Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

A420U30-1

S24-A420U30-1

eduqas Part of WJEC

MONDAY, 17 JUNE 2024 – 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.	**13**	
	3.	**13**	
	4.	**14**	
	5.	**21**	
	6.	**5**	
	7.	**10**	
	8.	**11**	
Section B	**Option**	**20**	
	Total	**120**	

A420U301 01

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 **2**(c).

JUN24A420U30101

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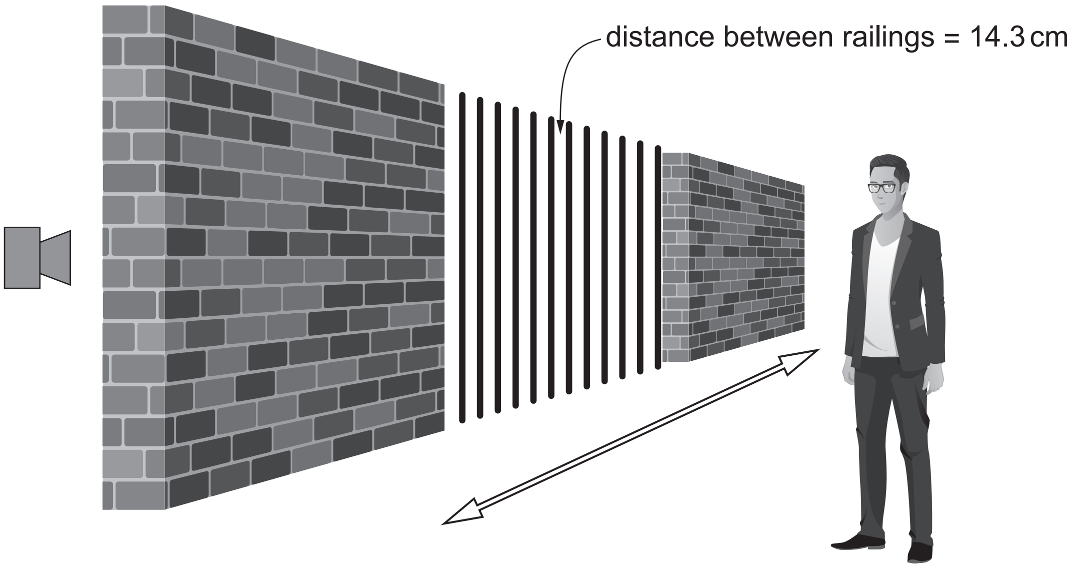
SECTION A

Answer **all** questions.

1. Morwenna and Dave carry out an experiment to show that the metal railings outside a school can act as a diffraction grating for sound waves. She uses a loudspeaker and Dave detects the sounds on the other side of the metal railings.



(a) When the frequency of the sound waves is 550 Hz, Dave states that he doesn't hear much sound from the loudspeaker and that there are no areas of loud sound as he walks backwards and forwards along the direction shown. Explain why the diffraction grating does not work at this frequency. The speed of sound is 342 $m\,s^{-1}$. [4]

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(b) Morwenna increases the frequency of the sound waves to 5500 Hz and Dave says that there are **5 directions** of very loud sound on the other side of the metal railings. Using a calculation, explain why this is to be expected. [3]

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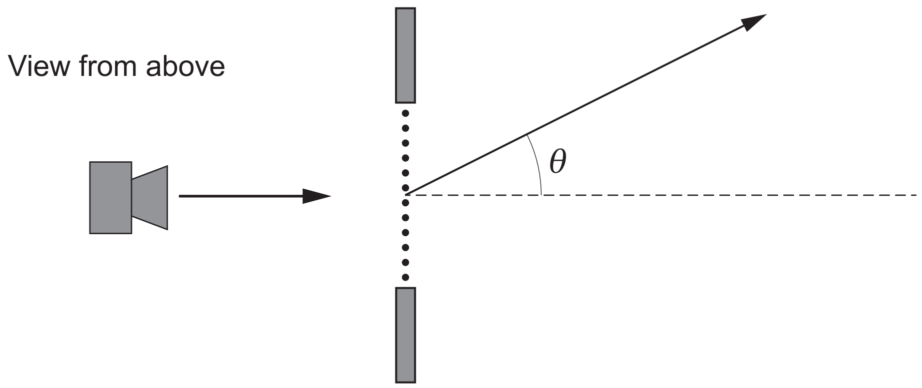
(c) Calculate all the angles, θ, at which you would expect the loud sounds to occur. [3]



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(d) Dave states, "The metal railings are very similar to a polariser for microwaves so the sound waves I'm detecting must be polarised." Determine to what extent Dave's statement is correct. [3]

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Turn over.

