Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

A420U30-1

O21-A420U30-1

WEDNESDAY, 20 OCTOBER 2021 – MORNING

PHYSICS – A level component 3
Light, Nuclei and Options

2 hours 15 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**13**	
	2.	**15**	
	3.	**12**	
	4.	**19**	
	5.	**10**	
	6.	**12**	
	7.	**8**	
	8.	**11**	
Section B	**Option**	**20**	
	Total	**120**	

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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 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**: 100 marks. Answer **all** questions. You are advised to spend about 1 hour 50 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*(a)***.

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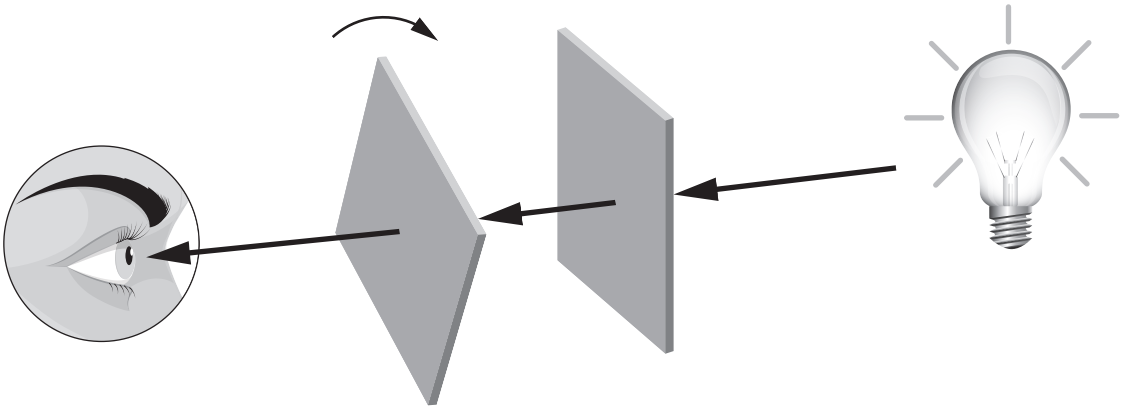
SECTION A

Answer **all** *questions.*

1. *(a)* (i) Angela holds one polarising filter in front of a filament bulb while rotating another in front of her eye. Describe how the brightness of the bulb changes as she rotates the polarising filter **through 360°**. Both filters are aligned initially. [3]



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(ii) She now examines light from a source which is partially polarised (a mixture of polarised and unpolarised light) by rotating a **single** polarising filter. Describe **and** explain how her observations differ from those of part *(a)*(i). [2]

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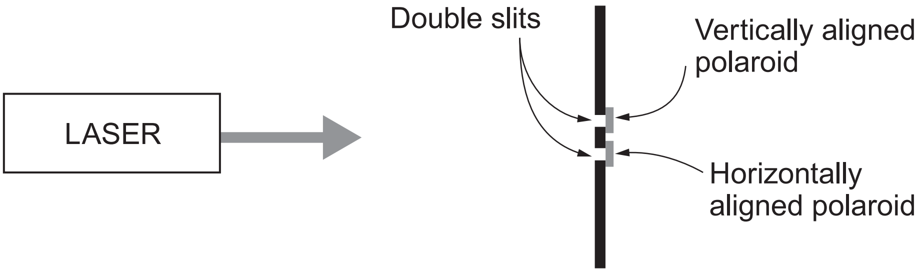
(b) In the following Young's double slit set-up, the laser emits unpolarised light. Two polarising filters are placed after the double slits so that the light from the top slit is vertically polarised whereas the light from the bottom slit is horizontally polarised. Evaluate whether or not this set-up can produce the usual equally spaced fringes. [3]



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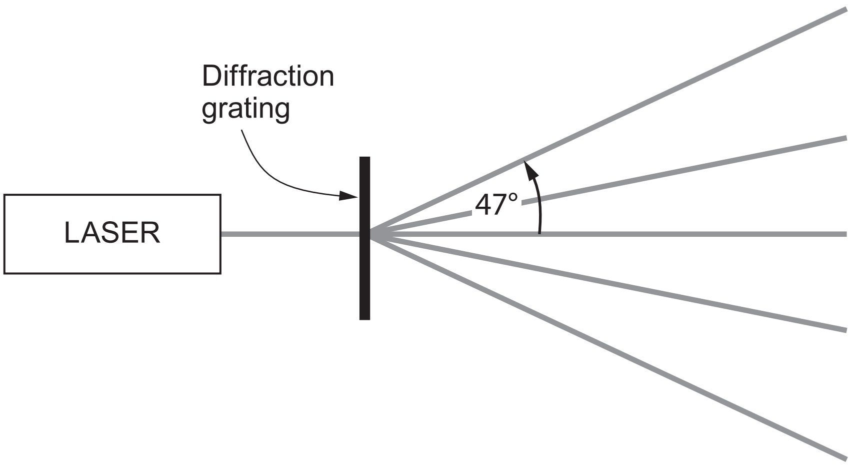
(c) While carrying out an experiment with a diffraction grating and a laser of wavelength 633 nm, the n = 2 bright fringe is observed at an angle of 47° as shown in the diagram.



(i) Calculate the number of lines **per mm** in the diffraction grating. [3]

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(ii) Another laser is used and it is found that the n = 3 bright fringe is at exactly the same angle (47°) as the n = 2 line of the 633 nm laser. Calculate the wavelength of the laser. [2]

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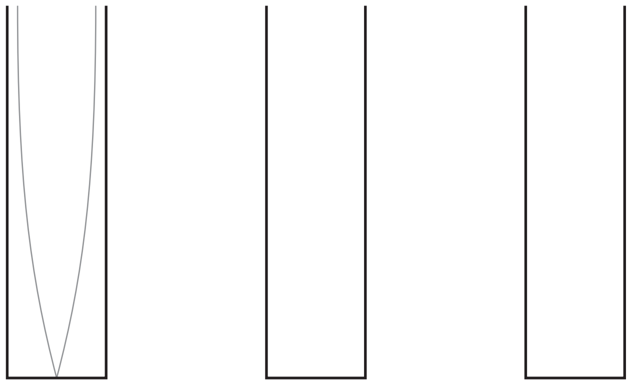
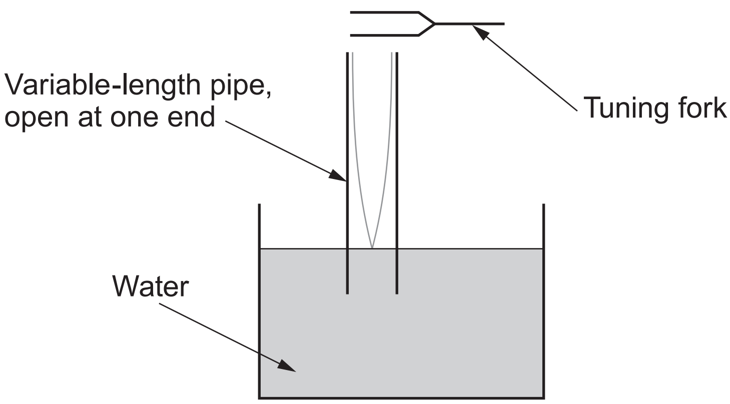
2. The lowest frequency stationary wave produced in a pipe, open at one end, and its amplitude profile is shown in the diagram on the left.



