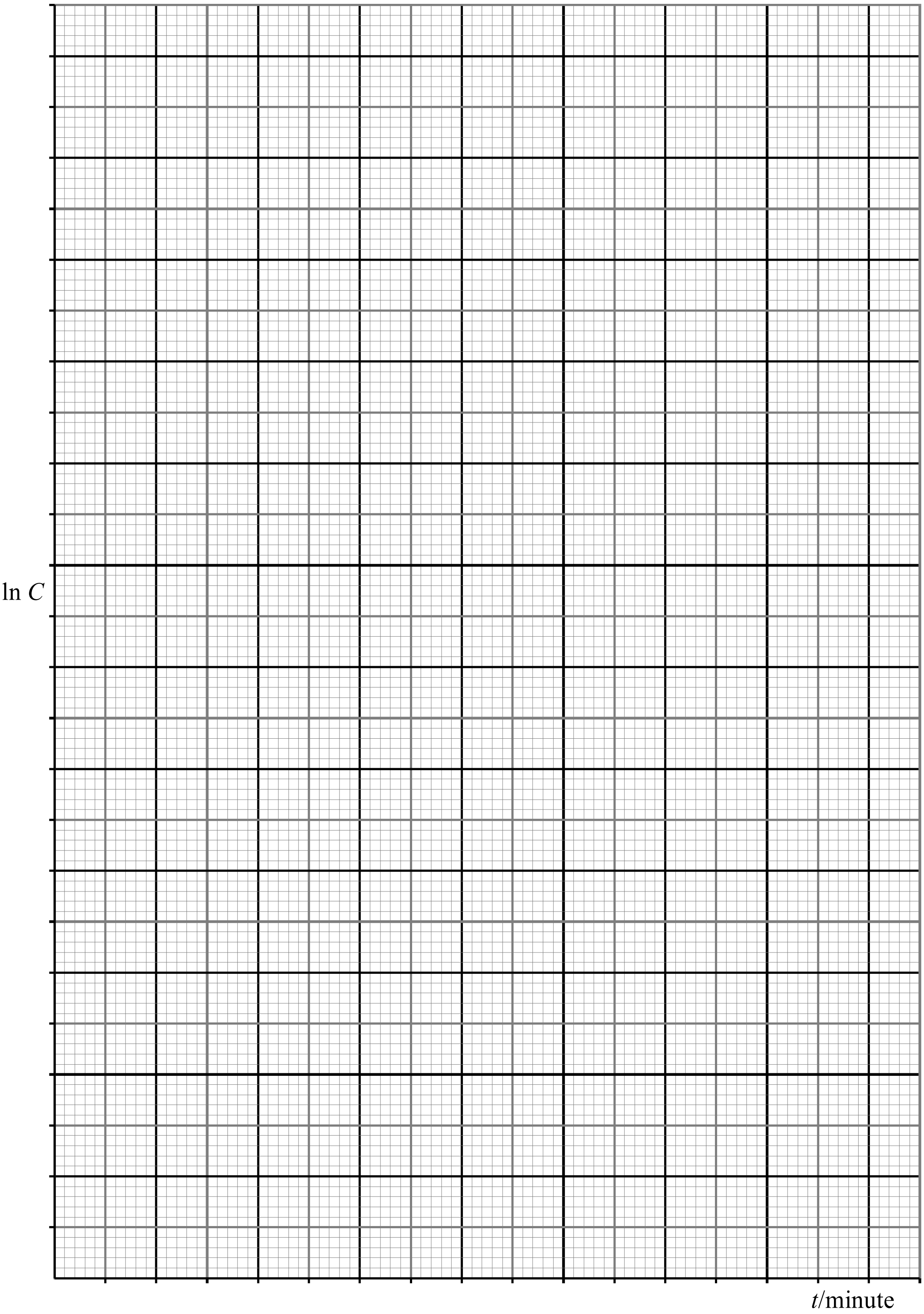

(5)

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(d) (i) Show that the decay constant of the substance is equal to the magnitude of the gradient of your graph.

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(ii) Calculate the half-life of the substance.

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(3)

(e) This particular experiment is likely to lead to an inaccurate value for the half-life. Suggest **two** ways in which the accuracy of the experiment could be improved.

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(2)

(f) The age of a piece of bone recovered from an archaeological site may be estimated by ^{14}C dating. All living organisms absorb ^{14}C but there is no further intake after death. The proportion of ^{14}C is constant in living organisms.

A 1 g sample of bone from an archaeological site has an average rate of decay of 5.2 Bq due to ^{14}C. A 1 g sample of bone from a modern skeleton has a rate of decay of 6.5 Bq.
The counts are corrected for background radiation.

Calculate the age, in years, of the archaeological samples of bone.

half life of ^{14}C = 5730 years

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(4)
(Total 16 marks)

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30. (a) Ancient rocks can be dated by measuring the proportion of trapped argon gas to the radioactive isotope potassium –40. Potassium –40 produces argon as a result of electron capture. The gas is trapped in the molten rock when the rock solidifies.

(i) Write down an equation to represent the process of electron capture by a potassium nucleus.

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(ii) The atomic masses of potassium –40 and argon –40 are 39.96401 u and 39.96238 u, respectively. Calculate the energy released, in MeV, when the process given in part (a)(i) occurs.

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(iii) An argon atom formed in this way subsequently releases an X-ray photon. Explain how this occurs.

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(5)

(b) Potassium –40 also decays by beta emission to form calcium –40.

(i) Write down an equation to represent this beta decay.

....

(ii) This process is eight times more probable than electron capture. A rock sample is found to contain 1 atom of argon –40 for every 5 atoms of potassium –40. The half-life of potassium –40 is 1250 million years. Calculate the age of this rock.

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(4)
(Total 9 marks)

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31. (a) State which type of radiation, α, β or γ,

(i) produces the greatest number of ion pairs per mm in air,

....

(ii) could be used to test for cracks in metal pipes.

....

....

(2)

(b) Specific radioisotope sources are chosen for tracing the passage of particular substances through the human body.

(i) Why is a γ emitting source commonly used?

....

....

(ii) State why the source should **not** have a very short half-life.

....

....

(iii) State why the source should **not** have a very long half-life.

....

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(3)

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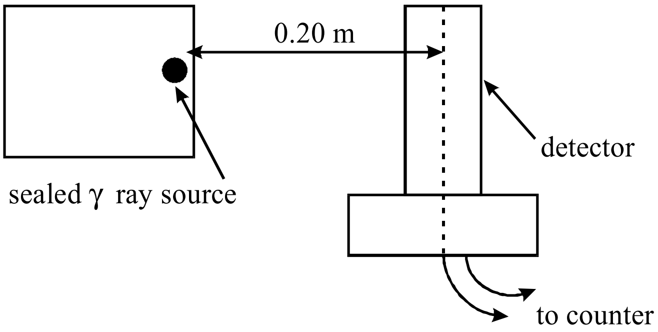
(c) A detector, placed 0.20 m from a sealed γ ray source, receives a mean count rate of 2550 counts per minute. The experimental arrangement is shown in the diagram below. The mean background radiation is measured as 50 counts per minute.



Calculate the least distance between the source and the detector if the count rate is not to exceed 6000 counts per minute.

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(5)
(Total 10 marks)

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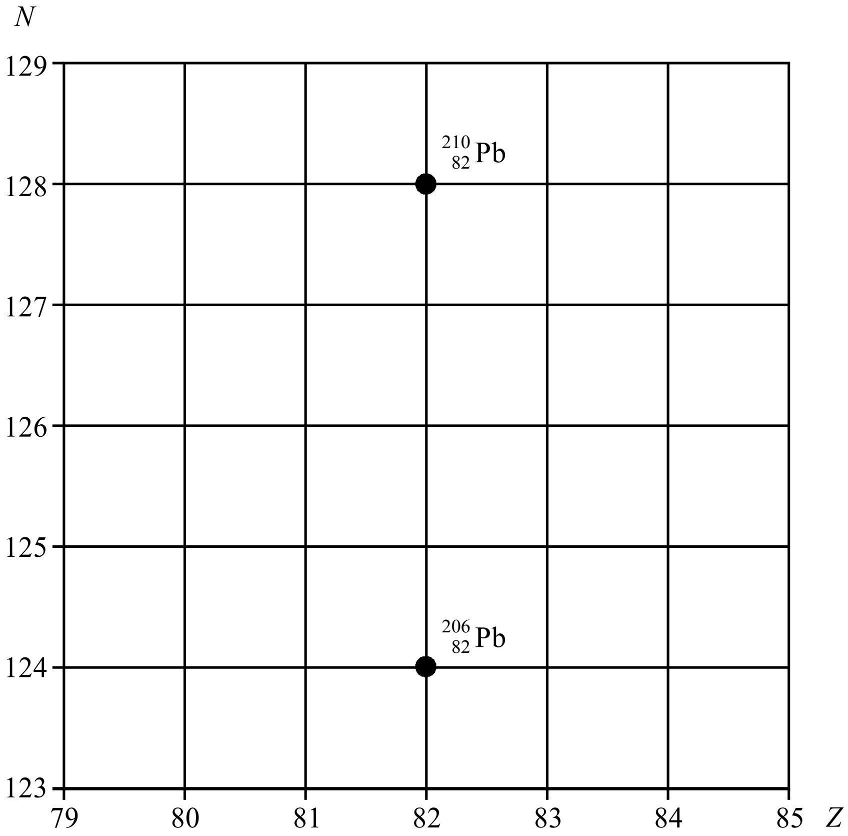
32. (a) The lead nuclide $^{210}_{82}$Pb is unstable and decays in three stages through α and β emissions to a different lead nuclide $^{206}_{82}$Pb. The position of these lead nuclides on a grid of neutron number, N, against proton number, Z, is shown below.



On the grid draw **three** arrows to represent one possible decay route.
Label each arrow with the decay taking place.

(3)

(b) The copper nuclide $^{64}_{29}$Cu may decay by positron emission or by electron capture to form a nickel (Ni) nuclide.
Complete the two equations that represent these two possible modes of decay.

positron emission $^{64}_{29}$Cu

electron capture $^{64}_{29}$Cu

(4)

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(c) The nucleus of an atom may be investigated by scattering experiments in which radiation or particles bombard the nucleus.

Name **one** type of radiation or particle that may be used in this investigation and describe the main physical principle of the scattering process.

State the information which can be obtained from the results of this scattering.

You may be awarded marks for the quality of written communication in your answer.

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(3)
(Total 10 marks)

33. (a) Suggest **two** reasons why an α particle causes more ionisation than a β particle of the same initial kinetic energy.

