Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

1420U40-1

S23-1420N40-1-R1

THURSDAY, 15 JUNE 2023 – MORNING

PHYSICS – A2 unit 4
Fields and Options

2 hours

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**11**	
	2.	**14**	
	3.	**19**	
	4.	**17**	
	5.	**10**	
	6.	**9**	
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.

Answer **all** questions.

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

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) 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 **5(b)**.

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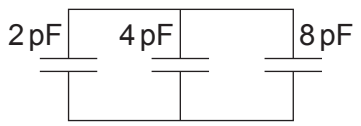
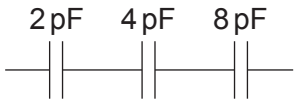
SECTION A

Answer **all** questions.

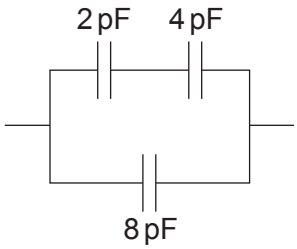
1. (a) Calculate the total capacitance of each of the following capacitor combinations. [6]



(i)



(ii)



(iii)

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(ii) .....

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(iii) .....

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(b) Michael, a laboratory technician, must make a 2.7 μF capacitor using only two square sheets of aluminium of side 42.0 cm. Determine whether or not it is realistic for Michael to produce a capacitance of 2.7 μF using these two sheets of aluminium and no dielectric. [4]

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(c) State what happens to the capacitance of a parallel plate capacitor when a dielectric is placed between the plates. [1]

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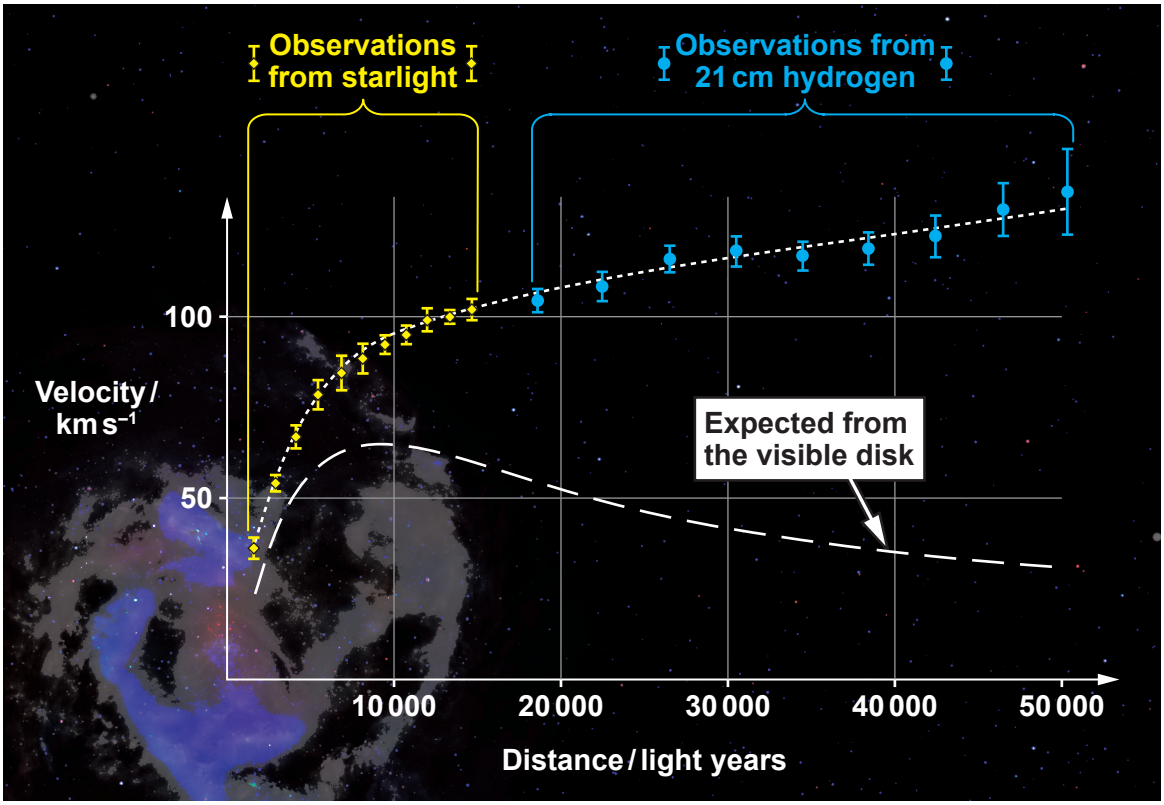
2. Light from a spiral galaxy is analysed and the following graph of velocity against distance from the centre of the galaxy is obtained.



(a) Show that the speed, v, of an object in a circular orbit of radius, r, about a massive object of mass, M, is given by: [3]

$$v = \sqrt{\frac{GM}{r}}$$

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(b) Hence, explain why the graph is considered to be evidence for dark matter. [3]

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(c) The lower curve in the graph suggests that an object a distance of 20 000 light years from the centre of the galaxy should have an orbital speed of approximately 50 km s^{-1}. Use this data to estimate the visible mass of the galaxy. (1 light year = 9.46×10^{15} m) [3]

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(d) The observed data at 30 000 light years from the galactic centre were obtained using microwaves of wavelength 21 cm. Calculate the approximate wavelength shift that was observed to obtain the data plotted at 30 000 light years. [3]

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(e) Use the Hubble equation to calculate the distance, from Earth, for a galaxy to have the same recessional speed as that of part (d). [2]