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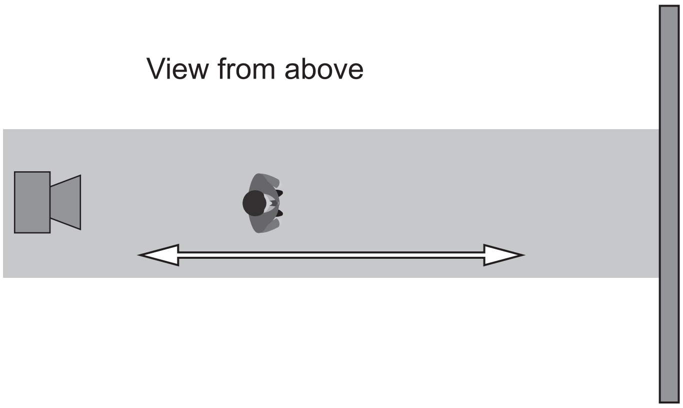
2. Robin and Eilir investigate stationary waves using sound waves and a wall.

View from above



(a) Explain why a stationary wave is produced between the loudspeaker and the wall. [3]

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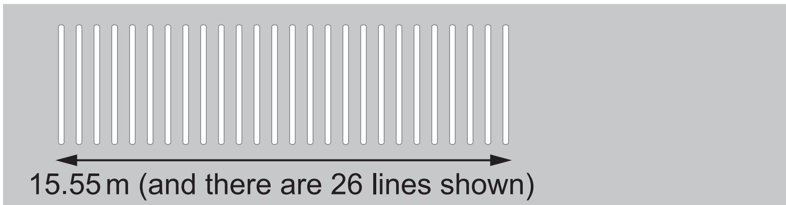
(b) While moving in the direction shown, Robin places a chalk line on the floor at each place where he detects a loud sound. The lines he places on the floor are shown.



Calculate the frequency of sound used (speed of sound = 342 $m\,s^{-1}$). [4]

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(c) State the differences between progressive and stationary waves. In your answer you should refer to amplitude, energy and phase. [6 QER]

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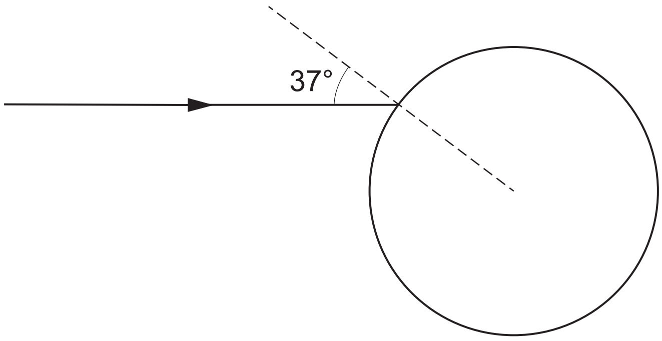
3. (a) A ray of light is incident upon a water droplet of refractive index 1.33.

(i) Calculate the angle of refraction. [2]



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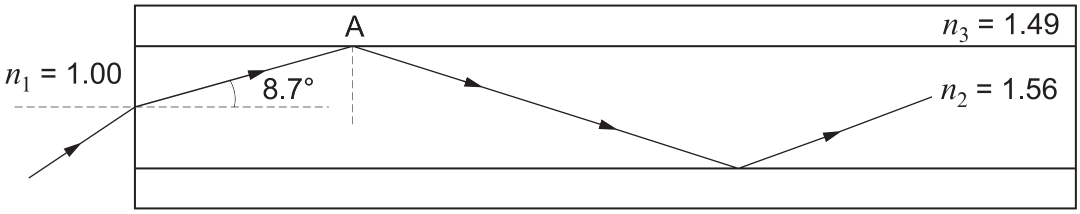
(ii) **Complete the diagram above** by showing the ray passing through the droplet and out of the other side. **Label the angles with their values.** [3]

(b) A ray of light enters an optical fibre as shown.



