GCE A level

1325/01

PHYSICS – PH5

Electromagnetism, Nuclei & Options

A.M. THURSDAY, 18 June 2015

1 hour 45 minutes plus your additional time allowance

Surname ______________________________

Other Names ______________________________

Centre Number ______________________________

Candidate Number 2 ______________________________

ADDITIONAL MATERIALS

In addition to this paper, you will require a calculator, a Case Study Booklet and a Data Booklet.

INSTRUCTIONS TO CANDIDATES

Use black ink, black ball-point pen or your usual method.

Write your name, centre number and candidate number in the spaces provided on the front cover.

Write your answers in the spaces provided in this booklet. If you run out of space, use the continuation pages at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 3 sections, A, B, and C.

Section A: 60 marks. Answer ALL questions. You are advised to spend about 1 hour (plus your additional time allowance) on this section.

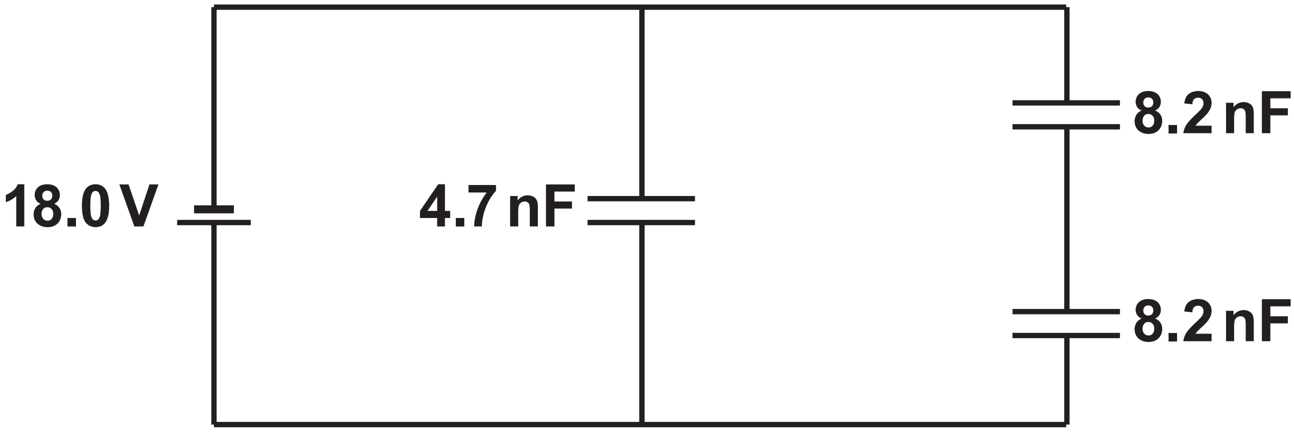
Section B: 20 marks. The Case Study. Answer ALL questions. You are advised to spend about 20 minutes (plus your additional time allowance) on this section.

Section C: Options; 20 marks. Answer ONE OPTION ONLY. You are advised to spend about 20 minutes (plus your additional time allowance) on this section.

SECTION A

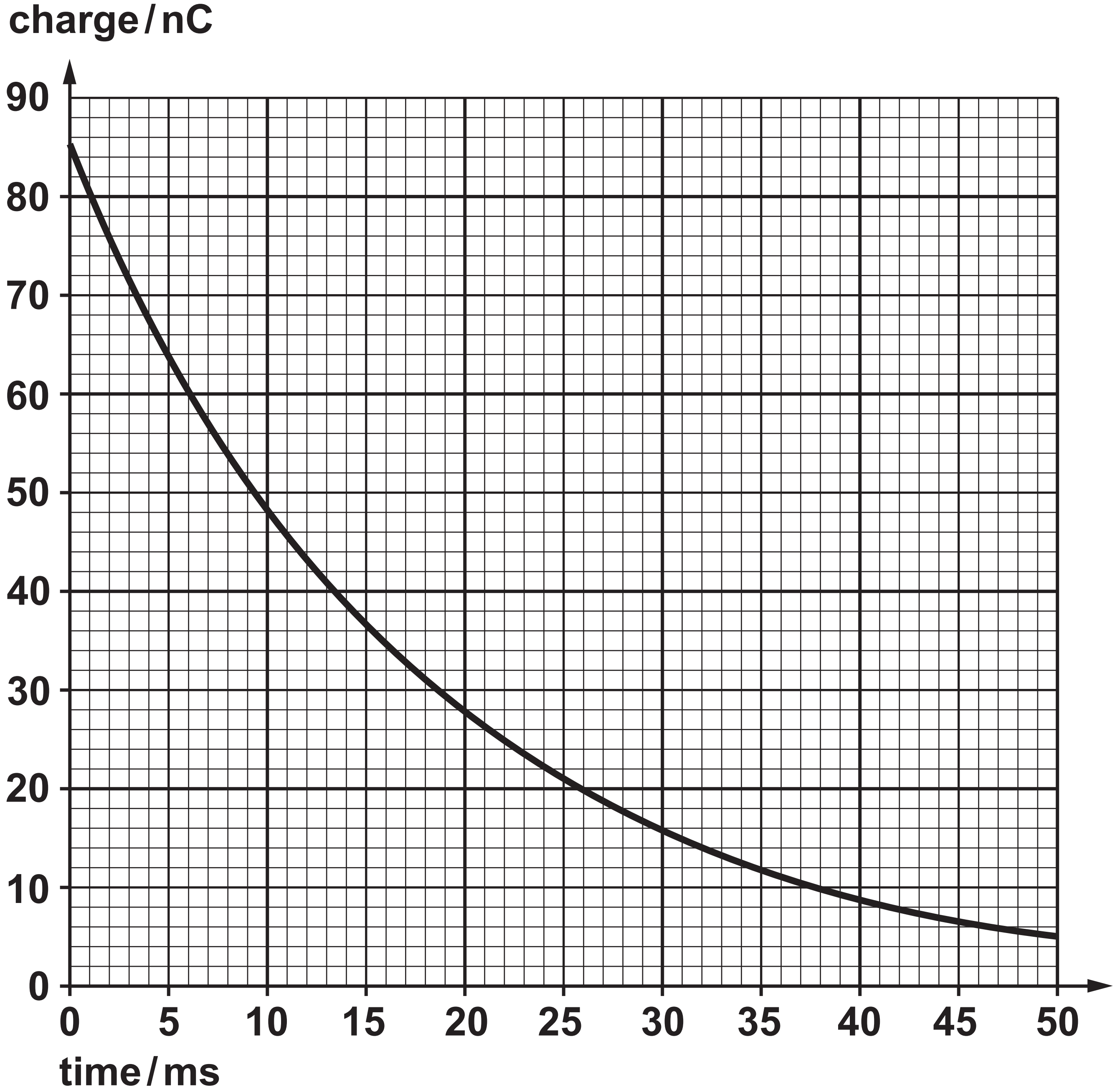
Answer ALL questions.

1. This question is about capacitors in the following circuit.



(a) (i) Calculate the charge stored by each of the capacitors. [2]

1(a) (ii) Calculate the total energy stored by all three capacitors. [2]



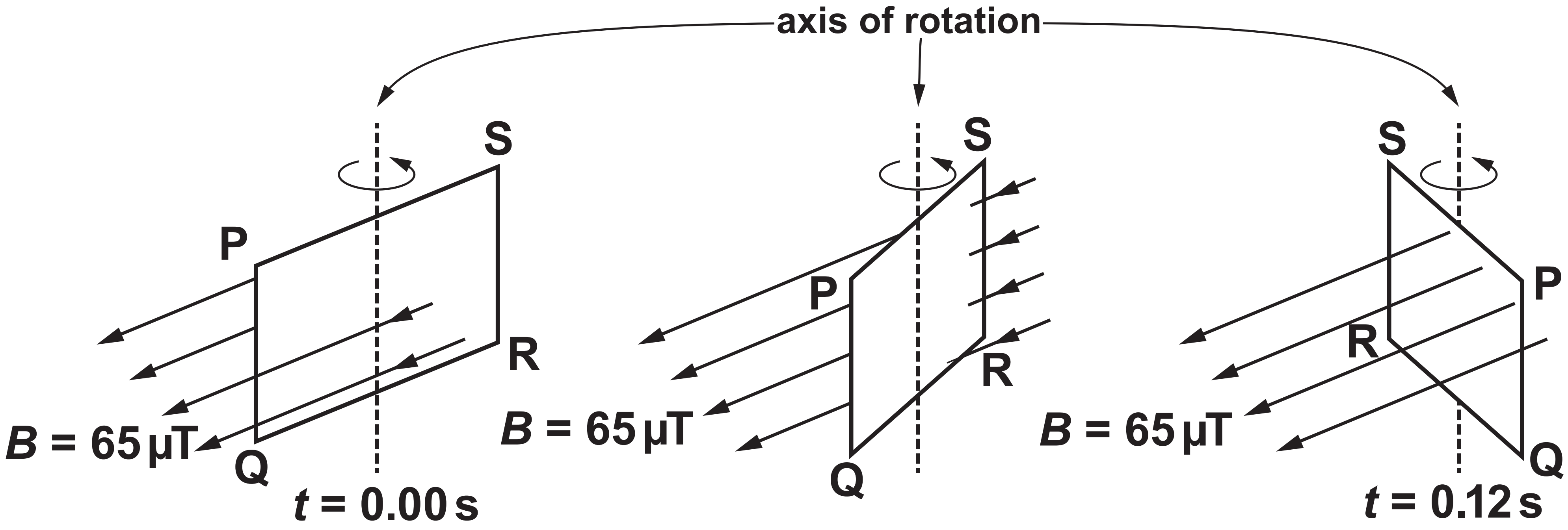
charge / nC
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
time / ms

1(b) The 4.7 nF capacitor is discharged through an unknown resistor and the graph opposite is obtained.

