Surname	Centre Number	Candidate Number
Other Names		2

GCE A LEVEL

1420U40-1

S18-1420U40-1

PHYSICS – A2 unit 4
Fields and Options

FRIDAY, 8 JUNE 2018 – MORNING

2 hours

	For Examiner's use only		
	Question	Maximum Mark	Mark Awarded
Section A	1.	18	
	2.	18	
	3.	16	
	4.	13	
	5.	15	
Section B	Option	20	
	Total	100	

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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. Do not use 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**: 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 **3*(d)***.

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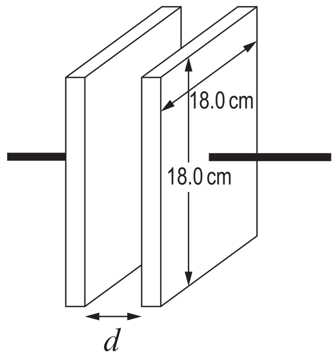
SECTION A

Answer **all** *questions.*

1. *(a)* (i) A laboratory technician has two square aluminium plates with sides of length 18.0 cm. Calculate the separation, d, of the plates that produces a capacitance of 2.0 nF. [3]



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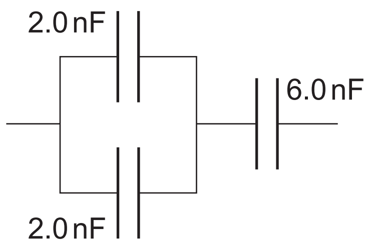
(ii) Calculate the capacitance of the capacitor combination shown. [3]



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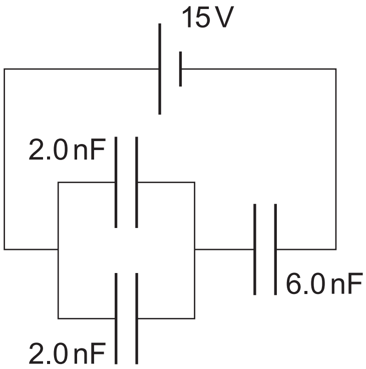
(iii) Show that the charge stored on a 2.0 nF capacitor in the following circuit is 18 nC. [3]



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(iv) Calculate the total energy stored by the capacitor combination. [2]

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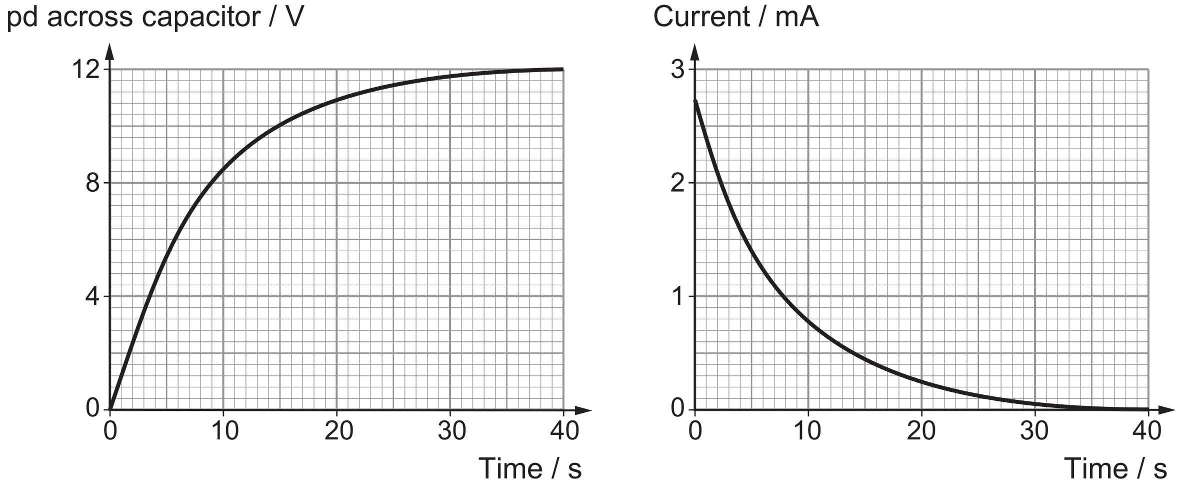
(b) A group of students investigated the **charging** of a capacitor through a resistor and obtained the following data.