(i) Show that refraction does not occur at A. [3]

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(ii) Explain how 'multimode dispersion' arises and outline the problem that it causes. [3]

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(iii) Explain how the problem of 'multimode dispersion' is solved in practice. [2]

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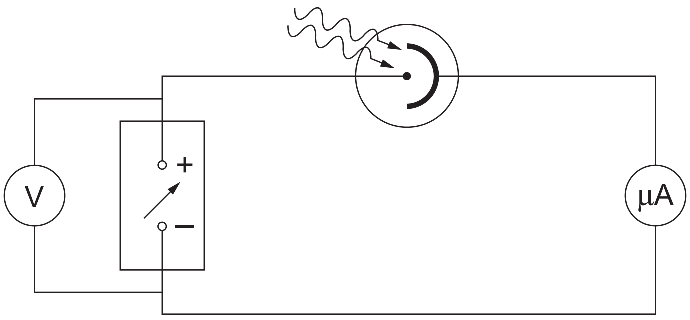
4. If other factors are kept constant, the current detected in the following circuit is proportional to the light intensity incident on the photocell.



(a) Explain why the current is proportional to the light intensity. [3]

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(b) State the **two** factors that should be kept constant for the current to be proportional to the light intensity for this photocell. [2]

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(c) Light of wavelength 410 nm is incident on the photocell.

(i) Calculate the work function of the metal of the photocell, given that the maximum speed of the photoelectrons is $3.9 \times 10^{5}\,m\,s^{-1}$. [3]

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(ii) The total light power incident on the photocell is $0.36\,\mu W$. Calculate the current in the circuit, stating any assumption that you make. [3]

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(d) The photoelectric effect is evidence of light behaving like particles. In 1802, Thomas Young carried out an experiment that was evidence of light behaving like a wave. In 1704, Newton had argued that light was made of particles whose size varied with colour. Explain how the scientific community has decided which of these theories to adopt. [3]

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5. Lawrence carries out an experiment to model the decay of radioactive nuclei using ten thousand 10 p coins. He uses the symbol, T, to represent the throw number, the symbol, N, to represent the number of remaining coins and the symbol, A, to represent the number of coins "decaying" in the throw. His results are shown in the table.

Throw number, T	Number of remaining coins before throw, N	Number of coins that decayed, A	$\ln N$	$\ln A$
0	10 000	5170	9.21	8.55
1	4830	2347	8.48	7.76
2	2483	1256	7.82	7.14
3	1227	614	7.11	6.42
4	613	302	6.42	5.71
5	311	153	5.74	5.03
6	158	68	5.06	4.22

(a) State briefly how he carried out the experiment. [4]

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(b) (i) State what you would expect the half-life of the 10 p coins to be. [1]

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(ii) The equations linking N, A and T are:

$$N = N_0 e^{-\lambda T} \qquad \text{and} \qquad A = A_0 e^{-\lambda T}$$

where N_0 is the initial number of coins (10 000), A_0 is the initial number of coins decaying (expected to be 5000) and λ is a decay constant related to the half-life.

Show that the expected gradient of the graph of $\ln N$ against T is $-\ln 2$. [3]