(i) Calculate the resistance of the resistor. [3]

1(b) (ii) Calculate the current when $t = 0$ s. [2]

(iii) By estimating the time taken for the capacitor to lose 90% of its charge or otherwise, calculate the time taken for the capacitor to lose 99% of its charge. [2]


axis of rotation
S
P
R
Q
B = 65 µT
t = 0.00 s
S
P
R
Q
B = 65 µT
S
P
R
Q
B = 65 µT
t = 0.12 s

2. A large square loop has sides of length 0.815 m and is rotated through 90° in a uniform magnetic field of 65 μT. The diagrams opposite show the same square loop at different times.

(a) Determine the magnetic flux through the square loop: [3]

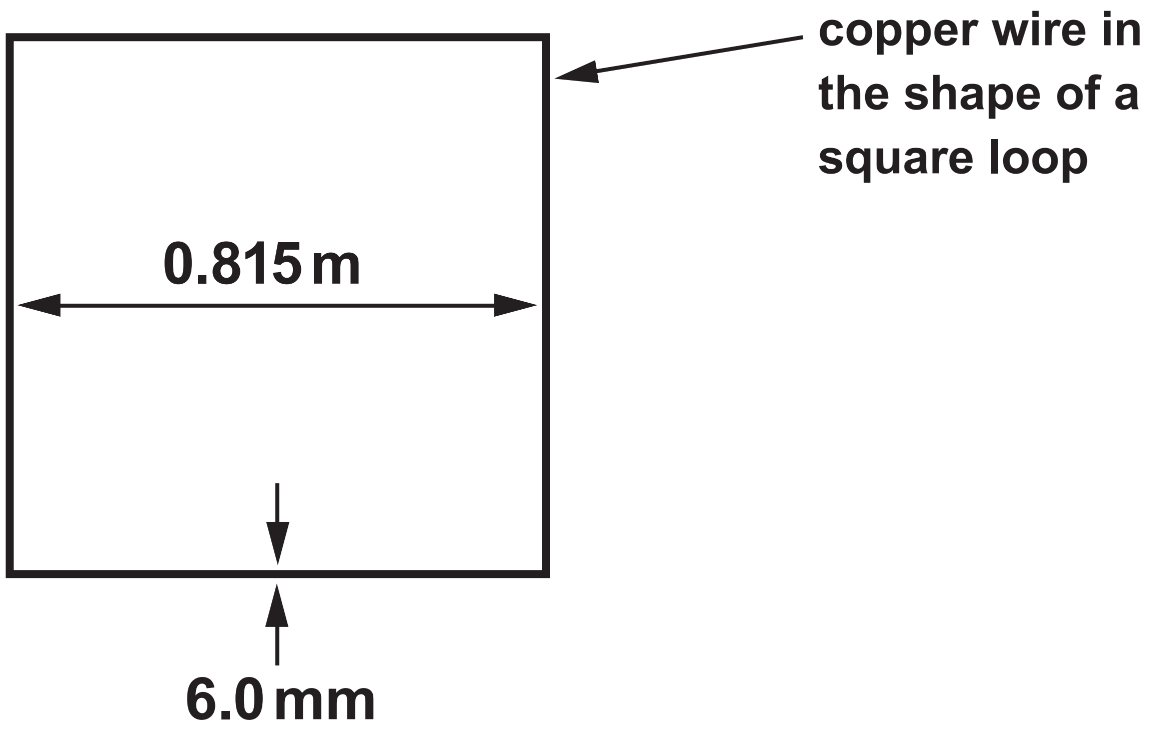
(i) when $t = 0.00$ s (sides QR and SP are parallel to the B-field);

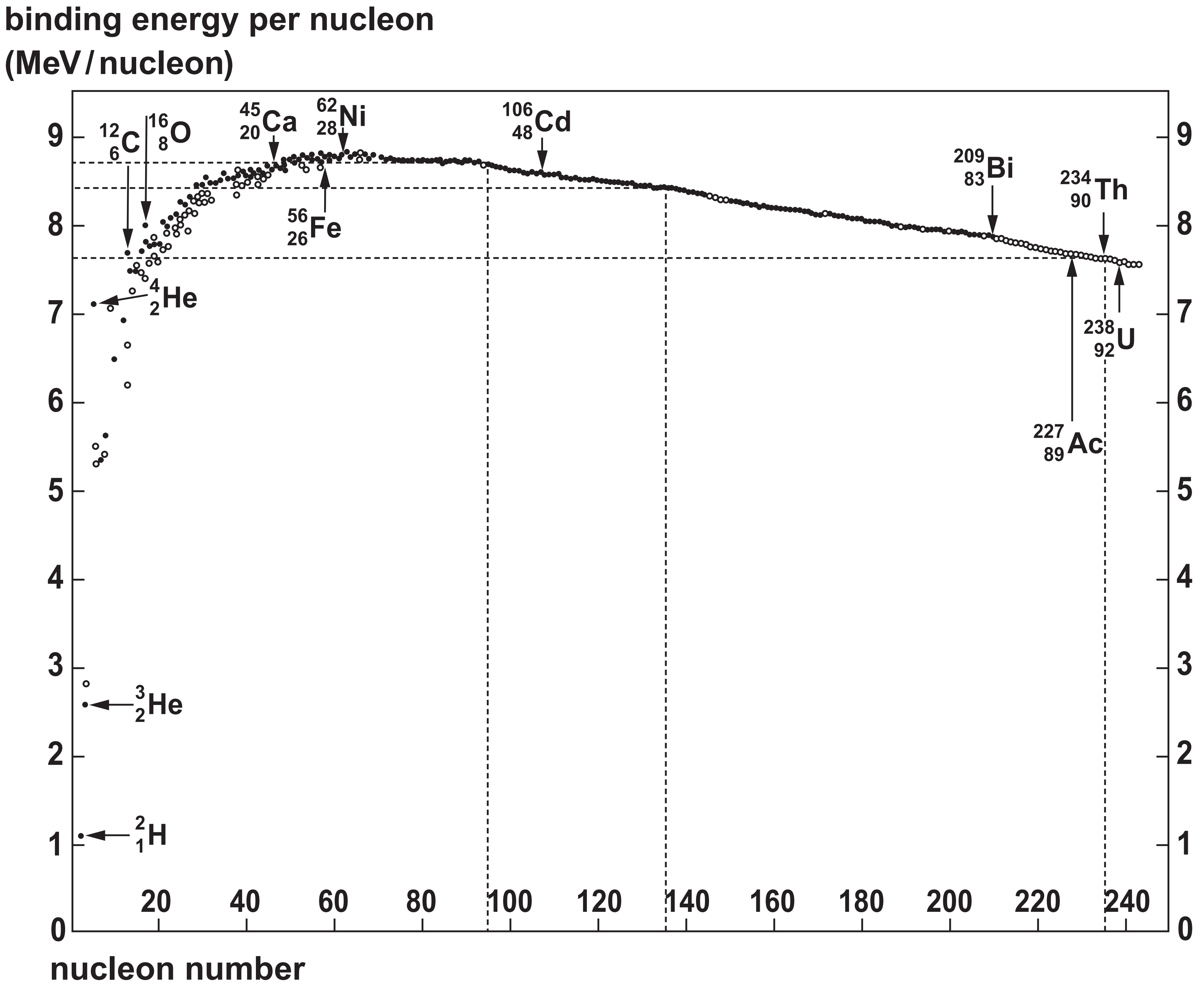
2(a) (ii) and when $t = 0.12\,s$ (PQ, QR, RS and SP are perpendicular to the B-field).

(b) The square loop is made of copper. Explain why there is a current in the loop as it is rotated. [2]

2(c) **Explain how Lenz's law will give the direction of the forces acting on the sides PQ and RS as the square loop is rotated. [2]**

2(d) **The copper wire from which the square loop is made has a circular cross-section of diameter 6.0 mm. The resistivity of copper is $1.67 \times 10^{-8}\,\Omega\,m$. Calculate the MEAN current flowing through the square loop as it is rotated between $t = 0.00\,s$ and $t = 0.12\,s$.** [5]





binding energy per nucleon
(MeV / nucleon)
nucleon number
$^{12}_{6}C$
$^{16}_{8}O$
$^{45}_{20}Ca$
$^{62}_{28}Ni$
$^{56}_{26}Fe$
$^{106}_{48}Cd$
$^{209}_{83}Bi$
$^{234}_{90}Th$
$^{238}_{92}U$
$^{227}_{89}Ac$
$^{4}_{2}He$
$^{3}_{2}He$
$^{2}_{1}H$
0 1 2 3 4 5 6 7 8 9
20 40 60 80 100 120 140 160 180 200 220 240