(i) Draw a circuit diagram of the apparatus that might have been used to obtain the data. [2]

(ii) Use the graphs to determine:

- the emf of the power supply;
- the resistance of the resistor;
- the capacitance of the capacitor. [5]

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2. *(a)* The escape velocity, v, of a mass, m, from a spherical mass, M, and radius, R, can be calculated using:

$$\tfrac{1}{2}mv^2 - \frac{GMm}{R} = 0$$

(i) Explain how this equation is an application of conservation of energy. [3]

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(ii) Calculate the escape velocity from the Sun ($M_{\text{Sun}} = 1.99 \times 10^{30}$ kg, $R_{\text{Sun}} = 6.96 \times 10^{8}$ m). [3]

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(b) (i) The temperature of the surface of the Sun is 5 780 K. Use a kinetic theory equation to show that the rms speed of a free electron on the surface of the Sun is approximately 500 km s^{-1}. [4]

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(ii) By considering your answers to *(a)*(ii) and *(b)*(i), explain why the Sun has a slight positive charge. [2]

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(iii) A student claims that a positive charge of approximately 0.08 C on the Sun is enough to produce an electrostatic force equal to the gravitational force on an escaping electron. Determine whether or not she is correct. [3]

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(iv) Estimate the percentage of lost electrons compared with the total number of electrons on the Sun. Assume that the Sun is mainly hydrogen and that it has lost 0.08 C of charge in the form of electrons. [3]

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3. *(a)* Explain why the age of the Universe can be approximated as $\frac{1}{H_0}$, where H_0 is the Hubble constant. [2]

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(b) The megaparsec (Mpc) is a unit of astronomical distance equal to 3.09×10^{22} m. Use Hubble's law to show that the expected redshift for a supernova at a distance of 1 Mpc for a wavelength of 486.1 nm is approximately 0.11 nm. [3]

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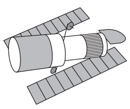
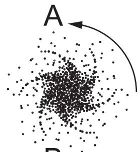
(c) The spiral galaxy shown is rotating anticlockwise and is viewed by the Hubble Space Telescope.

Images not to scale

Hubble Space Telescope





Rotating spiral galaxy

The measured **blue** shift at point A of the galaxy is 0.22 nm (for the 486.1 nm wavelength) and the measured **redshift** at point B of the galaxy is 0.66 nm (for the same wavelength). Calculate the recessional velocity of the galaxy and the rotational speed of the galaxy at A (assume that A and B have the same rotational speeds). [5]

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(d) Explain how spiral galaxies provide evidence for the existence of dark matter and how this evidence has been gathered. [6 QER]

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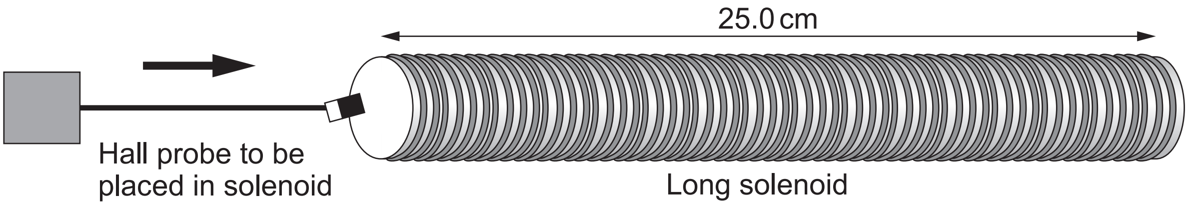
4. An experiment is carried out to measure the magnetic field in a long solenoid as the current in the solenoid is varied.



Theory states that the relationship between magnetic flux density, B, at the centre of the solenoid and current, I, is given by the equation:

$$B = \mu_0 nI$$

The results obtained are shown in the table and plotted on the grid opposite along with error bars and lines of maximum and minimum gradient.