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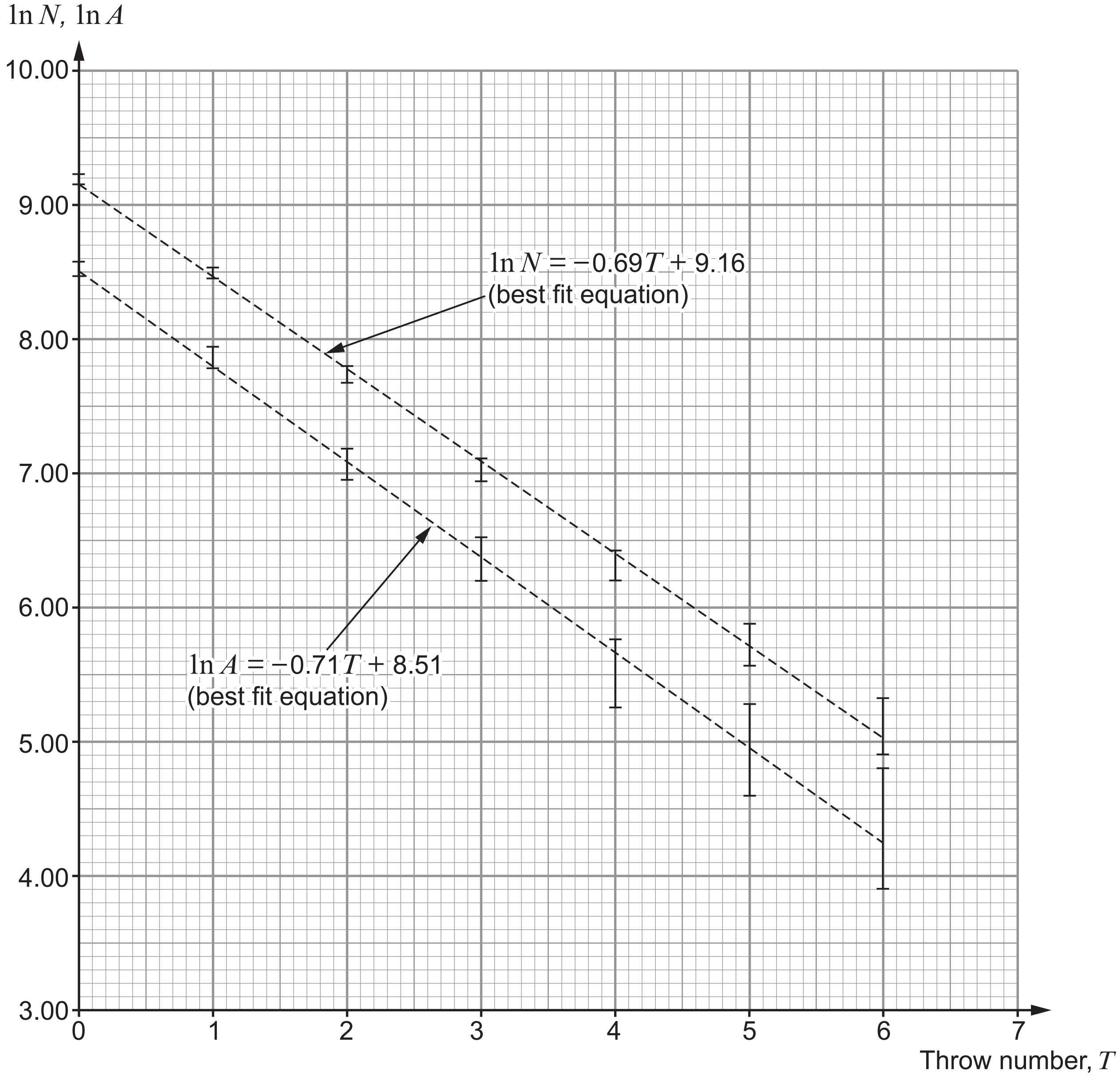
(c) Lawrence plots graphs of both $\ln N$ against T and $\ln A$ against T on the same axes using the data in the table.



Discuss to what extent the data in both graphs agree with theory. [6]

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(d) The absolute uncertainty in the activity is related to the square root of the activity, A itself. The error bars in the graph were calculated using:

$$\text{absolute uncertainty in } A = 4 \times \sqrt{A}$$

(i) Use the data for throw 5 to calculate the absolute uncertainty in A for throw 5. [2]

(ii) Hence, determine whether the error bar for throw 5 is correct on the graph of $\ln A$ against T. [3]

(iii) The error bars gradually increase in size on the graph of $\ln A$ against T. Explain what would happen to the error bars if a graph of A against T were plotted. [2]

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6. Aluminium-26 undergoes a process called electron capture to become magnesium-26. Lee states that this must be an electromagnetic force reaction. He then writes the following to represent the reaction:

$$^{26}_{13}\text{Al} + \text{e}^- \rightarrow {}^{26}_{12}\text{Mg}$$

Using conservation laws, explain to what extent Lee's conclusions are correct. (Note that the nucleon and proton numbers are correct for aluminium and magnesium.) [5]