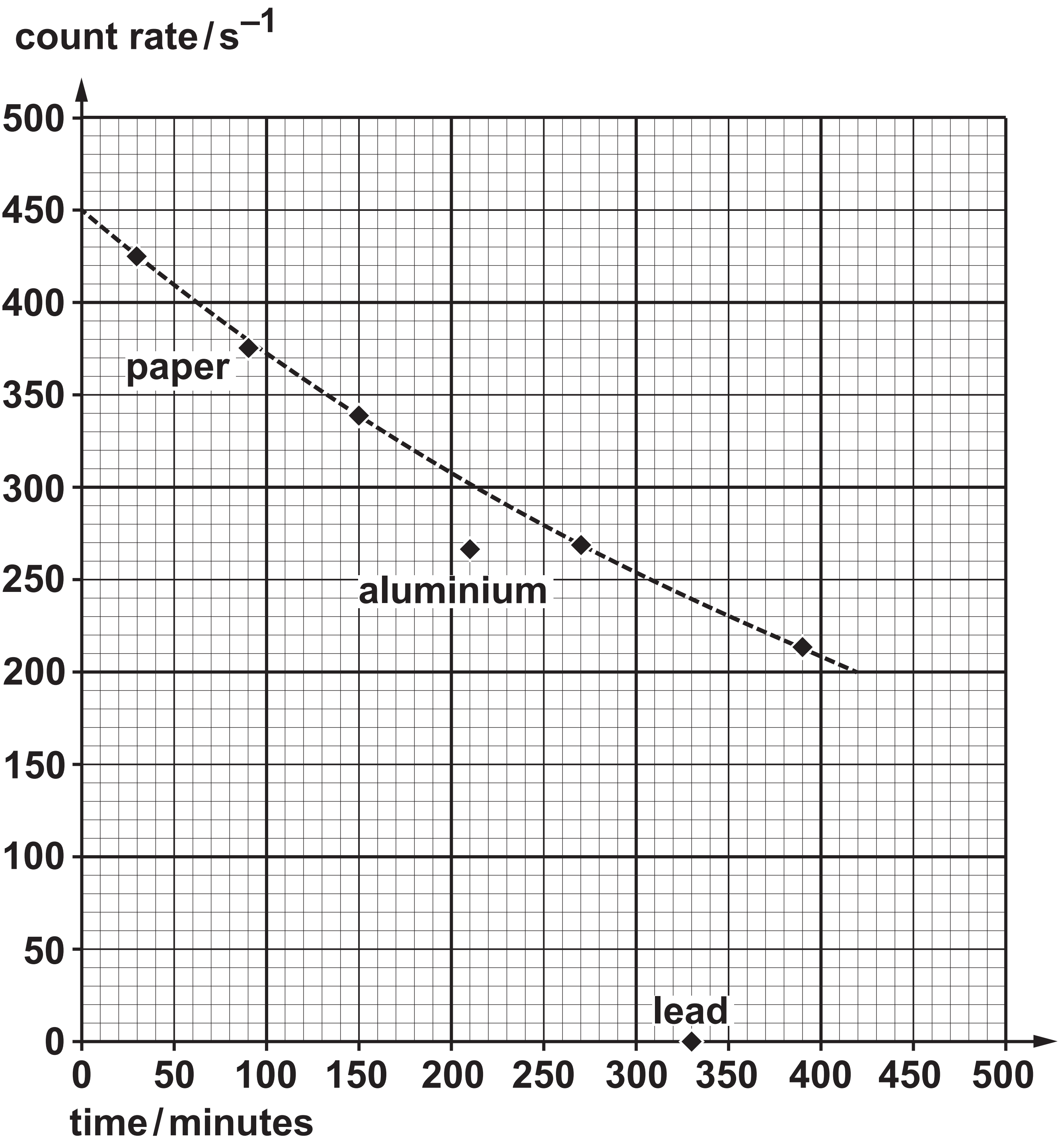
3(a) Some nuclei undergo fusion while others undergo fission. Both processes can result in the release of energy. Discuss these processes in terms of energy and stability. The binding energy per nucleon graph (shown opposite) is provided to assist your answer. [4]

3(b) Use data from the graph (opposite page 13) to estimate the energy released in the reaction. [2]

$$^{1}_{0}n \quad + \quad ^{1}_{1}p \longrightarrow {}^{2}_{1}H$$

3(c) **Use the graph (opposite page 13) to estimate the energy released in the following reaction. (Hint: use the binding energies on both sides of the reaction equation.) [4]**

$$ {}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{137}_{55}Cs + {}^{96}_{37}Rb + 3\,{}^{1}_{0}n $$


count rate / s^{-1}
500
450
400
350
300
250
200
150
100
50
0
paper
aluminium
lead
0
50
100
150
200
250
300
350
400
450
500
time / minutes

4. Technetium-99 emits ONLY γ (gamma) radiation. An experiment was carried out to show this. Various absorbers were placed between the source and detector at the times shown in the table below and the mean count rate was obtained.

Absorber	Time from the start of the experiment / min	Count rate / s^{-1}
none	30	425
1 sheet (0.1 mm) of paper	90	374
none	150	338
3 mm of aluminium	210	267
none	270	268
10 cm of lead	330	1
none	390	213

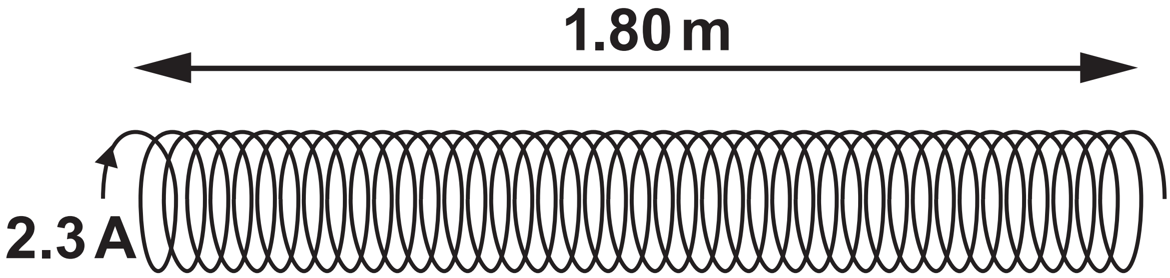
These results were plotted on a graph opposite. The decay curve of the technetium-99 itself is plotted as a dotted line which shows the activity dropping continuously as the experiment proceeded.

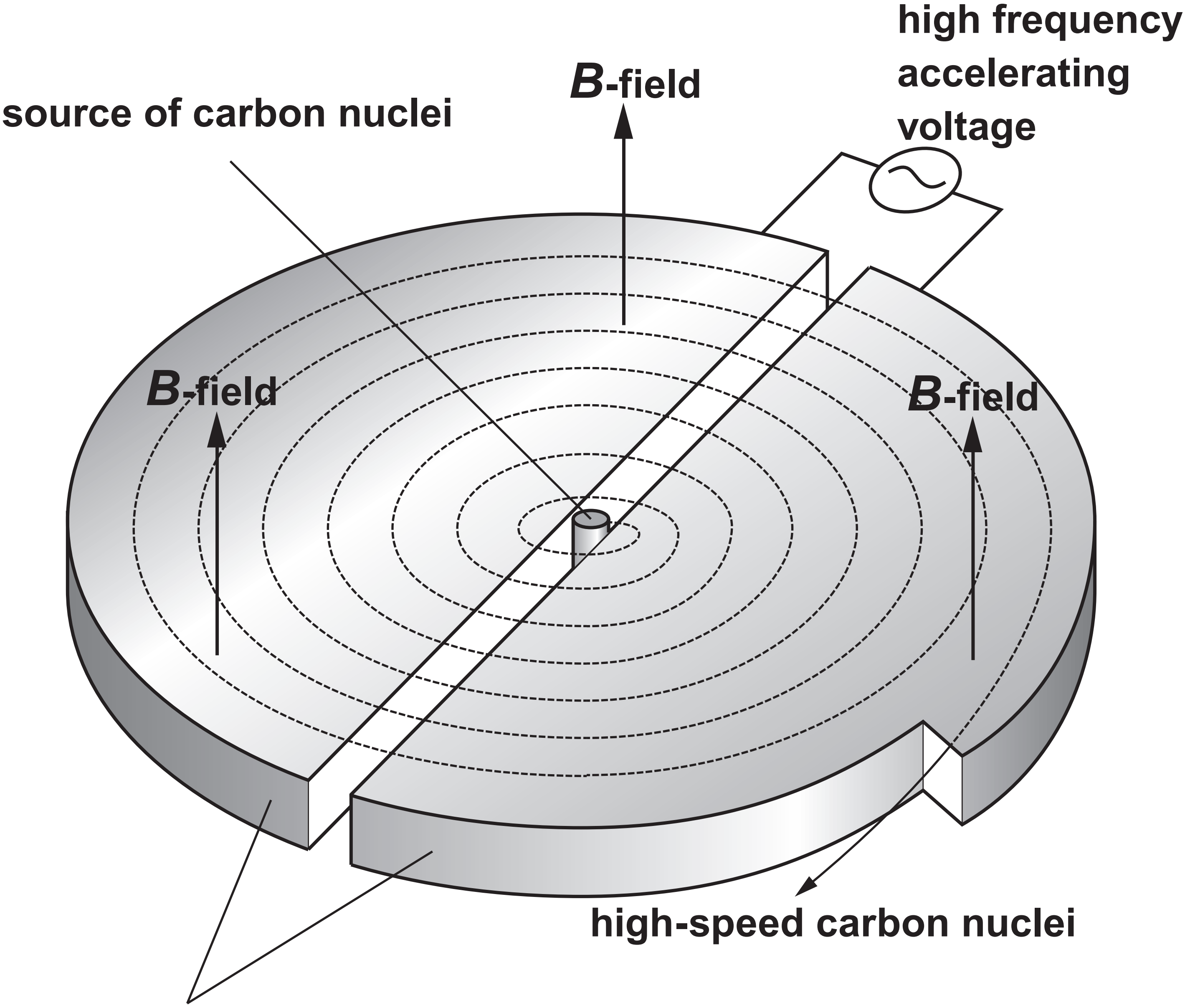
4(a) **Determine the half-life of technetium-99. [1]**

(b) **Explain why the results are consistent with technetium-99 only emitting γ radiation. [3]**

4(c) The detector only detects 0.6% of the γ radiation emitted by the source. Use the graph opposite page 16 and the half-life of technetium-99 to calculate the initial mass of technetium-99 (the mass of a technetium-99 atom is 99 u). [4]

5(a) A long thin solenoid carries a current of 2.3 A, has 12 000 turns and a length of 1.80 m. Calculate the magnetic field strength (B) in the centre of the long solenoid. [2]





high frequency accelerating voltage
B-field
source of carbon nuclei
B-field
B-field
high-speed carbon nuclei
dees

5(b) In a cyclotron a uniform magnetic field (B) provides a centripetal force while an electric field accelerates the charged particles as they cross between the dees. The resulting motion is a spiral as shown opposite.