You may be awarded marks for the quality of written communication in your answer.

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(2)

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(b) A radioactive source has an activity of 3.2×10^9 Bq and emits α particles, each with kinetic energy of 5.2 Me V. The source is enclosed in a small aluminium container of mass 2.0×10^{-4} kg which absorbs the radiation completely.

(i) Calculate the energy, in J, absorbed from the source each second by the aluminium container.

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(ii) Estimate the temperature rise of the aluminium container in **1 minute**, assuming no energy is lost from the aluminium.

specific heat capacity of aluminium = 900 J kg^{-1} K^{-1}

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(5)

(Total 7 marks)

34. A charged capacitor of capacitance 50 μF is connected across the terminals of a voltmeter of resistance 200 kΩ. When time $t = 0$, the reading on the voltmeter is 20.0 V.

Calculate

(a) the charge on the capacitor at $t = 0$,

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....

(1)

(b) the reading on the voltmeter at $t = 20$s,

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(2)

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(c) the time which must elapse, from $t = 0$, before 75% of the energy which was stored in the capacitor at $t = 0$ has been dissipated.

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(3)
(Total 6 marks)

35. A camera flashgun uses the discharge of a capacitor to provide the energy to produce a single flash. In a particular flashgun a 4700 µF capacitor is initially charged from a 90V supply.

(a) Calculate

(i) the charge stored by the capacitor when it is fully charged,

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(ii) the energy stored by the fully-charged capacitor,

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(iii) the average current which flows if total discharge of the capacitor takes place effectively in 30ms.

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(3)

(b) During a partial discharge of the capacitor the potential difference between its terminals falls from 90V to 80V. Calculate the energy discharged to the flashgun.

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(2)
(Total 5 marks)

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36. (a) For a capacitor of capacitance C, sketch graphs of charge, *Q,* and energy stored, *E,* against potential difference, *V*.

graph A

graph B

What is represented by the slope of graph A?

....

(3)

(b) A capacitor of capacitance 0.68 F is charged to 6.0 V. Calculate

(i) the charge stored by the capacitor,

....

....

(ii) the energy stored by the capacitor.

....

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(2)
(Total 5 marks)

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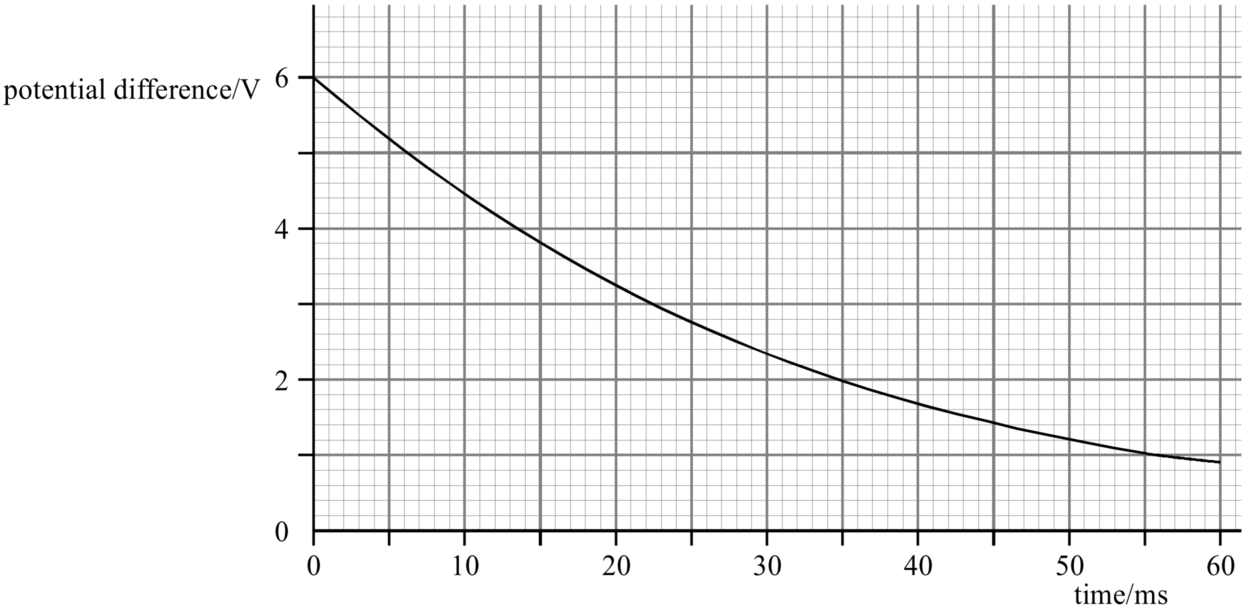
37. A student used a voltage sensor connected to a datalogger to plot the discharge curve for a 4.7 μF capacitor. She obtained the following graph.



Use data from the graph to calculate

(a) the initial charge stored,

....

(2)

(b) the energy stored when the capacitor had been discharging for 35 ms,

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(3)

(c) the time constant for the circuit,

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(3)

(d) the resistance of the circuit through which the capacitor was discharging.

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(2)
(Total 10 marks)

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38. A capacitor of capacitance 330 μF is charged to a potential difference of 9.0 V. It is then discharged through a resistor of resistance 470 kΩ.

Calculate

(a) the energy stored by the capacitor when it is fully charged,

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(2)

(b) the time constant of the discharging circuit,

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(1)

(c) the pd across the capacitor 60 s after the discharge has begun.

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(3)

(Total 6 marks)

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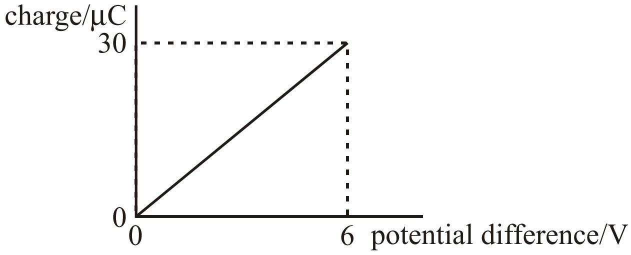
39. The graph shows how the charge stored by a capacitor varies with the potential difference across it as it is charged from a 6 V battery.



Which one of the following statements is **not** correct?

A The capacitance of the capacitor is 5.0 μF.

B When the potential difference is 2 V the charge stored is 10 μC.

C When the potential difference is 2 V the energy stored is 10 μJ.

D When the potential difference is 6 V the energy stored is 180 μJ.

(Total 1 mark)

40. A capacitor of capacitance *C* discharges through a resistor of resistance *R*. Which one of the following statements is **not** true?

A The time constant will increase if *R* is increased.

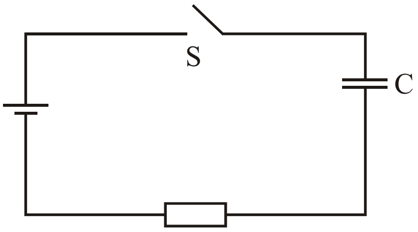
B The time constant will decrease if *C* increased.

C After charging to the same voltage, the initial discharge current will increase if *R* is decreased.

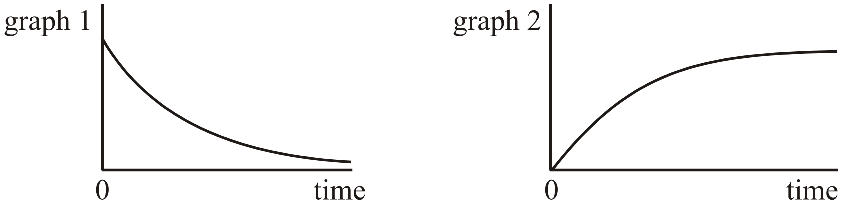
D After charging to the same voltage, the initial discharge current will be unaffected if *C* is increased.

(Total 1 mark)

41. In the circuit shown, the capacitor C is charged to a potential difference *V* when the switch S is closed.



Which line, **A** to **D**, in the table gives a correct pair of graphs showing how the charge and current change with time after S is closed?



	charge	**current**
A	graph 1	graph 1
B	graph 1	graph 2
C	graph 2	graph 2
D	graph 2	graph 1

(Total 1 mark)

42. A 1000 μF capacitor and a 10 μF capacitor are charged so that the potential difference across each of them is the same. The charge stored in the 1000 μF capacitor is Q_1 and the charge stored in the 10 μF capacitor is Q_2.

What is the ratio $\frac{Q_1}{Q_2}$?

A 100
B 10
C 1
D $\frac{1}{100}$

(Total 1 mark)

43. A 680 μF capacitor is charged fully from a 12 V battery. At time $t = 0$ the capacitor begins to discharge through a resistor. When $t = 25$ s the energy remaining in the capacitor is one quarter of the energy it stored at 12 V.

(a) Determine the pd across the capacitor when $t = 25$s.

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(2)

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(b) (i) Show that the time constant of the discharge circuit is 36 s.

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(ii) Calculate the resistance of the resistor.

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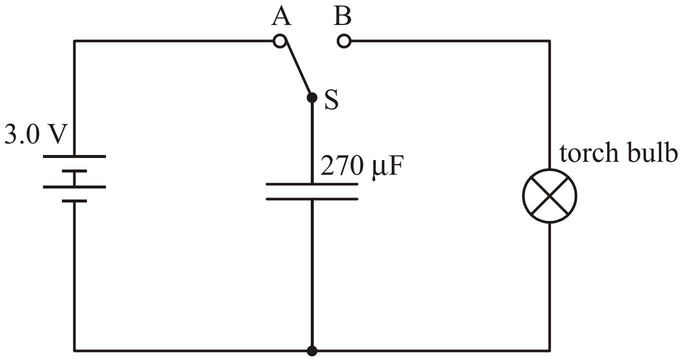
(4)
(Total 6 marks)

44. A torch bulb produces a flash of light when a 270 μF capacitor is discharged across it.



(a) The capacitor is charged to a pd of 3.0 V from the battery, as shown in the figure above.

Calculate

(i) the energy stored in the capacitor,

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....

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(ii) the work done by the battery.

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(3)

(b) The capacitor is discharged by moving switch S in the figure above from A to B. The discharge circuit has a total resistance of 1.5 Ω.

(i) Show that almost all of the energy stored in the capacitor is released when the capacitor pd has decreased from 3.0 V to 0.3 V.

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(ii) Emission of light from the torch bulb ceases when the pd falls below 2.0 V. Calculate the duration of the light flash.

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(iii) Assuming that the torch bulb produces photons of average wavelength 500 nm, estimate the number of photons released during the light flash.

