Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

S24-1420U40-1

1420U40-1

THURSDAY, 13 JUNE 2024 – MORNING

PHYSICS – A2 unit 4
Fields and Options

2 hours

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**10**	
	2.	**6**	
	3.	**16**	
	4.	**18**	
	5.	**18**	
	6.	**12**	
Section B	**Option**	**20**	
	Total	**100**	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a **Data Booklet**.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Answer **all** questions.

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

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B**.

Section **A**: 80 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.

Section **B**: 20 marks. Options. Answer **one option only**. You are advised to spend about 25 minutes on this section.

The number of marks is given in brackets at the end of each question or part-question.

The assessment of the quality of extended response (QER) will take place in question **2**.

Examiner only

SECTION A

Answer **all** questions.

1. A laboratory technician needs to make a 230 pF capacitor using two square metal plates of side length 8.7 cm.

(a) Calculate the separation of the metal plates in order to produce this capacitance. [3]

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(b) The technician states that the 230 pF capacitor stores approximately 0.9 μJ of energy when it stores a charge of 20 nC on its plates. Determine whether or not the technician is correct. [3]

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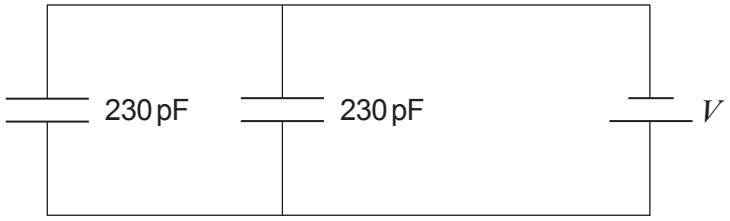
Examiner only

(c) By discussing the pd and charge on each of the capacitors, explain why the capacitance of the two 230 pF capacitors connected in parallel is 460 pF. [3]



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(d) **Draw a diagram** to show how you could combine three capacitors of 230 pF to provide a capacitance of approximately 150 pF. [1]

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Examiner only

2. Describe how you would carry out an experiment to investigate the discharging of a capacitor through a resistor to determine the time constant. [6 QER]

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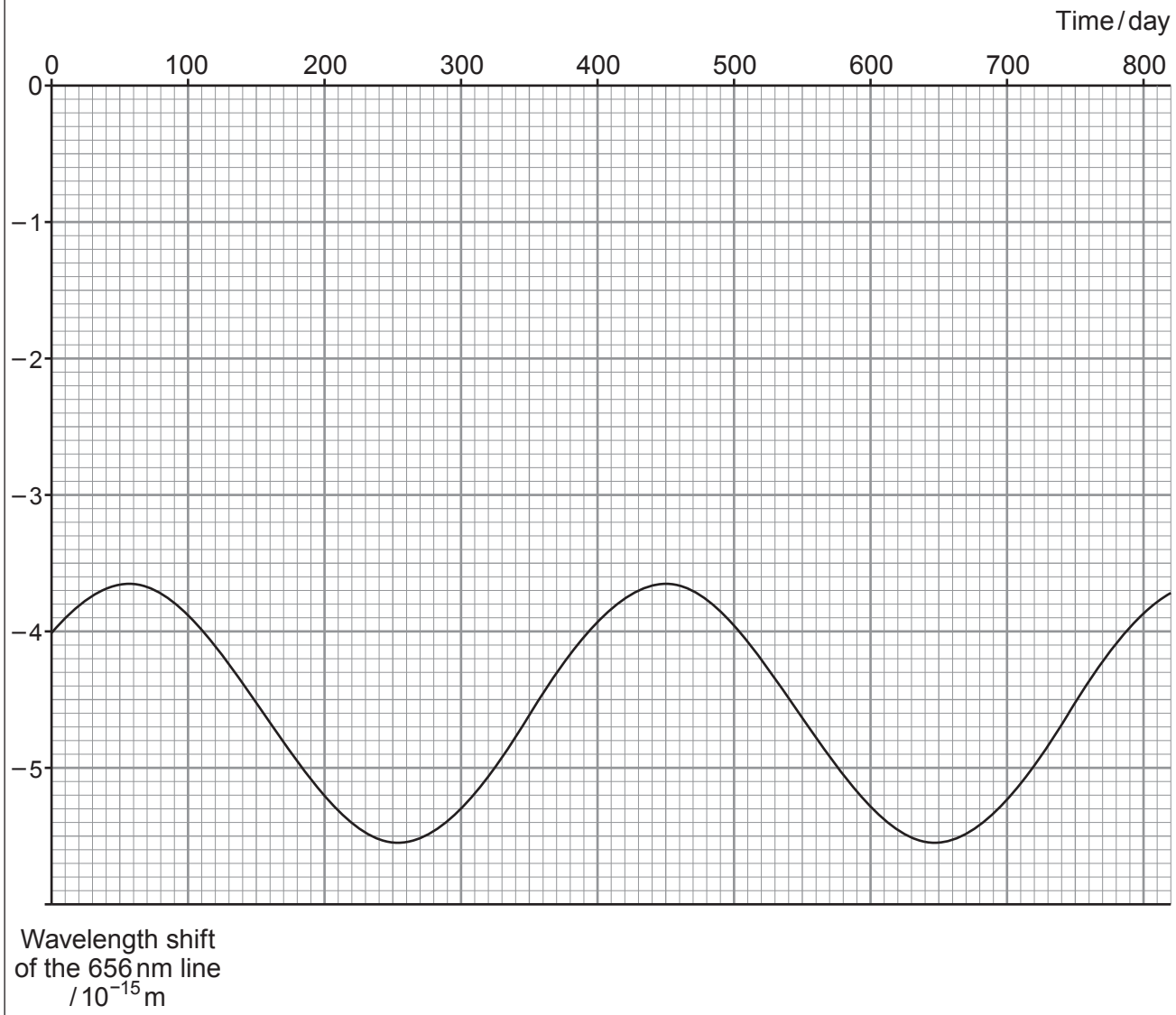
3. In the future, analysis of the 656 nm red hydrogen line from a distant star might reveal the following Doppler variation in wavelength (the star would be viewed edge-on).