(a) The next stationary wave has three times the frequency. **Draw the amplitude profile** for **this** stationary wave and the **third** stationary wave in the diagrams above. [3]

(b) Dwight uses a variable-length pipe, open at one end, and a set of tuning forks of different frequencies, f, to measure the speed of sound in air. He obtains the lengths, L, for the first stationary waves for all tuning forks and records them in the table.



Frequency, f / Hz	Length, L / cm				Speed of sound, c / m s^{-1}
	Reading 1	Reading 2	Reading 3	Mean	
256	32.0	32.2	32.2	32.1	329
288	28.5	28.2	27.9	28.2	325
320	25.3	25.4	25.2	25.3	324
341	23.7	23.9	23.7	23.8	325
384	21.0	20.9	20.8	20.9	321
426	18.6	18.6	18.2	18.5	315
480	16.2	16.6	16.0	....	....
512	15.0	15.3	15.6	15.3	313

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(i) Explain why the speed of sound is given by:

$$c = 4Lf$$

where c is the speed of sound in air. [2]

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(ii) **Complete the table** for the 480 Hz tuning fork. [2]
Space for calculations.

(iii) Dwight determined that the maximum uncertainty in the measured length was ± 0.3 cm and used this as the uncertainty in each mean length. He then produced the following table.

Frequency, f / Hz	Speed of sound, c / m s^{-1}
256	329 ± 3
288	325 ± 3
320	324 ± 4
341	325 ± 4
384	321 ± 5
426	315 ± 5
480	.... ± 6
512	313 ± 6

For the 512 Hz tuning fork, explain how Dwight obtained the figure 313 ± 6 m s^{-1} (you may assume that the frequency of the tuning fork is exact). [2]

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(iv) Dwight researches the speed of sound at 20 °C and finds that it should be 343 m s^{-1}. He concludes that the values of the speed of sound in the table are inaccurate and that some systematic error is responsible. Discuss whether or not these data are inaccurate and actually show a systematic error. [2]

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(v) Dwight's teacher comments that there is an *end correction* that must be included for sound waves in pipes. She states that the actual equation for the speed of sound is:

$$c = 4 \times (L + 0.3d) \times f$$

where $0.3d$ is known as the *end correction* and d is the diameter of the pipe. She measures the diameter of the pipe as 5.0 cm and corrects Dwight's data:

Frequency, f / Hz	Speed of sound, c / m s^{-1}
256	344 ± 3
288	342 ± 3
320	343 ± 4
341	345 ± 4
384	344 ± 5
426	341 ± 5
480	.... ± 6
512	344 ± 6

Calculate a corrected value for the speed of sound using the 480 Hz tuning fork data. [2]

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(vi) Discuss to what extent the final values are accurate and consistent with the published value of 343 m s^{-1}. [2]

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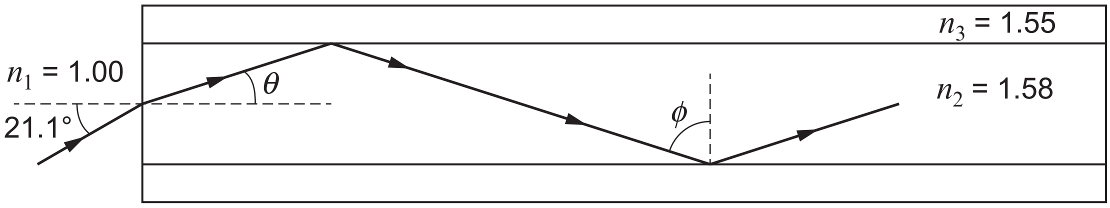
3. *(a)* For the optical fibre shown, calculate the angles θ and ϕ. [3]



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(b) Hence, determine whether the ray shown will travel a long distance along the optical fibre without a rapid drop in intensity. [3]

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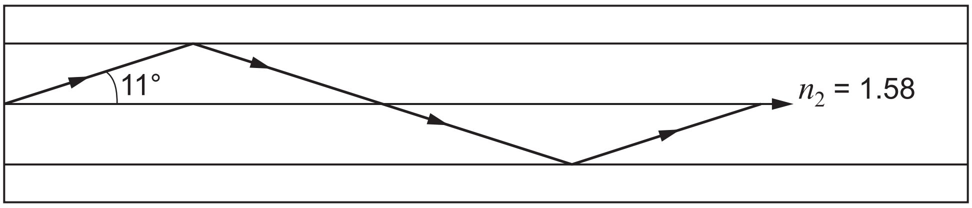
(c) Consider data sent down the core along two different paths – the central axis and at 11° to the central axis as shown in the diagram.



(i) Calculate the time delay between pulses sent along both paths when the length of the optical fibre is 3.5 km. [4]

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(ii) Hence, calculate the highest number of pulses per second that can be sent along the optical fibre without overlap, explaining your reasoning. [2]