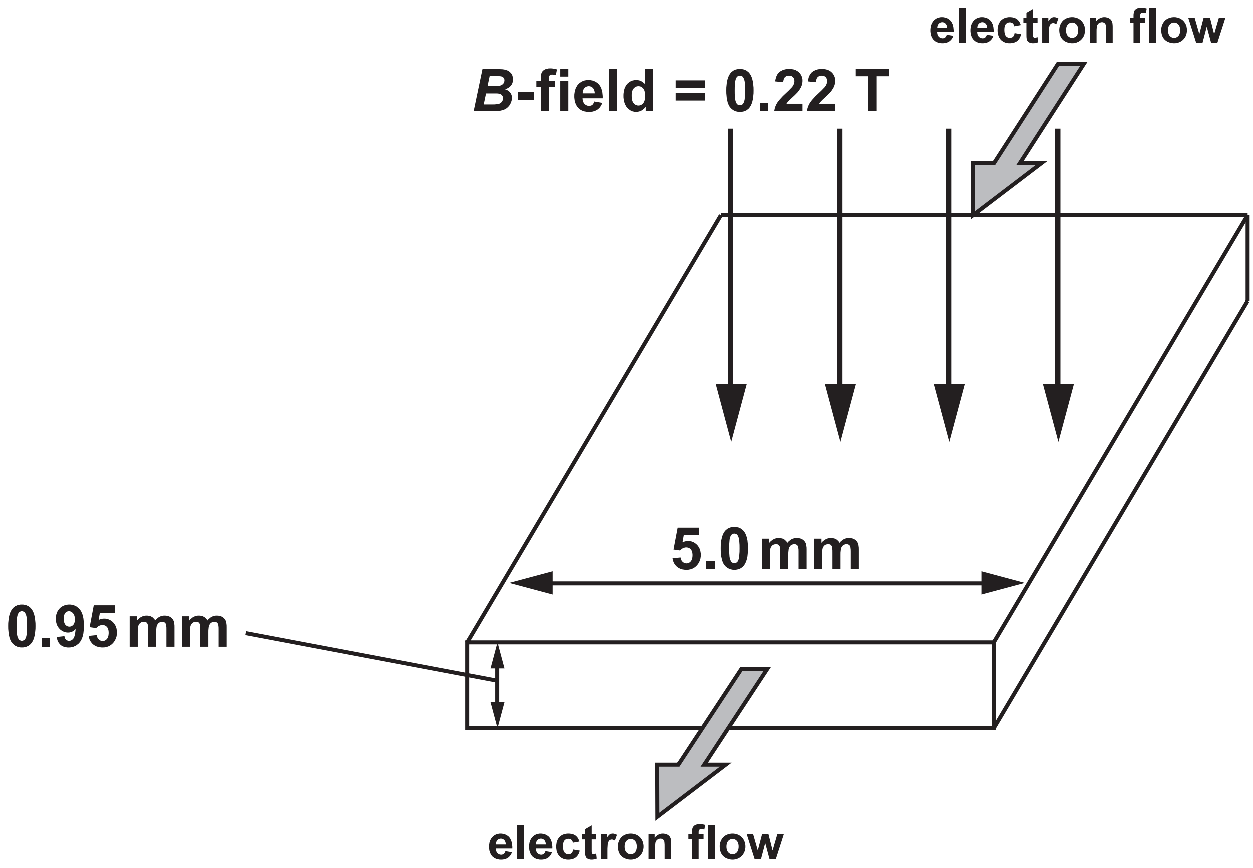
(i) By equating the centripetal force to the magnetic force, show that the frequency of the a.c. supply is given by: [3]

$$f = \frac{Bq}{2\pi m}$$

where q is the charge and m is the mass of the particle.

5(b) (ii) Calculate the cyclotron frequency for a carbon nucleus with $q = 6\,e$ and mass $m = 12\,\text{u}$ in a strong B-field of $3.3\,\text{T}$. [2]

5(b) (iii) **Calculate the final speed of a carbon nucleus after it has completed 12 'orbits' of the cyclotron and the potential difference between the dees is 14.5 kV (assume that the carbon nucleus starts from rest). [4]**


electron flow
B-field = 0.22 T
5.0 mm
0.95 mm
electron flow

6. Electrons flow through a semiconductor slice which is used as a Hall probe.

(a) Indicate on the diagram opposite:

(i) the face of the slice that becomes positively charged; [1]

(ii) a voltmeter suitably connected to measure the Hall voltage. [1]

(b) Calculate the Hall voltage if the drift velocity of the free electrons is $5.7 \times 10^{-3}\,\mathrm{m\,s^{-1}}$. [3]

6(c) **As electrons move through the slice, explain why no work is done on them by the Hall voltage. [1]**

6(d) The concentration of free electrons in the semiconductor slice is $7.0 \times 10^{22}\ m^{-3}$. Calculate the current in the slice. [2]

SECTION B

Answer ALL questions.

The questions refer to the case study.
Direct quotes from the original passage will not be awarded marks.

7(a) Give two reasons why only a SMALL fraction of the work done in compressing the gas is transferred to gravitational potential energy of the football (paragraphs 3 & 4). Note that losses due to heat and sound are negligible. [2]

7(b) Use the values $u = 20\,\mathrm{m\,s^{-1}}$, $m_0 = 1.5\,\mathrm{kg}$ and $\frac{\Delta m}{\Delta t} = 5.9\,\mathrm{kg\,s^{-1}}$ to calculate the speed of the rocket after $0.175\,\mathrm{s}$ (paragraph 11 and equation 2). [2]

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7(c) **Check that the units (or dimensions) of equation 4 are correct.**

$$\frac{\Delta m}{\Delta t} = \pi r^2 \rho u$$

[2]

7(d) **Calculate the exhaust speed of water from the rocket assuming a rate of change of mass of $9.5\,kg\,s^{-1}$ and the radius of the bottle neck is $1.1\,cm$ using equation 4 (density of water = $1\,000\,kg\,m^{-3}$). [2]**

7(e) Using your own words explain why 'the actual rocket does not keep up with its theoretical counterpart' (paragraphs 16-19 and equation 6).

[3]

7(f) **Calculate the initial exhaust speed of water leaving a bottle pumped to a pressure of 7.8×10^5 Pa (the outside atmospheric pressure is 1.0×10^5 Pa) using equation 6 (density of water = 1 000 kg m^{-3}).**

[2]

7(g) The table below refers to the terms on the right hand side of equation 8.

$$F_{res} = \pi r^2 \rho u^2 - mg - 0.0107v^2$$

Complete the table, the first row has been completed for you (paragraphs 20-22). [3]

Term	Description	During the first 0.2 s, this term		
		increases	remains constant	decreases
$\pi r^2 \rho u^2$	Thrust force from exhaust water			✓
mg				
$0.0107v^2$				

7(h) **Show that the first term ($\pi r^2 \rho u^2$) in equation 8 can be written as $2(p - p_{atm}) \times A_{neck}$ where**

A_{neck} is the cross-sectional area of the bottle opening (see equation 5 or 6). [2]

7(i) In practice, using Boyle's law is inappropriate because the gas cools as it expands.

(i) Explain why little or no heat flows when the gas in the bottle expands. [1]

(ii) Use the first law of thermodynamics to explain why the temperature of the gas decreases. [1]

SECTION C: OPTIONAL TOPICS

Option A:	**Further Electromagnetism and Alternating Currents**	☐
Option B:	**Revolutions in Physics – The Newtonian Revolution**	☐
Option C:	**Materials**	☐
Option D:	**Biological Measurement and Medical Imaging**	☐
Option E:	**Energy Matters**	☐

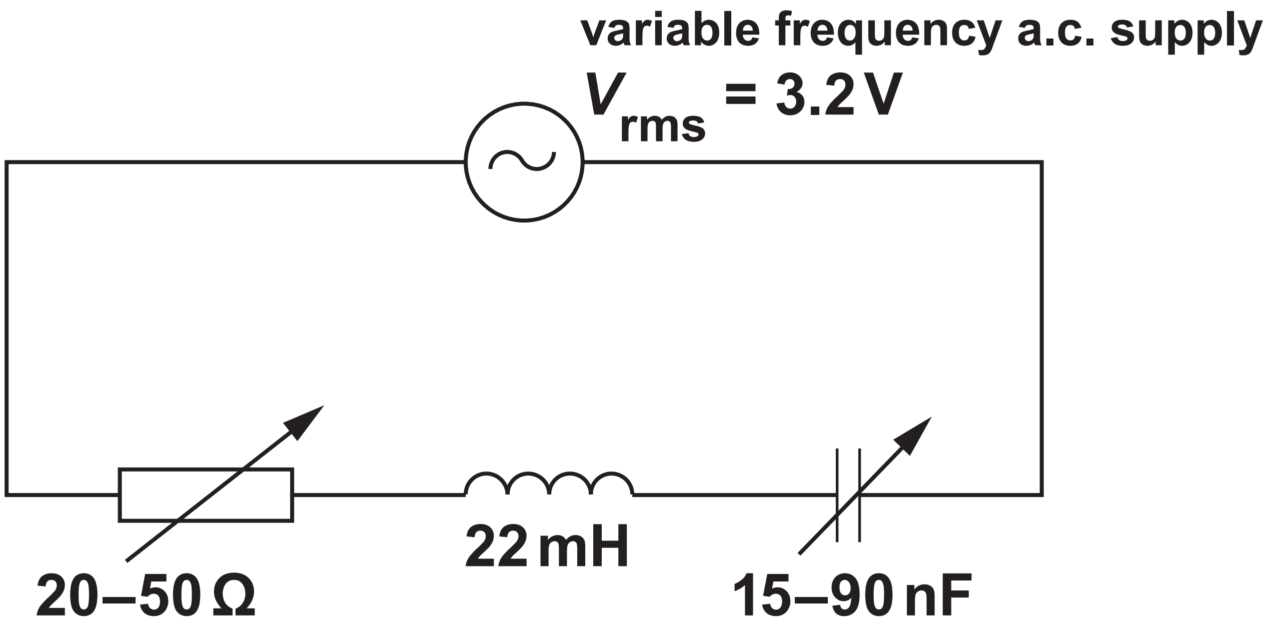
Answer the question on ONE TOPIC ONLY.