The mean wavelength is shorter than 656 nm on average because of the mean radial velocity of the star but the sinusoidal variation is caused by an orbiting planet.

Examiner only

(a) Use the data in the graph to show that the mean radial velocity of the star is approximately $-2\,m\,s^{-1}$ and that the orbital speed of the star around the centre of mass is approximately $0.4\,m\,s^{-1}$. [4]

(b) Explain briefly whether the light is blue-shifted or red-shifted. [1]

(c) Show that the radius of the star's orbit is approximately 2 000 km. [3]

Examiner only

(d) The star has a mass of 2.07×10^{30} kg.

(i) Calculate the distance between the star and the planet. [3]

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(ii) Calculate the mass of the orbiting planet (assume that the mass of the planet is much smaller than the mass of the star). [2]

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(e) The values of part (d) reveal that the star is very similar in mass to the Sun, the planet's distance from the star is very close to the distance between the Sun and Earth but that the mass of the planet is approximately 5 times that of the Earth. Discuss whether or not it is scientifically reasonable to conclude that life exists on this planet. [3]

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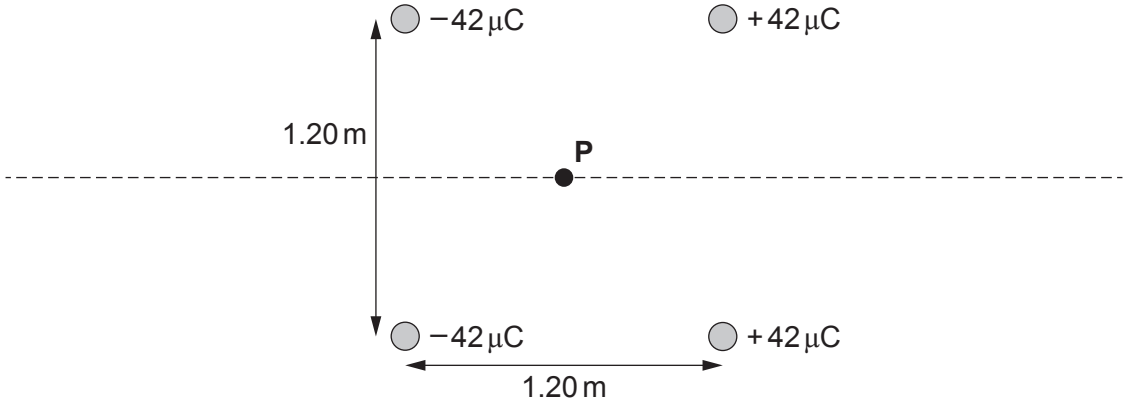
Examiner only

4. Four point charges are placed at the corners of a square of length 1.20 m as shown. Point **P** is located at the centre of the square.



(a) (i) Define electric field strength. [1]

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(ii) Show that the magnitude of the electric field strength at **P** due to any one of the four charges is approximately 520 kN C^{-1}. [3]

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(iii) Hence, calculate the resultant electric field strength at **P** and give its direction. [3]

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Examiner only

(b) A negative point charge is held at **P** and is free to move along the dotted line shown in the diagram with no resistive forces.

(i) Define electric potential. [1]

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(ii) Explain briefly why the potential energy of the negative charge is zero at **P**. [2]

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(iii) Aled states "The negative charge initially accelerates to the right, then slows down but will just about reach infinity if no resistive forces act." Discuss to what extent Aled's points are correct. [3]

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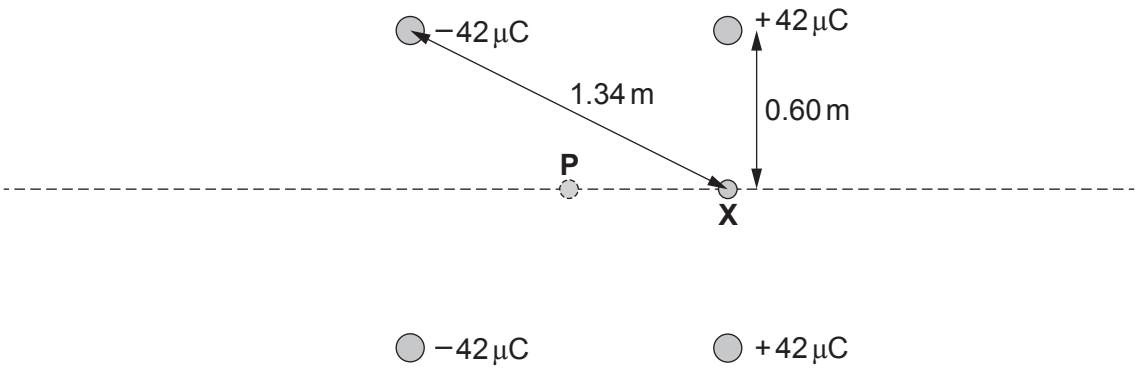
Examiner only

(iv) A charge of −38 nC and mass of 7.7×10^{-4} kg is released from rest from point **P**. Calculate the speed of the −38 nC charge when it reaches point **X** shown below.