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(8)
(Total 11 marks)

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45. What is the mass difference of the nucleus ${}^{7}_{3}\mathrm{Li}$?

Use the following data:
mass of a proton = 1.00728 u
mass of a neutron = 1.00867 u
mass of a ${}^{7}_{3}\mathrm{Li}$ nucleus = 7.01436 u

A 0.03912 u

B 0.04051 u

C 0.04077 u

D 0.04216 u

(total 1 mark)

46. (a) (i) Explain what is meant by the term *binding energy* for a nucleus.

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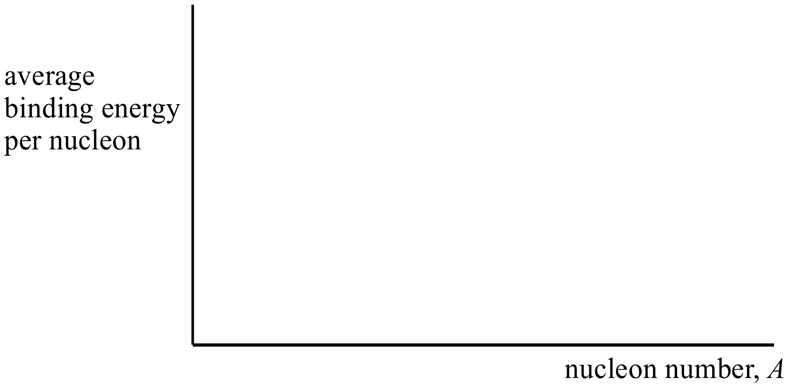
(ii) Sketch on the axes a graph of the average binding energy per nucleon against nucleon number *A*, giving approximate values of the scale on each axis.



(5)

(b) Use your graph to explain why energy is released when a neutron collides with a ${}^{235}_{92}\mathrm{U}$ nucleus causing fission.

(2)

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(c) Neutrons are released when nuclear fission occurs in $^{235}_{92}\text{U}$. Some of these neutrons induce further fission, others are absorbed without further fission and others escape from the surface of the material. The average number of neutrons released per fission is 2.5, of which at least one must produce further fission if a chain reaction is to be sustained.

Explain how a chain reaction can occur only if the piece of uranium has a certain minimum mass (the *critical mass*).

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(3)
(Total 10 marks)

47. Natural uranium consists of 99.3% $^{238}_{92}\text{U}$ and 0.7% $^{235}_{92}\text{U}$. In many nuclear reactors, the fuel consists of enriched uranium enclosed in sealed metal containers.

(a) (i) Explain what is meant by *enriched uranium.*

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(ii) Why is enriched uranium rather than natural uranium used in many nuclear reactors?

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(2)

(b) (i) By considering the neutrons involved in the fission process, explain how the rate of production of heat in a nuclear reactor is controlled.

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(ii) Explain why all the fuel in a nuclear reactor is **not** placed in a single fuel rod.

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(5)
(Total 7 marks)

48. (a) Nuclear fission can occur when a neutron is absorbed by a nucleus of uranium-235. An incomplete equation for a typical fission reaction is given below.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + \text{X} + 3\,^{1}_{0}\text{n}$$

(i) State the nuclear composition of X.

proton number ....

neutron number ....

(ii) Name the element of which X is an isotope.

....

(3)

(b) In a small nuclear power plant one fifth of the fission energy is converted into a useful output power of 10 MW. If the average energy released per fission is 3.2×10^{-11} J, calculate the number of uranium-235 nuclei which will undergo fission per day.

....

....

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(3)
(Total 6 marks)

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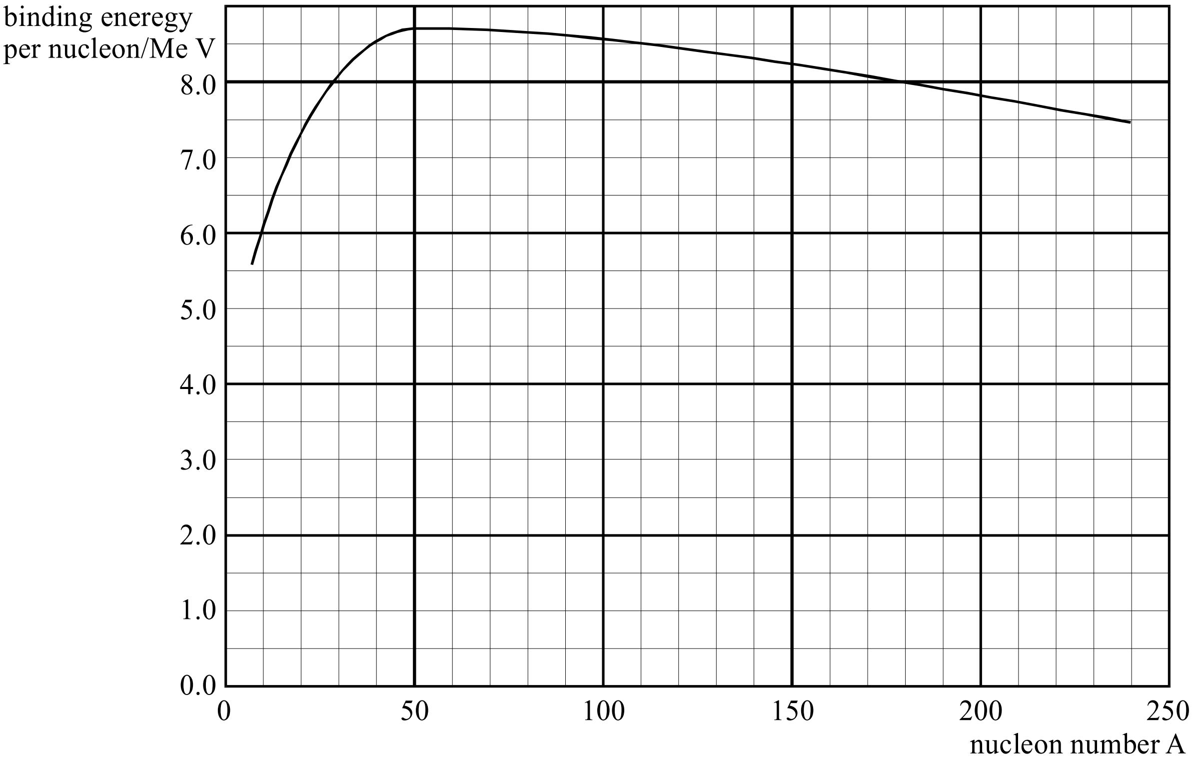
49. (a) (i) Complete the equation below which represents the induced fission of a nucleus of uranium ${}^{235}_{92}\mathrm{U}$.

$${}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{98}_{38}\mathrm{Sr} + {}_{54}\mathrm{Xe} + {}^{1}_{0}\mathrm{n}$$

(ii) The graph shows the binding energy per nucleon plotted against nucleon number A.

Mark on the graph the position of each of the three nuclei in the equation.



(iii) Hence determine the energy released in the fission process represented by the equation.

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(6)

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(b) (i) Use your answer to part (a)(iii) to estimate the energy released when 1.0 kg of uranium, containing 3% by mass of ${}^{235}_{92}\text{U}$, undergoes fission.

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(ii) Oil releases approximately 50 MJ of heat per kg when it is burned in air. State and explain **one** advantage and **one** disadvantage of using nuclear fuel to produce electricity.

advantage ....

....

....

....

disadvantage ....

....

....

....

(6)
(Total 12 marks)

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50. A space probe contains a small fission reactor, fuelled by plutonium, which is designed to produce an average of 300W of useful power for 100 years. If the overall efficiency of the reactor is 10%, calculate the minimum mass of plutonium required.

energy released by the fission of one nucleus of $^{239}_{94}\text{Pu} = 3.2 \times 10^{-11}$ J

the Avogadro constant = 6.0×10^{23} mol^{-1}

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(Total 7 marks)

51. (a) Explain what is meant by the *binding energy* of a nucleus.

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(2)

(b) Using data from the Data booklet, calculate the binding energy. in MeV, of a nucleus of ^{5}Li.

....

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(5)
(Total 7 marks)

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52. (a) With reference to the process of nuclear fusion, explain why energy is released when two small nuclei join together, and why it is difficult to make two nuclei come together

You may be awarded marks for the quality of written communication in your answer.

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(3)

(b) A fusion reaction takes place when two deuterium nuclei join, as represented by

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n}$$

mass of ^{2}H nucleus = 2.01355 u
mass of ^{3}He nucleus = 3.01493 u
mass of neutron = 1.00867 u

Calculate

(i) the mass difference produced when two deuterium nuclei undergo fusion,

....

....

....

....

(ii) the energy released, in J, when this reaction takes place.

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....

(3)
(Total 6 marks)

53. What is the binding energy of the nucleus $^{238}_{92}\text{U}$?

Use the following data:

mass of a proton = 1.00728 u
mass of a neutron = 1.00867 u
mass of a $^{238}_{92}\text{U}$ nucleus = 238.05076 u
1 u = 931.3 MeV

- **A** 1685 MeV
- **B** 1732 MeV
- **C** 1755 MeV
- **D** 1802 MeV

(Total 1 mark)

54. A deuterium nucleus and a tritium nucleus fuse together to form a helium nucleus, releasing a particle X in the process, according to the equation

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + \text{X}\ .$$

Which one of the following correctly identifies X?

- **A** electron
- **B** neutron
- **C** positron
- **D** proton

(Total 1 mark)

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55. The mass of the beryllium nucleus, ${}^{7}_{4}\mathrm{Be}$, is 7.01473 u. What is the binding energy **per nucleon** of this nucleus?

Use the following data:

mass of proton = 1.00728 u
mass of neutron = 1.00867 u
1u = 931.3 MeV

A 1.6 MeV nucleon^{-1}

B 5.4 MeV nucleon^{-1}

C 9.4 MeV nucleon^{-1}

D 12.5 MeV nucleon^{-1}

(Total 1 mark)

56. (a) The mass of a nucleus ${}^{A}_{Z}\mathrm{X}$ is M.

(i) If the mass of a proton is m_p, and the mass of a neutron is m_n, give an expression for the mass difference Δm of this nucleus.

Δm = ...