Place a tick (✓) in one of the boxes above, to show which topic you are answering.

You are advised to spend about 20 minutes on this section.

Option A: Further Electromagnetism and Alternating Currents

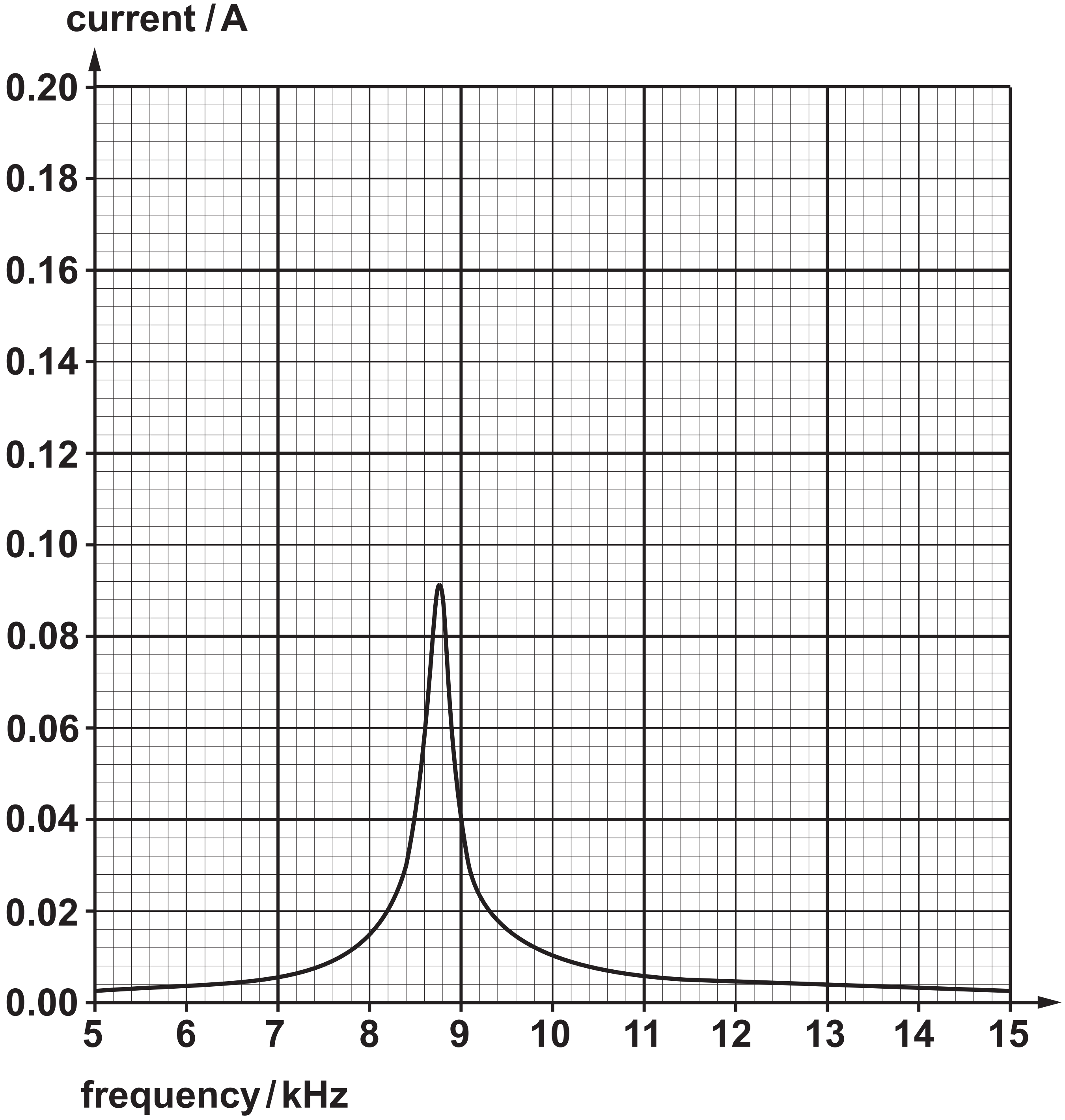
8(a) In the following circuit, both the Q factor and the resonance frequency can be varied by varying the capacitance and the resistance. However, the inductance remains constant.



8(a) (i) Show that the maximum and minimum resonance frequencies are approximately 8 800 Hz and 3 600 Hz respectively. [3]

8(a) (ii) Calculate the maximum Q factor and the minimum Q factor. [4]

8(b) **When $R = 35\,\Omega$ and $C = 15\,\text{nF}$, the frequency of the supply is adjusted to twice the resonance frequency (approximately 17 600 Hz). Calculate the rms current. [3]**


current / A
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
5
6
7
8
9
10
11
12
13
14
15
frequency / kHz

8(c) The resonance curve for the circuit with $R = 35\,\Omega$ and $C = 15\,\text{nF}$ is shown opposite.

(i) Add TWO LABELLED curves to the graph showing the variation of current against frequency when $R = 20\,\Omega$ and $C = 15\,\text{nF}$ and when $R = 50\,\Omega$ and $C = 15\,\text{nF}$. [4]

Space for your calculations if needed.

8(c) (ii) Use the equation

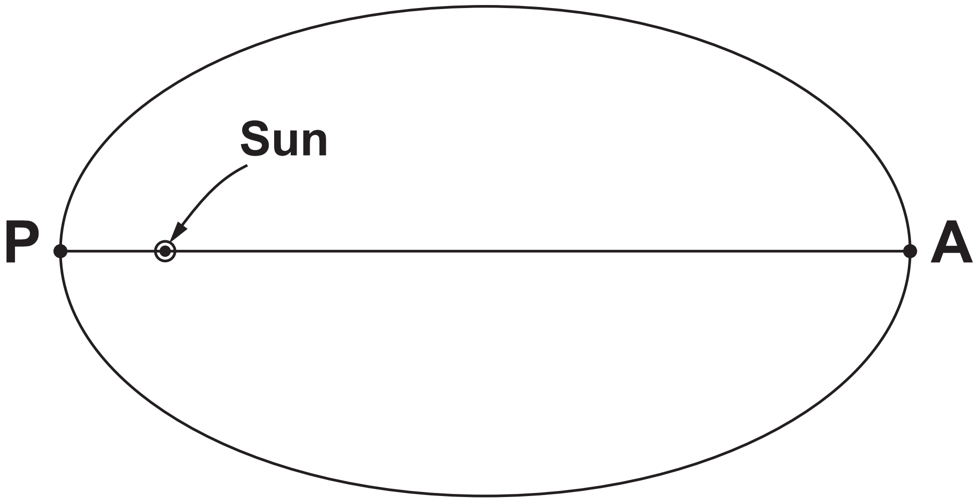
$$Z = \sqrt{\left(\omega L - \frac{1}{\omega C}\right)^2 + R^2}$$

to explain in detail why the current varies with frequency as shown in the graph opposite page 41 (no calculations are required). [6]

Option B: Revolutions in Physics – The Newtonian Revolution

9(a) (i) Tycho Brahe and another astronomer, 570 km away, were able to make simultaneous angle measurements on heavenly bodies. They could measure parallax down to about $\frac{1}{60}$ degree (0.017°) due to their different locations. Show clearly, GIVING A LABELLED DIAGRAM, that the furthest distance away of a body for which they could measure parallax was about 2×10^6 km. Assume the body to be directly overhead. [3]

9(a) (ii) Tycho Brahe and his associate could easily measure parallax for the Moon (0.40×10^6 km away) but were barely able to detect the parallax of a comet which appeared in 1577. Explain why this provided evidence against Aristotle's division of the universe into sublunary and superlunary (beyond the Moon) regions, where different laws applied. [2]