Current / A ±0.01 A	Magnetic flux density / mT ±2 mT
0.50	11
1.00	20
1.50	29
2.00	41
2.50	49

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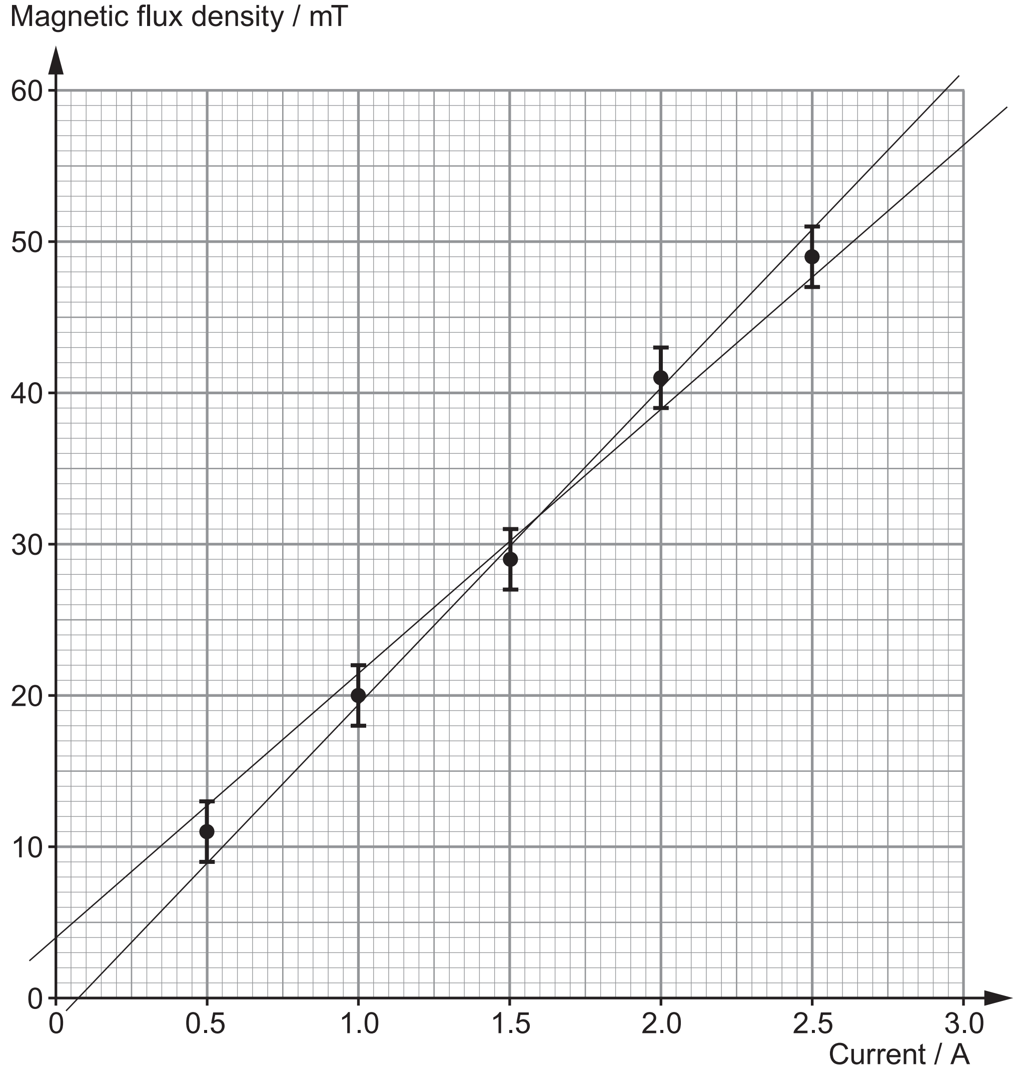

(a) Calculate the mean value of the gradient along with its **percentage** uncertainty. [4]

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(b) Calculate the number of turns in the solenoid along with its **absolute** uncertainty. The percentage uncertainty in the length of the solenoid is 0.4 %. [3]

(c) (i) The solenoid manufacturer states that there are exactly 5 000 turns in the solenoid. Evaluate the accuracy of your value obtained in part *(b)* and whether or not the graph is in agreement with the equation: $B = \mu_0 nI$. [4]

(ii) Suggest a reason for the disagreement between the manufacturer's stated value (5 000 turns) and your value calculated in part *(b)*. Suggest how the experimental technique might be improved for better agreement. [2]

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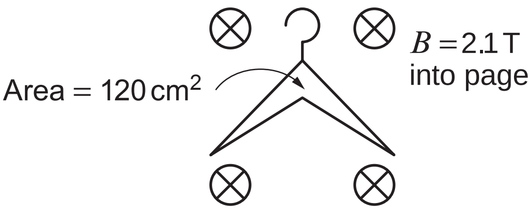
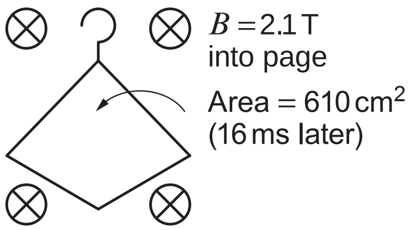
5. An experiment is carried out in a very strong uniform magnetic field in order to confirm Faraday's Law under extreme conditions. A coat hanger made of aluminium wire is bent from Shape 1 to Shape 2 in a time of 16 ms.