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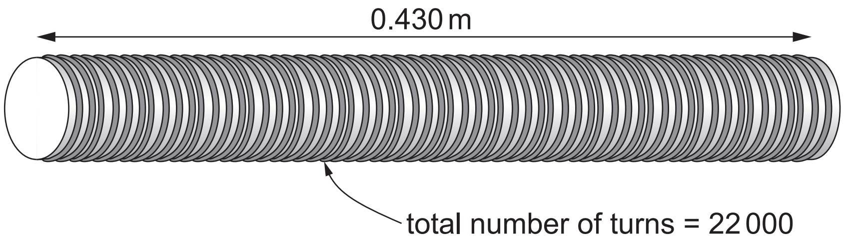
7. (a) The long solenoid shown below has a magnetic flux density of 58.2 mT in its centre. Calculate the current in the solenoid. [3]



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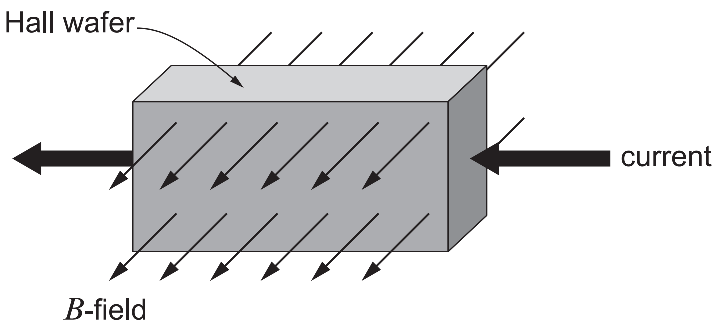
(b) (i) Explain how the Hall voltage arises. [3]



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(ii) The drift velocity of electrons in a Hall wafer is 13.0 cm s^{-1} and the width of the Hall wafer is 0.58 cm. Calculate the expected Hall voltage when this Hall wafer is placed in the long solenoid where the maximum magnetic flux density is 58.2 mT. [2]

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(iii) The actual measured Hall voltage is significantly below the value in (b)(ii) even though all values quoted are correct. Suggest what a competent experimental physicist should do to obtain the correct Hall voltage reading on the probe. [2]

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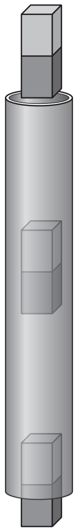
8. When a strong magnet is dropped through a hollow copper tube, the magnet quickly reaches a low terminal velocity. It continues to fall slowly until it emerges from the copper tube. Copper is a good conductor but is not a magnetic material.



(a) Explain why the magnet reaches a low terminal velocity while inside the copper tube. [5]

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(b) The inner diameter of the copper tube is 1.50 cm, its outer diameter is 1.60 cm and its length is 1.205 m. Calculate the mass of the copper tube.
Density of copper = 8960 kg m^{-3} [3]

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(c) The mass of the magnet is 325 g and the specific heat capacity of copper is 389 J K^{-1} kg^{-1}. Calculate the rise in temperature of the copper tube when the magnet falls through it. [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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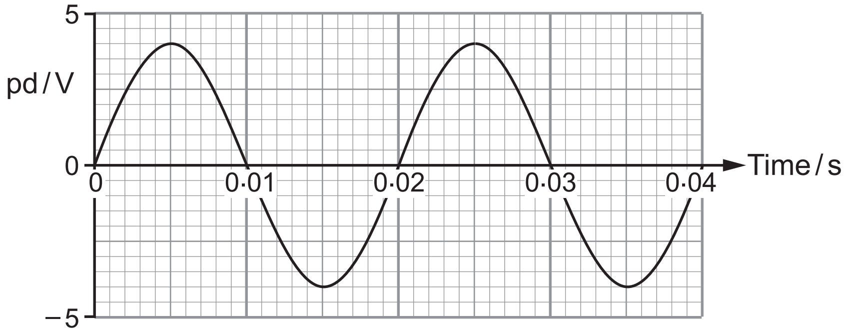
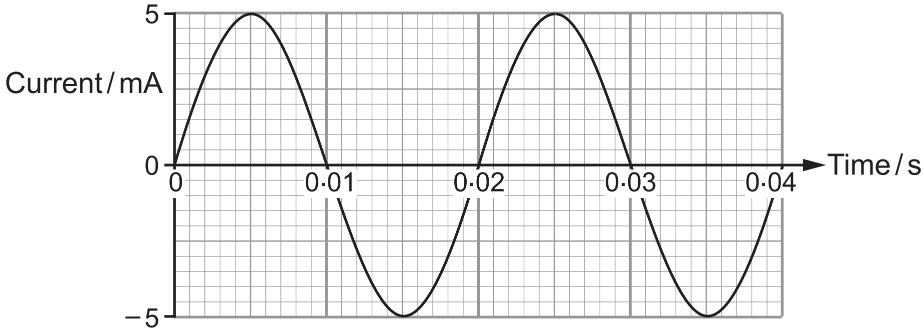
Option A – **Alternating Currents**