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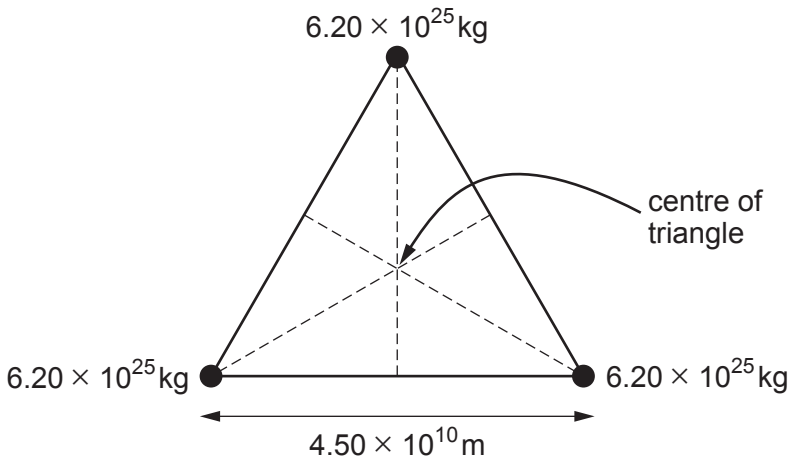
3. Three planets of equal mass are arranged in an **equilateral triangle** as shown.



(a) (i) Show that the gravitational force exerted by one planet on another is approximately 1.3×10^{20} N. [2]

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(ii) Hence, explain why the resultant gravitational force experienced by any of the planets is approximately 2×10^{20} N towards the centre of the triangle. [4]

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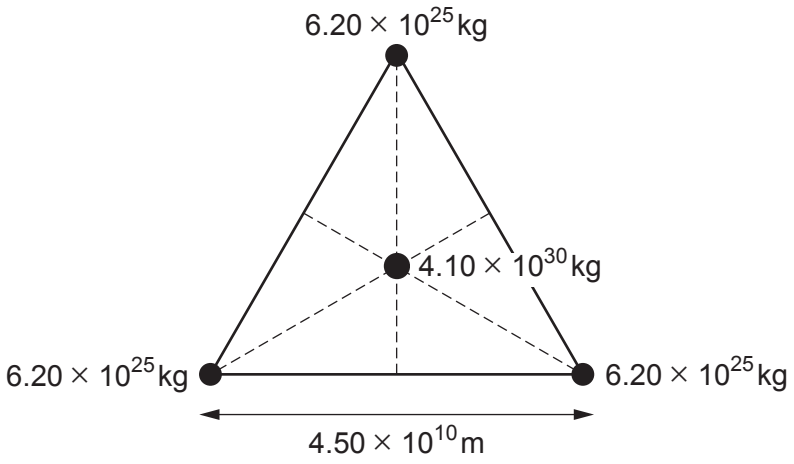
(b) A star is located at the centre of the triangle.



(i) By adding to the diagram, show that the distance between the star and any of the planets is given by: [2]

$$\frac{4.5 \times 10^{10}}{2 \times \cos 30°}$$

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(ii) Rhodri states that the force calculated in part (a)(ii) is negligible compared with the gravitational force exerted on a planet by the star. Determine whether or not Rhodri is correct. [2]

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(c) (i) Show that the gravitational potential at the position of a planet due to the star and the other two planets is approximately $-1 \times 10^{10}\,\mathrm{J\,kg^{-1}}$. [3]

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(ii) Rhodri now states that, if an object with kinetic energy 7×10^{35} J struck one of the planets, the planet would gain enough energy to escape the gravitational pull of the star. Discuss to what extent Rhodri's statement might be correct. [3]

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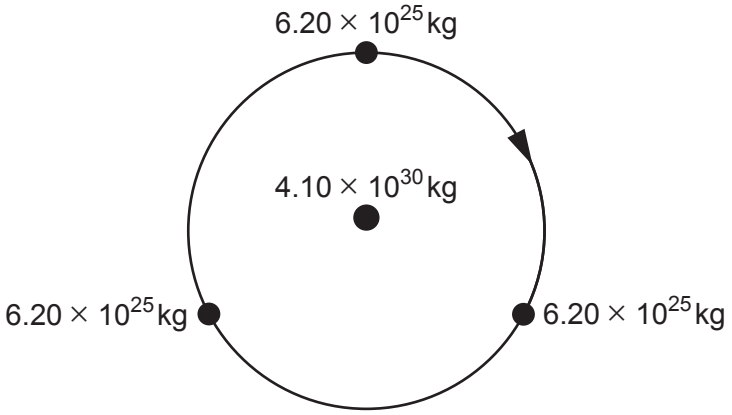
(d) The three planets, whilst orbiting the star, stay in an equilateral triangle. Delyth claims that these planets cannot be detected by the periodic Doppler shift of the star. Determine whether or not Delyth is correct. [3]



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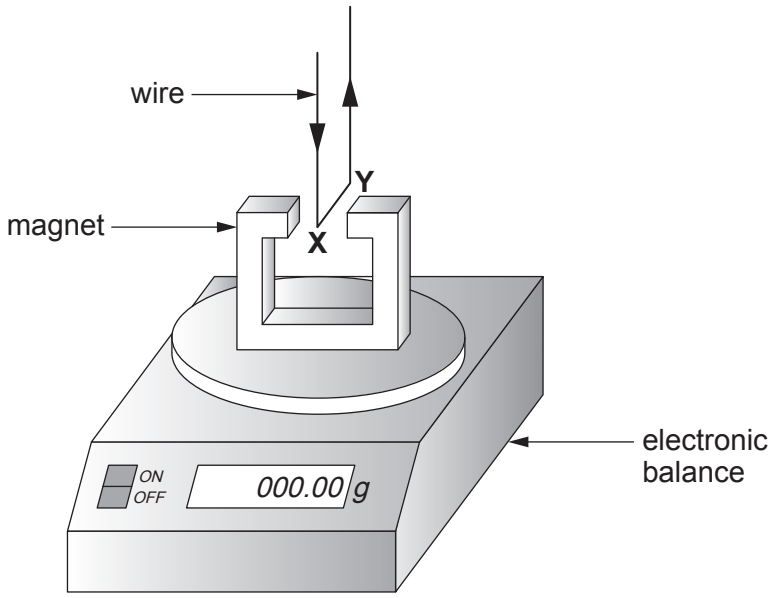
4. The following set-up is used to investigate the force on a current-carrying wire in a magnetic field.