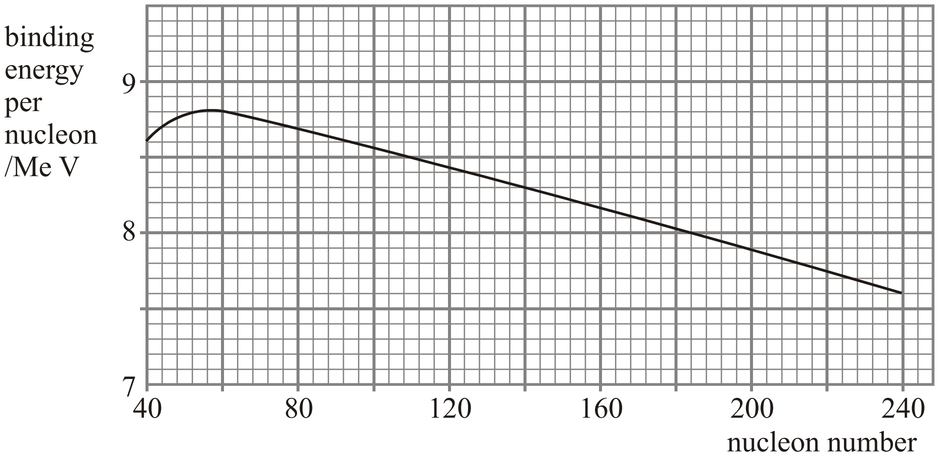
(ii) Give an expression for the binding energy per nucleon of this nucleus, taking the speed of light to be c.

....

....

(2)

(b) The figure below shows an enlarged portion of a graph indicating how the binding energy per nucleon of various nuclides varies with their nucleon number.



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(i) State the value of the nucleon number for the nuclides that are most likely to be stable. Give your reasoning.

....

....

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....

(ii) When fission of uranium 235 takes place, the nucleus splits into two roughly equal parts and approximately 200 Me V of energy is released. Use information from the figure above to justify this figure, explaining how you arrive at your answer.

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(5)
(Total 7 marks)

57. In the reaction shown, a proton and a deuterium nucleus, $^{2}_{1}$H, fuse together to form a helium nucleus, $^{3}_{2}$He

$$^{1}_{1}\mathrm{p} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + \mathrm{Q}$$

What is the value of Q, the energy released in this reaction?

mass of a proton = 1.00728 u
mass of a $^{2}_{1}$H nucleus = 2.01355 u
mass of a $^{3}_{2}$He nucleus = 3.01493 u

A 5.0 MeV
B 5.5 MeV
C 6.0 MeV
D 6.5 MeV

(Total 1 mark)

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58. (a) When a nucleus of uranium -235 fissions into barium -141 and krypton -92, the change in mass is 3.1×10^{-28} kg. Calculate how many nuclei must undergo fission in order to release 1.0 J of energy by this reaction.

....

....

....

....

....

(2)

(b) A nuclear power station produces an electrical output power of 600 MW. If the overall efficiency of the station is 35%, calculate the decrease in the mass of the fuel rods, because of the release of energy, during one week of continuous operation.

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(4)

(Total 6 marks)

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Teacher Resource Bank

GCE Physics B: Physics in Context

Additional Sample Questions (Specification A)

Mark Scheme

PHYB5 – Energy Under the Microscope

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Dr Michael Cresswell, Director General.

1. (a) (i) B,C **(1)**

(ii) B, C **(1)** 2

(b) $pV = nRT$ **(1)**
pair of values taken from graph on curve A **(1)**
$n = 0.02$ (mol) **(1)** 3

(c) $pV = nRT$ with $n = 0.02$ and pair of values taken from curve C
[or $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ with $T_1 = 300$ K and pairs of values taken from curve A (p_1, V_1) and curve C (p_2, V_2)] **(1)**
correct substitution gives 600K (±40K) **(1)** 2

(d) work done is area enclosed by indicator diagram loop **(1)**
satisfactory graphical method used to estimate area **(1)**
scaling factor correctly used (gives $W = 70$J) **(1)** 3

[10]

2. (a) (i) ΔQ (heat) **added** (**to** gas) **(1)**
ΔU **increase** in internal energy (of gas) **(1)**
ΔW work done **by** gas **(1)**

(ii) temperature is constant (in isothermal expansion) **(1)**
absolute temperature depends upon internal energy **(1)**
hence $\Delta U = 0$ **(1)** max 5

(b) (i) isothermal line C shown correctly **(1)**
constant volume line D shown correctly **(1)**

(ii)

process	ΔQ / J	ΔU / J	ΔW / J
A	**–83**	0	–83
B	+200	+200	**0**
C	**+139**	**0**	+139
D	**–200**	**–200**	0
whole cycle	**+56**	**0**	**+56**

max 5

(iii) max possible efficiency $\left(= \frac{T_H - T_C}{T_H}\right) = \frac{500 - 300}{500} = 0.4$ (or 40%) **(1)**

actual efficiency of ideal cycle = $\frac{\text{work output per cycle}}{\text{heat input at high temperature}} = \frac{56}{139}$

(= 0.4 or 40%) **(1)** 9

[14]

3. (a) ΔQ is heat supplied <u>to</u> the gas **(1)**

ΔW is work done <u>by</u> the gas **(1)**

ΔU is <u>increase</u> in internal energy **(1)** 3

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(b) (i) $\Delta Q = 100\text{J}$ **(1)**

(ii) $\Delta W(= p\Delta V) = (1.5 \times 10^5) \times (20 \times 10^{-6}) = 3.0\text{J}$ **(1)**

(iii) $\Delta U = 100 - 3 = 97\text{J}$ **(1)** 3

(c) (i) $\Delta Q = 100\text{J}$**(1)**

(ii) $\Delta W = 0$

(iii) $\Delta U = 100\text{J}$ (i), (ii), (iii) all correct **(1)** 1

[7]

4. (a) (i) $\eta = \dfrac{T_\text{H} - T_\text{C}}{T_\text{H}}$ **(1)** $\dfrac{1103 - 290}{1103} = 0.74$ or 74% **(1)**

(ii) $\eta\left(= \dfrac{P_\text{out}}{P_\text{in}}\right)$ **(1)** $= \dfrac{1.5}{78}$ = 0.019 or 0.02 (1.9% or2%) **(1)** 4

(b) (i) C **(1)**

(ii) low work function:
electrons need little energy to leave surface (*)
lower temperature needed at cathode (*)
higher k.e. at any cathode temperature (*)
(*) any one **(1)**

high melting point:
allows high temperature cathode (*)
gives high *theoretical* efficiency (*)
(*) any one **(1)**

low resistivity:
lower power (I^2R)loss in motor circuit (*)
higher *actual* efficiency (*)
(*) any one **(1)** 4

[8]

5. (a) (i) AB:
adiabiatic compression
work done on air
temperature increase
valves closed
any two **(1) (1)**

(ii) BC:
work is done by gas
fuel injected
fuel burns
volume increase at constant pressure
any two **(1) (1)**

(iii) CD:
work done by gas
adiabatic expansion
temperature decrease
any two **(1) (1)**

(iv) DA:
pressure decrease at constant volume (to atmospheric) **(1)**
exhaust valve open [or gases expelled] **(1)** max 6

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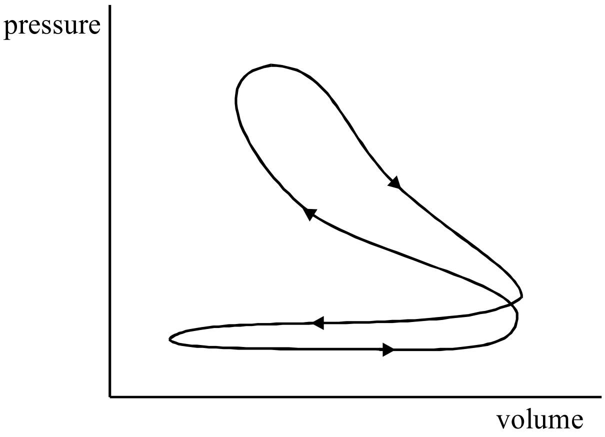
(b) (i)



same maximum and minimum volumes (*)
smaller maximum pressure, no instantaneous changes (*)
induction and exhaust below and above atmospheric pressure respectively (*)
(*) any three **(1) (1) (1)**

(ii) correct reason attributed to one correct difference
[e.g. finite opening and closing time of valves
incomplete mixing of fuel vapour and air,
incomplete combustion, viscosity of gases] **(1)** 4

[10]

6. (a) (i) $\eta_{\max} = \dfrac{T_H - T_C}{T_H}$ **(1)**

$= \dfrac{913 - 293}{913} = 68\%$ **(1)**

(ii) 0.68×200 kW = 136 kW **(1)** 3

(b) (i) $P_{out} = 0.34 \times 200 = 68$ kW **(1)**

(ii) power to reservoir =200 – 68= 132 kW **(1)**

(iii) $0.52 \times 132 = 68.6$ kW **(1)** 4

(iv) $\eta = \dfrac{\text{total power out}}{\text{power in}} = \dfrac{68.6 + 68}{200} = 69\%$ **(1)** 4

(c) theoretical efficiencies of single and two stage engines *exactly* same (*)
efficiency of two stage engine cannot be greater (*)
apparent difference due to rounding errors in calculations (*)
(*) any two **(1) (1)**
hence designer's argument is false **(1)** 3

[10]

7. (a) (i) correct p and V from graph **(1)**

$n = \dfrac{8.00 \times 10^4 \times 2.00 \times 10^{-3}}{8.31 \times 300}$ **(1)** (= 0.064 mol)

(ii) $V_2 = V_1 \dfrac{T_2}{T_1} = 3.3 \times 10^{-3}\ \text{m}^3$ **(1)** 3

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(b) (i) $\frac{3}{2}RT$ or $\frac{3}{2}N_AkT$ **(1)**

(ii) total kinetic energy $\left(=\frac{3}{2}nRT\right)$ = 1.5 × 8.3 × 0.064 × 300 **(1)** = 239 J **(1)**

molecules have no potential energy **(1)**
no attractive forces [or elastic collisions occur] **(1)** max 4

(c) ΔQ = heat entering (or leaving) gas
ΔU = change (or increase) in internal energy
ΔW = work done
[**(1) (1)** for three definitions, deduct one for each incorrect or missing]

(i) $\Delta Q = \Delta U$ **(1)**
temperature rises but no work done **(1)**

(ii) $\Delta Q = \Delta U + \Delta W$ **(1)**
temperature rises and work done in expanding **(1)** max 5

(d) (i) $\Delta U = \frac{3}{2}nR(500 - 300)$ = 159 J **(1)**(= ΔQ)

(ii) $p\Delta V = 8.0 \times 10^4 \times (3.3 - 2.0) \times 10^{-3}$ = 104 J **(1)**
$\therefore \Delta Q = \Delta U + p\Delta V$ = 263 J **(1)** 3

[15]

8. (a) work done per cycle = area enclosed by indicator loop **(1)**
suitable method to estimate area (e.g. counting squares) **(1)**
correct scaling factor used (e.g. 1 small square ≡ 2 mJ) **(1)**
work output /cycle = (670 ± 40) mJ **(1)**
(indicated power = work per cycle × n cycles per sec gives)
5.0 = 0.67 × n and n = 7.4(6) cycles per sec (≈ 450 per min) **(1)** 5

(b) (i) output power = $\frac{\text{work done}}{\text{time taken}} = \frac{42 \times 1.2}{12}$ = 4.2 W **(1)**

$\eta_{\text{mech}} = \frac{\text{output power}}{\text{indicated power}} = \frac{4.2}{5.0}$ = 0.84 **(1)**

(ii) frictional heat generated **(1)**
in the moving parts of the engine **(1)** 4

The Quality of Written Communication Marks are awarded for the quality of answers to this question.