[5]



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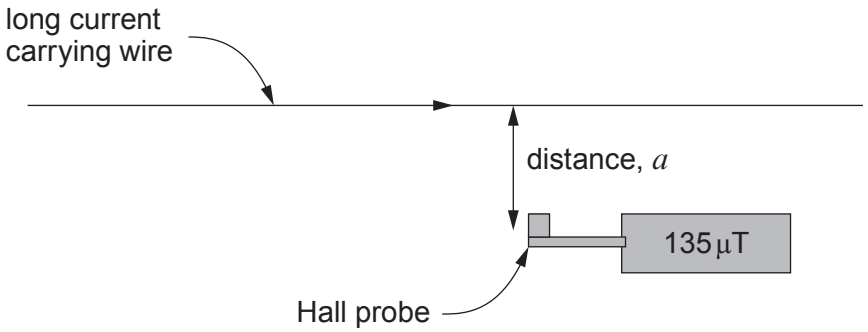
5. Michael carries out an experiment to determine how the magnetic field, B, due to a long current carrying wire varies with distance, a, from the wire.



His results are recorded in a table and a graph of $\ln(B)$ against $\ln(a)$ is plotted using the corrected B-field.

a/m	Measured B-field/T	Corrected B-field, B/T	$\ln(a/\text{m})$	$\ln(B/\text{T})$
0.010	0.000529	0.000499	−4.61	−7.60
0.020	0.000279	0.000249	−3.91	−8.30
0.040	0.000157	.....	.....	.....
0.080	0.000092	0.000062	−2.53	−9.69
0.160	0.000063	0.000033	−1.83	−10.32
0.300	0.000046	0.000016	−1.20	−11.04

(a) Explain why the corrected B-field, B must be obtained. [1]

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(b) **Complete the table** above and **plot the missing point** on the graph opposite (no error bars are required). [3]

(c) The gradient of the steepest line is −1.03. Calculate the gradient of the least steep line. [2]

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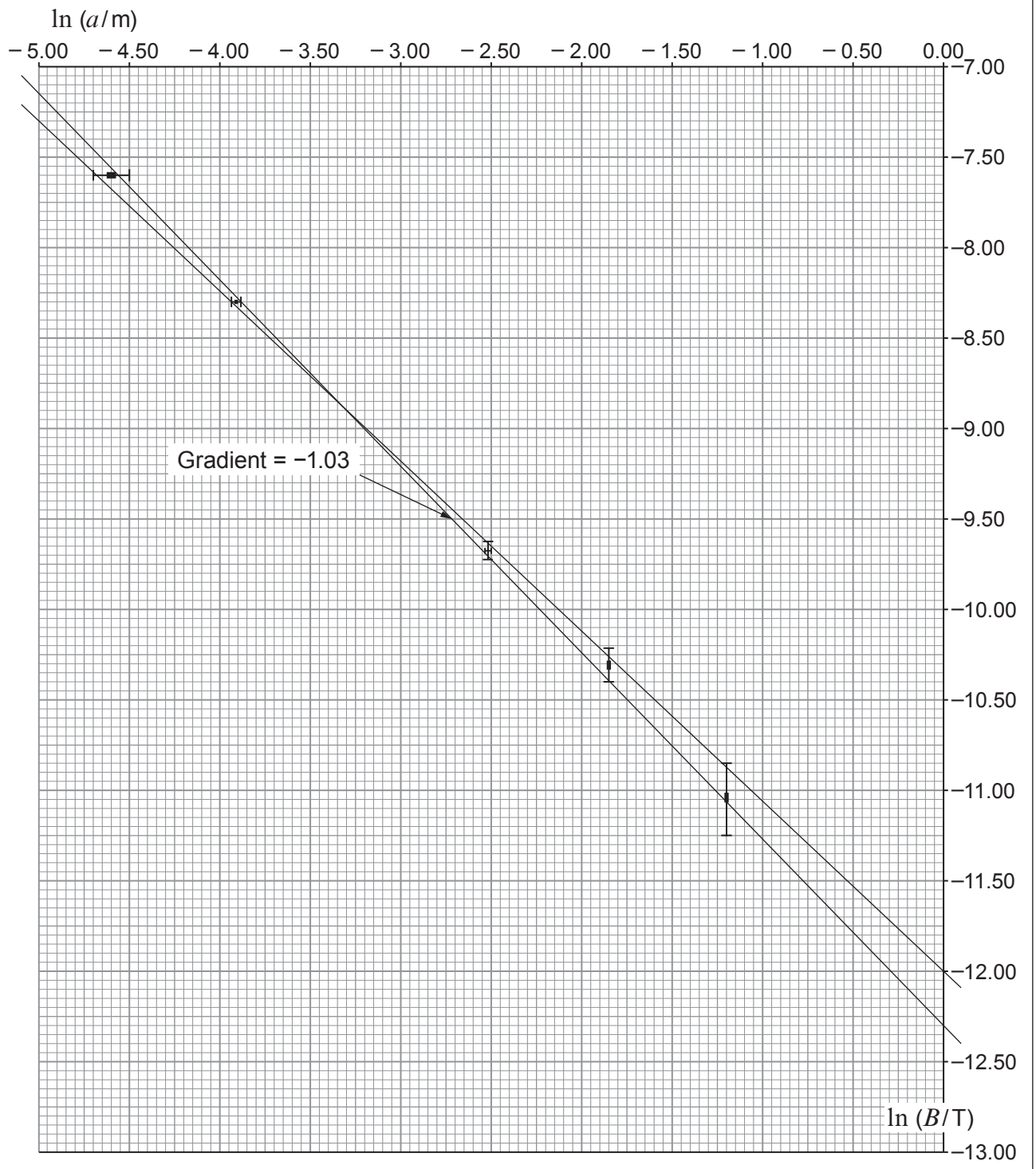
Examiner only



(d) Use the equation $B = \frac{\mu_0 I}{2\pi a}$ to show that the expected mean gradient is −1 and that the expected $\ln(B)$ intercept is $\ln\left(\frac{\mu_0 I}{2\pi}\right)$. [2]

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Turn over.

