Surname	Centre Number	Candidate Number
Other Names		2

GCE A LEVEL – NEW

A420U30-1

S17-A420U30-1

Part of WJEC

PHYSICS – A level component 3
Light, Nuclei and Options

THURSDAY, 29 JUNE 2017 – MORNING

2 hours 15 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**8**	
	2.	**20**	
	3.	**9**	
	4.	**11**	
	5.	**16**	
	6.	**9**	
	7.	**11**	
	8.	**10**	
	9.	**6**	
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.

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 continuation page 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 **Q9**.

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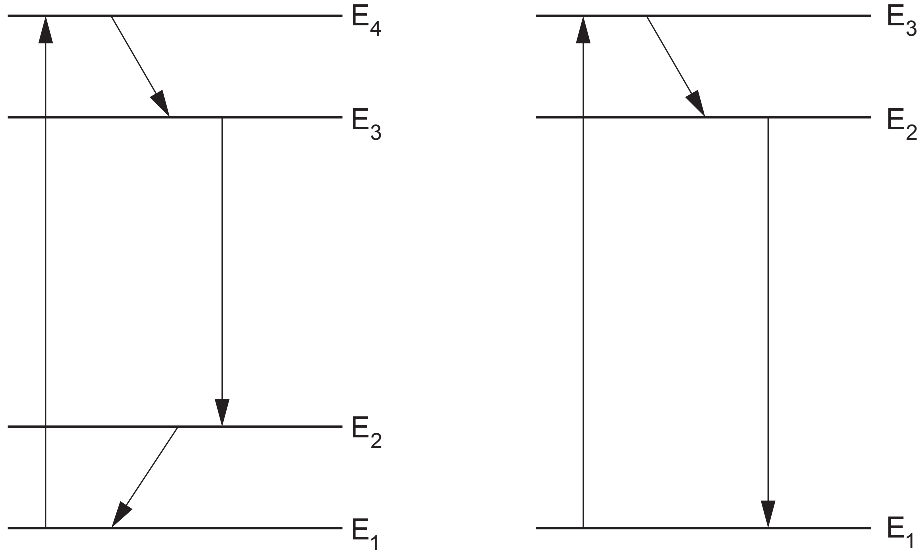
SECTION A

Answer **all** *questions.*

1. *(a)* **Label** the pumping and stimulated emission transitions in the four **and** three level laser systems shown below. [2]



(b) Explain why a population inversion can be achieved far more easily in a four level system than in a three level system. [4]

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(c) Give **two** reasons why the top level (E4 in the four level system and E3 in the three level system) must have a short lifetime. [2]

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2. *(a)* A carbon-14 nucleus decays as shown:

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}}$$

(i) Show how charge, baryon number and lepton number are conserved in this decay. [3]

(ii) Give two reasons why this must be a weak nuclear force interaction. [2]

(b) The decay constant of carbon-14 is $3.83 \times 10^{-12}\ \mathrm{s}^{-1}$.

(i) Calculate its half-life in years. [3]

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(ii) The natural ratio of carbon-14 to carbon-12 is 1.00×10^{-12} i.e.

$$\frac{\text{number of } ^{14}_{6}\text{C nuclei}}{\text{number of } ^{12}_{6}\text{C nuclei}} = 1.00 \times 10^{-12}$$

Calculate the activity of 12 g of naturally occurring carbon. [3]

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(iii) In an old tree found preserved in a peat bog in Ireland, much of the carbon-14 has decayed but the carbon-12 all remains. The ratio of carbon-14 to carbon-12 in this old tree has dropped to 0.34×10^{-12}. Calculate the age of the old tree. [3]

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(c) Carbon-11 ($^{11}_{6}\text{C}$) is proton rich and undergoes positron decay to a stable isotope of boron (B). Complete the following decay equation for carbon-11. Space is provided should you require analysis of lepton number, baryon number and charge. [3]

$$^{11}_{6}\text{C} \longrightarrow$$

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(d) On the 14 March 2013, the discovery of the Higgs boson was first announced by CERN. Some physicists were convinced that they had discovered the Higgs boson, others believed that there are many different types of Higgs bosons while others claim that this was just another particle and not the Higgs boson. Explain how it may or may not be decided which, if any, of these claims is correct. [3]

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3. A tritium nucleus decays into helium-3 as follows:

$$^{3}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}}$$

$$\left[\begin{array}{ll} \text{mass of } ^{3}_{1}\mathrm{H} = 3.01550\,\mathrm{u} & \text{mass of } ^{3}_{2}\mathrm{He} = 3.01493\,\mathrm{u} \\ m_{\mathrm{e}} = 0.00055\,\mathrm{u} & \text{mass of } \bar{\nu}_{\mathrm{e}} = 0.00000\,\mathrm{u} \\ \multicolumn{2}{c}{1\,\mathrm{u} = 931\,\mathrm{MeV}} \end{array}\right]$$

(a) Calculate the energy released in the decay of tritium. [3]

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(b) The mass of a proton is 1.00728 u and the mass of a neutron is 1.00866 u.

