Surname	Centre Number	Candidate Number
Other Names		2

GCE A LEVEL

A420U30-1

S19-A420U30-1

PHYSICS – A level component 3
Light, Nuclei and Options

MONDAY, 3 JUNE 2019 – AFTERNOON

2 hours 15 minutes

	For Examiner's use only		
	Question	Maximum Mark	Mark Awarded
Section A	1.	9	
	2.	9	
	3.	10	
	4.	10	
	5.	11	
	6.	8	
	7.	21	
	8.	8	
	9.	9	
	10.	5	
Section B	Option	20	
	Total	120	

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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 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 additional 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 question **3**(*b*).

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SECTION A

*Answer **all** questions.*

1. *(a)* State the difference between transverse and longitudinal waves. [2]

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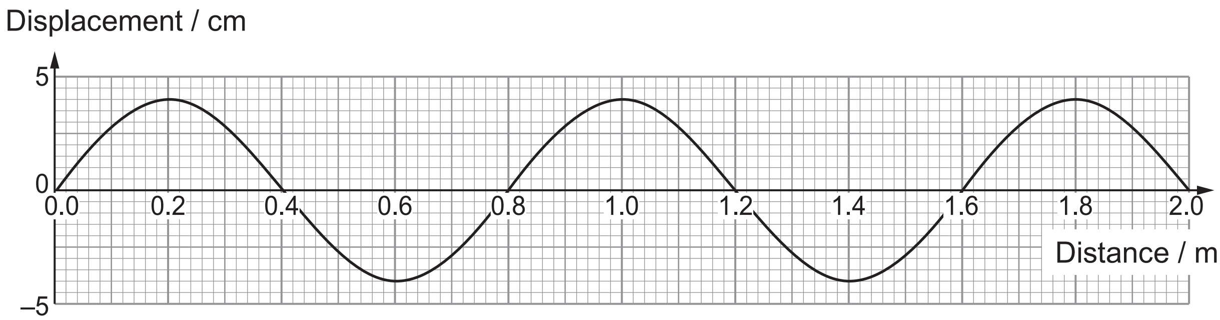
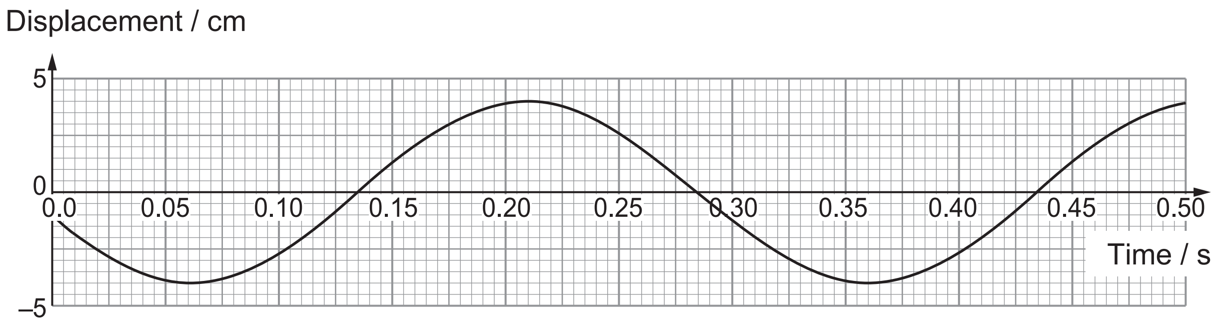
(b) The variation of displacement with respect to position and time is shown in the following two graphs for the same surface wave on water.

Graph of displacement against distance (at a given time)



Graph of displacement against time (at a given distance)



(i) State the amplitude of the wave. .... [1]

(ii) State the wavelength of the wave. .... [1]

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(iii) Calculate the speed of the wave. [3]