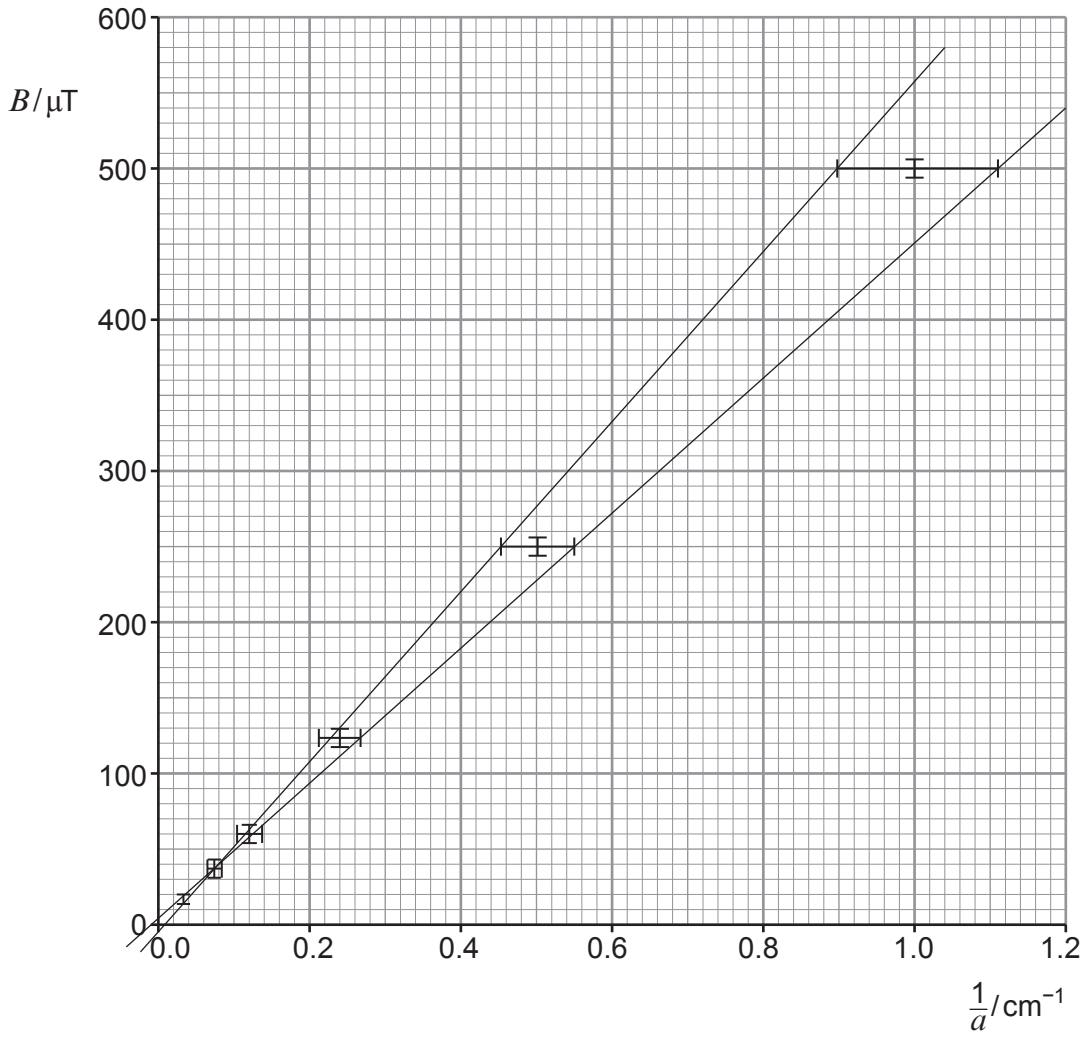
Examiner only

(e) Explain to what extent the graph confirms the relationship $B = \frac{\mu_0 I}{2\pi a}$. [3]

(f) Calculate the current in the wire along with its **absolute** uncertainty. [5]

Examiner only

(g) Bethan analyses Michael's data by plotting a graph of B against $\frac{1}{a}$.



Explain briefly why Michael's log graph is more suitable than Bethan's graph for this data set (no calculations are required). [2]

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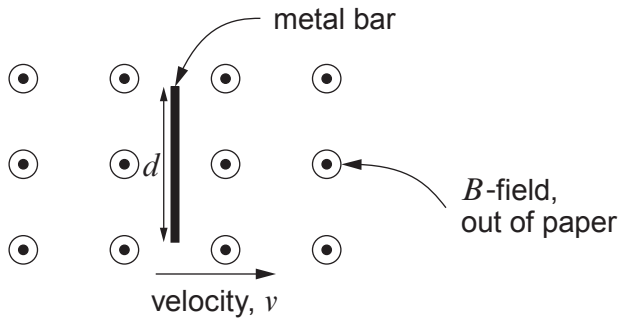
Turn over.

Examiner only

6. (a) The diagram shows a metal bar moving with velocity, v, through a uniform magnetic field, B.