Shape 1



Shape 2

(a) (i) Show that a mean emf of 6.4 V is induced in the coat hanger. [2]

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(ii) Show on the diagram of Shape 2 the direction of the induced current and state very briefly how you determined this direction. [2]

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(b) The aluminium wire has a circular cross-section of diameter 3.0 mm and the length of the wire through which the current flows is 91 cm. Show that the mean current in the wire is approximately 1 900 A (resistivity of aluminium = $2.65 \times 10^{-8}\,\Omega\,$m). [3]

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(c) Iestyn claims that changing the shape of the coat hanger from Shape 1 to Shape 2 in 16 ms in the magnetic field will increase its temperature by less than 1 °C. Determine, using appropriate calculations, whether or not Iestyn is correct. (Density of aluminium = 2 700 kg m^{-3}, specific heat capacity of aluminium = 897 J kg^{-1} K^{-1}.) [5]

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(d) For medical research, it is decided to investigate the effect of this strong magnetic field (2.1 T) on patients with metal replacement joints to see if the metal joints become hot or undergo large forces (during MRI scans). Discuss the ethics of such an experiment. [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**

6. *(a)* The sinusoidal emf produced by a rotating coil in a magnetic field has a **peak** emf of 18.0 V and a frequency of 70.0 Hz. The coil is connected to the y-input of an oscilloscope.

(i) The output of the rotating coil is used to power a small lamp of known resistance. Explain how you would calculate the rms input power to the lamp from the known resistance and **peak** emf. [2]

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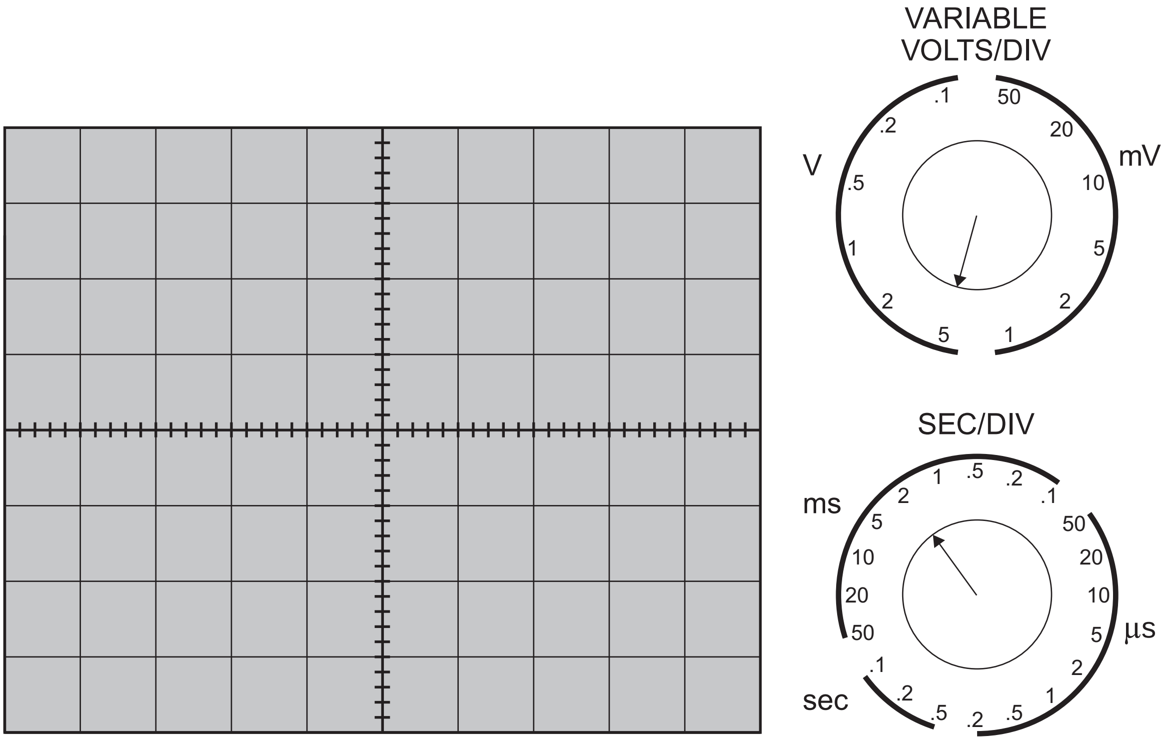
(ii) Draw a typical trace that might be seen on the oscilloscope screen with the oscilloscope settings shown. [5]