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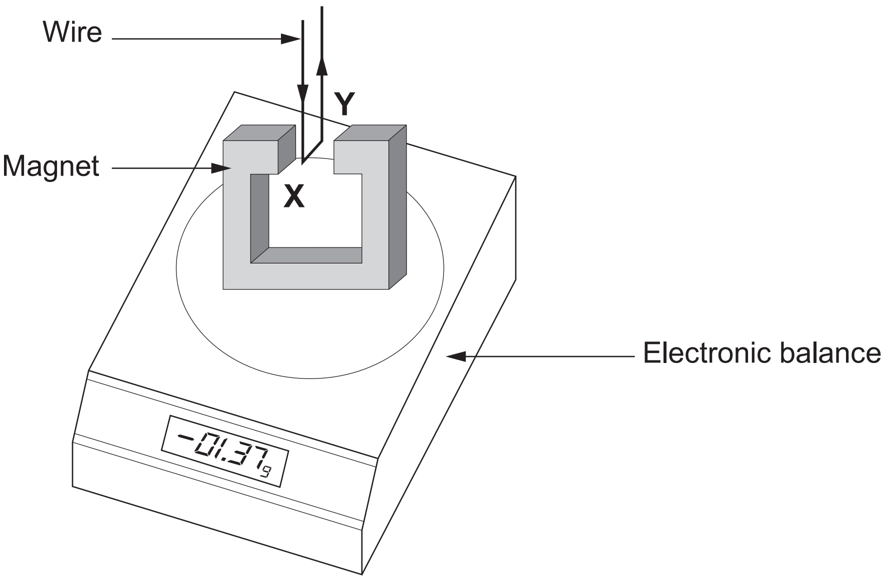
4. Greg uses the following set-up to investigate the force on a current-carrying wire in a magnetic field and to determine the magnetic flux density.



The portion **XY** of the wire which is in the magnetic field, has been placed carefully so that the current is from **X** to **Y** at 90° to the direction of the magnetic field.
While there is no current, the balance is reset to display 00.00 g.
When there is a current in the direction shown, the electromagnetic force results in a negative reading on the display of the balance.
This signifies an upward force on the magnet and a downward force on the wire.

(a) (i) Greg states that the forces on the wire and the magnet are a Newton's third law pair of forces. Explain briefly why Greg is correct. [2]

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(ii) The left pole of the magnet is a north pole. Explain how this is consistent with the information above, naming the rule that you used. [1]

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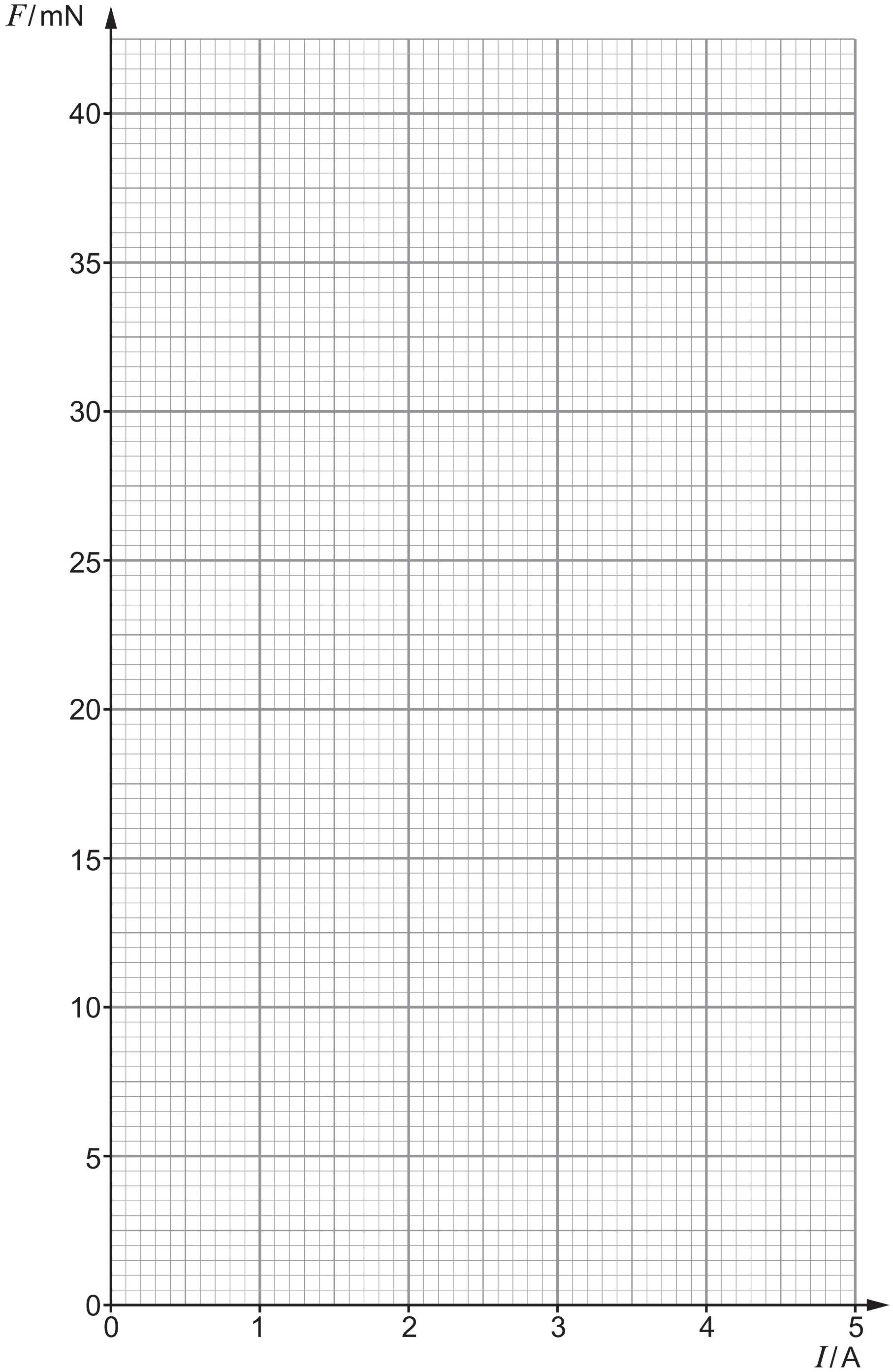
(b) Greg varies the current, I, in the wire and notes the electronic balance reading each time and uses these to calculate the magnetic force, F. He records all his results in a table.

Current, I / A	Balance reading / g	Magnetic force, F / mN
0.80	0.69	....
1.60	1.37	13.4
2.40	2.06	20.2
3.20	2.74	....
4.00	3.43	33.6
4.80	4.11	40.3

(i) **Complete the table.** [2]
Space for calculations.