(i) Calculate the binding energy per nucleon of a tritium nucleus. [3]

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(ii) The binding energy per nucleon of a helium-3 nucleus (i.e. 2.6 MeV/nucleon) is slightly lower than the answer to *(b)*(i). How does this show that binding energy per nucleon is not the only measure of stability? [3]

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4. An insulated wire is made into a long solenoid of length 4.00 m by winding it around a pipe of diameter 3.00 cm. The wire is 0.25 mm thick and is wound so that each loop just touches the next.

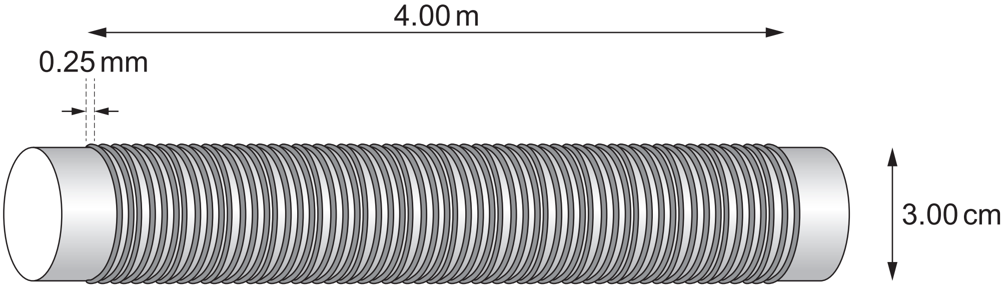

Diagram not to scale

(a) Show that the length of the wire is approximately 1.5 km. *You may assume that the insulation thickness is negligible.* [3]

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(b) Show that a steady current of approximately 25 mA is carried in the wire when a pd of 12.0 V is applied across its ends. The resistivity of the wire is $1.59 \times 10^{-8}\ \Omega\,\text{m}$. [3]

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(c) Calculate the magnetic field strength, B, inside the solenoid. [2]

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(d) Explain whether or not the solenoid could produce a magnetic field of 2 T. You should include a calculation to reinforce your answer. [3]

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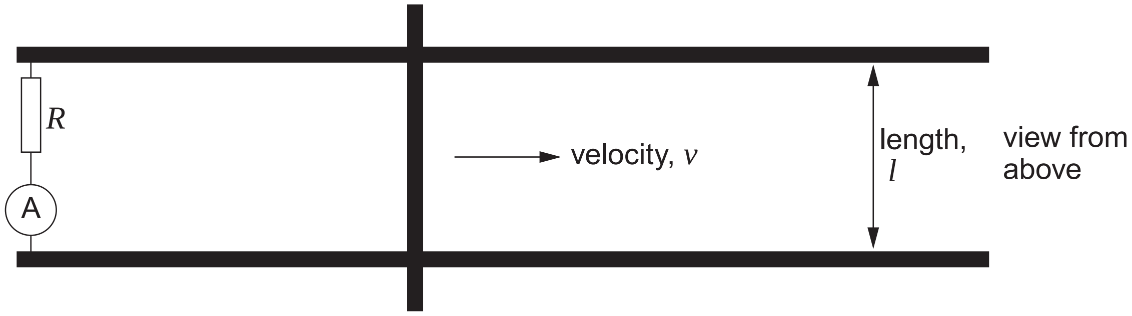
5. An experiment is carried out on a flat, horizontal railway track to measure the vertical component of the Earth's magnetic field, B. A metal conductor is placed across the railway tracks and moved quickly in the direction shown.



(a) (i) Explain why a current is detected by the ammeter. [2]

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(ii) Explain why the current is independent of the horizontal component of the Earth's magnetic field. [1]

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(b) Use Faraday's law to derive the expression for the current: [3]

$$I = \frac{Bl}{R}v$$

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(c) The results obtained are tabulated.

Velocity / $m\,s^{-1}$ $\pm 1\,m\,s^{-1}$	Current / μA $\pm 10\,\mu A$
20	40
40	80
60	110
80	150

(i) Without drawing a graph, explain whether or not the data are consistent with the equation: [4]

$$I = \frac{Bl}{R}v$$

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(ii) Use the data in the table with the smallest percentage uncertainties to calculate the vertical component of the Earth's magnetic field, B, together with its **absolute uncertainty** (l = 1.400 m, R = 43.0 Ω with negligible uncertainties). [6]