9. (a) A sinusoidal alternating pd is applied across a resistor, R.





(i) Calculate the mean power dissipated in the resistor. [3]

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(ii) Calculate the energy dissipated per cycle in the resistor. [2]

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(iii) Determine the number of times per second the instantaneous power dissipation in the resistor reaches a maximum. [2]

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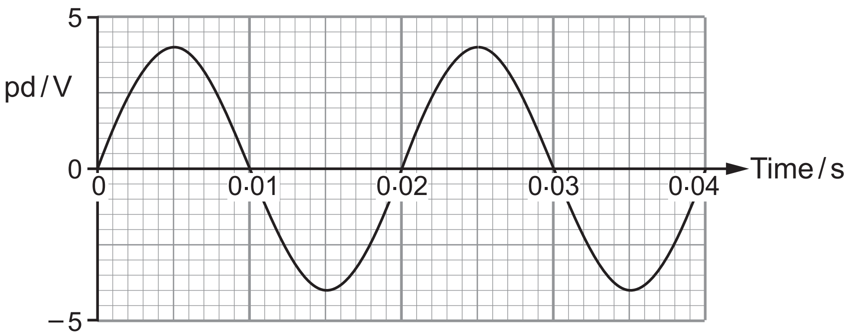
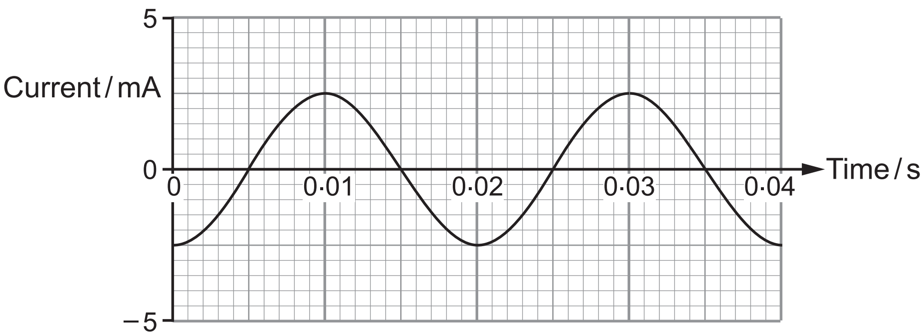
(b) The same alternating pd is now connected across a different component, X, and the following graphs are produced.





State how the graphs show that component X is an inductor. [1]

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(c) The resistor and inductor are now connected in series. The same alternating pd is applied across the combination.

(i) Use a labelled phasor diagram to show that the impedance, Z, of the circuit is given by: [3]

$$Z = \sqrt{X_L^{\,2} + R^2}$$

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(ii) Morgan knows that no power is dissipated in an inductor with zero resistance. He therefore claims that adding the inductor will not affect the mean power dissipated in the circuit. Determine whether Morgan is correct. [4]

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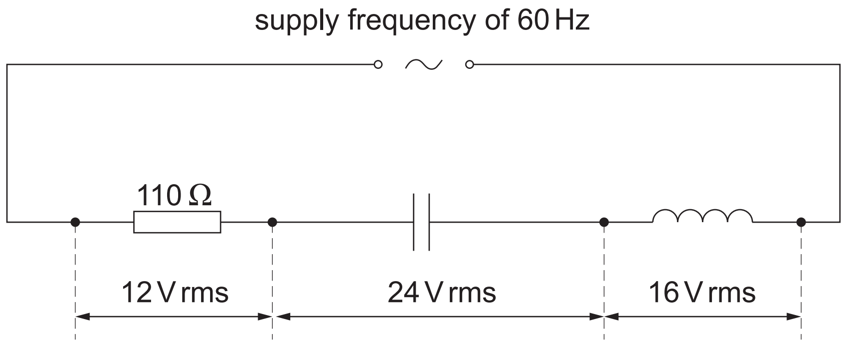
(d) Morgan now sets up the following circuit.