Space for calculations.



 (1420U40-1) **Turn over.**

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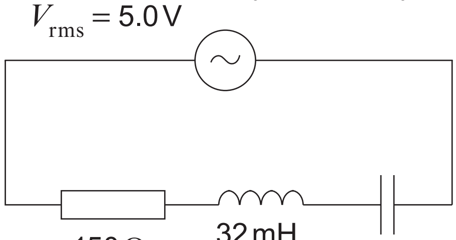
(b) An LCR circuit is shown below.



(i) Explain why the resonance frequency of the circuit occurs when: [3]

$$\omega L = \frac{1}{\omega C}$$

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(ii) Calculate the resonance frequency of the circuit. [2]

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(iii) Calculate the rms current when the frequency of the supply is 324 kHz. [3]

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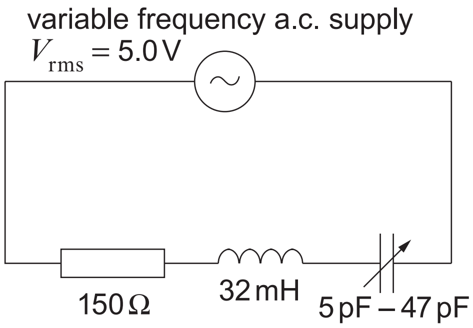
(iv) A student claims that the following circuit cannot have a peak pd above 1.5 kV across the capacitor. Investigate whether or not he is correct. [5]

(It may be useful to note that $\frac{\omega_0 L}{R} = \frac{1}{R}\sqrt{\frac{L}{C}}$.)



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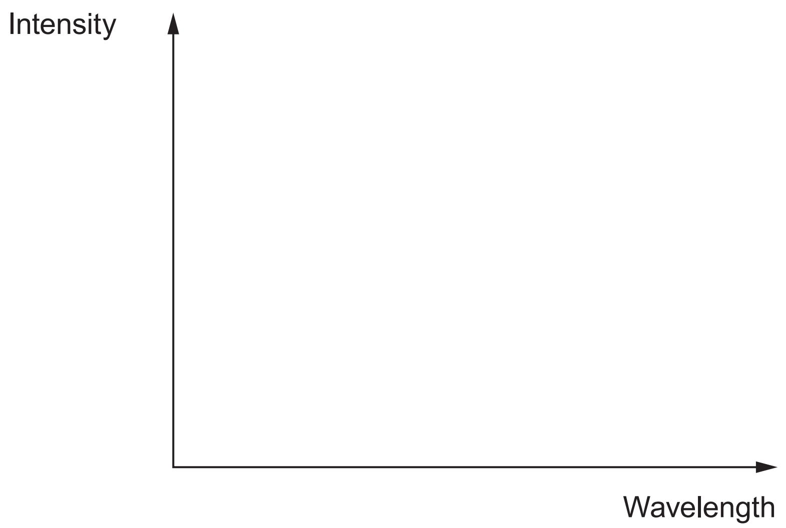
Option B **– Medical Physics**

7. An X-ray machine has a working potential difference of 75 000 V.

(a) (i) Sketch a graph of intensity against wavelength for the resulting X-ray spectrum. Label the main features of this spectrum, including a value for the minimum wavelength. [2]

Space for calculation



(ii) At the working potential difference the current in the tube is 120 mA and the efficiency of the X-ray machine is 0.7 %. Calculate the rate of production of heat. [2]