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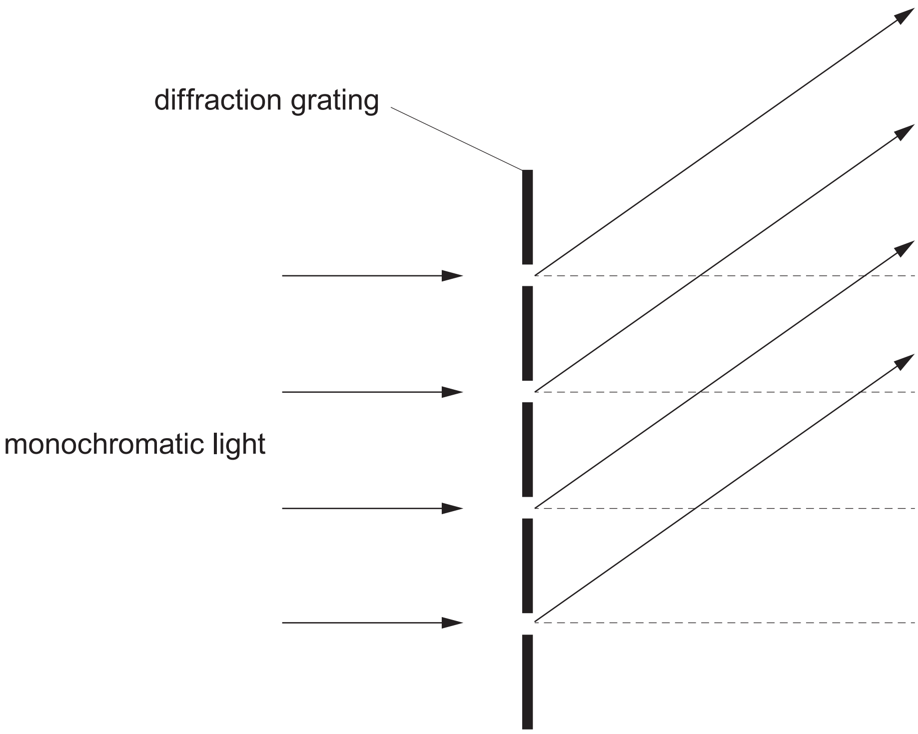
6. *(a)* Adding to the diagram, derive the equation $n\lambda = d\sin\theta$ for a diffraction grating. [3]



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(b) A diffraction grating has 250 lines per mm and light of wavelength 532 nm is incident normally upon it. Calculate the angle between the first and second order light beams. [4]

(c) Another diffraction grating has half the angle between the first and second order light beams when light of wavelength 532 nm is incident upon it. Estimate the number of lines per mm of this second diffraction grating. [2]

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7. *(a)* Explain how two source interference patterns arise. [4]

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(b) The diagram shows the two source interference pattern due to two in-phase sources in a ripple/water tank.

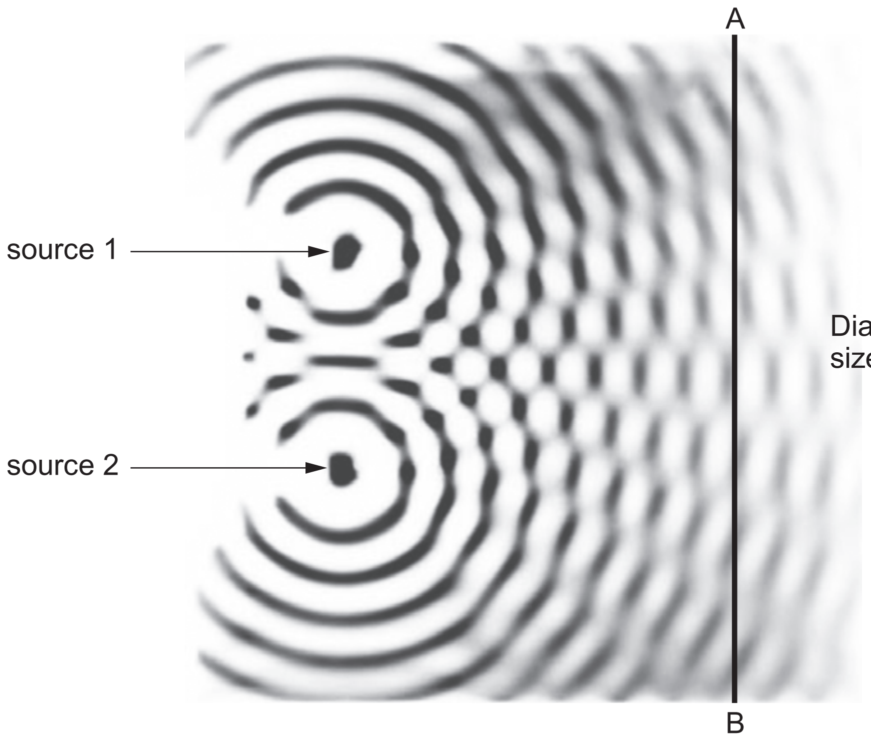

Diagram is actual size (scale 1:1)