The part **XY** of the wire which is in the magnetic field, has been placed carefully so that the current is from front to back at 90° to the direction of the magnetic field. When there is no current the balance is reset to display 000.00 g. When there is a current in the direction shown, the magnetic force results in a positive reading on the display of the balance.
However, this signifies an upward force on the wire.

(a) (i) Explain briefly why the magnetic force must be upward on the part **XY** of the wire. [2]

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(ii) **On the diagram**, indicate which is the North pole of the magnet, **and** state below which rule you used to obtain your answer. [2]

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(iii) Explain why the vertical parts of the wire have no effect on the reading displayed by the electronic balance. [1]

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(b) Bronwen varies the length of XY and records the electronic balance reading each time when a current of 5.00 A flows. She records all her results in a table and plots a graph of magnetic force against length of wire.

(i) **Complete the table and plot** the two missing points on the graph. [4]

Length of XY / cm	Balance reading / g	Magnetic force / 10^{-3} N
1.0	0.56	5.5
2.0	1.22	.....
3.0	1.75	17.2
4.0	2.36	23.1
5.0	2.89	28.4
6.0	3.32	32.6
7.0	.....	35.8

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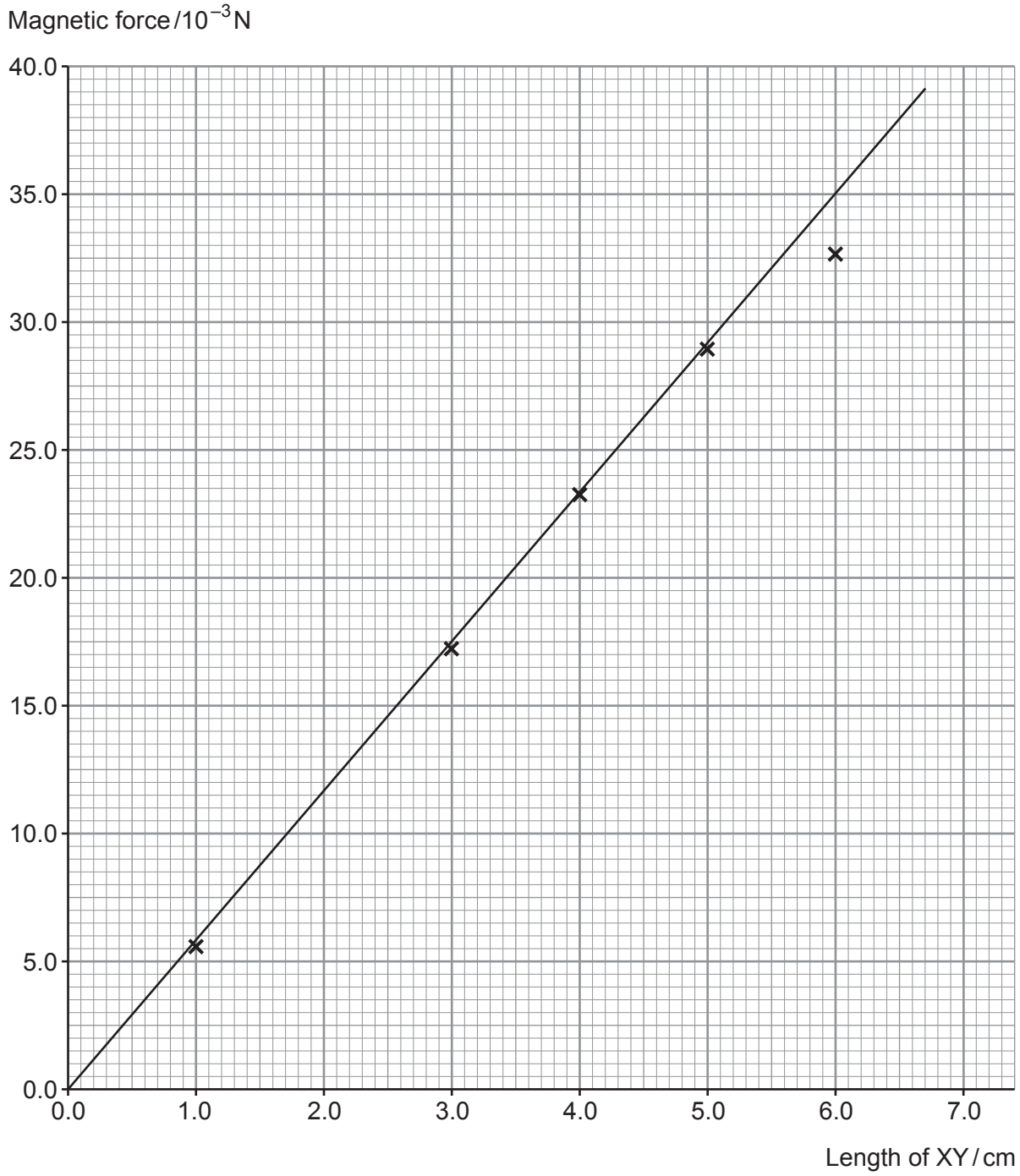

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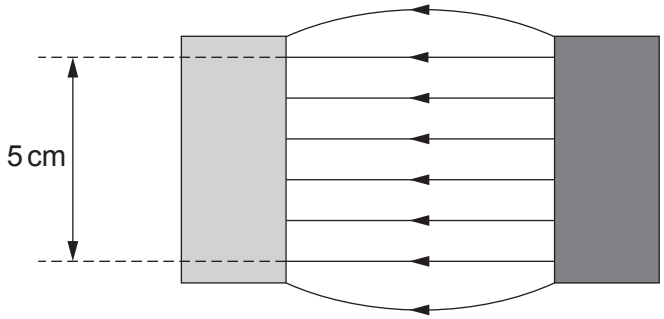
(ii) The region of uniform magnetic field between the poles of the magnet is of length 5 cm only. Evaluate whether or not Bronwen has drawn the line of best fit correctly. [3]