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(iii) A metal plate of thickness 1.4 mm is used to reduce the intensity of the X-rays produced to 60 % of the incident intensity. If a second identical plate is now also placed in the beam, calculate the new transmitted **percentage** intensity. [3]

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(b) (i) Describe how the Doppler shift principle can be used to measure the speed of blood through an artery. [2]

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(ii) Ultrasound of frequency 2 MHz was used to calculate the speed of blood and a Doppler shift of 200 Hz was detected. The measurement was taken at an angle of 40^{o} to the direction of flow and the speed of ultrasound through the blood is $1500\,m\,s^{-1}$. Calculate the speed of blood flow. [2]

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(c) (i) Describe the properties of technetium–99m (Tc–99m) that make it such a good radioisotope in the effective diagnosis of medical problems. Justify your choice of properties. [3]

(ii) Explain clearly how a gamma camera is used to detect the gamma rays given off by a technetium–99m source. [3]

(iii) In positron emission tomography a positron annihilates an electron producing two photons of energy 0.511 MeV. By setting out your reasoning clearly, determine whether or not the value of the photon energy is correct. [3]

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Option C – **The Physics of Sports**

8. *(a)* Define angular acceleration. [2]

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(b) A gymnast begins a routine to dismount from the horizontal bar by increasing her angular velocity from $3.4\,\mathrm{rad\,s^{-1}}$ to $8.0\,\mathrm{rad\,s^{-1}}$ in a time of 2.3 s. The moment of inertia of the gymnast is $34\,\mathrm{kg\,m^2}$.

(i) Calculate the torque on the gymnast. [4]

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(ii) The gymnast lets go of the bar and somersaults in the air before she lands on her feet on the ground. Explain why the gymnast pulls in her arms and adopts a tuck position as she is in the air. [4]

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(iii) The gymnast, of mass 52 kg, lands on the mat with a velocity of $5.7\,\text{m}\,\text{s}^{-1}$ and comes to rest in a time of 0.26 s. Show clearly that the mean force exerted by the gymnast on the mat is approximately 1 000 N. [3]

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(c) In a separate event, a male gymnast performs a routine on the rings as shown.

(i) Explain in terms of centre of gravity why he does not rotate. [2]

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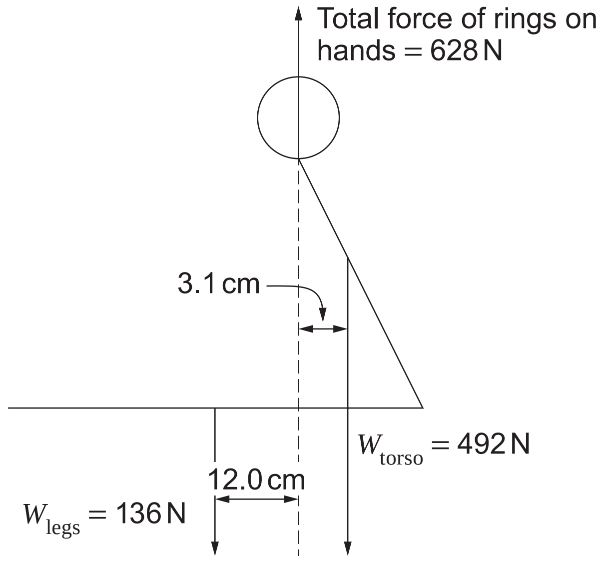
(ii) At a later point the forces acting on the gymnast are shown in the following diagram. Justify, using calculations, the motion of the gymnast. [5]



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Option D – **Energy and the Environment**

9. *(a)* (i) The Sun has a surface temperature of 5800 K and a radius of 7.0×10^8 m. Stating the name given to the law you use, show that the power radiated by the Sun (Solar Luminosity) is approximately 4×10^{26} W. [3]

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(ii) The main energy production mechanism in the sun is the proton-proton cycle. This consists of several fusion reactions, the net effect of which is to combine a number of protons to form one helium nucleus as shown:

$$\text{..........}\ {}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2\text{v}_\text{e} + 2\,{}^{0}_{+1}\text{e}$$

I. **Complete** the equation. [1]

II. Name the particle which has the symbol ${}^{0}_{+1}\text{e}$. [1]

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(iii) The energy released in the reaction is 26.7 MeV. Use this information and the answer to *(a)*(i) to determine the mean rate of production of helium nuclei in the Sun. [2]