(i) Calculate the rms current in the circuit. [2]

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(ii) Hence, calculate the value of the capacitor. [3]

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Option B – **Medical Physics**

10. (a) Electrons are accelerated in an X-ray tube.

(i) Describe the energy changes that occur inside an X-ray tube. [3]

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(ii) Calculate the frequency of the X-rays at the cut-off wavelength of 48 pm. [2]

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(iii) The accelerating voltage is 25 kV. Use this value to determine the maximum energy of the X-ray photons in J. [2]

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(iv) Use the information above to obtain a value for the Planck constant, h. [2]

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(b) Doctors are concerned that a patient has developed deep vein thrombosis (blood clots) in their legs. They have decided to investigate this further and have the choice of the following forms of imaging:

X-ray **MRI** **ultrasound** **fluoroscopy** **CT scan**

Evaluate the suitability of **all five** types of imaging techniques for diagnosing the patient. [5]

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(c) A small volume of Human serum albumin (HSA) labelled with iodine-125 of activity 160 Bq is injected into the bloodstream of a patient. A sample of 0.6 ml of blood is taken a few hours later and is found to have an activity of 0.020 Bq. Calculate the volume of blood in ml in the patient, **stating any assumptions you make**. [2]
(The half-life of iodine-125 is several months.)

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(d) (i) Define 'equivalent dose' **and** 'effective dose'. [2]

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(ii) The effective dose for alpha particles incident on the skin is 2.2 mSv and the equivalent dose is 0.22 Sv. Determine the tissue weighting factor, W_T, for skin. [2]

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Option C – **The Physics of Sports**

11. (a) The following photograph shows a skier taking part in a downhill race.

(i) State the **two** factors that increase a skier's stability against toppling. [2]

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(ii) The speed of a downhill skier changes from u to 1.25u. At the same time, the effective cross-sectional area of the skier changes from A to 0.85A. Calculate how the drag force on the skier will change, stating any assumptions you make. [4]

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(iii) A skier of mass 72 kg moving at a speed of 25 m s^{-1} crashes into a barrier and is brought to rest in a time of 0.89 s. Determine the force exerted on the skier by the barrier. [2]

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(b) A puck used in an ice hockey match is a circular disk of mass 160 g and diameter 80 mm.

(i) Calculate the angular velocity of a puck with rotational kinetic energy of 1.3 J. The moment of inertia of a puck is given by the equation $I = \frac{1}{2} mr^2$. [3]

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(ii) An ice hockey player takes a shot at goal from a distance of 15 m. The puck is hit at an angle of 25° to the horizontal and with an initial speed of 23 m s^{-1}. Evaluate whether a goal can be scored if the height of the goal is 1.2 m. Ignore the effects of air resistance. [5]

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(c) An ice skater is rotating with both arms outstretched. His arms are now pulled in. Explain why the rate of rotation of the skater will increase. [4]

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Option D – **Energy and the Environment**

12. (a) (i) A student incorrectly writes the Archimedes principle as:

‘An object wholly immersed in a liquid experiences a force equal to the mass of the fluid dispersed by the object’.

Write the correct version of this principle. [2]

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(ii) Ice has a density of $920\,\text{kg}\,\text{m}^{-3}$. A **freshwater** iceberg floats in **seawater** of density $1020\,\text{kg}\,\text{m}^{-3}$. Starting from the Archimedes principle, determine the fraction of the volume of the iceberg that will be below the surface. Show your reasoning clearly. [3]