Examiner only

(ii) Plot a graph of F against I and draw a line of best fit. [3]



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(iii) Explain to what extent the data show that the force is proportional to the current. [3]

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(iv) The length of the portion **XY** of the wire is 5.0 cm. Determine the magnetic flux density, B, of the field between the poles of the magnet **and** quote it to an appropriate number of significant figures. [4]

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(v) Nancy claims that the forces on the **vertical portions of the wire** have not been considered in the answer to part (iv) and that the answer will be inaccurate because of this. Evaluate whether or not Nancy is correct. [2]

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(vi) The value of the magnetic flux density in part (iv) is slightly inaccurate for another reason which has nothing to do with human error or meter inaccuracies. Discuss what might be the cause of this inaccuracy. [2]

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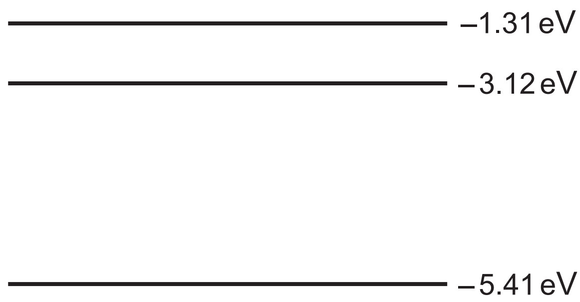
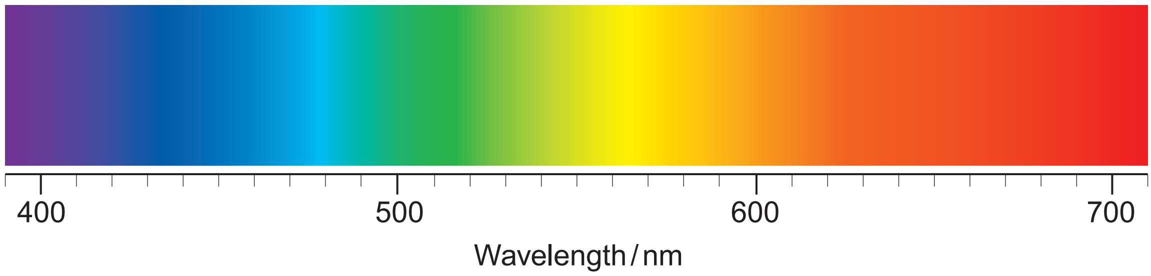
5. *(a)* Describe the appearance of line emission spectra and absorption spectra, how they can be produced **and** explain the atomic processes responsible for their production. [6 QER]

Examiner only

(b) The energy levels of a gas are shown below.



Transitions between these energy levels provide two visible photon energies and one ultraviolet photon energy. **Add to the diagram below** to indicate the two absorption lines expected for this gas within the wavelength range shown. [4]



Space for calculations.

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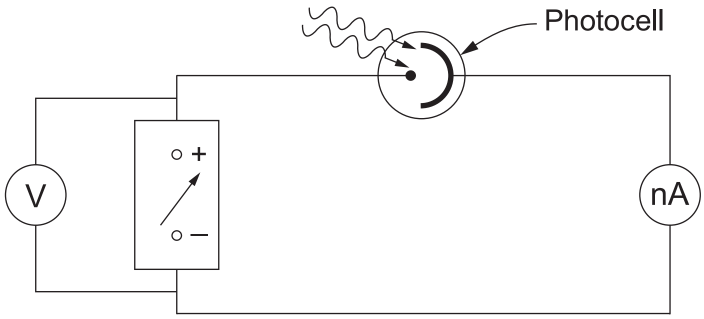
6. A photocell is used to demonstrate the photoelectric effect.



(a) Explain what is meant by the photoelectric effect. [3]

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(b) Light of frequency 655 THz and intensity $96.0\,\text{W}\,\text{m}^{-2}$ is incident on the photocell which has an emitting surface area of $2.50\,\text{cm}^2$.

(i) Calculate the number of photons per second incident on the photocell. [4]

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(ii) Calculate the current, given that only 0.54 % of the incident photons lead to electrons that are collected at the anode. [2]

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(c) Explain how the maximum kinetic energy of electrons can be measured using this apparatus. [3]

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7. The following is a nuclear reaction that is believed to take place in stars.

$$^{3}_{2}\text{He} + ^{1}_{1}\text{H} \longrightarrow ^{4}_{2}\text{He} + e^{+} + \nu_e$$

(a) Show how conservation of baryon number, charge and lepton number apply to this reaction. [3]

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(b) The electron neutrino indicates that this is a weak force interaction. State another clear indicator that this reaction is a weak force interaction. [1]

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(c) The masses of the particles in the reaction are:

Particle	Mass / kg	Particle	Mass / kg	Particle	Mass / kg
$^{3}_{2}\text{He}$	5.006×10^{-27}	$^{4}_{2}\text{He}$	6.645×10^{-27}	ν_e	0
$^{1}_{1}\text{H}$	1.673×10^{-27}	e^{+}	9.11×10^{-31}	....	....

Calculate the energy released in the reaction. [2]

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(d) Another more common nuclear reaction for $^{3}_{2}\text{He}$ in stars is:

$$^{3}_{2}\text{He} + ^{3}_{2}\text{He} \longrightarrow ^{4}_{2}\text{He} + 2^{1}_{1}\text{H}$$

Sophie claims that this is a strong nuclear force reaction. Determine whether or not Sophie is correct. [2]

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8. *(a)* State Faraday's law and Lenz's law of electromagnetic induction. [3]

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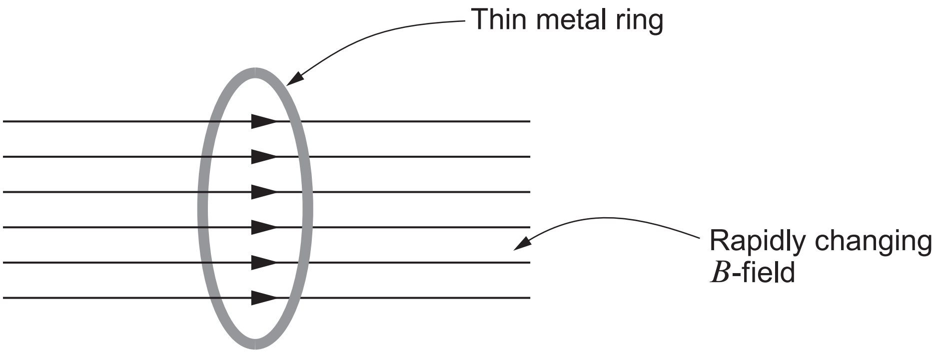
(b) (i) Varying magnetic, B, fields can lead to heating effects. Explain why the metal ring becomes hot in the set-up shown below. [2]



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(ii) Calculate the current in the ring if the rate of change of the B-field is 67 T s^{-1}, the ring has a **radius** of 7.0 cm and a resistance of 0.087 Ω. [3]

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(c) The rapidly changing electromagnetic fields of microwaves are known to cause heating effects but are also thought, by some, to cause cancer.