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(iii) Determine the magnetic flux density, B, of the uniform magnetic field between the poles of the magnet and quote it to an appropriate number of significant figures. The current in the wire is 5.00 A. No uncertainty is required in your value of B. [5]

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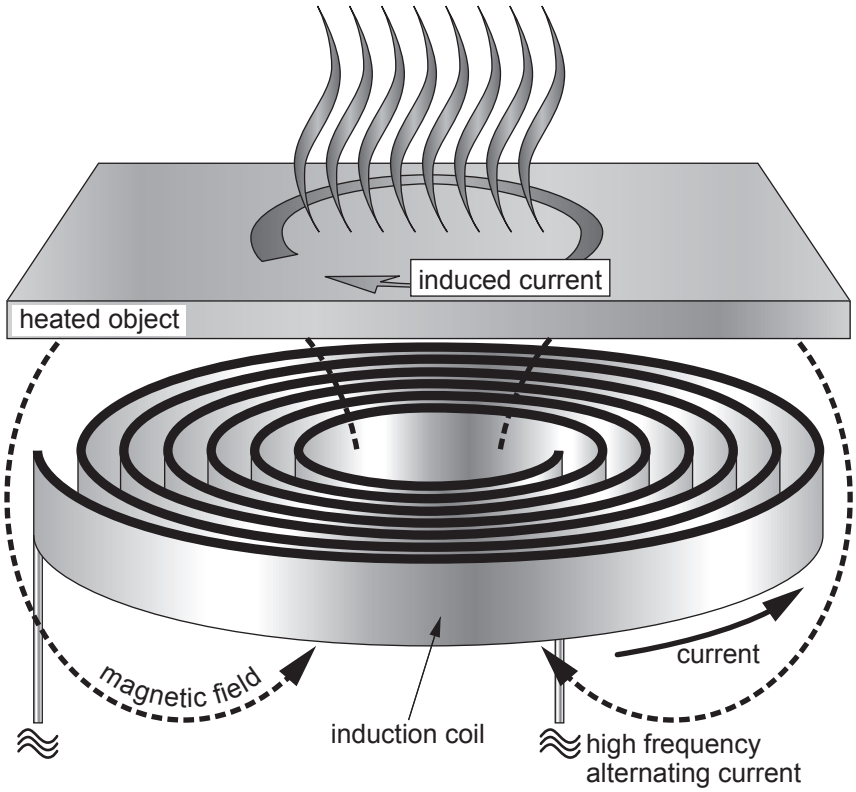
5. (a) The diagram shows how conductors can be heated using a varying magnetic field.



Explain why the heated object gets hot **and** why a high frequency alternating current is used. [4]

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(b) Explain how a Hall voltage arises in a Hall probe, how it is measured **and** how this can be used to measure the magnetic flux density. A diagram should be included in your answer. [6 QER]

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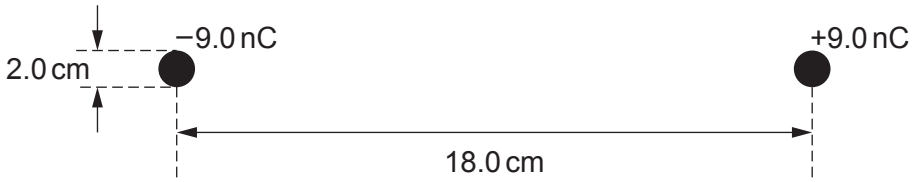
6. Two small spheres of radius 1.0 cm carry uniform charges of +9.0 nC and –9.0 nC. Their centres are separated by a distance of 18.0 cm as shown. Treat the charges as being at the centres of the spheres.



(a) (i) Show that the potential at the surface of the negative sphere is approximately –7500 V. [3]

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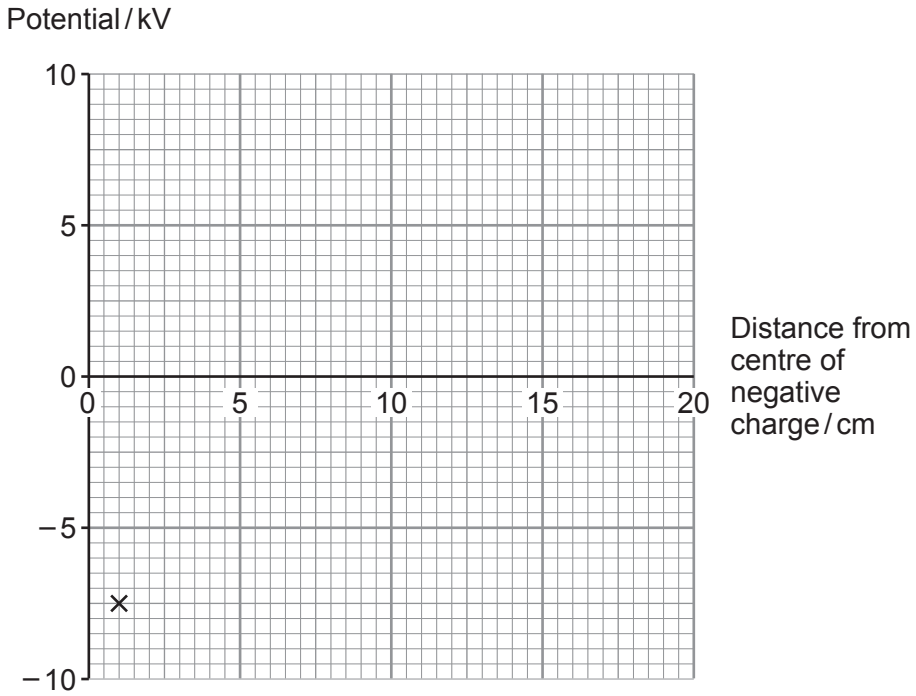
(ii) Sketch the graph for the electric potential between the two charges (the potential has been plotted for the surface of the negative charge). [3]



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(b) Explain why the electric field on the right-hand surface of the negative sphere is approximately 810 000 N C^{-1} and directed towards the left. [3]

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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.