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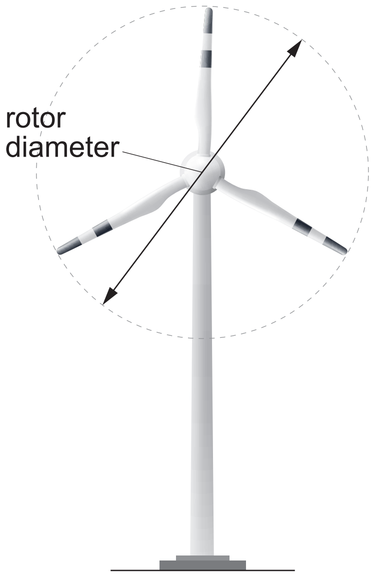
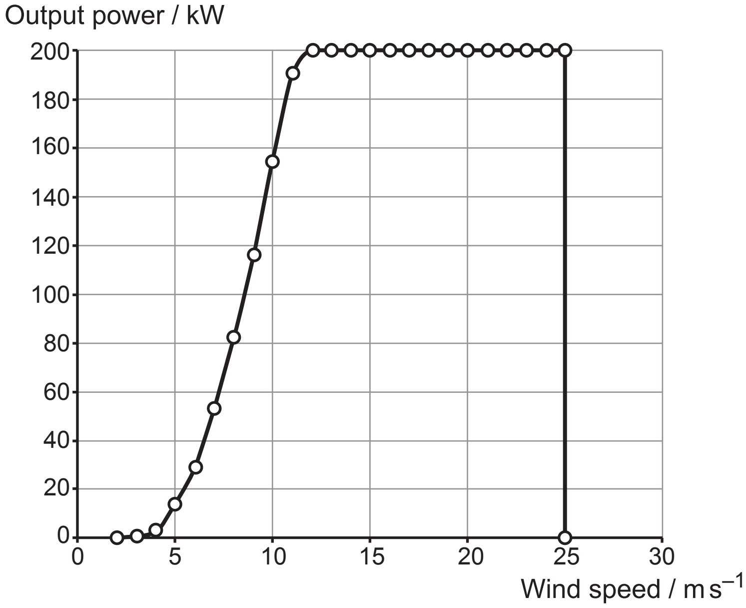
(b) The electrical power output from a wind turbine varies with wind speed, as shown below.





(i) The efficiency of the turbine in transferring the power from the wind to electrical power is 42% at a wind speed of 10 m s^{-1}. Determine the rotor diameter given the density of air is 1.2 kg m^{-3}. [4]

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(ii) Account for the low efficiency in transferring the maximum power from the wind to electrical power. [2]

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(iii) The UK-based JET laboratory produced 59 MW of electrical power for a few seconds through nuclear fusion. Calculate the number of wind turbines needed to produce this amount of power if they are operating at their maximum power output. [1]

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(iv) Explain briefly the difficulties associated with producing sustained nuclear fusion power. [3]

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(c) Plasterboard has a thermal conductivity value of $0.18\,W\,m^{-1}\,K^{-1}$. Brick has a thermal conductivity value of $0.55\,W\,m^{-1}\,K^{-1}$. An internal wall consists of a 15 mm layer of plasterboard either side of a 110 mm brick as shown below. The temperature difference between the two sides of the wall is 7 °C.

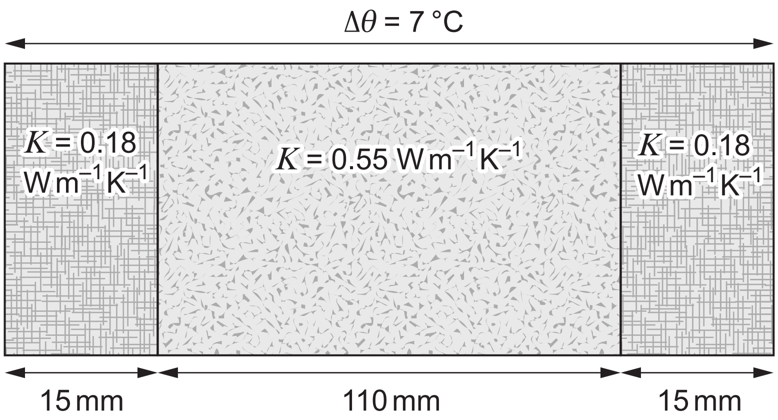

Diagram not to scale

Charlene calculates the rate of heat transfer per unit area through the wall to be $19\,W\,m^{-2}$. Determine whether Charlene is correct. [5]

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

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