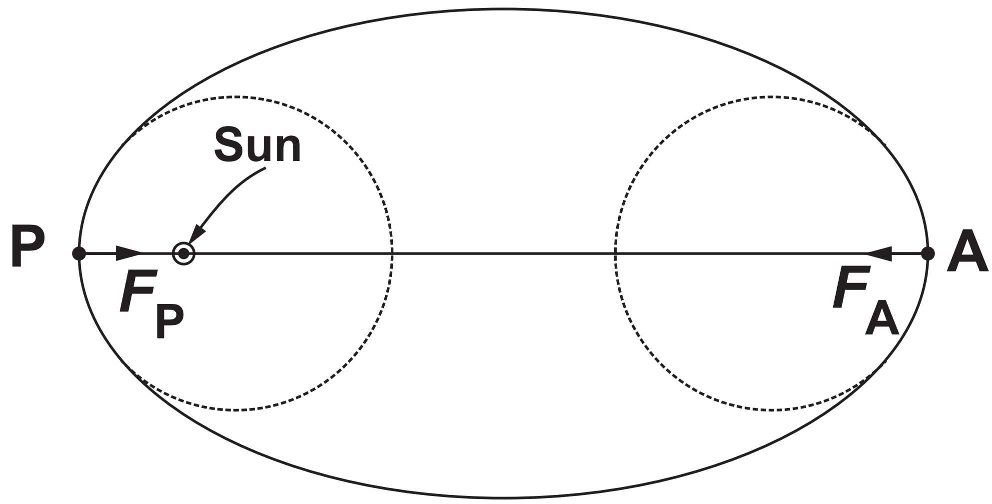

Sun
P
A

9(b) (i) A planet's speed and distance from the Sun at perihelion (P) and aphelion (A) are related by:

$$r_P \, v_P = r_A \, v_A$$

Derive this from Kepler's EQUAL AREA law (Kepler's second law), ADDING TO THE DIAGRAM opposite to assist your explanation. [3]

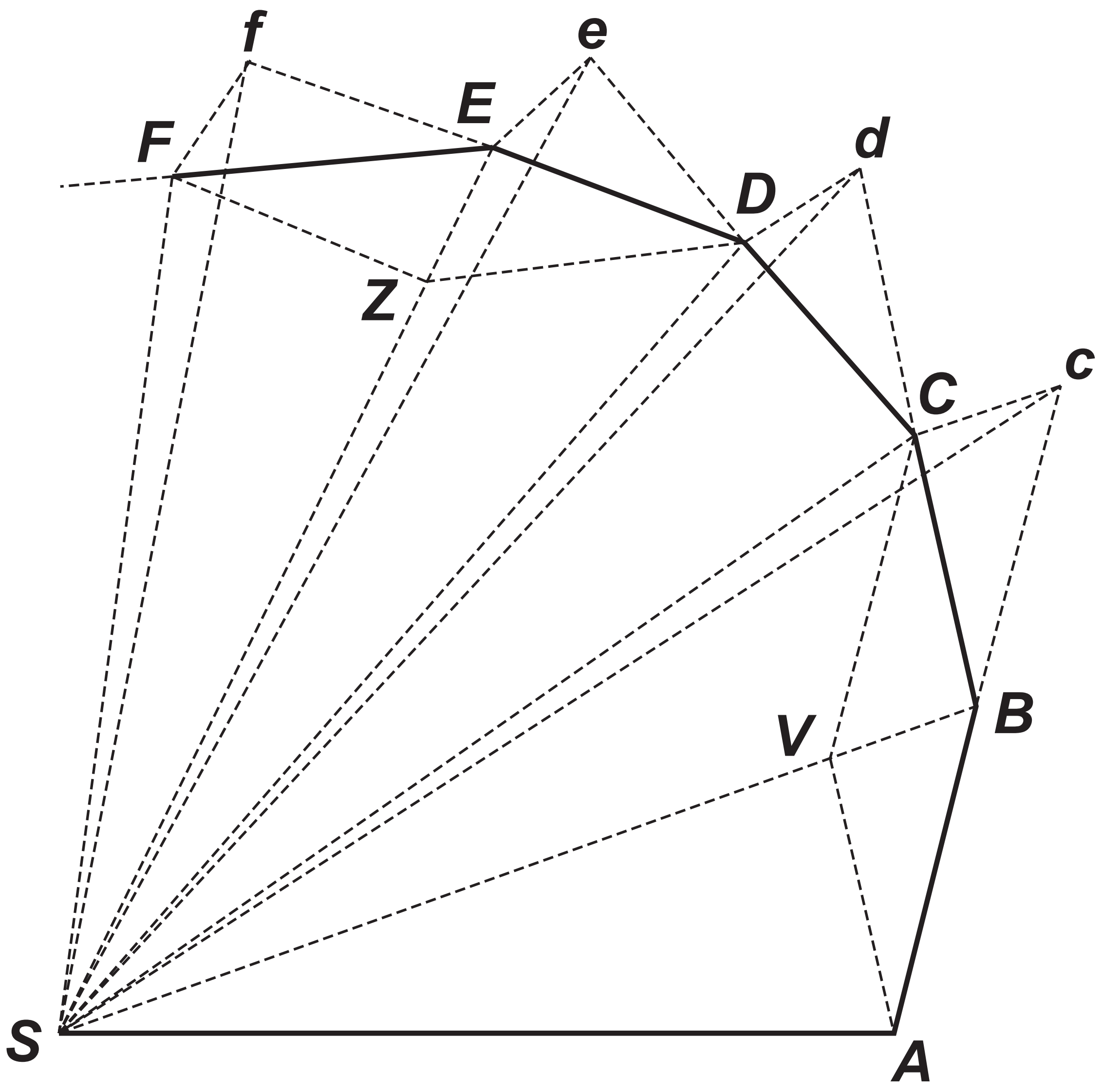
9(b) (ii) For Jupiter, $r_P = 7.41 \times 10^8$ km and $r_A = 8.16 \times 10^8$ km. Evaluate the PERCENTAGE change in Jupiter's speed as it goes from A to P. [2]


Sun
P
A
F_P
F_A

9(b) (iii) At P and A a planet's elliptical path coincides with circles of equal radius as shown opposite.

I. Show that the ratio of forces $\frac{F_P}{F_A}$ on the planet at P and A is $\frac{v_P^2}{v_A^2}$. [1]

9(b) (iii) II. **Use the relationship in (b)(i) to show clearly that this is consistent with an inverse square law force between the Sun and planet. [1]**

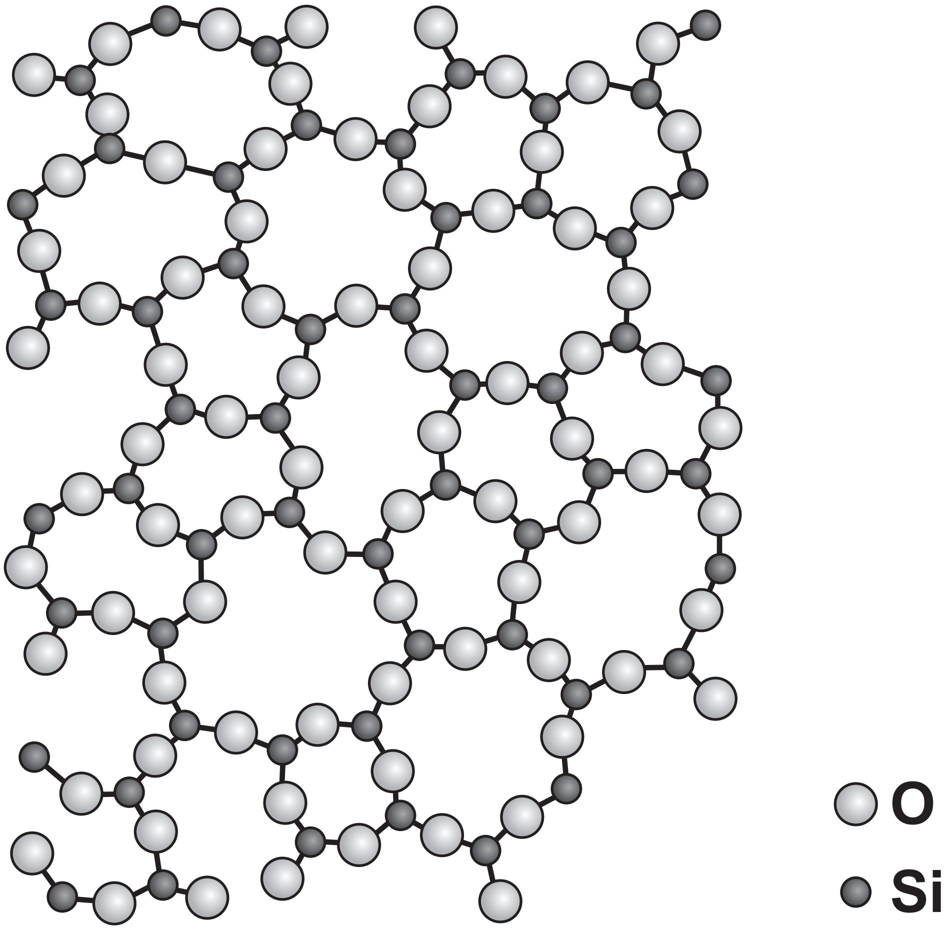

f
e
E
F
d
D
Z
C
c
B
V
S
A

9(c) **The diagram opposite, from Newton's Principia, shows the motion of a body acted upon by short, sharp forces at regular intervals.**

(i) **In which direction(s) do these forces act?** **[1]**

(ii) **State what Newton was able to show about the triangles *ASB*, *BSC*, *CSD* and how the argument could be applied to the motion of planets.** **[3]**

9(c) (iii) **Over forty years before Newton published the Principia, Descartes had proposed a quite different explanation for why planets orbited the Sun. What was Descartes' explanation, why did many people find it more satisfying than Newton's, and why is it now almost forgotten? [4]**


O
Si

Option C: Materials

10(a) The picture opposite shows the microscopic structure of glass, an amorphous solid.

Explain the following macroscopic properties of glass.