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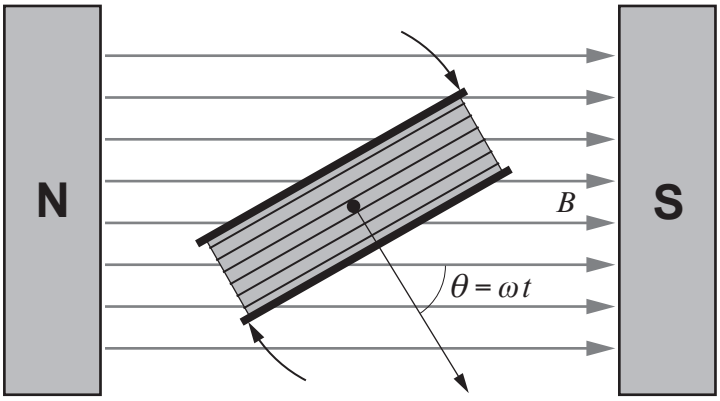
Option A – **Alternating Currents**

7. (a) A diagram of a rotating coil in a magnetic field is shown below.



The coil rotates 50 times per second in a field of flux density 0.215 T.
The coil has 2650 turns and cross-sectional area $2.35 \times 10^{-3}\,m^2$. (Note that $\theta = 0$ when $t = 0$)

(i) Calculate the peak induced emf in the coil. [2]

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(ii) Calculate the flux linkage of the coil when $t = 5.0$ ms.
[Hint: put your calculator in radian mode.] [2]

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(iii) Calculate the induced emf in the coil when $t = 5.0$ ms. [1]

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(iv) Vanessa states that her answers to parts (ii) and (iii) are consistent with the coil having completed a quarter of a cycle. Determine whether or not she is correct. [3]

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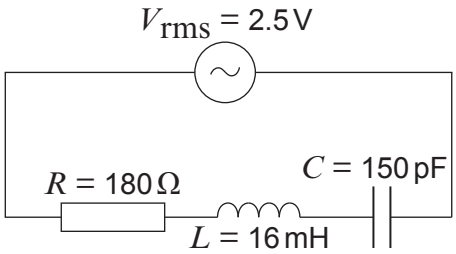
(b) (i) Calculate the resonance frequency of the following circuit. [2]



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(ii) Explain why the rms current at resonance is approximately 14 mA. [2]

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(iii) Calculate the rms current in the circuit when the frequency is 105 kHz. [4]

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(iv) Explain why your answers to parts (b)(i), (b)(ii) and (b)(iii) suggest that the circuit has a high Q factor. [2]

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(v) Thomas considers the effect, on this circuit, of increasing the capacitance only. He believes that this will decrease the Q factor. Determine whether or not he is correct. [2]

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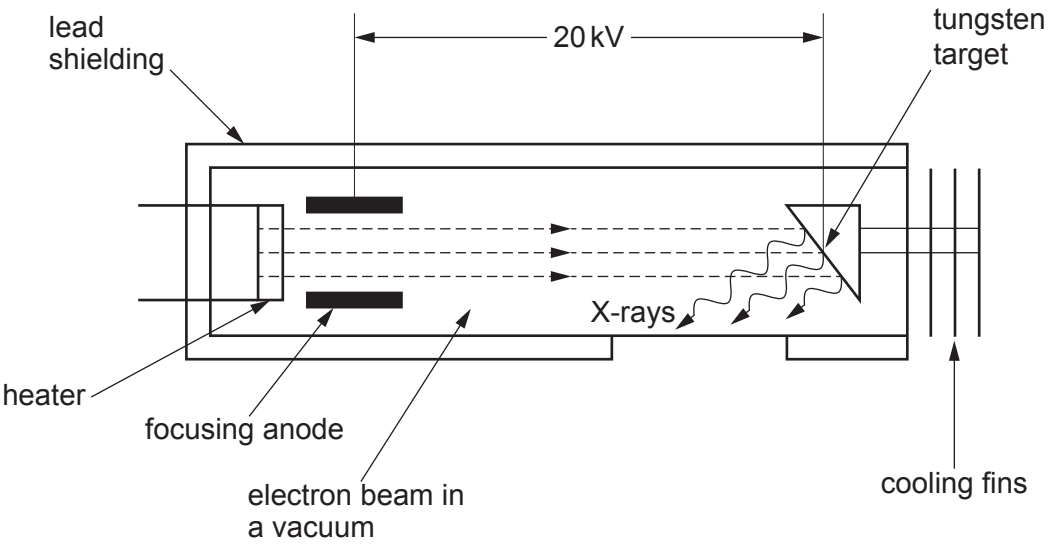
Option B – **Medical Physics**

8. (a) Below is a simplified diagram of the inside of an X-ray tube.