The Devon town of Totnes has banned the modern mobile phone network 5G even though this network is limited to an intensity of 10 $W m^{-2}$, the same as all other microwave mobile networks.

The intensity of electromagnetic radiation from the Sun on Totnes is around 1 000 $W m^{-2}$. Discuss whether Totnes Council has used scientific information wisely in their decision making. [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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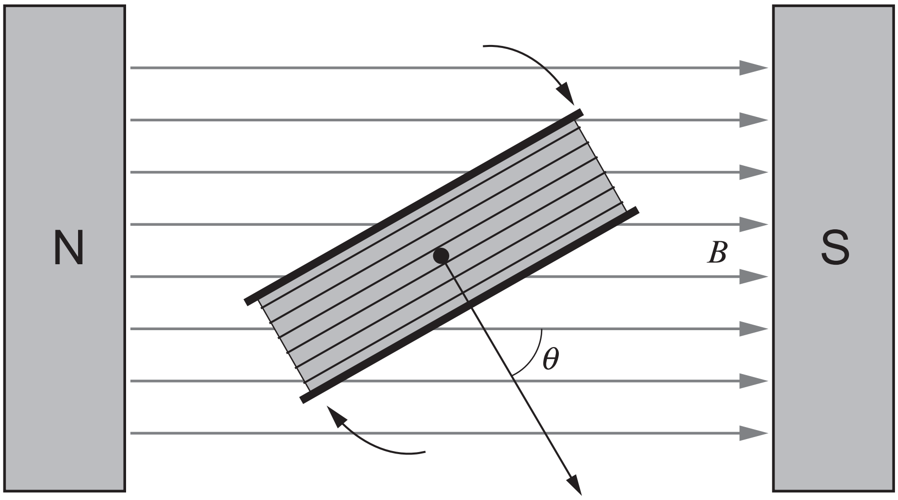
Option A – Alternating Currents

9. *(a)* The coil shown has a cross-sectional area of 24.0 cm^2, 350 turns and is rotated at a frequency of 50 Hz in a uniform magnetic field of 9.2 mT. The angle, θ, shown is zero at time t = 0.



(i) State at which values of θ the maxima and minima values of flux through the coil occur. [2]

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(ii) Explain at which value of θ the maximum induced emf occurs. [2]

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(iii) Calculate the induced emf when t = 2.5 ms. [3]

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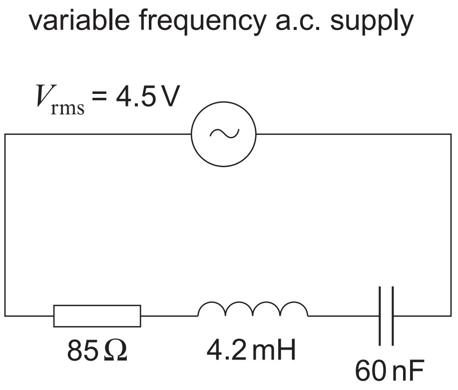
(b) The following RCL circuit is set up.



(i) Show that the resonance frequency of the circuit above is approximately 10 000 Hz. [1]

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(ii) Explain why the maximum rms current is approximately 50 mA. [1]

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(iii) Show that the rms current in the circuit is approximately 17 mA when the frequency is 16 kHz. [3]