Show that the rate of cutting of flux is Bvd. [2]

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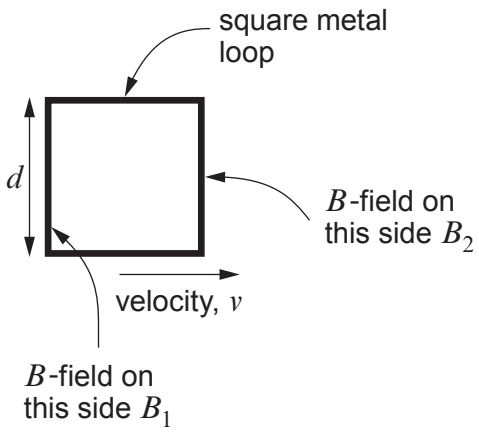
(b) A square metal loop moves through a **non-uniform** B-field with the field coming out of the paper.



Examiner only

(i) Use the expression in part (a) to explain why the induced emf in the square metallic loop is given by: [3]

$$(B_2 - B_1)vd$$

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(ii) The B-field, through which the square metal loop moves, increases with distance at a rate of $1.20\,\text{T}\,\text{m}^{-1}$ (in the direction of the velocity). The square loop has sides of length 3.8 cm and moves at a speed of $8.8\,\text{m}\,\text{s}^{-1}$. Show that the induced emf in the square metal loop is approximately 15 mV. [2]

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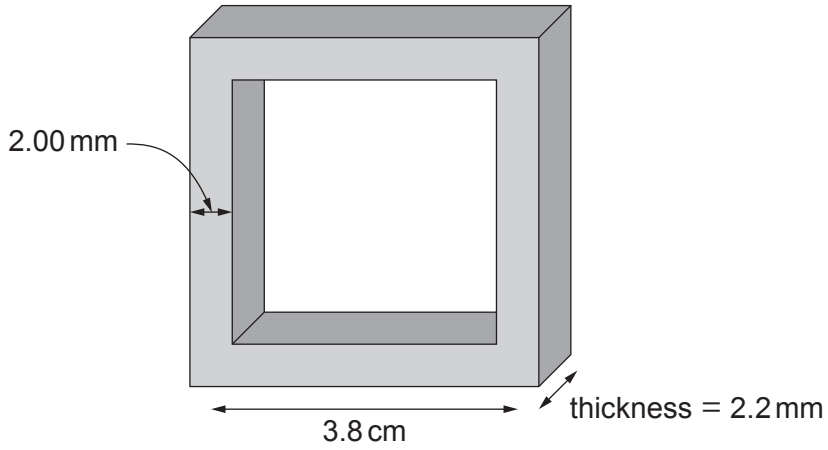
Examiner only

(iii) The square metal loop is made of silver of resistivity $1.59 \times 10^{-8}\,\Omega\,\text{m}$ and its dimensions are shown in the diagram below:



Calculate the current in the square loop. [5]

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SECTION B: OPTIONAL TOPICS

Option A – **Alternating Currents** ☐

Option B – **Medical Physics** ☐

Option C – **The Physics of Sports** ☐

Option D – **Energy and the Environment** ☐

Answer the question on **one topic only**.

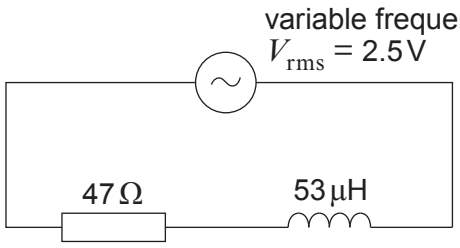
Place a tick (✓) in one of the boxes above, to show which topic you are answering.

You are advised to spend about 25 minutes on this section.

Examiner only

Option A – **Alternating Currents**

7. (a) (i) Explain why the pd across the resistor decreases as the frequency of the supply increases. [2]



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(ii) Calculate the frequency when the pd across the resistor and inductor are equal. [2]

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(iii) Calculate the rms pd across the resistor when it is equal to the rms pd across the inductor. [2]

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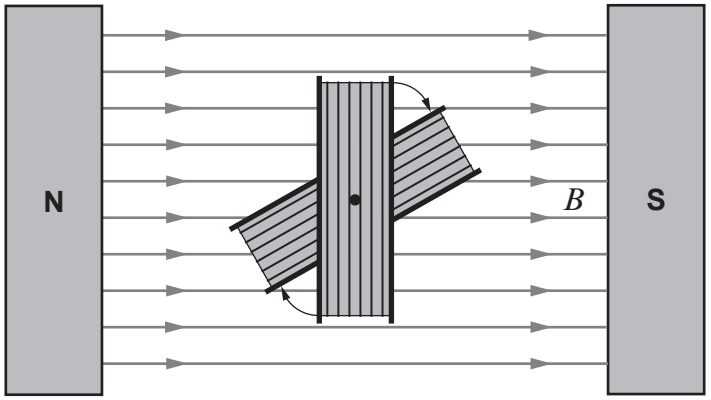
Examiner only

(b) A square coil of N turns and cross-sectional area, A, is rotated with angular velocity, ω, in a magnetic field of flux density, B.