(i) **Place an X** on the line AB at any point where there is a path difference of 3 wavelengths between waves from the two sources. [1]

(ii) **Place a Y** on the line AB at any point where there is a path difference of 1.5 wavelengths between waves from the two sources. [1]

Examiner only

(c) (i) The diagram is actual size. Measure the wavelength of the waves accurately by using the distance between wavefronts. [2]

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(ii) Hence check whether or not the equation: $\lambda = \dfrac{a\Delta y}{D}$ is a good approximation for the given diagram. **Show your working.** [3]

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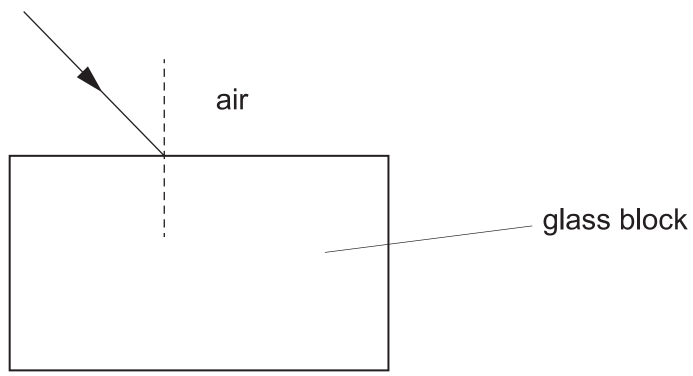
8. An experiment is carried out to investigate Snell's law. Laser light is passed through a glass block and the angles of incidence and refraction are measured using a protractor.



(a) **Draw** the refracted ray and the ray emerging from the glass block on the above diagram. [2]

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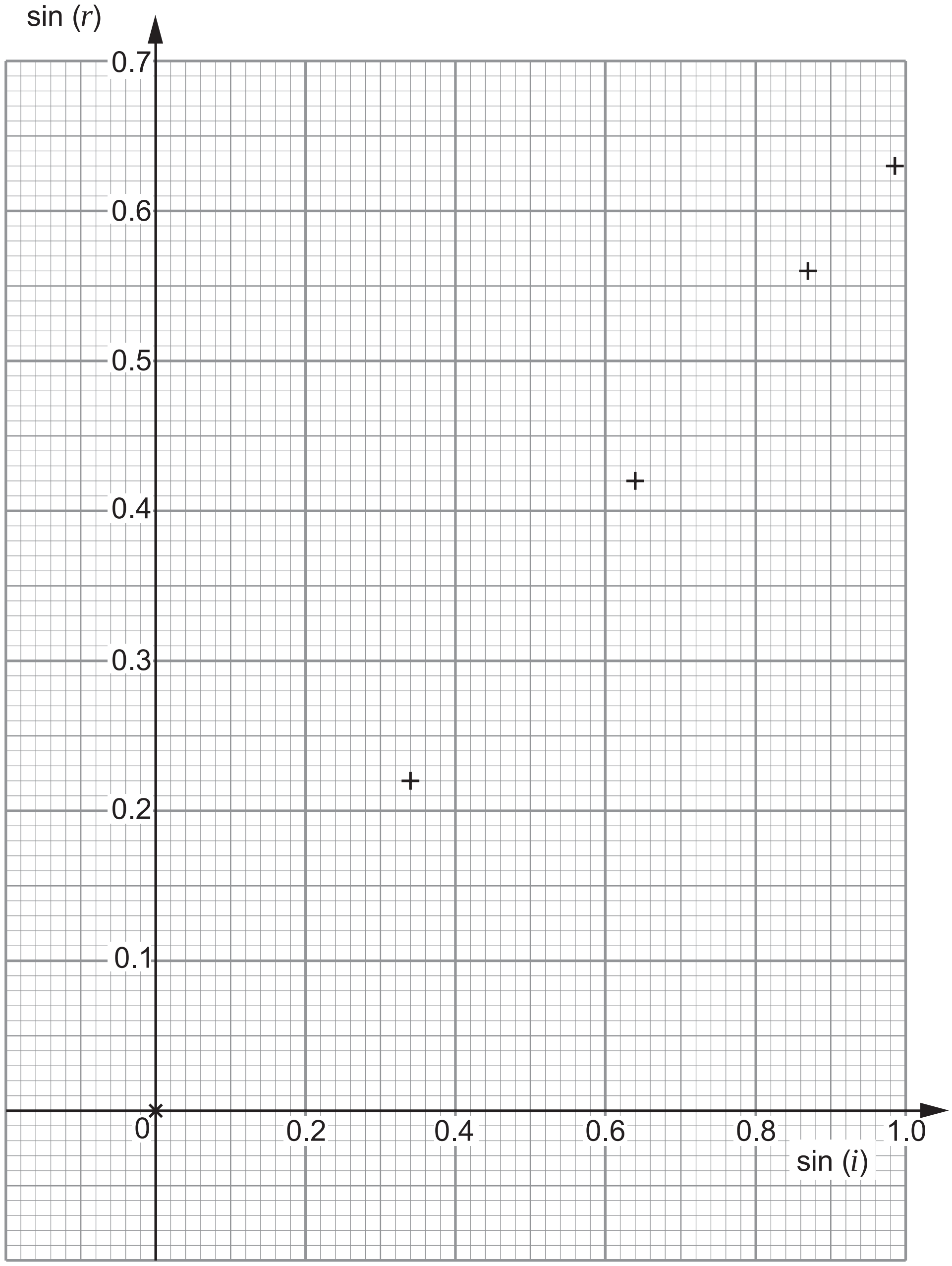
(b) The results obtained are collated in the following table and plotted on the grid.