[9]

9. (a) pV = constant for any two points online AB **(1)**
two points chosen and constant calculated **(1)**
(e.g. at A, $pV = 1.0 \times 10^5 \times 1.0 \times 10^{-3}$ = 100 (J)
at B, $pV = 5.0 \times 10^5 \times 0.2 \times 10^{-3}$ = 100 (J)) 2

(b) A → B and C → A **(1)** 1

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(c) $W = p\Delta V$

$= 5.0 \times 10^5 \times (1.0 - 0.2) \times 10^{-3} = 400$ (J) **(1)** 2

(d) (i) C **(1)** 1

(ii) $pV = nRT$ **(1)**

$5.0 \times 10^5 \times 1.0\times10^{-3} = 6.9 \times 10^{-2}\ 8.3 \times T$ **(1)**

T=870K (872K) **(1)**

(allow C.E. if wrong point in (i)) 4

[9]

10. (i) mass of one atom = $\dfrac{0.21}{6.0\times10^{23}} = 3.5\times10^{-25}$ kg **(1)**

(ii) energy supplied = $23 \times 10^3 \times 3.5\times10^{-25}$ **(1)**

$= 8.1 \times 10^{-21}$ J **(1)** (8.05×10^{-21} J

(allow C.E. for value from (i))

(iii) (use of **$\tfrac{1}{2} mv^2 = E_K$** gives) $\tfrac{1}{2} \times 3.5 \times 10^{-25} \times v^2 = 8.1 \times 10^{-21}$ **(1)**

$v = \left(\dfrac{2.0\times8.1\times10^{-21}}{3.5\times10^{-25}}\right)^{1/2} = 220$ m s^{-1} **(1)** (215 m s^{-1})

($E_K = 8.05 \times 10^{-21}$ gives $v = 214$ m s^{-1}) (allow C.E. for value of E_K from (ii)) 5

[5]

11. (a) work per cycle = area enclosed = $6 \times 10^5 \times 4.5 \times 10^{-3} = 2.7$ (kJ) **(1)**

power = work output per sec = $\dfrac{2700}{0.20} = 13.5$ kW **(1)**

(allow C.E. for incorrect work per cycle) 2

(b) modified engine uses less steam per cycle **(1)**
so lower energy input per cycle **(1)**
input energy per cycle ≈ 1/3 of that in unmodified cycle **(1)**
work output per cycle is less than for unmodified cycle **(1)**
work output per cycle > ½ of that in unmodified cycle **(1)**
hence greater efficiency **(1)** max 4

QWC 2

[6]

12. (a) (i) current heats the wire **(1)**
electrons (in filament) gain (sufficient) k.e. (to leave the filament) **(1)**

(ii) electrons would collide with gas atoms/molecules **(1)** 3

(b) (i) k.e. = (eV = $1.6\times10^{-19} \times 3600$) = 5.8×10^{-16}(J) **(1)**

(ii) $\frac{1}{2} m\upsilon 2 = eV$ **(1)**

$\upsilon = \left(\sqrt{\dfrac{2eV}{m}}\right) = \sqrt{\dfrac{2\times1.6\times10^{-19}\times3600}{9.1\times10^{-31}}}$ **(1)** $= 3.6 \times 10^7$ ms^{-1} **(1)** 4

[7]

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13. (a) (i) arrow pointing towards centre of curvature **(1)**

(ii) velocity [or direction of motion] is perpendicular

to the direction of the force **(1)**

work done is force × distance moved in the direction of the force **(1)**

no work done as there is no motion in the direction of the force **(1)** max 3

(b) (i) 25mm **(1)**

$\frac{1}{2}mv^2 = eV$ **(1)**

$\frac{mv^2}{r} = Bev$ **(1)**

$\frac{e}{m} = \frac{2V}{B^2r^2}$ **(1)** = $\frac{2\times 3200}{(7.6\times 10^{-3})^2 \times 0.025^2}$ **(1)** 1.8×10^{11} Ckg $^{-1}$ **(1)** 6

[9]

14. (a) (i) $V\left(=\frac{W}{Q}\right) = \frac{6.0\times 10^{-16}}{1.60\times 10^{-19}}$ **(1)**= 3750 V **(1)**

(ii) heats the filament [or cathode or wire] **(1)**
to enable electrons to gain (sufficient) k.e. to leave filament
[or cause thermionic emission] **(1)** 4

(b) (i) electron moves towards positive plate
curve in field **(1)**
and straight beyond **(1)**

(ii) $t\left(=\frac{l}{v}=\frac{0.060}{3.6\times 10^7}\right)$ = 1.67 ns **(1)**

(iii) $y = -\frac{1}{2}at^2$ **(1)**

$a = \frac{eV_\text{p}}{md}$ **(1)**

combine to give $\frac{e}{m} = \frac{2yd}{V_\text{p}t^2}$ **(1)** = $\frac{2\times 12.5\times 10^{-3}\times 25\times 10^{-3}}{1250\times(1.67\times 10^{-9})^2}$ **(1)**

= 1.8×10^{11} C kg^{-1} **(1)** max 8

[12]

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15. (a) each electron experiences an electrostatic force (vertically) upwards **(1)**
this force does not change as the electron moves across the field **(1)**
each electron (therefore) has a (constant) acceleration vertically upwards **(1)**
velocity of each electron has a constant horizontal component of velocity **(1)**
[or has an increasing vertical component of velocity]
so the direction of motion/velocity becomes closer and closer to a vertical line (as electron moves across the field) **(1)**
[or angle to the vertical becomes less] Max 4

QWC 1

(b) (i) (for beam to be undeflected)
force due to electric field, eE (or qE) **(1)**
equals force due to magnetic field, Bev **(1)** (gives $v = \frac{E}{B}$)

(ii) (k.e. at anode) = $\frac{1}{2}mv^2 = eV_A$ **(1)**
gives $\frac{e}{m} = \frac{v^2}{2V_A}$ **(1)** (i.e. = $\frac{E^2}{2B^2V_A}$)

(iii) $E(= \frac{V}{d}) = \frac{3800}{50\times10^{-3}}$ **(1)** (= 7.6×10^4 (V m^{-1}))

$$\frac{e}{m} = \left(\frac{E^2}{2B^2V_A}\right) = \frac{(7.6\times10^4)^2}{2\times(1.9\times10^{-3})^2\times4500}$$ **(1)**

= 1.8×10^{11} C kg^{-1} **(1)** 7

[11]

16. (a) (i) emission of (conduction) electrons from a heated metal (surface) or filament/cathode **(1)**
work done on electron = eV **(1)**

(ii) gain of kinetic energy (or $\frac{1}{2}mv^2) = eV$; rearrange to give required equation **(1)** 3

(b) (i) work done = force × distance moved in direction offeree **(1)**
force (due to magnetic field) is at right angles to the direction of motion/velocity
[or no movement in the direction of the magnetic force
∴ no work done] **(1)**
electrons do not collide with atoms **(1)**

any two **(1)(1)**

[alternative for 1st and 2nd marks
(magnetic) force has no component along direction of motion **(1)**
no acceleration along direction of motion **(1)**
or acceleration perpendicular to velocity]

$r = \frac{mv}{Be}\left(orBev = \frac{mv^2}{r}\right)$ **(1)**

$v^2 = \frac{2eV}{m}$ **(1)**

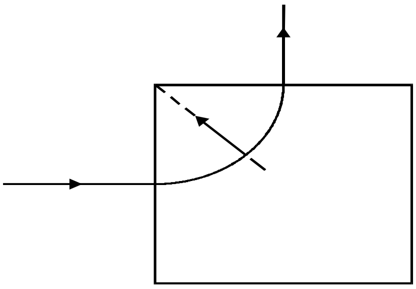
$$\therefore r^2\left(=\frac{m^2v^2}{B^2e^2}\right)=\frac{m^2}{B^2e^2}\times\frac{2eV}{m}=\frac{2mV}{B^2e}$$ **(1)**

(iii) (rearranging the equation gives) $\frac{e}{m}=\frac{2V}{B^2r^2}$ **(1)**

$\frac{e}{m}=\frac{2\times530}{(3.1\times10^{-3})^2\times(25\times10^{-3})^2}=1.7(6)\times10^{11}\,\text{Ckg}^{-1}$ **(1)** 7

[10]

17. (a)



(uniformly) curved path continuous with linear paths at entry and exit points **(1)**
arrow marked F towards top left-hand corner **(1)** 2

(b) into (the plane of) the diagram **(1)** (not accept "downwards") 1

(c) $F(=BQv) = 0.50 \times 1.60 \times 10^{-19} \times 5.0 \times 10^6$ **(1)**
$= 4.0 \times 10^{-13}$ N **(1)** 2

(d) B must be in opposite direction **(1)**
(much) smaller magnitude $\left(\approx\frac{1}{2000}\right)$ **(1)** 2

[7]

18. (a) (i) *including, for example:*
positron is an antimatter particle; proton is a matter particle (*)
positron is a lepton; proton is a hadron (*)
positron has a smaller rest mass than a proton (*)
positron is not composed of other particles; proton is made up of quarks (*)
(*) any two **[1] [1]**

(ii) proton path has greater radius of curvature than positron **(1)**

(iii) radius of curvature $r = \frac{mv}{Be}$ and v, B and e are constants **(1)**
therefore r proportional to m **(1)**
mass of proton is (much) greater than mass
of positron (at same speed) **(1)** max 5

(b) (i) C - 14 **(1)**

(ii) C - 10 **(1)**
as this is furthest from stability **(1)** 3

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(c) rest mass of electron = 0.51 MeV therefore total energy available = (2.2 +2 × 0.51)= 3.22 (MeV) **(1)**

gamma photons produced have average energy = $\frac{3.22}{2}$ = 1.6 MeV**(1)** 2

[10]