(i) State the main function of the heater **and** explain why there must be a vacuum between the heater and the tungsten target. [2]

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(ii) The electron beam has a current of 100 mA. Determine how many electrons arrive at the tungsten target per second. [2]

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(iii) Estimate the velocity of an electron in the X-ray tube as it hits the target. [3]

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(iv) Determine the minimum wavelength, λ_{min}, of the X-rays produced by this tube. [3]

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(b) (i) An ultrasound probe can be used to study the speed of blood flow from the heart. Explain how the probe produces ultrasound **and** how the speed of blood flow can be determined. [3]

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(ii) In measuring the speed of blood flow, the frequency of ultrasound used is 2.0 MHz and it travels through the blood at 1570 m s^{-1}. A frequency shift of 0.23 kHz is measured when the ultrasound is incident at an angle of 37° to the blood flow. Calculate the speed of the blood flow. [2]

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(c) Doctors are concerned that a patient is suffering from an overactive thyroid gland (hyperthyroidism). They have the choice of the following techniques to help diagnose this.

X-ray **MRI** **ultrasound** **CT scan** **radioactive tracers**

Evaluate the suitability of **all five** types of imaging techniques for detecting an overactive thyroid gland. [5]

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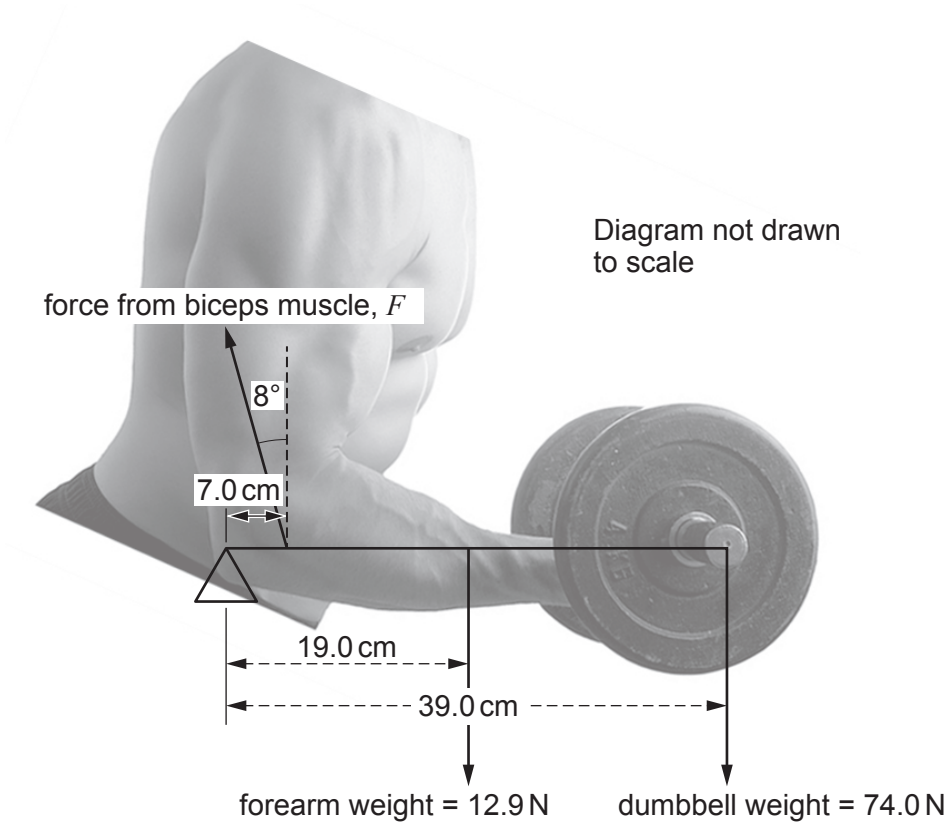
Option C – **The Physics of Sports**

9. (a) An athlete lifts a dumbbell of weight, 74.0 N as shown in the following diagram. Calculate the magnitude of the force, F, that the biceps muscle exerts on the athlete's forearm assuming that the elbow can be modelled as a pivot. [2]



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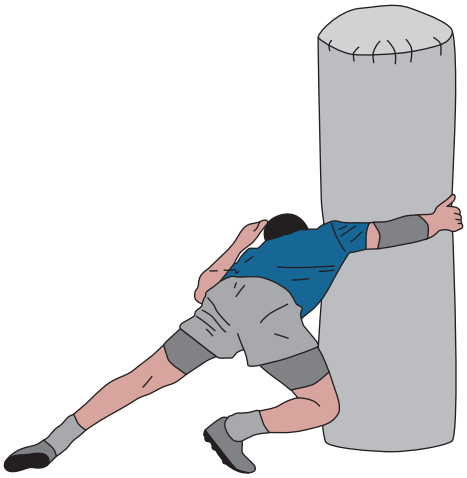
(b) A rugby player of mass 117 kg runs at a tackle pad with an initial velocity 7.75 m s^{-1}. In the collision with the tackle pad, the player experiences a mean force of 5500 N for a contact time of 0.176 s. This force is in the exact opposite direction to the initial velocity. Calculate the final velocity of the rugby player after the collision. [3]



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(c) (i) During a rugby match, a player wishes to kick the ball as far as possible. Describe the factors that affect the drag force on the ball. You may use the following diagrams to support your answer. [3]

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(ii) A kicking coach thinks that, if the number of revolutions per second of the ball is doubled, then the rotational kinetic energy of a rugby ball will also double. Evaluate whether or not the coach is correct. [2]

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(iii) The rugby ball is dropped on to two playing surfaces, A and B. Evaluate whether the playing surfaces are different. [3]

Playing surface	Initial height / m	Bounce height / m
A	7.8	1.2
B	4.5	0.7

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(iv) When a rugby ball is kicked it gains an angular velocity of 37.7 rad s^{-1} in a time of 17.0 ms. The moment of inertia of the rugby ball is 0.0028 kg m^2. Calculate the torque exerted on the ball by the kicker's foot. [2]