Incident angle (i) / degrees ±1°	Refracted angle (r) / degrees ±1°	sin (i)	sin (r)
0	0	0.00 ± 0.02	0.00 ± 0.02
20	13	0.34 ± 0.02	0.22 ± 0.02
40	25	0.64 ± 0.01	0.42 ± 0.02
60	34	0.87 ± 0.01	0.56 ± 0.01
80	39	0.985 ± 0.005	0.63 ± 0.01



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(i) **Add error bars** to the data points and also draw the lines of maximum gradient and minimum gradient. [4]

(ii) Determine the refractive index of the block along with a value for its **absolute uncertainty**, quoting your results to an appropriate number of significant figures. [4]

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9. Explain the advantages of monomode optical fibres over multimode optical fibres when transmitting a rapid sequence of pulses. [6 QER]

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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

10. *(a)* A 900 W toaster is supplied with a sinusoidally varying pd of **peak** pd 325 V. Calculate:

(i) the **rms** current; [2]

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(ii) the resistance of the toaster. [2]

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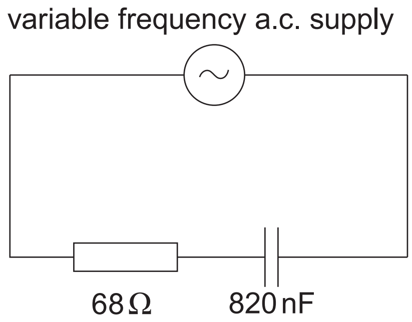
(b) Helen claims that the following circuit will have a minimum impedance of 68 Ω when the frequency is very low but that the impedance will be extremely large at high frequencies.



Deduce whether or not Helen is correct. [5]

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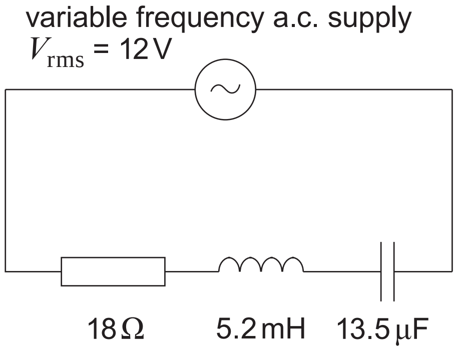
(c) (i) Explain why the rms current at resonance of the following circuit is approximately 700 mA. [2]



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(ii) Show that the resonance frequency (f_0) is approximately 600 Hz. [2]

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(iii) Calculate the rms current when the frequency of the supply is increased to $1.5f_0$. [4]

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(iv) Explain why the rms current is the same when the frequency is decreased to $\frac{f_0}{1.5}$. [3]

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Option B – Medical Physics

11. *(a)* Describe briefly how X-rays are produced in an X-ray tube. [2]

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(b) (i) When a beam of X-rays passes through bone the X-rays are absorbed and the beam becomes attenuated. The thickness of bone needed to reduce the original intensity by 50 % is known as the half value thickness, $x_{\frac{1}{2}}$. Show that $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$ where μ is the attenuation coefficient. [3]

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(ii) A beam of X-rays is used to detect a fracture in a bone. If the half value thickness for these X-rays in bone is 1.5 cm, calculate the thickness of bone that reduces the incident intensity by 60 % of the original intensity. [3]

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(iii) X-ray imaging is not suitable for diagnosing brain tumours. Explain why, and suggest a more suitable technique giving your reasons. [3]

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(c) An ultrasound probe can be used to check the development of an unborn baby. Explain how a piezoelectric transducer can be used to produce ultrasound. [2]

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(d) The table below gives some ultrasound properties of different body tissues.