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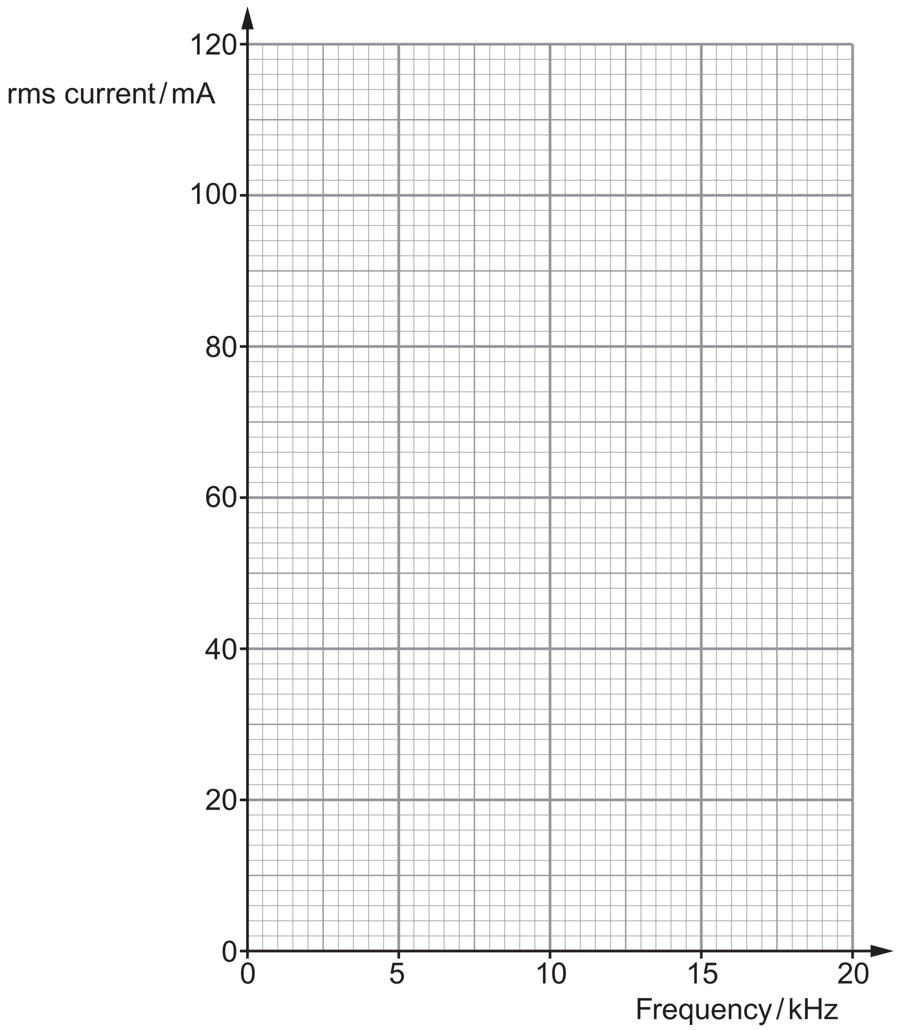
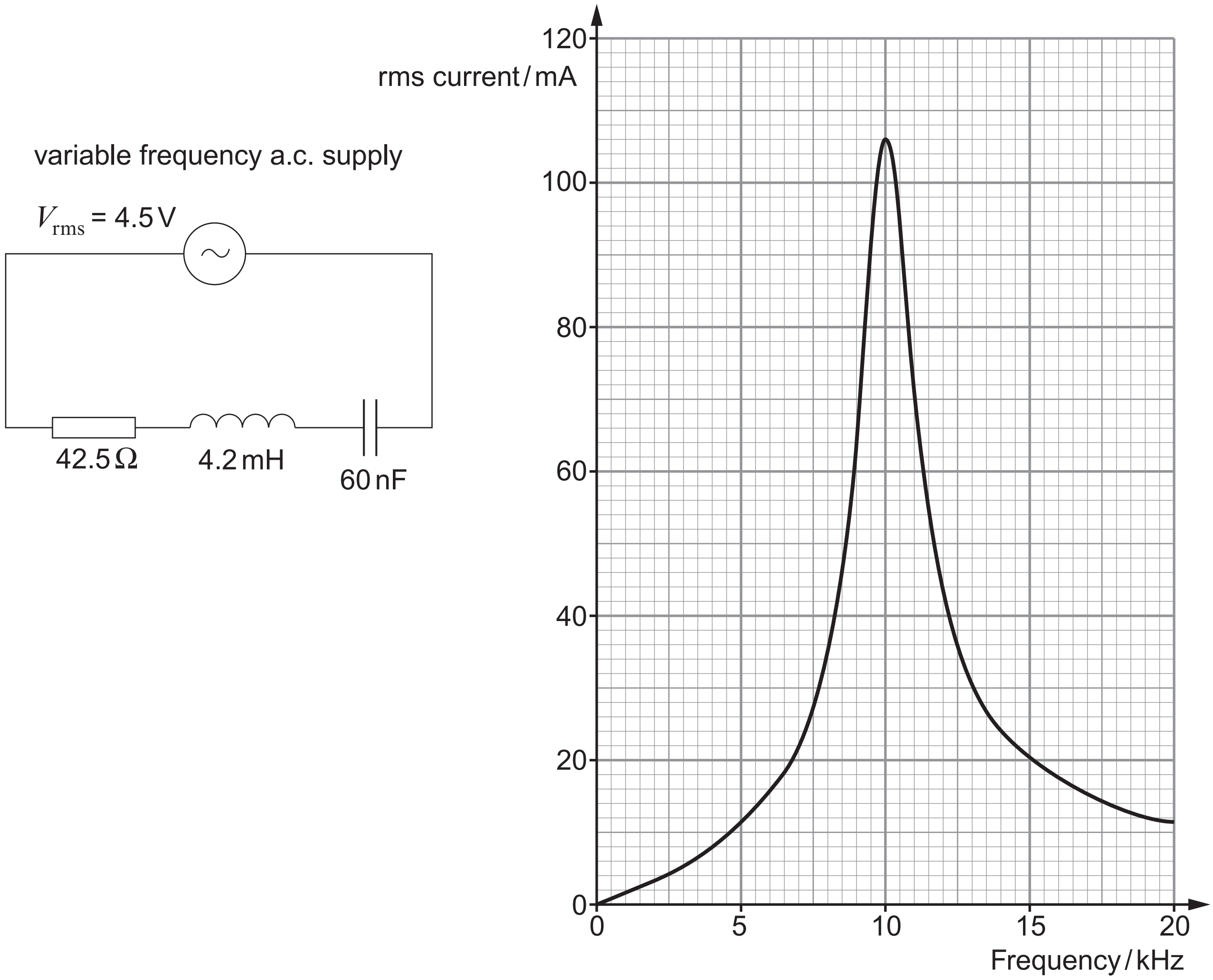
(iv) Use the results of parts (i), (ii) and (iii) to sketch a graph of rms current against frequency for the circuit on the axes provided. [3]



Examiner only

(c) Caitlin claims that the graph below shows the variation of rms current with frequency for the RCL circuit shown (the same circuit as in part *(b)* but with the resistance halved). Determine whether or not Caitlin is correct. [5]



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Option B – Medical Physics

10. *(a)* The electrons in an X-ray tube are accelerated by a pd of 45 kV.

(i) Determine the kinetic energy in **Joule** with which an electron hits the target after accelerating through this voltage. [2]

(ii) Determine the minimum wavelength of the X-rays. [2]

(iii) The X-ray tube has an efficiency of 0.5 % and the anode current is 0.12 A. Calculate the power of the X-rays produced. [2]

(b) The fraction, $\frac{I_R}{I_0}$, of ultrasound reflected at a boundary between two materials of acoustic impedance Z_1 and Z_2 is given by the equation:

$$\frac{I_R}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

Using the information given in the table below determine the fraction of ultrasound that is reflected at the air / skin boundary. [2]

Medium	Density / kg m^{-3}	Speed of ultrasound / m s^{-1}
air	1.300	340
skin	1.075×10^3	1 590

Examiner only

(c) (i) A magnetic resonance image (MRI) scanner can be used to detect tumours in a patient's body. Describe the effect a strong magnetic field has on hydrogen and how the hydrogen absorbs and emits radio waves. [2]

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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) Explain how PET scanners work. [3]

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Examiner only

(e) Doctors are concerned that a patient, who has a pacemaker fitted, has developed deep vein thrombosis (DVT) – blood clots in the leg leading to slow blood flow. They have the choice of the following techniques to diagnose this.

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

Evaluate the suitability of **all five types** of imaging techniques for detecting blood clots in the leg. [5]

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Option C – The Physics of Sports

11. *(a)* (i) Explain which player, **A** or **B**, is in a more stable position. [2]

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(ii) Explain what is meant by the statement that the coefficient of restitution of a netball ball and the floor of the court is 0.8. [2]

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(iii) Use the data in the table to show that a wood floor surface has the greater coefficient of restitution. [2]

Surface	Mean drop height / m	Mean bounce height / m
wood	1.25	0.62
rubber mesh	1.30	0.51

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Examiner only

(b) (i) In a practice match a player applies spin to the ball when passing to a team-mate. A spectator suggests that applying spin has no effect on the flight of the ball. Explain whether the spectator is correct. [3]

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(ii) Determine the torque applied to the ball to enable it to spin at a rate of 7.3 rad s^{-1} from rest in 0.3 s. The mass of the ball is 450 g and diameter 220 mm. The moment of inertia is given by the equation $I = \frac{2}{3}mr^2$. [4]