19. B **(1)**

20. (a) (i) the same or constant **(1)**
regardless of the speed of the observer or source **(1)**

(ii) physical laws have the same form in all frames **(1)** 3

(b) (i) $T_{\frac{1}{2}}$ of beams of mesons = 8.6 ns × $\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}$ **(1)**

$= 8.6 \times (1 - 0.95^2)^{-\frac{1}{2}} = 27.5$ ns **(1)**

(ii) beam reduces to 25% in 2 half-lives **(1)**
v(= 0.95 c) = 2.85 × 10^8 m s^{-1} **(1)**
distance = 2 × 27.5 ns × 2.85 × 10^8 m s^{-1} **(1)**
= 15.6 m **(1)** 6

[9]

21. (a) k.e. (= work done = qV [or 1.6 × 10^{-19} × 2200]) = 3.5 × 10^{-16} J **(1)**

$\frac{1}{2}mv^2 = 3.5 \times 10^{-16}$ J

hence $v \left(= \sqrt{\frac{2 \times 3.5 \times 10^{-16}}{9.1 \times 10^{-31}}}\right) = 2.8 \times 10^7$ m s^{-1} **(1)** 2

(b) (i) all the k.e. goes to one photon **(1)**
hf = k.e. [or 3.5 × 10^{-16} J] **(1)**

$\lambda = \frac{c}{f}$ **(1)**

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{3.5 \times 10^{-16}}$ **(1)**

= 5.7 × 10^{-10} m **(1)**

(ii) $\lambda = \frac{h}{mv}$ **(1)**

$= \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 2.8 \times 10^7} = 2.6 \times 10^{-11}$ m **(1)** 7

[9]

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22. (a) (i) speed of light (in free space) independent of motion of source **(1)**
and of motion of observer **(1)**
[*alternative (i)*
speed of light is same in all frames of reference **(1)**]

(ii) laws of physics have same form in all inertial frames **(1)**
inertial frame is one in which Newton's 1st law of motion obeyed **(1)**
laws of physics unchanged in coordinate transformation
from one inertial frame of reference to any other inertial frame **(1)** max 4

(b) (i) $m\left(=m_0\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}\right) = 1.88\times10^{-28}\,(1-(0.996)^2)^{-\frac{1}{2}}$ **(1)**

$= 2.10\times10^{-27}$ kg **(1)**

(ii) $t_0 = 2.2\times10^{-6}$ s **(1)**

$t\left(=t_0\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}\right) = 2.2\times10^{-6}\left(1-(0.996)^2\right)^{-\frac{1}{2}}$ (s) **(1)**

$= 2.46\times10^{-5}$ (s) **(1)**

$s(=vt = 3.00\times10^8\times0.996\times2.46\times10^{-5}) = 7360$ m **(1)**

[*alternative (ii)*
$l\left(=vt = 0.996\times3.0\times10^8\times2.2\times10^6\right) = 657$ (m) **(1)**

correct substitution of l in $l = l_0\sqrt{1-\frac{v^2}{c^2}}$ **(1)**

$l_0\left(=\frac{l}{\sqrt{1-\frac{v^2}{c^2}}}\right) = \frac{657}{\sqrt{1-0.996^2}}$ **(1)**

$l_0 = 7360$ m **(1)** 6

[10]

23. (a) path curves upwards from O to P
path is tangential to curve at P and straight beyond P 2

(b) (i) magnetic field exerts a force on a moving charge/electron **(1)**
magnetic force has a downwards component (at all points)
[or magnetic force < electric force] **(1)**

(ii) magnetic force = Bev **(1)**

electric force $\left(=\frac{eV_p}{d}\right) = eE$ **(1)**

$Bev = eE$ (gives $v = \frac{E}{B}$) **(1)** 5

(c) work done (or eV) = gain of kinetic energy (or $\frac{1}{2}mv^2$) **(1)**

$\frac{e}{m} = \frac{v^2}{2V}$ **(1)**

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$= \frac{(3.2\times10^7)^2}{2\times2900} = 1.8\times10^{11}\ \text{C kg}^{-1}$ **(1)** 3

[10]

24. (a) magnetic force perpendicular to (direction of) motion (or velocity) **(1)**
force does not change speed (or force does no work) **(1)**
force causes direction of motion to change **(1)**
force (or acceleration) is centripetal/ acts towards centre of curvature **(1)**
velocity is tangential **(1)** max 3
QWC 2

(b) (i) magnetic force = Bev **(1)**

centripetal acceleration $= \frac{v^2}{r}$, $\therefore Bev = \frac{mv^2}{r}$ **(1)** (gives $v = \frac{Ber}{m}$)

(ii) $\frac{mv^2}{r} = Bev$ gives $\frac{e}{m} = \frac{v}{Br}$ **(1)**

$= \frac{3.2\times10^7}{7.3\times10^{-3}\times25\times10^{-3}}$ **(1)**

$= 1.75\times10^{11}\ \text{C kg}^{-1}$ **(1)** 5

[8]

25. (a) (i) $t_0 = 800$ (s) **(1)**

(use of $t = t_0\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}$ gives) $t = 800(1-0.994^2)^{-1/2}$ **(1)**

$= 7300$ s **(1)**

(ii) distance ($= 0.994ct = 0.994\times3\times10^8\times7300$)
$= 2.2\times10^{12}$m **(1)** (2.18×10^{12}m)
(allow C.E. for value of t from (i)) 4

(b) space twin's travel time = proper time (or t_0) **(1)**

time on Earth, $t = t_0\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}$ **(1)**

$t > t_0$
[or time for traveller slows down compared with Earth twin] **(1)**
space twin ages less than Earth twin **(1)**
travelling in non-inertial frame of reference **(1)** max 3

[7]

26. D **(1)**

27. (a) (i) proton number 82 and nucleon number 214 **(1)**

(ii) Pb **(1)** 2

(b) (i) kinetic energy [or electrostatic potential energy] **(1)**

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(ii) $\Delta m = \frac{E}{c^2}$ **(1)**

$= \frac{8.6\times10^{-13}}{(3\times10^8)^2} = 9.6 \times 10^{-30}$ kg **(1)** 3

[5]

28. (a) (i) proton number = 36 **(1)**
neutron number = 56 **(1)**

(ii) krypton **(1)** 3

(b) one-fifth efficiency so total output ($= 10 \times \frac{100}{20} = 50$(MW) **(1)**

energy in one day = $50\times 10^6 \times 24 \times 3600$(J) **(1)** ($4.32 \times 10^{12}$ J)

fission atoms per day = $\frac{4.32\times10^{12}}{3.2\times10^{-11}} = 1.35 \times10^{23}$ **(1)** 3

[6]

29. (a) time for half of (active) nuclei (of radioactive substance) to decay **(1)** 1

(b)

t/minute	0	10	20	30	40	50	60
number of counts in 30s, *C*	60	42	35	23	18	14	10
ln *C*	4.094	3.738	3.555	3.135	2.890	2.639	2.303

Correct values of ln *C* above **(1)** 1

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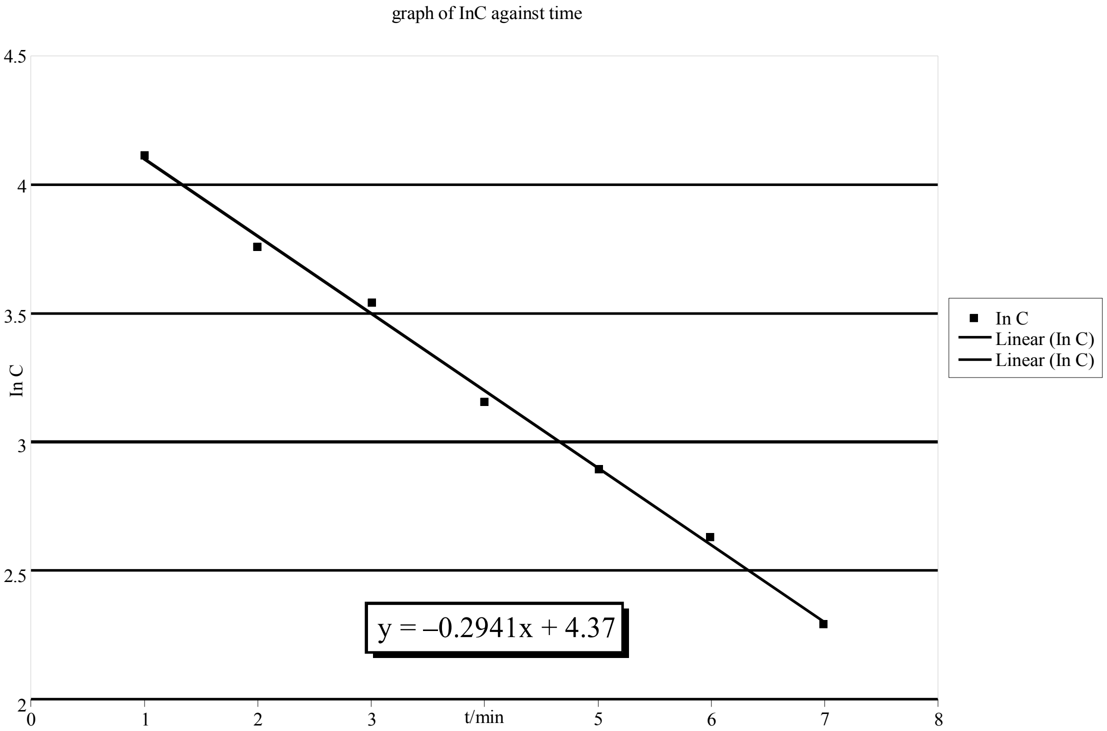
(c) (i) seven points correctly plotted **(1) (1)** [six points correct **(1)**]



(ii) best straight line through points **(1)**

sensible scale **(1)**

(iii) from sensible triangle on graph **(1)**

gradient **=– (1)** 0.030 [0.294] **(1)** (min^{-1}) (min^{-1}) max 5

(d) (i) $C = C_0 e^{-\lambda t}$, ln C – ln $C_0 = -\lambda t$

hence using $y = mx + c$, λ = (–)gradient **(1)**

(ii) half–life = $\dfrac{\ln 2}{\lambda} = \dfrac{0.693}{0.03}$ **(1)** = 23 min **(1)** 3