Material	Density / $kg\,m^{-3}$	Velocity / $m\,s^{-1}$	Acoustic impedance / $kg\,m^{-2}\,s^{-1}$
Muscle	1 075	1 590	
Fat	925	1 450	
Bone	1 908	4 080	

(i) **Complete the table** by calculating the different values for acoustic impedance. [2]

(ii) The fraction of ultrasound reflected at a boundary is given by the reflection coefficient, R, where:

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

Between which **two** tissues would the greatest amount of ultrasound be reflected? Justify your answer numerically. [3]

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(e) A typical MRI scanner operates with a Larmor frequency of 64 MHz. Calculate the magnetic field strength, B, that would be needed to provide this, and state which patients would **not** be able to undergo MRI scans. [2]

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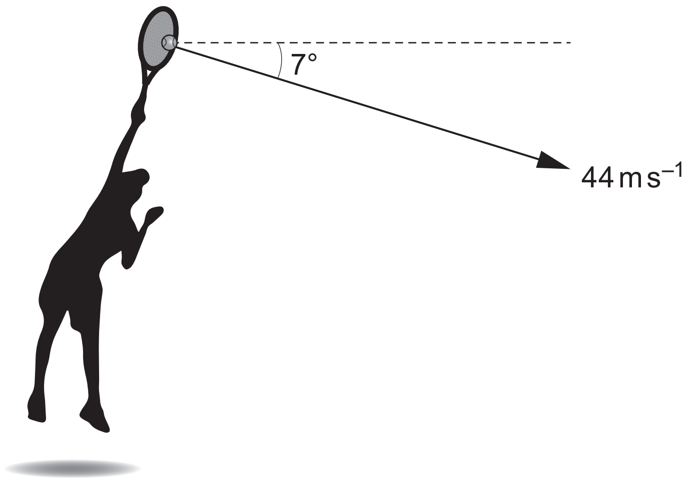
Option C – The Physics of Sports

12. *(a)* (i) At the start of a tennis game, a player serves the ball with an initial velocity of $44\,\text{m}\,\text{s}^{-1}$ at an angle of 7° to the horizontal as shown below. The maximum horizontal distance for the ball to stay in play is 18.29 m. If the ball remains in the air for a time of 0.41 s, determine if the ball lands in play from the serve. *Ignore the effects of air resistance for this part of the question.* [3]



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(ii) The tennis ball has a mass of 0.056 kg and is momentarily at rest before being hit by the racquet. Determine the mean force exerted by the racquet on the ball if they remain in contact for a time of 6.0 ms. [2]

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(b) (i) The coefficient of restitution between the ball and the floor is 0.74. Explain what this statement means. [2]

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(ii) Determine the **second** bounce height of a tennis ball if the ball is dropped from a height of 1.95 m (the coefficient of restitution between the ball and the floor is 0.74). [3]

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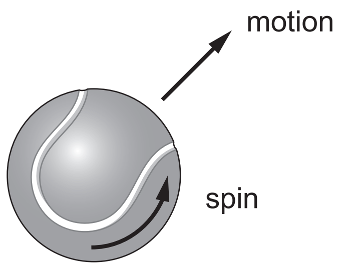
(c) (i) During the game, the player plays a shot and applies spin to the ball. Explain how the ball will travel through the air by discussing the forces acting on the ball. Label the forces and their directions on the diagram provided. [4]



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(ii) The ball is hit with a velocity of $16.4\,\text{m}\,\text{s}^{-1}$ and spins at a rate of 3500 revolutions per minute. Determine the **total** kinetic energy of the ball if the diameter of the ball is 7.0 cm and its mass is 0.056 kg.

Note: a tennis ball can be considered to be a thin spherical shell. [4]

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(iii) Determine the drag force acting on the ball if the drag coefficient for a tennis ball is 0.53 and the density of air is $1.2\,\text{kg}\,\text{m}^{-3}$. [2]

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Option D – Energy and the Environment

13. *(a)* (i) Assuming that the Earth emits radiation as a black body at a temperature of 288 K, confirm that the peak wavelength of the radiation emitted by the Earth is in the infra-red part of the electromagnetic spectrum. [2]