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(b) Due to absorption in the atmosphere, the maximum intensity of the Sun's radiation received at the Earth's surface in the UK is about 750 W m^{-2}. Show that this corresponds to approximately 50 % of the solar intensity reaching the Earth's atmosphere. [Sun-Earth distance = 1.50×10^{11} m]. [2]

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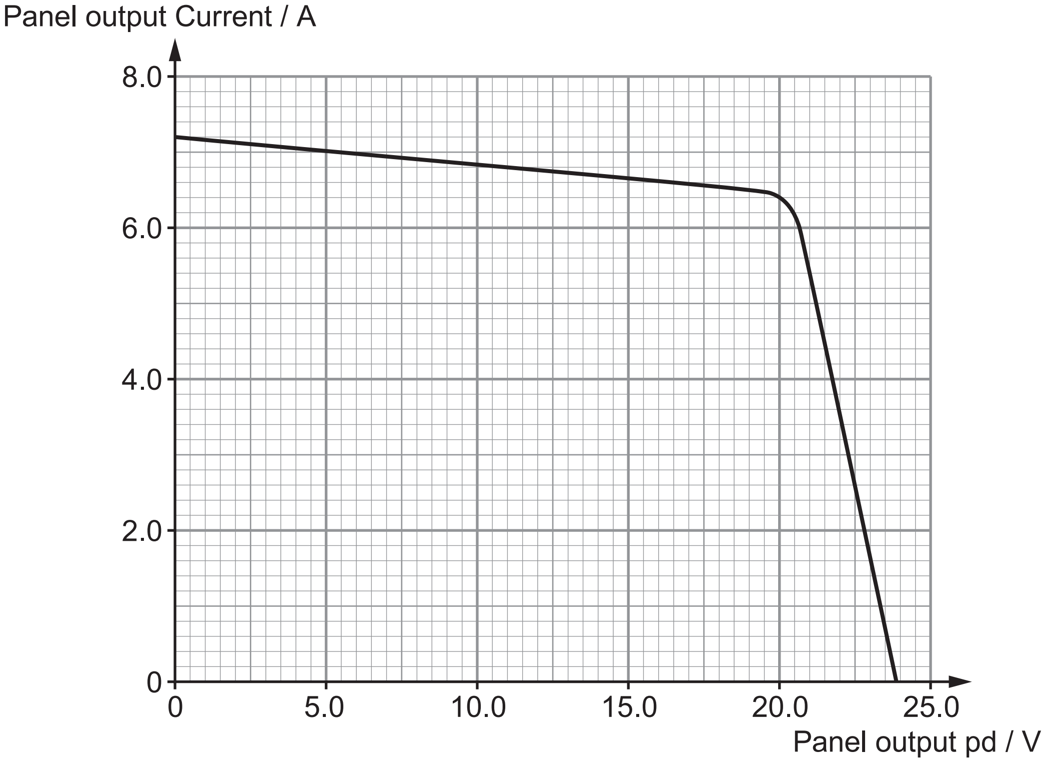
(c) Solar (PV) panels are used to produce electricity from the solar radiation incident upon them. The output power of PV panels depends on the load resistance and the intensity of the radiation. The graph shows the output characteristics for a solar panel of area 1 m^2 for varying values of load resistance for a constant **light power of 750 W**.



(i) Engineers designing this panel require that it produces at least 15 % of the maximum input power. Determine whether or not the panel meets this requirement when operating at maximum output power. [3]

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(ii) Determine the number of panels of this type needed to power a 1 kW electric kettle, and explain why, **in reality**, the actual number of panels needed will be greater. [3]

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(d) Scientists attempting to generate electricity by nuclear fusion on Earth must overcome a number of difficulties. One condition which needs to be satisfied is to ensure a high enough temperature.

(i) Explain in terms of energy and the interaction of particles why a high temperature is necessary. [3]

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(ii) For a particular nuclear fusion reaction to be successful the value of its *triple product* must be $\geq 2.6 \times 10^{28}\,\text{s K m}^{-3}$. Plasma of volume $75\,\text{m}^3$ contains 2.2×10^{22} reacting particles at a temperature of $120 \times 10^{6}\,\text{K}$. If a confinement time of 0.8 seconds is achieved, determine whether or not fusion is possible under these conditions. [2]

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END OF PAPER

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

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