(i) Glass fibres are brittle, showing no plastic deformation before fracture. [2]

10(a) (ii) **A sheet of glass can be fractured accurately and cleanly if its surface is scratched and then the glass is bent slightly. [You may wish to draw a labelled diagram to support your answer.] [2]**

10(a) (iii) **During production, car windscreens are strengthened by using jets of cold air to cool the outer surfaces of the hot glass. This causes the outside to contract quickly while the inside remains soft. Later, the inside cools and contracts. Explain how this process makes the windscreen difficult to break. [2]**

10(b) Advanced aircraft and spacecraft applications require aluminium based alloys which are able to operate under extremely diverse conditions. The properties of three of these alloys are given in the table.

Aluminium alloy	Young modulus / GPa	Yield strength / MPa	Maximum tensile strain / %
Alloy **A**	80	800	9
Alloy **B**	80	1 000	5
Alloy **C**	60	600	15

The graph opposite page 59 shows the stress against strain graph for alloy **A**.

(i) Use information from the graph to confirm that the Young modulus of alloy **A** is 80 GPa. [1]

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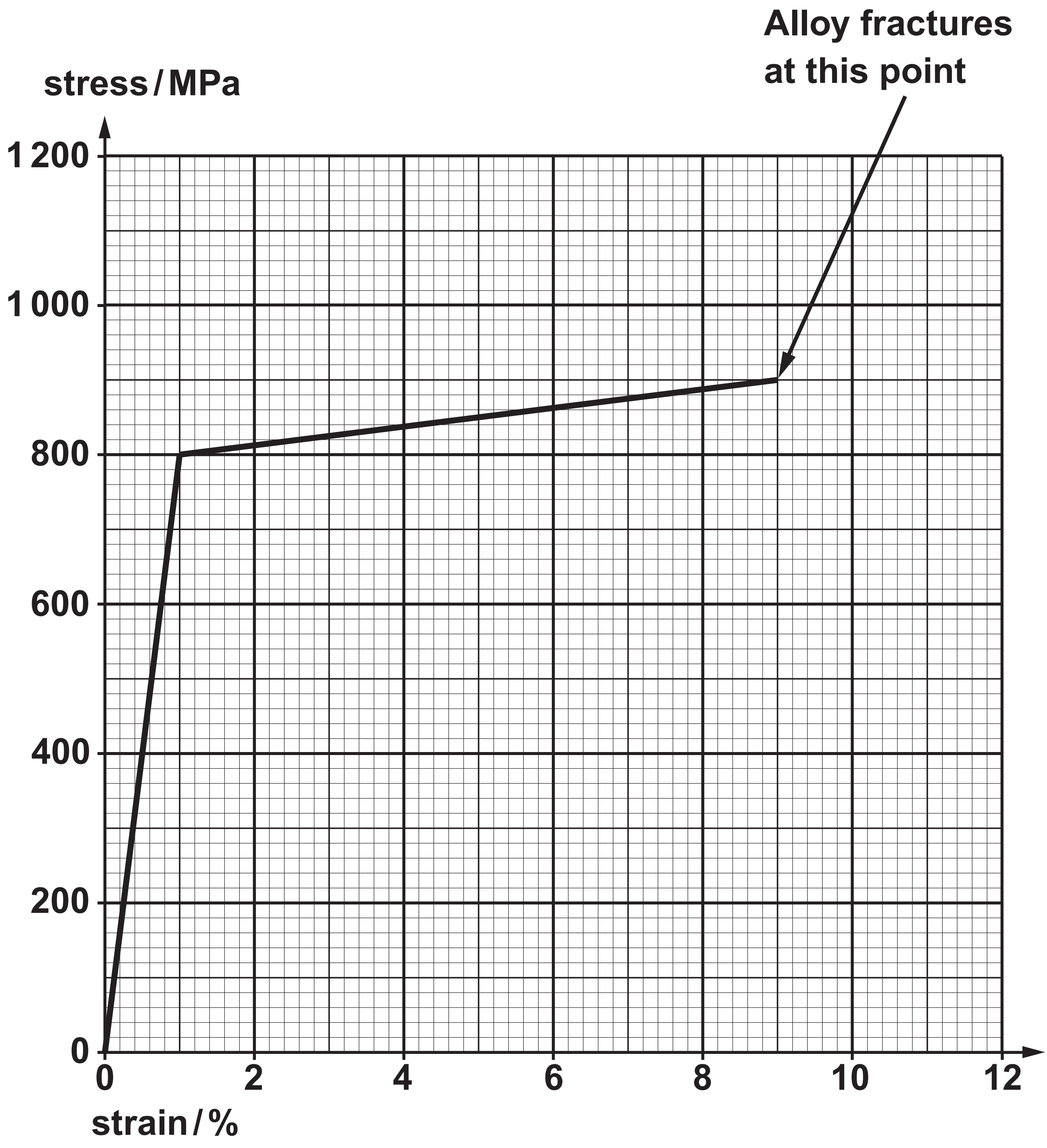
10(b) (ii) Alloy A is in the form of a cylinder of length 2.5 m and diameter 2.5 mm. Determine the work done to stretch this alloy to breaking point. [3]



Alloy fractures
at this point
stress / MPa
1 200
1 000
800
600
400
200
0
0
2
4
6
8
10
12
strain / %

10(b) (iii) Draw, on the same axes, a simplified stress against strain graph for ALLOY **B** using data from the table on page 57. [3]

(iv) When these alloys are placed under a constant stress over a long period of time all three undergo CREEP leading to NECKING and eventually fracture.

I. Explain the terms in CAPITALS. [2]

CREEP: ______________________________________

____

____

____

NECKING: ______________________________________

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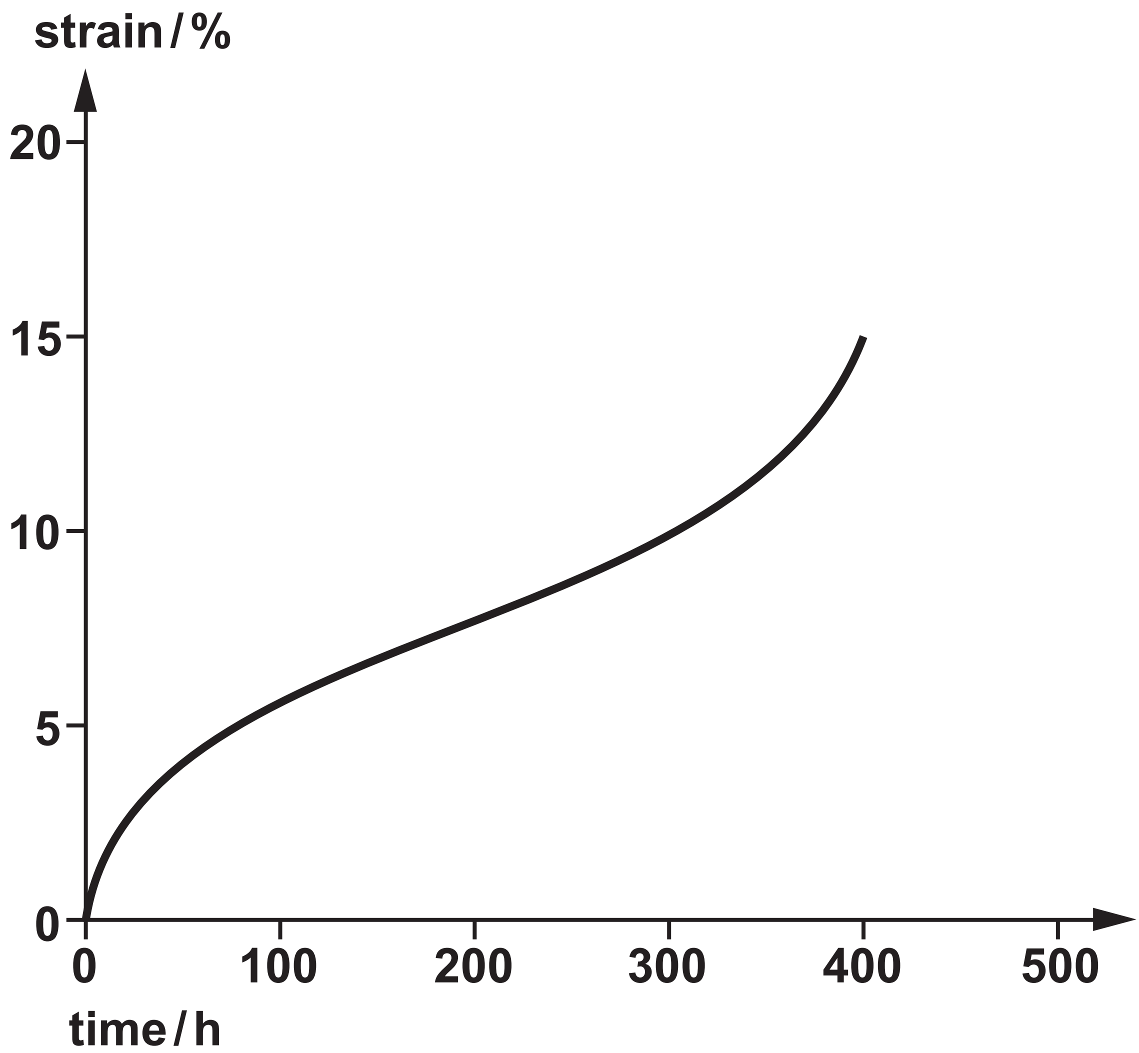
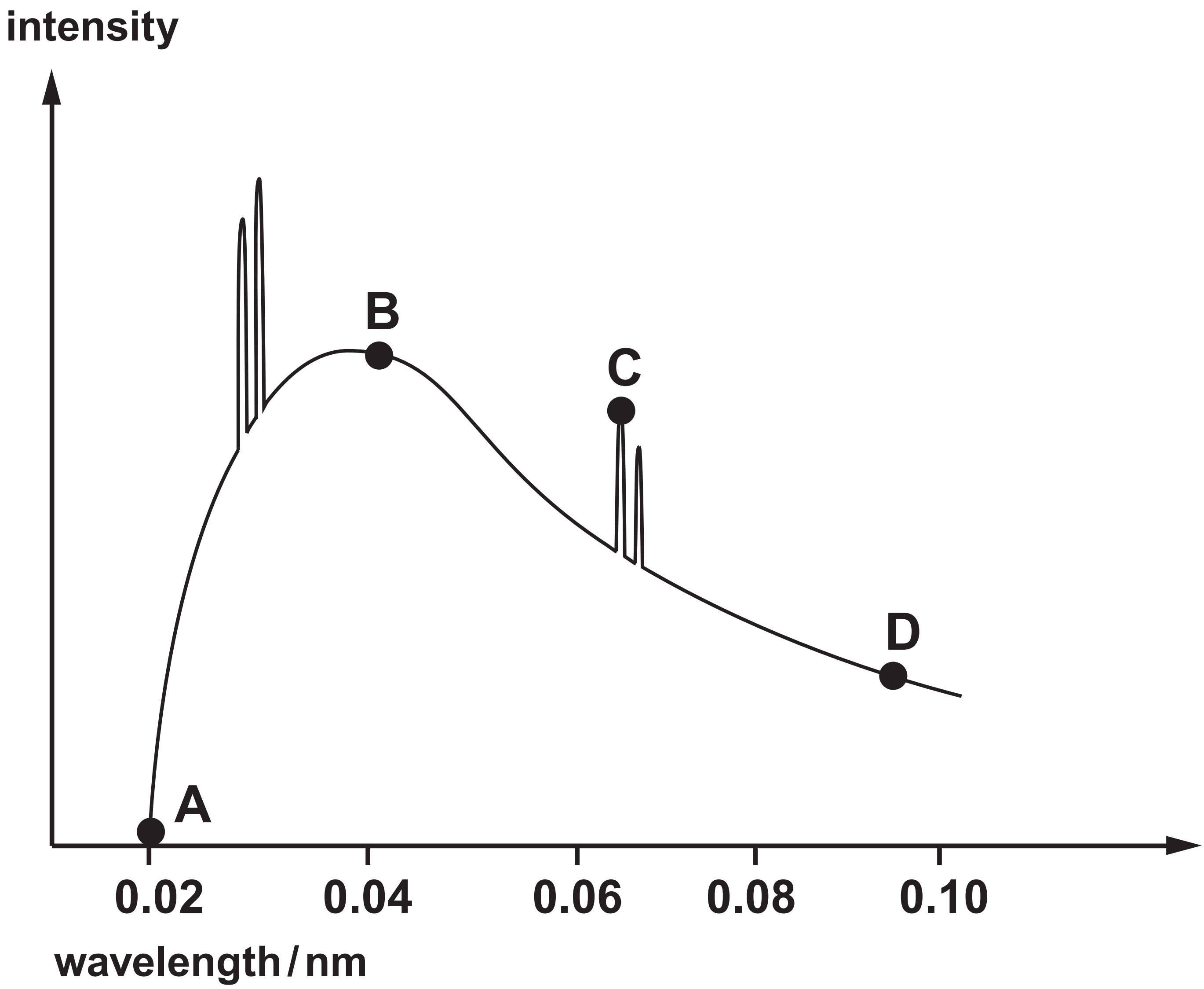
10(b) (iv) II. A creep curve for ALLOY **C** is shown. The alloy was subjected to a constant stress of **100 MPa**. Using information in the table on page 57, sketch on the same graph (below) a creep curve which could represent alloy **C** when it is subjected to a constant stress of **120 MPa**. [2]