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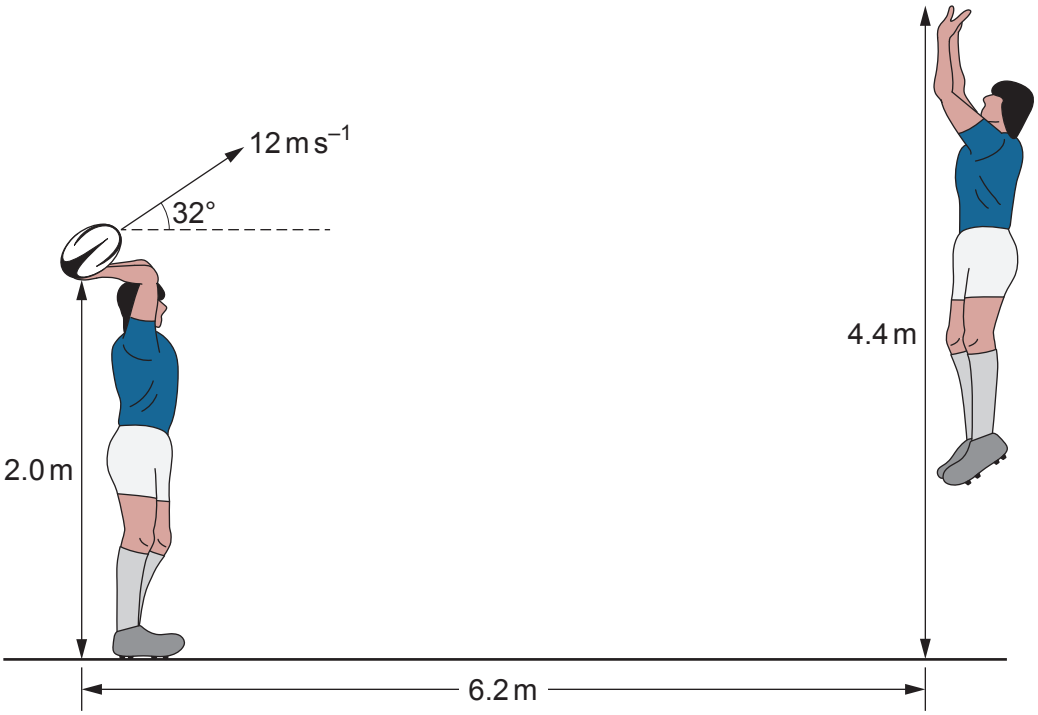
(v) A player throws a ball from a height of 2.0 m with an initial speed of 12 m s^{-1} at an angle of 32° to the horizontal. The maximum height reached by the player catching the ball is 4.4 m and he is standing 6.2 m away from the thrower. Explain why it is possible for the catcher to catch the ball. [5]



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Option D – **Energy and the Environment**

10. (a) (i) The mean temperature of the Earth is 288 K. Assuming it behaves as a black body, show that the wavelength of the peak emission of radiation is in the infra-red region of the electromagnetic spectrum. [2]

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(ii) Carbon dioxide, methane and water vapour are greenhouse gases. Describe the role these gases play in the greenhouse effect. [3]

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(b) (i) The Greenland ice sheet is the second largest ice sheet in the world. Over the last two decades the mean decrease in volume of Greenland's ice is $3.0 \times 10^{11}\,\text{m}^3\,\text{year}^{-1}$. Estimate the volume of water released into the surrounding ocean in this time period. [$\rho_{\text{ice}} = 920\,\text{kg}\,\text{m}^{-3}$, $\rho_{\text{water}} = 1\,000\,\text{kg}\,\text{m}^{-3}$] [2]

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(ii) Satellite images show that the edge of the Greenland ice sheet appears brown in places. Scientists report that this discolouration is due to microscopic plants flourishing in the melting ice. Explain the effect this could have on the rate at which the ice melts. [2]

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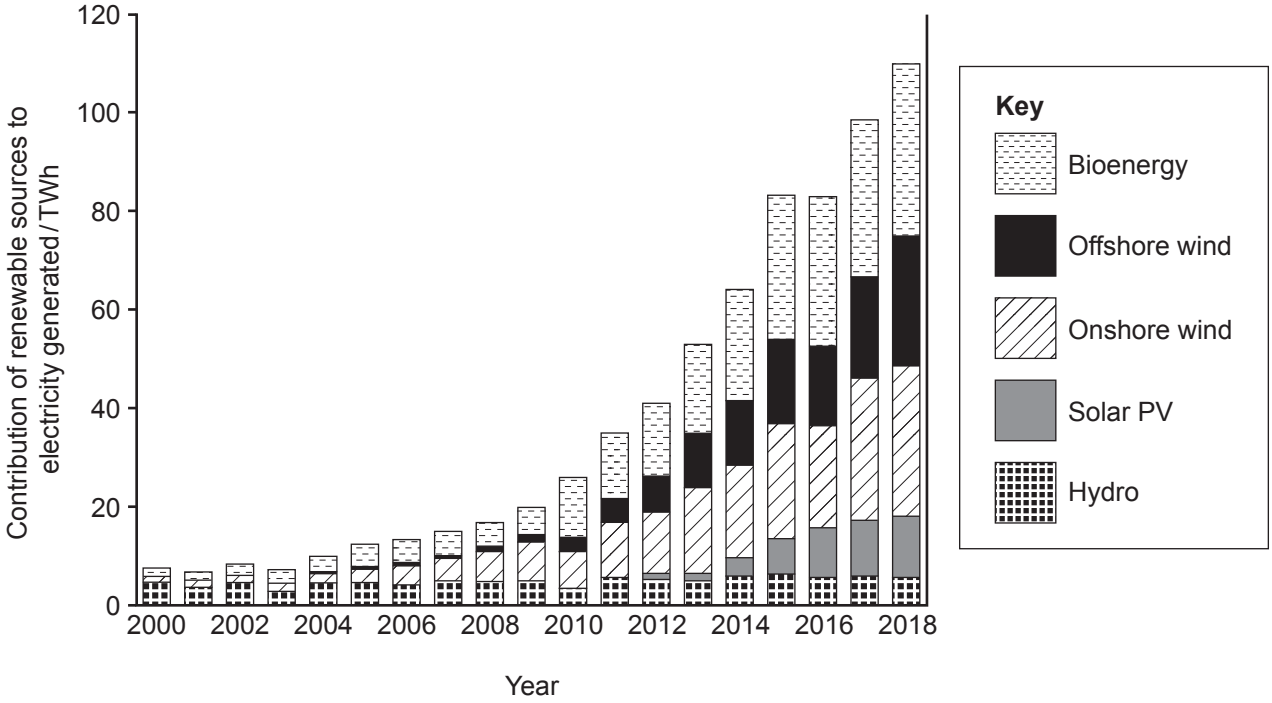
(c) The graph shows how renewable sources have contributed to the electricity generated in the UK between 2000 and 2018.