The peak induced emf is given by the equation:

$$V = \omega BAN$$

(i) Explain in terms of Faraday's law why the emf is proportional to each of B and A. [3]

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(ii) Explain at which point in the cycle the peak emf occurs. [1]

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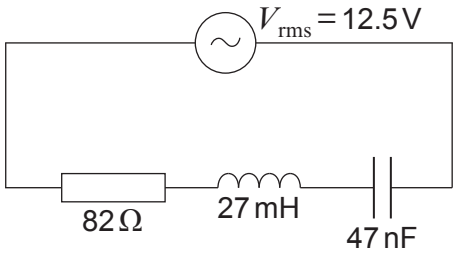
Examiner only

(c) Calculate the rms current in the following circuit:

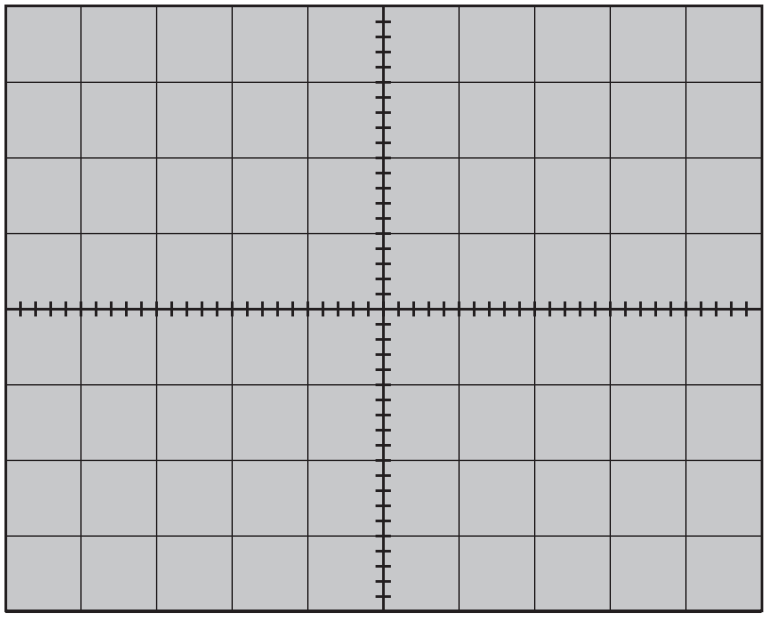


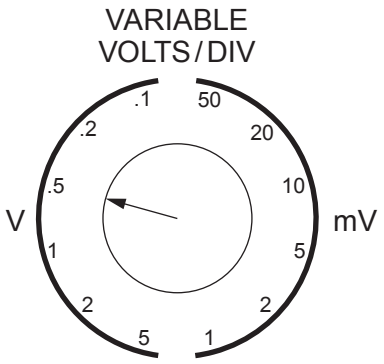
(i) at resonance; [1]

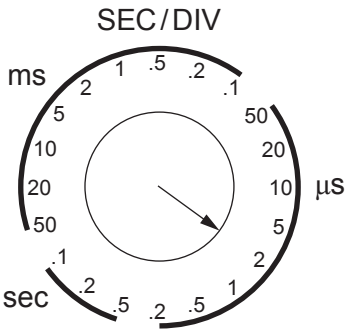
(ii) at twice the resonance frequency. [4]

Examiner only

(d) Tomos wants to display a wave trace on an oscilloscope for an a.c. power supply of frequency 67.5 kHz and rms pd 240 mV. Determine whether or not the settings of the oscilloscope shown below are appropriate. [5]







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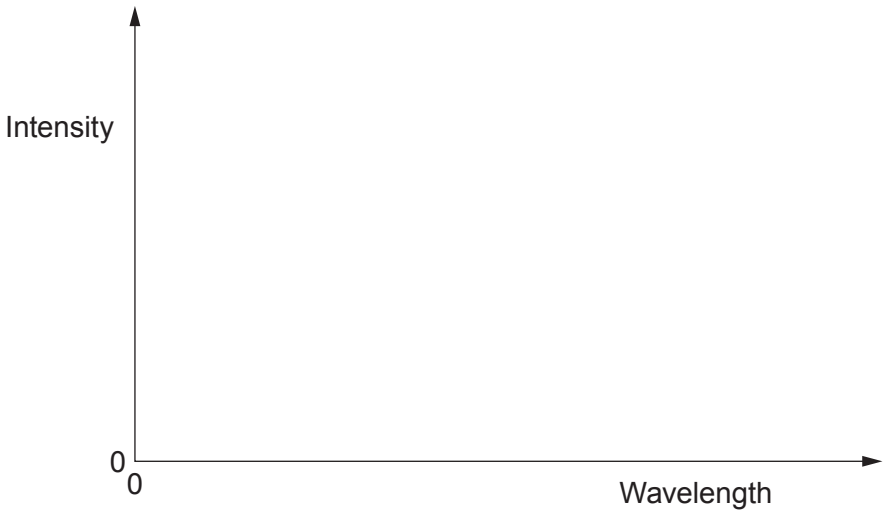
Examiner only

Option B – **Medical Physics**

8. (a) **Sketch two graphs** to show how the intensity of X-rays from an X-ray tube varies with wavelength for an X-ray tube operating at two different voltages, one at 30 kV and the other at 50 kV.

Label the main features of the graphs and also show which graph is at the higher voltage.
Space for calculations. [4]



(b) (i) Ultrasound can be used to measure the speed of blood through an artery. If ultrasound of frequency 1.5 MHz travelling at an angle of 30° to the direction of blood flow shows a Doppler shift of 200 Hz, calculate the speed of blood flow. The speed of ultrasound through the blood is 1570 m s^{-1}. [2]

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(ii) Suggest why it is important for doctors to monitor the rate of blood flow in a patient. [1]

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Examiner only

(c) (i) A magnetic resonance scanner (MRI) can be used to detect tumours in a patient's body. Describe how an MRI scanner works. [3]

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(ii) The MRI scanner has a magnetic field of 1.4 T. Determine the wavelength of electromagnetic radiation that should be used to detect the tumour. [2]

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(d) (i) PET scanners are often used to diagnose tumours in patients. Calculate the energy of the emitted gamma rays ($m_{\text{positron}} = m_{\text{electron}} = 0.000\,549$ u, 1 u = 931 MeV). [2]

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(ii) Explain why PET scanners are not commonly found in smaller hospitals. [1]

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Examiner only

(e) Doctors are concerned about the growth of an unborn baby and have the choice of the following imaging techniques.