10(b) (v) **During production the strength of the alloy is controlled by a process called cold working (or work hardening). Describe this process and explain how it increases the strength of the alloy under production. [3]**



intensity
B
C
D
A
0.02
0.04
0.06
0.08
0.10
wavelength / nm

Option D: Biological Measurement and Medical Imaging

11. An X-ray spectrum is shown opposite.

(a) Which of the points correspond to X-ray photons produced:

(i) by rapidly decelerating electrons; [1]

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(ii) after knocking out the inner electrons of the target atom; [1]

____

(iii) with the greatest energy per photon? [1]

____

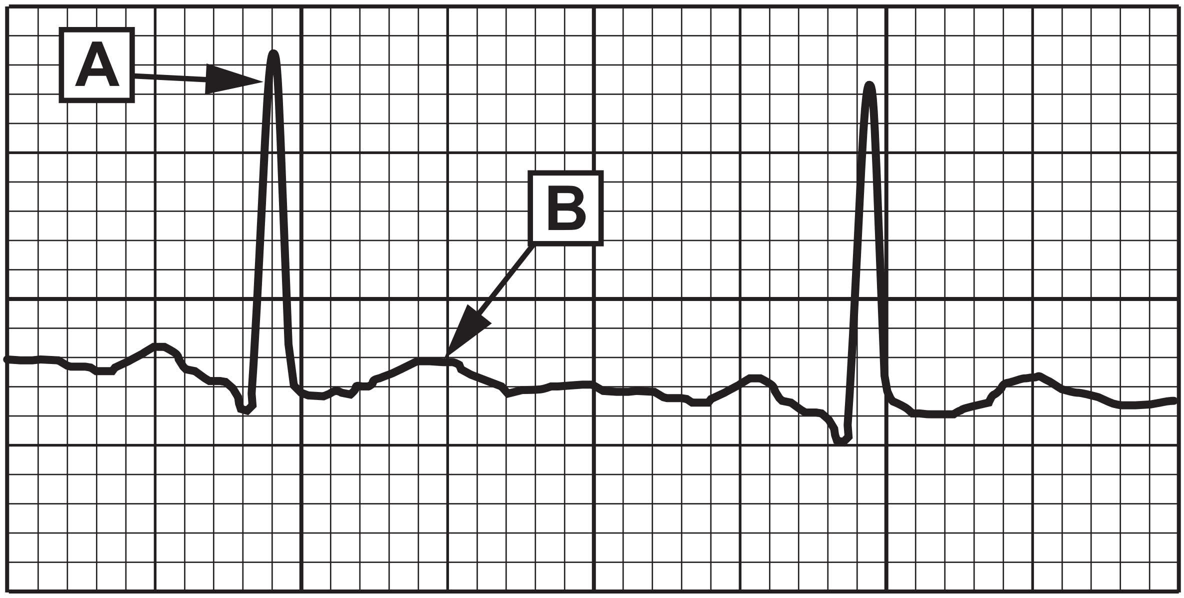
11(b) Use information from the graph opposite page 62 to calculate the accelerating pd used in the X-ray tube. [2]

11(c) **Before taking an X-ray photograph the X-ray beam emerging from the tube is passed through an aluminium filter. Explain why it is necessary for the X-rays to be filtered. [2]**

(d) (i) Name the region of the electromagnetic spectrum used in MRI scans. [1]

11(d) (ii) Briefly explain the function of this electromagnetic radiation in the working of an MRI scan. [2]

(iii) Describe one disadvantage of MRI scanning as an imaging technique. [1]


A
B

11(e) **The diagram opposite shows an ECG trace for a healthy person.**

State what electrical event and physical change occur at:

(i) Point A; [2]

Electrical event

Physical change

11(e) (ii) Point B. [2]

Electrical event

Physical change

11(f) Ultrasound can be used to measure the speed at which blood is flowing. When reflected off a red blood cell, the wavelength of the ultrasound changes.

(i) What is the name given to this effect? [1]

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(ii) If ultrasound of wavelength 500 μm is used, its speed when travelling through blood is 1 500 m s^{-1} and the wavelength received at the detector is 500.4 μm. Calculate the speed of the flow of blood.

[2]

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11(g) (i) PET scans are often used to detect tumours. What part of the electromagnetic spectrum do PET scanners detect? [1]

(ii) Why are PET scanners NOT commonly used in district hospitals? [1]

Option E: Energy Matters

12(a) Explain why it is important to enrich uranium before it is suitable to be used in a fission nuclear power station. [3]

12(b) In a breeder nuclear reactor uranium-238 is changed into plutonium. Explain the advantage of this and how it is achieved. [2]

12(c) State TWO possible advantages of deuterium-tritium fusion over uranium-235 fission. [2]

12(d) For nuclear fusion to be a viable energy resource a deuterium-tritium plasma must have a large enough confinement time (τ), a high enough temperature (T) and a high enough concentration (number per m^3) of deuterium and tritium particles (n). These conditions are usually expressed as:

$$\tau T n \geq 3.5 \times 10^{28}\ \text{s K m}^{-3}$$

(i) Explain why a high temperature (T) is necessary. [3]

12(d) (ii) A confinement time (τ) of $0.9\,\mathrm{s}$ and a temperature of 120 million Kelvin are attainable. Calculate the minimum density of plasma required in $\mathrm{kg\,m^{-3}}$ (the mean mass of deuterium and tritium ions is $2.5\,\mathrm{u}$). [3]

12(e) The energy that can be produced from 1 kg of uranium-235 is 8.3×10^{13} J whereas the energy available from 1 kg of deuterium-tritium is 3.4×10^{14} J. Calculate the energy that can be produced from 1 kg of anti-matter (remember that anti-matter and matter annihilate). [2]

12(f) Coal, biomass, uranium-235, natural gas and wind are five energy resources with similar mean costs per MWh of energy production (£40-£60 per MWh). Discuss other advantages AND disadvantages of all five energy resources. [5]

END OF PAPER

Question number	Additional page, if required. Write the question numbers in the left-hand margin.

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