Note: Hydro bar includes shoreline wave/tidal (0.009 TWh in 2018)

(i) Compare the contribution of solar photovoltaic (Solar PV) with hydroelectric power since 2010 **and** suggest a reason for this difference. [2]

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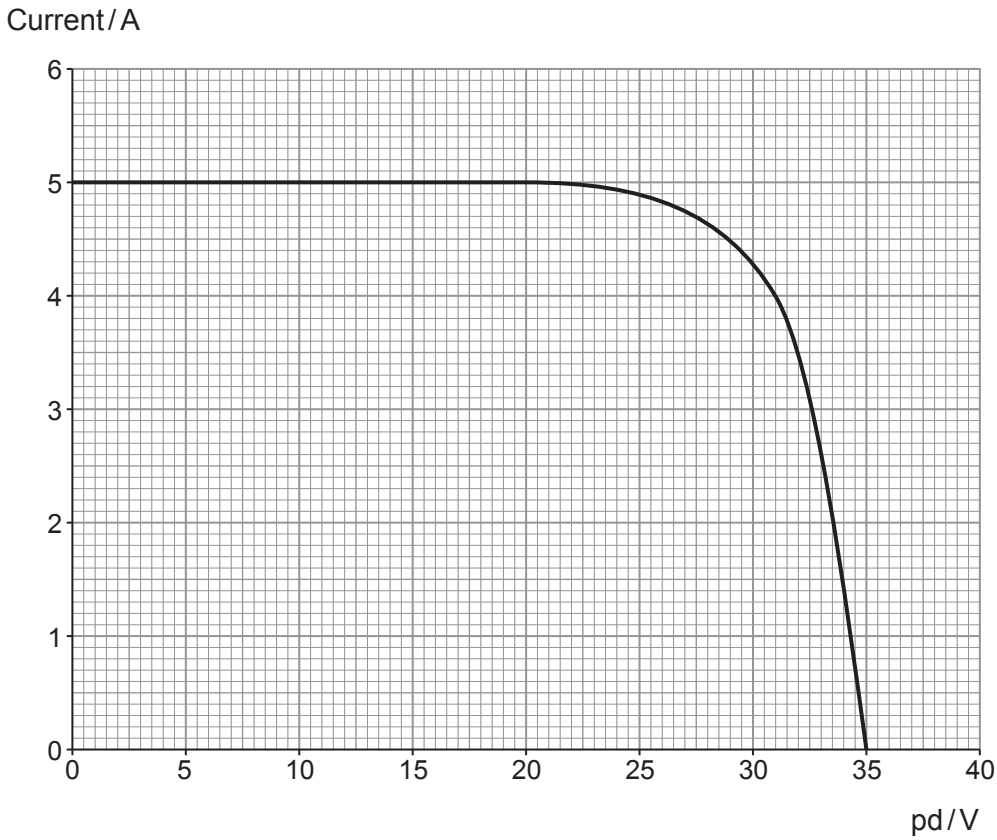
(ii) A solar panel provides electrical power for a load resistor. The graph below shows the current-potential difference characteristics of a solar panel operating under an intensity of $600\,W\,m^{-2}$.



The solar panel has a surface area of $1.2\,m^2$. Determine the efficiency of the solar panel when it is operating at its maximum power output. [4]

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(d) (i) The ground floor of a house has an area of 60 m^2. The floor is made from concrete of thickness 120 mm. If the top surface of the concrete is 19 °C and the lower surface is 5 °C, show that the rate of heat flow through the concrete is approximately 5000 W. $K_{concrete}$ = 0.700 W m^{-1} K^{-1} [2]

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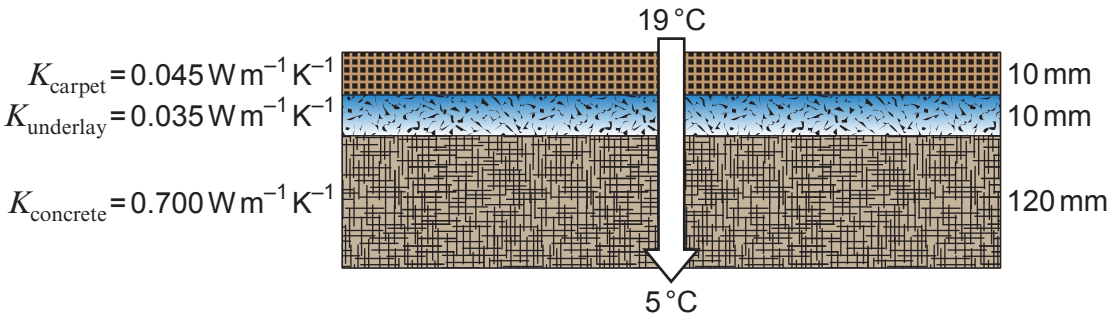
(ii) A carpet fitting company adds underlay and carpet on to the concrete as shown in the diagram.

Diagram not drawn to scale



It is stated by the carpet fitting company that the rate of heat flow through the floor will reduce to a quarter of the value calculated in part (d)(i). Evaluate if this claim is correct. [3]

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