X-ray **fluoroscopy** **ultrasound B-scan** **ultrasound A-scan** **CT scan**

Evaluate the suitability of **all five** types of imaging techniques for unborn babies. [5]

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Examiner only

Option C – **The Physics of Sports**

9. (a) (i) Liam wishes to buy a baseball bat with a large moment of inertia and he chooses **bat B** from the following list in a catalogue. Evaluate whether he has chosen the correct bat. [2]

Bat	Mass / kg	Length / cm
A	1.00	85
B	1.10	82
C	1.05	85

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(ii) Calculate the angular momentum of a baseball bat if it has a moment of inertia of $0.35\,\text{kg}\,\text{m}^2$ and is rotating at $63\,\text{rad}\,\text{s}^{-1}$. [2]

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(b) (i) Calculate the torque that the pitcher must exert on a 145 g baseball with radius 3.70 cm to increase the baseball's spin from zero to 2400 revolutions per minute in a time of 0.20 s.
The moment of inertia of a baseball is given by the equation $I = \frac{2}{5}mr^2$. [4]

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Examiner only

(ii) Calculate the rotational kinetic energy gained by the ball. [2]

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(iii) By considering both the linear and rotational motion, explain why baseball players wear a glove on the hand that they use to catch the ball. [3]

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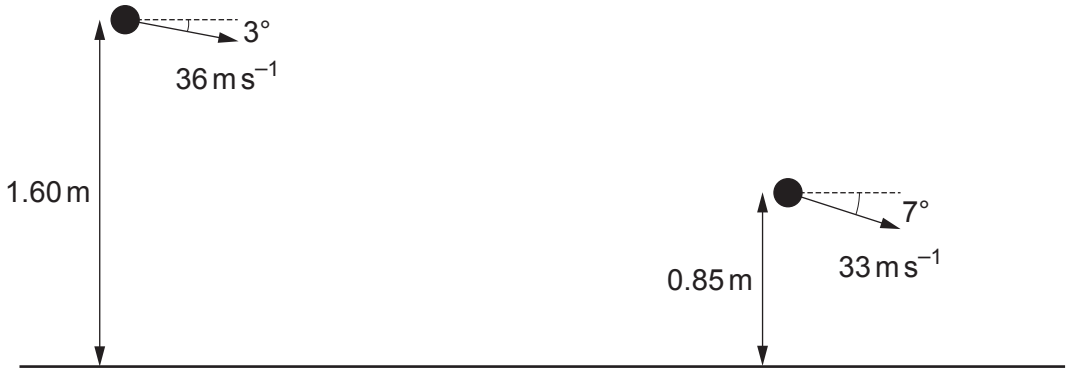
(c) A fielder throws the ball towards a teammate. The ball is initially thrown from 1.60 m above the ground with a speed of 36 m s^{-1} at an angle of 3° below the horizontal. When the ball is caught it is 0.85 m above the ground and has a speed of 33 m s^{-1} at an angle of 7° below the horizontal.



(i) Explain how the information in the diagram shows that air resistance must be acting on the ball. [2]

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Examiner only

(ii) Evaluate whether the vertical acceleration of the ball is equal to the acceleration due to gravity. [3]

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(iii) Explain why a spinning ball may travel further in air than a non-spinning ball. [2]

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Examiner only

Option D – **Energy and the Environment**

10. (a) The proton-proton chain accounts for the majority of the energy output from the Sun. The initial stage of the proton-proton chain is shown below.

$$ {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{2}_{1}\mathrm{H} + \mathrm{e}^{+} + \nu_{\mathrm{e}} $$

(i) State which force is responsible for this reaction. [1]

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(ii) Determine the energy released by one such reaction. [2]

Masses: ${}^{1}_{1}\mathrm{H} = 1.00728\,\mathrm{u}$ ${}^{2}_{1}\mathrm{H} = 2.01355\,\mathrm{u}$

$\mathrm{e}^{+} = 0.00055\,\mathrm{u}$ $\nu_{\mathrm{e}} = 0.000\,00\,\mathrm{u}$

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(b) (i) Define the 'solar constant'. [2]

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(ii) Suggest why the solar constant is not considered to be a constant by the scientific community. [1]

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Examiner only

(iii) The temperature of the Sun's surface is 5780 K. Given that the surface area of the Sun is 6.1×10^{18} m^2, determine the intensity of the Sun's radiation at a distance of 1.50×10^{11} m from its centre **and** state the name of a law used in your calculation. [4]

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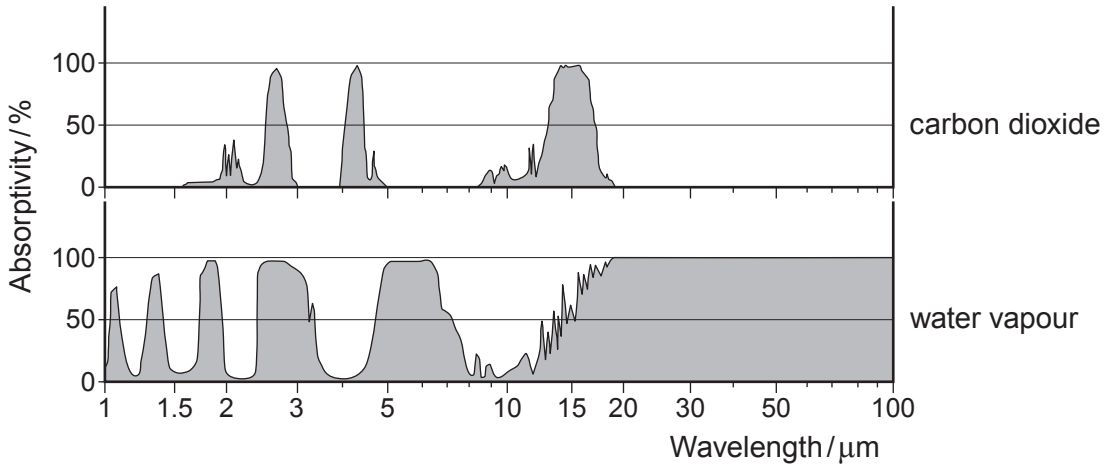
(c) The graph below shows the absorption spectra for carbon dioxide and water vapour as a function of the wavelength of the radiation incident on the gas in our atmosphere.