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(iii) During a different pass of the ball; the rotational kinetic energy of the ball is 4.4 J. Determine the number of revolutions per second of the ball. [3]

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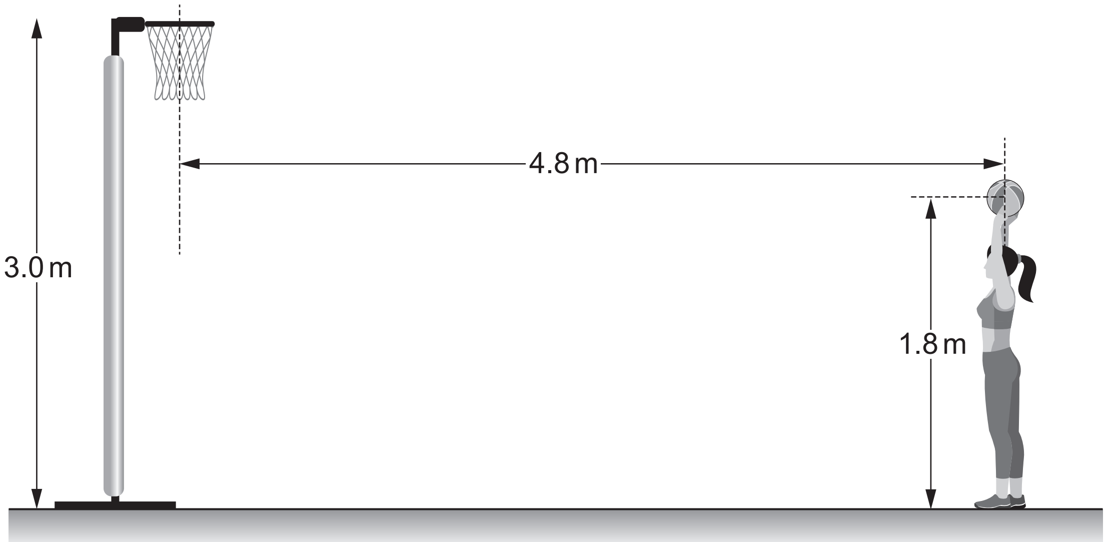
Examiner only

(c) A player aims to shoot a goal. The horizontal distance is 4.8 m and the height of the scoring hoop is 3.0 m. The ball is thrown with an initial speed of 8.0 m s^{-1} at an angle of 30° above the horizontal, from a height of 1.8 m. Assume that air resistance is negligible for this part.



(i) Determine the time of flight for the ball to reach the scoring hoop. [2]

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(ii) Evaluate whether or not a goal is scored. [2]

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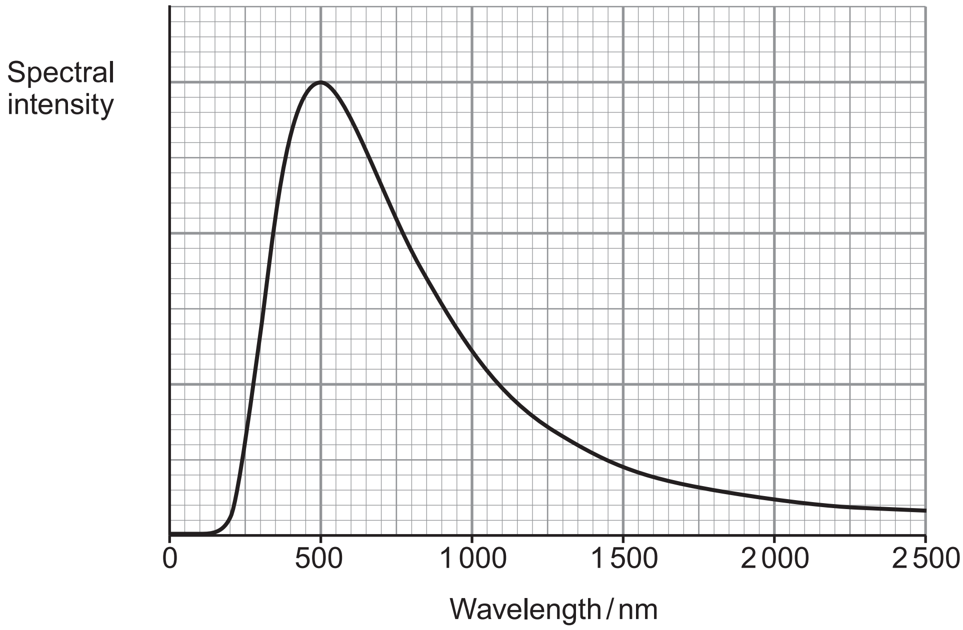
Option D – Energy and the Environment

12. *(a)* The graph below shows the radiation received from the Sun at the top of the Earth's atmosphere as a function of wavelength.



Describe how a graph of the radiation **emitted** from the Earth detected by a satellite outside the atmosphere would be different from the graph shown. [3]

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Turn over.

Examiner only

(b) (i) State Archimedes' principle. [2]

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(ii) Harry adds a block of ice to a measuring cylinder containing saltwater. This causes the measuring cylinder reading to increase by $100\,cm^3$. The density of saltwater is $1\,020\,kg\,m^{-3}$ and the density of ice is $920\,kg\,m^{-3}$. Determine the volume of the block of ice **above** the surface. [3]

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(iii) The block of ice is left to melt. Harry says the ice melting will dilute the saltwater, decreasing its density. He suggests that adding an identical cube of ice would now increase the measuring cylinder reading by **more than $100\,cm^3$**. Evaluate whether or not Harry is correct. [2]

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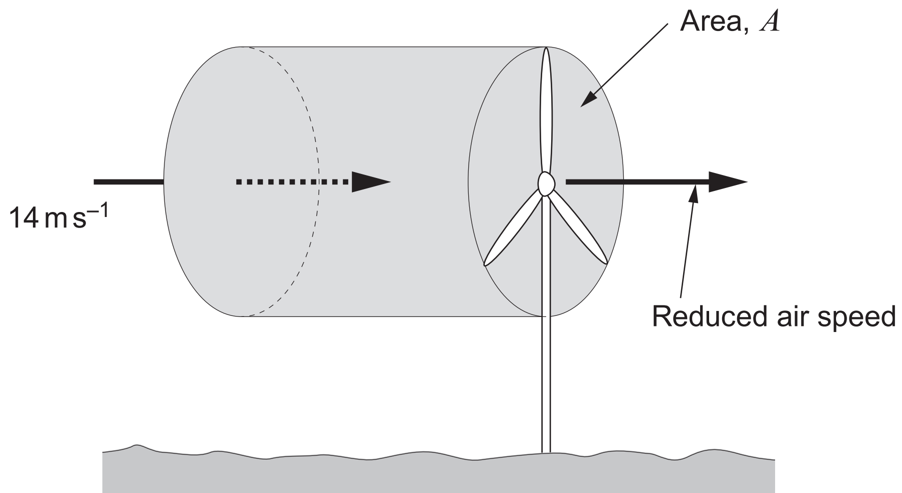
Examiner only