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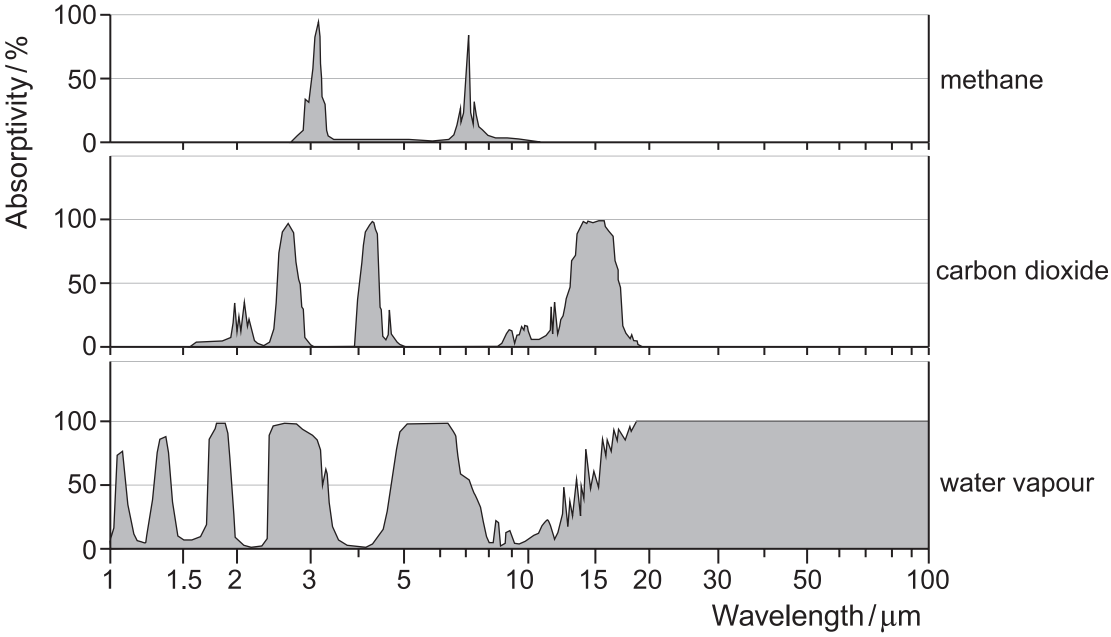
(ii) The graphs below show greenhouse gas absorption spectra for methane (CH_4), carbon dioxide and water vapour as a function of the wavelength of the radiation incident on the gas. An absorptivity of zero % means no radiation is absorbed, whilst an absorptivity of 100 % means that all the incident radiation is absorbed.



I. Make three observations from these graphs regarding absorption of infra-red by these gases. [3]

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II. Studies show that the concentration levels of these gases in the atmosphere continue to increase. Choose two of these gases and give one reason as to why the concentration level is increasing for each of your choices. [2]

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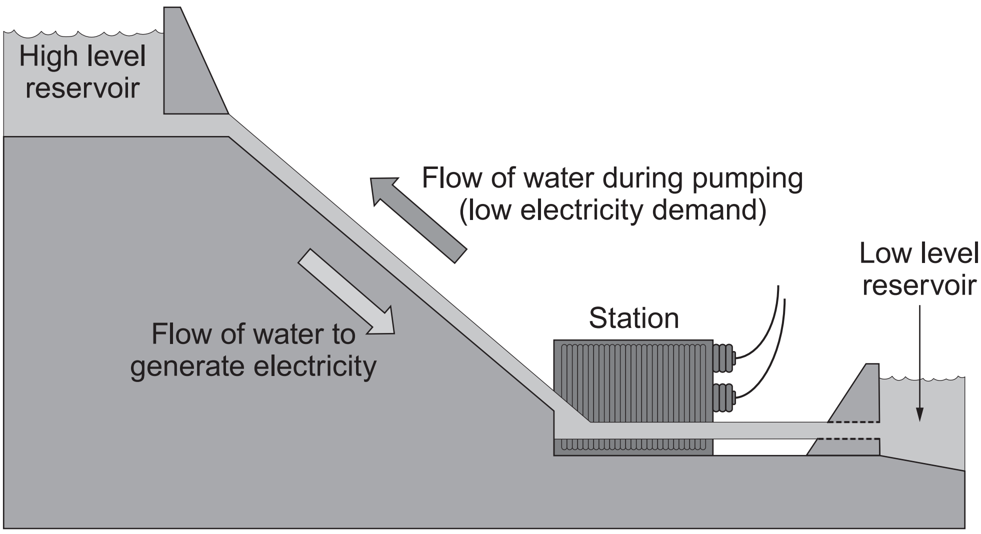
(b) The diagram shows a pumped storage hydroelectric power station. The station has a power output of 120 MW and the height difference between the high level reservoir and the turbine units is 420 m.



(i) Assuming the generating process is 85 % efficient, calculate the mass of water passing through the turbines per second. [3]

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(ii) The power station has a mean **annual** output of 240 GWh of electrical energy. Calculate the mean time during which the power station is in use per day. Give your answer in hours. [2]

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(iii) Without considering energy losses, give one reason why this power station would not be able to produce significantly more than 240 GWh of energy per year. [1]