Studies show that the greenhouse effect is being enhanced by increased levels of carbon dioxide and water vapour. Use the graph to explain this, assuming the Earth emits radiation as a black body with a mean temperature of 288 K. [4]

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Examiner only

(d) Nuclear fission of uranium fuel is used on Earth in order to generate electrical energy. Natural uranium is composed of U-235 and U-238 nuclei.

(i) Explain why enrichment of uranium is required before it is used in a fission reactor. [2]

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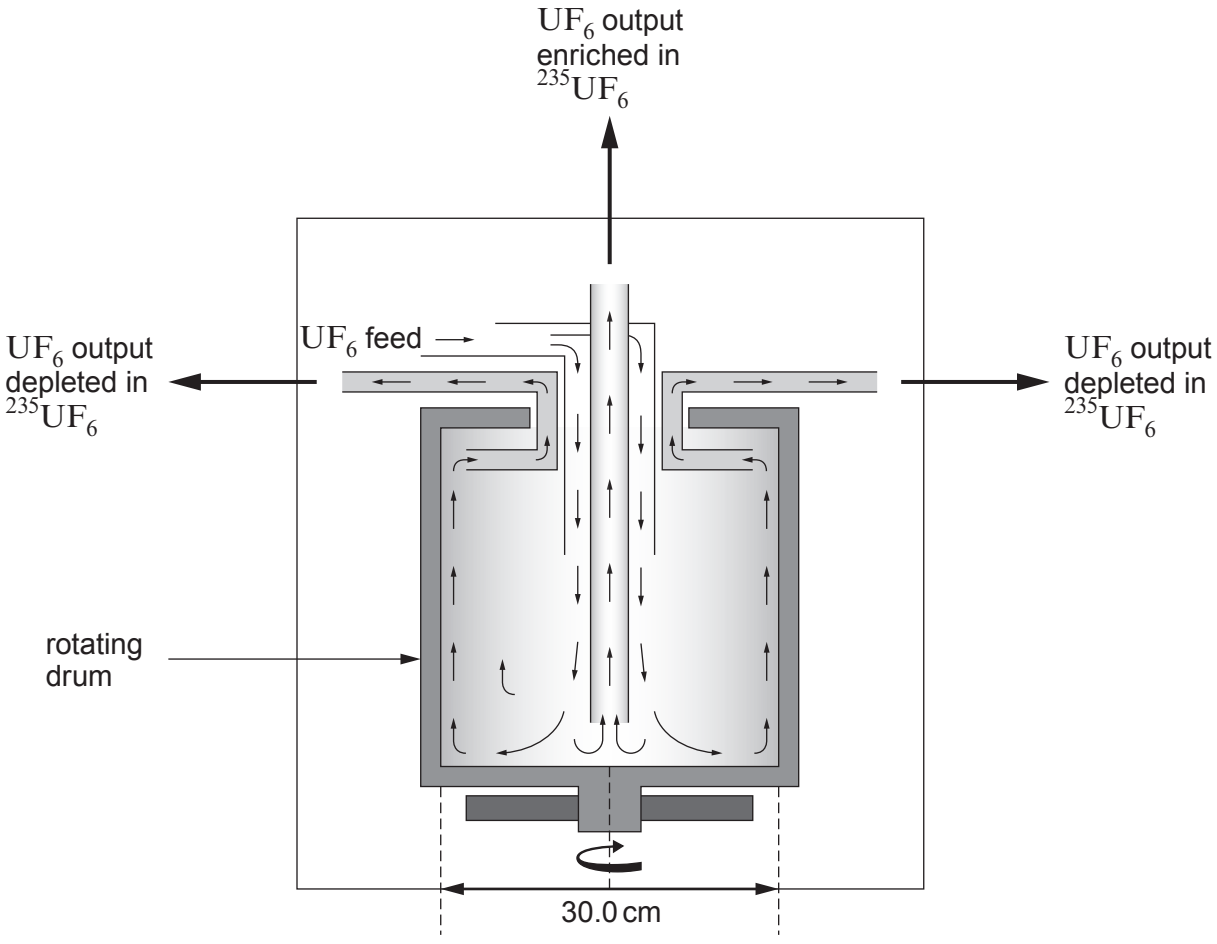
(ii) U-235 and U-238 are both reacted with fluorine to create $^{235}UF_6$ and $^{238}UF_6$ gas molecules. These gas molecules are then fed into a gas centrifuge consisting of a rotating drum where they undergo circular motion.



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The diameter of the rotating drum is 30.0 cm and the speed of the outer surface of the rotating drum is 350 m s^{-1}. Calculate the number of revolutions per second made by the drum. [2]

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(iii) The output from the centrifuge has 1.15 times more $^{235}UF_6$ than was initially fed in. This enriched mixture is transferred into a series of identical centrifuges. Determine the number of centrifuges required to enrich the $^{235}UF_6$ in the gas mixture from 0.7 % to 5.0 %. [2]

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END OF PAPER

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

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