(c) (i) An offshore turbine has blades which sweep out an area of radius 82 m. The area swept out by the blades is always at right angles to the wind direction.
When the incoming air speed is $14\,m\,s^{-1}$, the energy transferred to the turbine from the air per second as it passes through the blades is 16 MW. Determine the mean speed of the air after it has passed through the blades. (Density of air = $1.2\,kg\,m^{-3}$.) [3]



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(ii) Under the above conditions the turbine can produce an electrical energy output of 210 MWh in 24 hours. Calculate the efficiency of the electricity production. [2]

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Examiner only

(d) (i) Define the U value of a building structure. [1]

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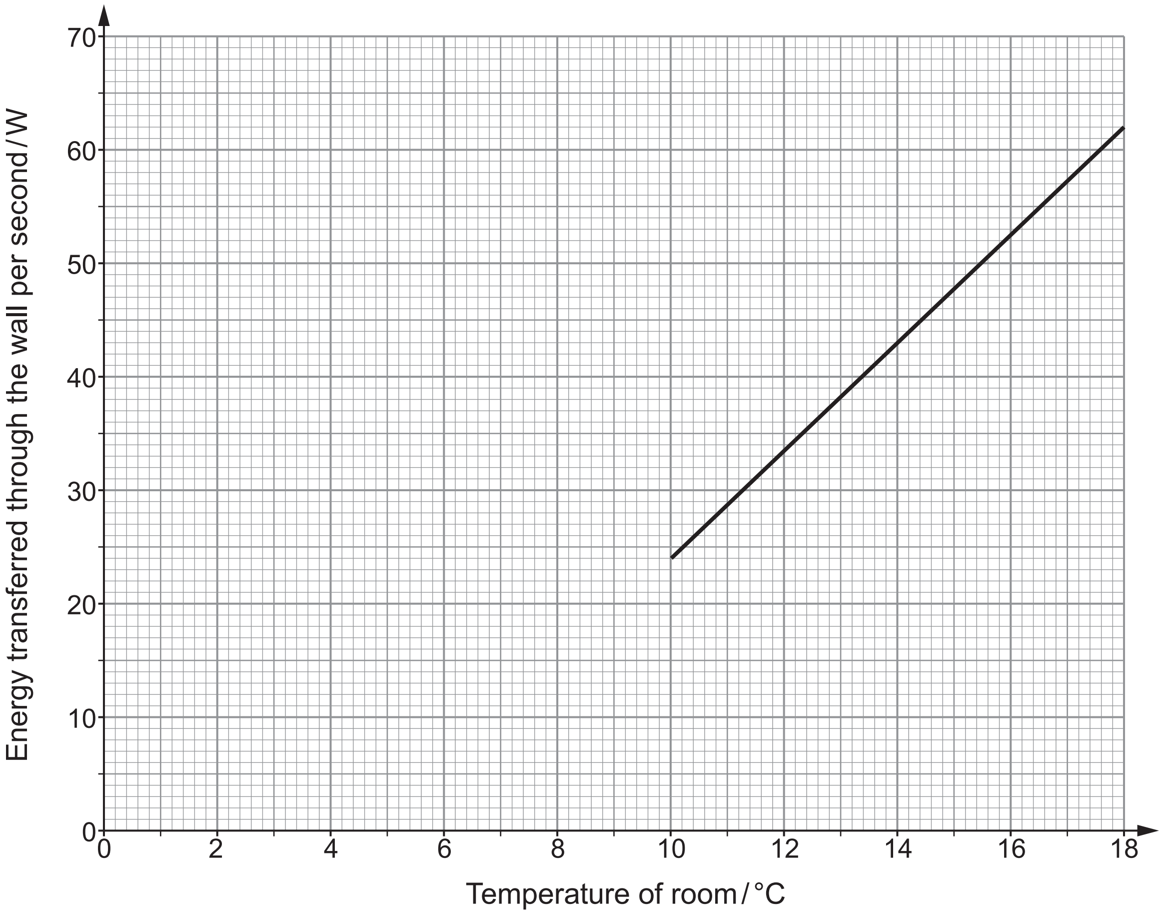
(ii) A room inside a building has one external wall measuring 5 m × 4 m. The graph below shows how the energy transferred through the wall per second varies with the temperature inside the room. (The temperature outside the building remains constant.)



Use the graph to determine the temperature outside the building and the U value of the wall. [3]

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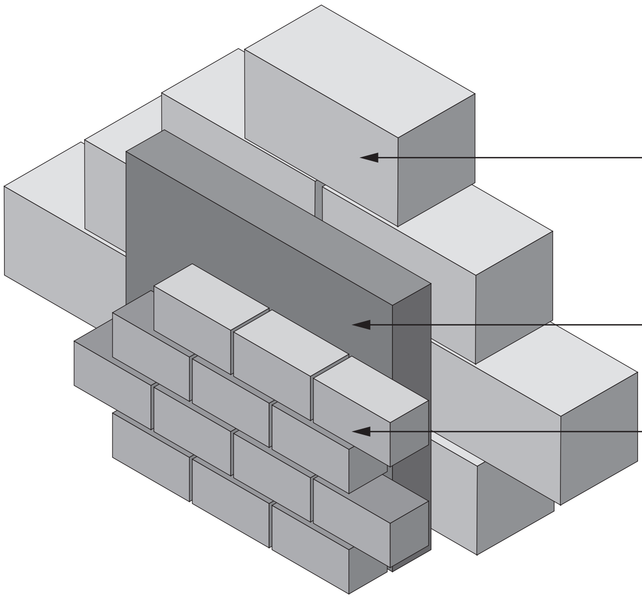
(iii) The external wall consists of three layers as shown.



Bob uses the thermal conductivity values of the three materials to calculate a theoretical energy loss per second when the room temperature is 10 °C. He notices his correctly calculated value is greater than 24 J s^{-1}. Give a reason for this. [1]

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