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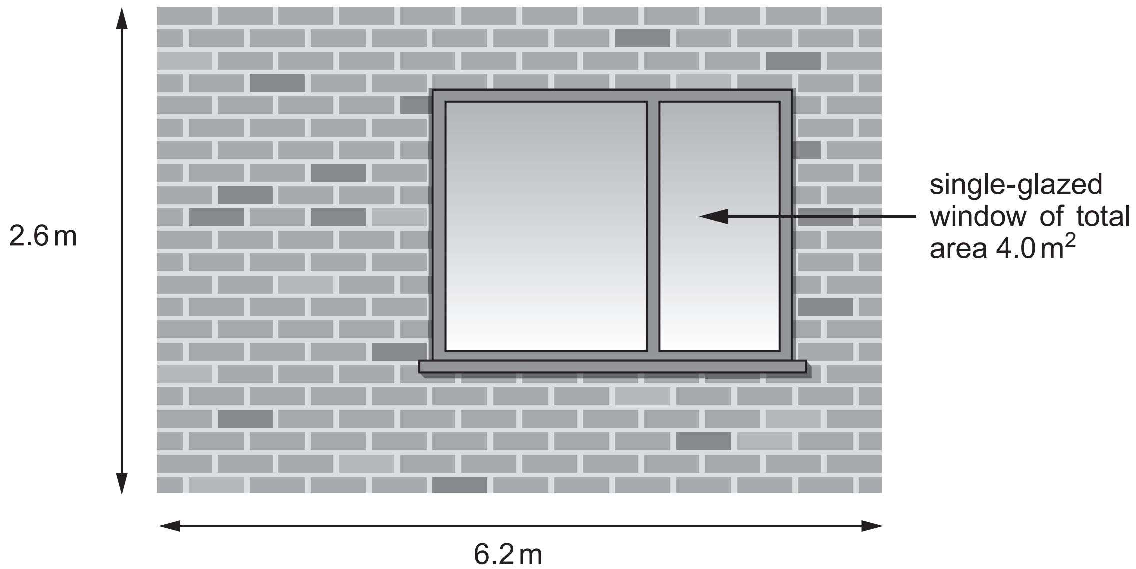
(c) The interior of a house is maintained at a constant temperature of 20 °C. A room in the house has one exterior wall of dimensions 2.6 m × 6.2 m and a window of area 4.0 m^2 as shown.



(i) The rate of heat transfer through the window is 154 W. Calculate the total rate of heat loss from the room when the external temperature on a windless day is 12 °C. [2]

$$[U_{\text{wall}} = 1.6\,\text{W m}^{-2}\,\text{K}^{-1}]$$

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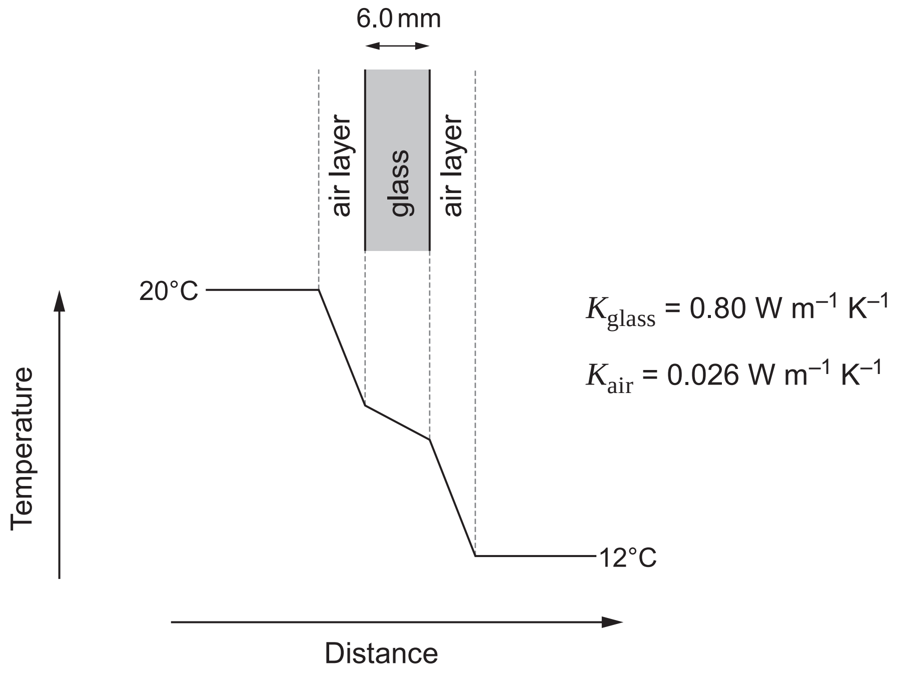
(ii) The heat loss through the window is kept low by a thin layer of stationary air in contact with the inside and outside of the window. These layers provide insulation. The temperature variation across the region of the window is shown below. The thickness of the window pane is 6.0 mm.



I. Use the rate of heat loss through the window to show that the temperature difference across the glass is approximately 0.3 °C. [2]

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II. Calculate the thickness of each of the layers of air. You should assume that the two layers of air have equal thickness. [2]

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III. Without calculation, explain how the rate of heat loss through the window would be different if it were a breezy day. [1]

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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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