(e) count over longer period than half minute [or repeat experiment] **(1)**

use stronger source **(1)**

use background count correctly**(1)** max 2

(f) for ^{14}C, $\lambda = \dfrac{0.693}{T_{½}}$ =1.21 × 10^4 (year) **(1)**

$$-\lambda t \left(= \ln \frac{R}{R_0} \right) = \ln \left(\frac{5.2}{6.5} \right) \textbf{(1)} = -0.223\ \textbf{(1)}$$

$t = \dfrac{0.223}{1.21 \times 10^{-4}}$ = 1840(year) **(1)** 4

[16]

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30. (a) (i) ${}^{40}_{19}\text{K} + \text{e}^- \rightarrow {}^{40}_{18}\text{Ar}$ **(1)** + $\nu_{(\text{e})}$ **(1)** (+Q)

(ii) $\Delta m = 39.96401 - 39.96238 = 0.00163$ u **(1)**

$Q(= 0.00163 \times 931) = 1.5(\text{MeV})$ **(1)**

(iii) orbital electron vacancy due to electron capture **(1)**

outer electron fills vacancy and emits X – ray photon **(1)** max 5

(b) (i) ${}^{40}_{19}\text{K} \rightarrow {}^{40}_{20}\text{Ca} + \text{e}^-$ **(1)** + $\overline{\nu_{(\text{e})}}$ **(1)**

(ii) use of beta emission 8 times more probable than electron capture **(1)**

use of number of potassium atoms equals 5 times number of argon atoms **(1)**

leading to evaluation of 36% **(1)**

use of the decay equation **(1)**

correct answer **(1)**

for example:

14 atoms of K–40 originally

becomes 8 atoms of Ca–40 + 1 atom of Ar–40 + 5 atoms K–40 unchanged

36% of K–40 not decayed

use $N = N_0 e^{-\lambda t}$ to give $t = \dfrac{-T_{1/2}\ln 0.36}{\ln 2} = 1860 \times 10^6$ yr max 4

[9]

31. (a) (i) α (radiation) **(1)**

(ii) γ (radiation) **(1)** 2

(b) (i) the radiation needs to pass through the body (to be detected) **(1)**

(ii) (otherwise) the activity of the source becomes too weak (during measurements) **(1)**

(iii) the decaying source may remain in the body for a long time and could cause damage **(1)**

[or the activity of the source will be low unless a large quantity is used ($T_{1/2} \propto 1/\lambda$)] 3

(c) corrected count rate at 0.2 m (= 2550 – 50) = 2500 (c min^{-1}) **(1)**

corrected count rate at least distance (= 6000 – 50) = 5950 (c min^{-1}) **(1)**

use of $I = k\dfrac{I_o}{x^2}$ (or in the form $\dfrac{I_1}{I_2} = \left(\dfrac{x_2}{x_1}\right)^2$) **(1)**

(allow C.E. for using uncorrected count rate)

gives least distance = $0.20 \times \left(\dfrac{2500}{5950}\right)^{1/2}$ **(1)**

least distance = 0.13 m **(1)** 5

[10]

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32. (a) (on grid: first arrow to start from $^{210}_{82}\text{Pb}$; arrows must be consecutive;
last arrow must end on $^{206}_{82}\text{Pb}$)
arrow showing the change for an α emission **(1)**
arrow showing the change for a β emission **(1)**
correct α and two β emissions in any order **(1)** 3

(b) (positron emission) $^{64}_{29}\text{Cu} \rightarrow {}^{64}_{28}\text{Ni} + \beta^{+} + \nu_{\text{e}}$ (+Q) **(1)** **(1)**
(electron capture) $^{64}_{29}\text{Cu} + {}^{0}_{-1}e \rightarrow {}^{64}_{28}\text{Ni} + \nu_{(\text{e})}$ (+Q) **(1)** **(1)** 4

(c) (the following examples may be included)

α particles **(1)**
coulomb/electrostatic/electromagnetic repulsion
[or K.E. converted to P.E. (as α particle approaches nucleus)] **(1)**
information:
any of the following: proton number, nuclear charge,
upper limit to nuclear radius
mass of nucleus is most of the mass of atom **(1)**

[alternative
(high energy) electron (scattering) **(1)**
diffraction of de Broglie Waves by nucleus **(1)**
information:
any of the following: nuclear radius, nuclear density **(1)**] 3
QWC 2
[10]

33. (a) reasons:
α particle has much more mass/momentum than β particle
α particle has twice as much charge as a β particle
α particle travels much slower than a β particle any **two (1) (1)** 2
QWC 1

(b) (i) energy absorbed per sec (= energy released per sec)

$$= 3.2 \times 10^{9} \times 5.2 \times 10^{6} \times 1.6 \times 10^{-19} \text{ (1)}$$

$$= 2.7 \times 10^{-3} \text{ (J) (1) } (2.66 \times 10^{-3} \text{ (J)})$$

(ii) temperature rise in 1 minute $\left(= \dfrac{\text{energy absorbed in 1 minute}}{\text{mass} \times \text{specific heat capacity}} \right)$

$$= \frac{2.7 \times 10^{-3} \times 60}{0.20 \times 10^{-3} \times 900}$$ (for numerator) **(1)** (for denominator) **(1)**

= 0.90 K (or °C) **(1)**
(allow C.E. for incorrect value in (i)) 5
[7]

34. (a) $Q_{\text{o}} = CV = 50 \times 10^{-6} \times 20 = 1.0$ mC **(1)** 1

(b) $CR = 50 \times 10^{-6} \times 200 \times 10^{3} = 10$ (s) **(1)**

$Q = Q_{\text{o}}\, \mathrm{e}^{-t/CR} = 1.0 \times 10^{-3} \times \mathrm{e}^{-2} = 0.14 \times 10^{-3}$ C

$V = Q/C = 2.8$ V **(1)** 2

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(c) final energy stored = 0.25 (0.5 Q_o^2/C) **(1)**

$Q = 0.5\ Q_o = Q_o\ e^{-t/10}$ **(1)**

$t = 6.9$ s **(1)** 3

[6]

35. (a) (i) $Q = 0.42(3)$C **(1)**

(ii) $E = 19$ J **(1)**

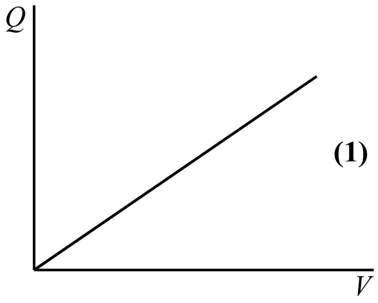
(iii) $I = 14$A **(1)** 3

(b) $E = \frac{1}{2} C\,(90^2 - 80^2)$ [or $E_{80} = 15$(J)] **(1)**

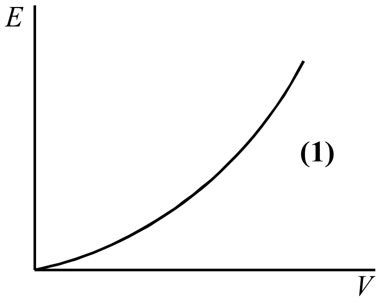
leading to 4.0 J 2

[4]

36. (a)



(1)



(1)

capacitance [or charge per volt or Q/V] **(1)** 3

(b) (i) $Q = CV$ (=0.68 × 6.0)=4.1C **(1)**

(ii) $\mathrm{E}\left(=\frac{1}{2}QV=\frac{1}{2}\times 4.1\times 6.0\right)=12\mathrm{J}$ **(1)** 2

[5]

37. (a) $Q = CV$ **(1)**

(= $4.7 \times 10^{-6} \times 6.0$) = 28×10^{-6} C or 28 μC **(1)** 2

(b) $E = ½CV^2$ **(1)**

= $½ \times 4.7 \times 10^{-6} \times 2.0^2$ **(1)**

= 9.4×10^{-6} J **(1)**

[or $E = ½QV$ **(1)**

= $½ \times 9.4 \times 10^{-6} \times 2.0$ **(1)**

= 9.4×10^{-6} J **(1)**] 3

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(c) time constant is time taken for V to fall to $\frac{V_o}{e}$ **(1)**
$\therefore V$ must fall to 2.2 V **(1)**
time constant = 32 ms **(1)**
[or draw tangent at $t = 0$ **(1)**
intercept of tangent on t axis is time constant **(1)**
accept value 30 - 35 ms **(1)**]
[or $V = V_0 \exp(-t/RC)$ or $Q = Q_0 \exp(-t/RC)$ **(1)**
correct substitution **(1)**
time constant = 32 ms **(1)**] 3

(d) time constant = RC **(1)**
$R = \frac{32 \times 10^{-3}}{4.7 \times 10^{-6}}$ = 6800 Ω **(1)**
(allow C.E. for value of time constant from (c)) 2
[10]

38. (a) Q (= CV = 330 × 9.0) = 2970 (μC) **(1)**
E (= ½QV) = ½ _ 2.97 × 10^{-3} × 9.0 = 1.34 × 10^{-2}J **(1)**
[or E (= ½CV^2) = ½ × 300 × 10^{-6} × 9.0^2 **(1)** = 1.34 × 10^{-2}J **(1)**] 2

(b) time constant (= RC) = 470 × 103 × 330 × 10^{-6} = 155 s **(1)** 1

(c) $Q\left(= Q_0 e^{-t/RC}\right)$= 2970 × $e^{-60/155}$
= 2020 (μC)
(allow C.E. for time constant from (b))
$V\left(= \frac{Q}{C}\right) = \frac{2020}{330} = 6.11\text{V}$ **(1)**
(allow C.E. for Q)
[or $V = V_0 e^{-t/RC}$ **(1)** = 9.0 $e^{-60/155}$ **(1)** = 6.11 V **(1)**] 3
[6]

39. D **(1)**

40. B **(1)**

41. D **(1)**

42. A **(1)**

43. (a) $E \propto V^2$ (or $E = {}^1/_2 CV^2$) **(1)**

pd after 25 s = 6 V **(1)** 2

(b) (i) use of $Q = Q_0\,\mathrm{e}^{-t/RC}$ or $V = V_0\,\mathrm{e}^{-t/RC}$ **(1)**

(e.g. $6 = 12\mathrm{e}^{-25/RC}$) gives $\mathrm{e}^{\frac{25}{RC}} = \frac{12}{6}$ and $\frac{25}{RC} = \ln 2$ **(1)**

($RC = 36(.1)$ s)

[alternatives for (i):

$V = 12\,\mathrm{e}^{-25/36}$ gives $V = 6.0$ V **(1)** (5.99 V)

or time for pd to halve is $0.69RC$

▸ $RC = \frac{25}{0.69}$ **(1)** = 36(.2) s]

(ii) $R = \frac{36.1}{680 \times 10^{-6}}$ **(1)** = $5.3(0) \times 10^{4}$ **Ω(1)** 4

[6]

44. (a) (i) E (= ½ CV^2) = $0.5 \times 270 \times 10^{-6} \times 3.0^2$ **(1)**

= $1.2(2) \times 10^{-3}$ J **(1)**

(ii) W(=QV= CV^2 = $270 \times 10^{-6} \times 3.0^2$) = $2.4(3) \times 10^{-3}$ J **(1)** 3

(b) (i) (at 0.3 V), E (= $0.5 \times 270 \times 10^{-6} \times 0.3^2$)

= 0.012×10^{-3}(J) = $0.01\,E_0$ **(1)**

energy released by capacitor = $0.99\,E_0$ **(1)**
(= 99% E_0)

[or energy released by capacitor = $1.22 \times 10^{-3} - 1.2 \times 10^{-5}$

= 1.21×10^{-3} (J) which is almost all the initial energy]

(ii) RC= $1.5 \times 270 \times 10^{-6} = 4.05 \times 10^{-4}$ (s) **(1)**

(use of $V = V_0\,\mathrm{e}^{-t/RC}$ gives) $2.0 = 3.0\,\mathrm{e}^{-t/RC}$ **(1)**

t (= $-RC \ln(2.0/3.0)$) = $(-)4.05 \times 10^{-4} \times (-)0.405$

= $1.6(4) \times 10^{-4}$ s **(1)**
(allow C.E. for value of RC)

(iii) energy of a photon = $\left(\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{500 \times 10^{-9}}\right)$

= 4.0×10^{-19}(J) **(1)**
(3.98×10^{-19} J)

energy released by capacitor when it discharges from 3.0 to 2.0 V

= $1.2(2) \times 10^{-3} - (0.5 \times 270 \times 10^{-6} \times 2.0^2) = 6.8 \times 10^{-4}$**(J) (1)**

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number or photons released = $\frac{6.8\times10^{-4}}{4.0\times10^{-19}}$ $=1.7 \times 10^{15}$ **(1)** 8

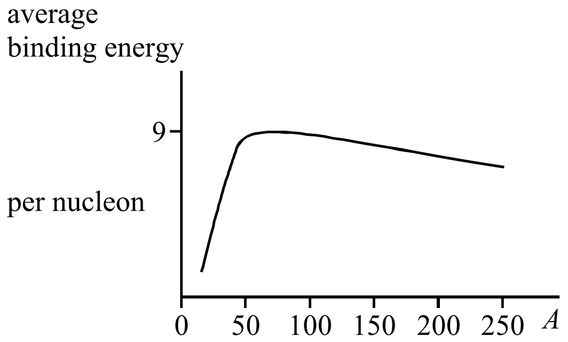
(allow C.E. for energy of photon and energy released)

[11]

45. D **(1)**

46. (a) (i) binding energy is the work done on nucleons to separate nucleons completely
[or the energy **released** by nucleons when nucleus is formed from separated nucleons] **(1)**

(ii)



curve: correct shape, maximum at A between 40 – 60 **(1)**
sharp rise from <50 (binding energy)$_{max}$ **(1)**
gradual fall to > 60% (binding energy)$_{max}$

scales: binding energy per nucleon to 8 – 10 MeV **(1)**
A to > 220 **(1)** max 5

(b) uranium splits into two fragments **(1)**
binding energy **per nucleon** rises (causing energy release) **(1)** 2

(c) number of neutrons escaping is proportional to surface area **(1)**
as mass increases a smaller fraction escapes **(1)**
because surface/volume ratio decreases **(1)**
hence fraction producing fission increases as mass increases **(1)** max 3

[10]

47. (a) (i) proportion of U-235 is greater than in natural uranium **(1)**

(ii) induced fission more probable with U-235 than with U-238 **(1)** 2

(b) (i) for steady rate of fission, one neutron per fission required to go on to produce
further fission **(1)**
each fission produces two or three neutrons on average **(1)**
some neutrons escape [or some absorbed by U-238 without fission] **(1)**
control rods absorb sufficient neutrons (to maintain steady rate of fission) **(1)**

(ii) neutrons need to pass through a moderator **(1)**
to slow them (in order to cause further fissions or prevent U-238 absorbing them) **(1)**

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neutrons that leave the fuel rod (and pass through the moderator)
are unlikely to re-enter the same fuel rod **(1)**
makes it easier to replace the fuel in stages **(1)** max 5

[7]

48. (a) (i) proton number = 36 **(1)**
neutron number = 56 **(1)**

(ii) krypton **(1)** 3

(b) one-fifth efficiency so total output (= $10 \times \frac{100}{20}$ = 50(MW) **(1)**

energy in one day = $50\times 10^6 \times 24 \times 3600$(J) **(1)** ($4.32 \times 10^{12}$ J)

fission atoms per day = $\frac{4.32\times10^{12}}{3.2\times10^{-11}}$ =1.35×10^{23} **(1)** 3

[6]

49. (a) (i) $^{235}_{92}\text{U} + {}^{1}_{0}n \rightarrow {}^{98}_{38}\text{Sr} + {}^{135}_{54}\text{Xe} + 3\,{}^{1}_{0}n(+Q)$ **(1)**

(ii) three correct positions to within ±2 on x-axis **(1)** **(1)** (one mark if two correct)

(iii) *estimate of energy released*:
binding energy of U-235 nucleus = (235 × 7.5) = 1763(±15)(MeV) **(1)**
binding energy of Sr-98 = (98 × 8.6) = 843(±15)(MeV) **(1)**
binding energy of Xe-135 = (135 × 8.4) = 1134(±15)(MeV) **(1)**
binding energy released = 1134 + 843 – 1763 = 214MeV **(1)**
(±40MeV) max 6

(b) (i) 235g of U-235 releases $6 \times 10^{23} \times 214 \times 1.6 \times 10^{-13}$J = 2.1×10^{13}(J) **(1)**
1.0 kg of uranium containing 3% U-235 contains 30g of U-235 **(1)**
energy from 1.0kg of uranium = $\frac{2.1\times10^{13}\times30}{235}$ = 2.6×10^{12}J [[1.6×10^{25} MeV]] **(1)**

(ii) *advantage*:
less mass of fuel used **(1)** because more energy per kilogram **(1)**
[alternative: less harm to environment **(1)** because does not generate greenhouse gases **(1)**
or any statement **(1)** argued **(1)**]
disadvantage:
hazardous waste **(1)** because fission products are radioactive **(1)**
[alternative: long term responsibility **(1)** because waste needs to be stored for many years **(1)**
or any statement **(1)** argued **(1)**] max 6

[12]

50. 100y = 100 × 365 × 24 × 3600 (= 3.15×10^9 s) **(1)**
energy needed = $3.15 \times 10^9 \times 300$ **(1)** × 10 **(1)** (= 9.46×10^{12} J)
number of disintegrations = $\frac{9.46\times10^{12}}{3.2\times10^{-11}}$ (= $2.96 \times 10^{23)}$ **(1)**

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number of moles needed = $\frac{2.96\times10^{23}}{6.02\times10^{23}}$ (= 0.49) **(1)**
molar mass = 0.239kg **(1)**
mass needed = 0.49 × 0.239 = 0.117 kg **(1)**

[7]

51. (a) binding energy is the energy needed to separate **(1)**

the (individual) neutrons and protons (of the nucleus) **(1)**

[or energy available **(1)**

when nucleus formed from (individual) neutrons and protons **(1)**] 2

(b) ^{5}Li nucleus consists of 2 neutrons and 3 protons **(1)**

atomic mass of ^{5}Li nucleus = 5.01250 – (3 × 0.00055) = 5.01085 (u) **(1)**

mass of 2 neutrons and 3 protons

= (2 × 1.00867) + (3 × 1.00728) = 5.03918(u) **(1)**

mass defect = 5.03918 – 5.01085 = 0.02833(u) **(1)**

binding energy = 0.02833 × 931.3 = 26.4MeV**(1)** 5

[7]

52. (a) mass difference increases
or B.E. (per nucleon) or stability is greater for nucleus after fusion **(1)**
(greater) mass difference
or increase in B.E. (per nucleon) implies energy released **(1)**
both nuclei charged positively or have like charges **(1)**
electrostatic repulsion **(1)** max 3
QWC 2

(b) (i) Δm (= 2 × (2.01355) – (3.01493 + 1.00867))
= 3.5×10^{-3} u **(1)** (5.81×10^{-30} kg)

(ii) $\Delta E = 3.5 \times 10^{-3} \times 931.3$ (MeV) **(1)** (= 3.26 MeV)
= $3.26 \times 10^6 \times 1.6 \times 10^{-19} = 5.22 \times 10^{-13}$ (J) **(1)** 3

[6]

53. C **(1)**

54. B **(1)**

55. B **(1)**

56. (a) (i) $\Delta m = Zm_p + (A - Z)m_n - M$ **(1)**

(ii) binding energy per nucleon = $\frac{(\Delta m)c^2}{A}$ **(1)** 2

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(b) (i) A in range 54 → 64 **(1)**
stability increases as binding energy per nucleon increases **(1)**
[or binding energy per nucleon is a measure of stability]
[or large binding energy per nucleon shows nucleus is difficult to break apart] 5

(ii) binding energy per nucleon increases from about 7.6 to 8.5 **(1)**
increase of about 0.9 MeV for 235 nucleons **(1)**
hence 210 MeV (≈ 200 MeV) in total **(1)**

[7]

57. B **(1)**

58. (a) for one reaction $\Delta E\ (= \Delta m\ c^2) = 3.1 \times 10^{-28} \times (3.00 \text{ x } 10^8)^2$ **(1)**
$= (2.79\times10^{-11}\text{J})$

number of nuclei required $= \dfrac{1}{2.79\times10^{-11}} = 3.5(8) \times 10^{10}$ **(1)**

[or equivalent credit for any other valid method] 2

(b) output power from reactor = $\dfrac{600}{0.35} = 1700\,(\text{MW})$ **(1)**

(1714 MW)

energy output from fuel rods in one week
$= 1.70 \times 10^9 \times 24 \times 7 \times 3600$ **(1)**

$(= 1.03 \times 10^{15}\text{ J})$

$\Delta m\left(=\dfrac{\Delta E}{c^2}\right) = \dfrac{1.03\times10^{15}}{(3.0\times10^8)^2}$ **(1)**

$= 1.14 \times 10^{-2}$ kg **(1)**

[or equivalent credit for any other valid method] 4

[6]

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