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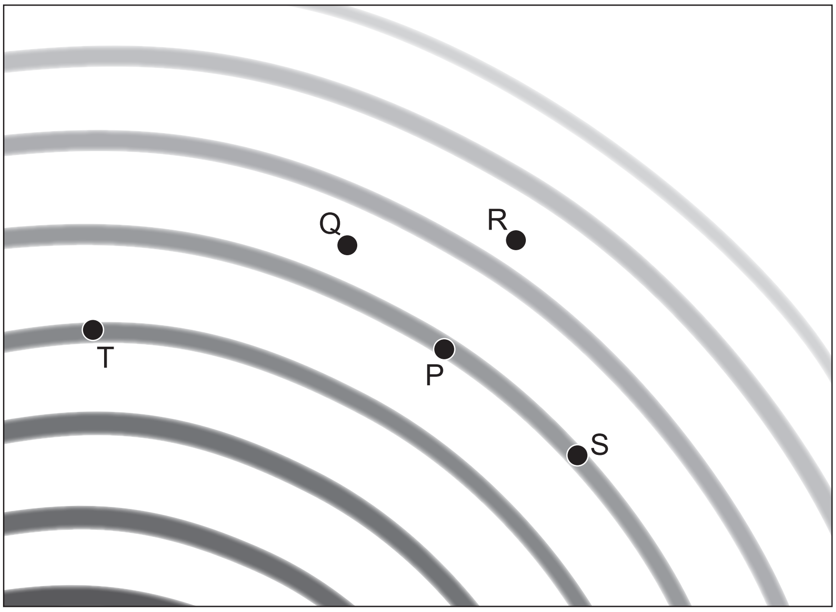
(c) A wavefront diagram for waves on the surface of water is shown.



(i) **Draw an arrow** to indicate the direction of motion of the wavefront at point **S**. [1]

(ii) State the point(s) oscillating in phase with point **P**. .... [1]

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2. *(a)* Single slit diffraction of light is demonstrated by using a red laser and the results are shown below. The two different diffraction patterns are obtained by varying the slit width only.

Figure 2a

Figure 2b

(i) Explain whether Figure 2a or Figure 2b has the wider slit. [2]

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(ii) State what can be done to the single slit to obtain the greatest amount of diffraction. [1]

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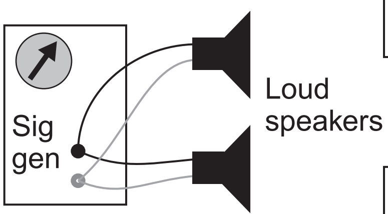
(b) Tick (✓) the appropriate boxes to show which of the following arrangements allow an interference pattern to be observed/heard. [2]



☐ Yes

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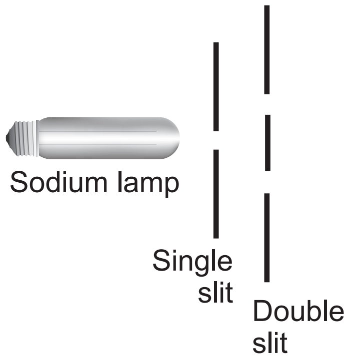

☐ Yes

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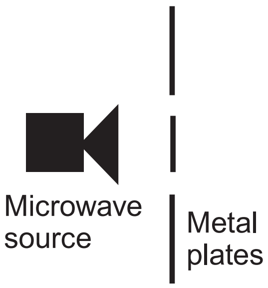

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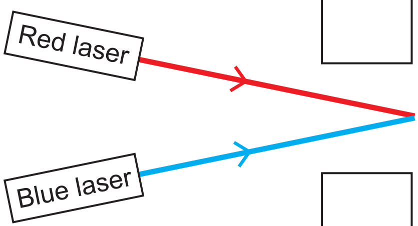

☐ Yes

☐ No

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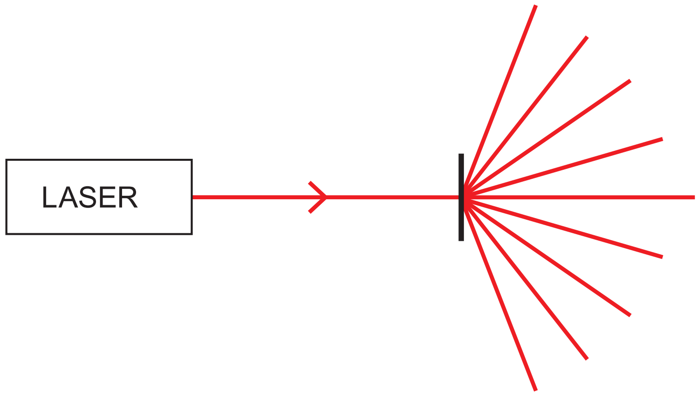
(c) Laser light is shone at a diffraction grating with slit separation 2.4 µm and a total of nine bright beams are produced (see below). Determine the maximum and minimum possible wavelengths for the laser light. [4]

Diagram not to scale



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3. *(a)* (i) Explain why a population inversion is not usually possible with a 2-level energy system pumped using light. [2]

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(ii) State an advantage of semiconductor lasers and an example of their use. [2]

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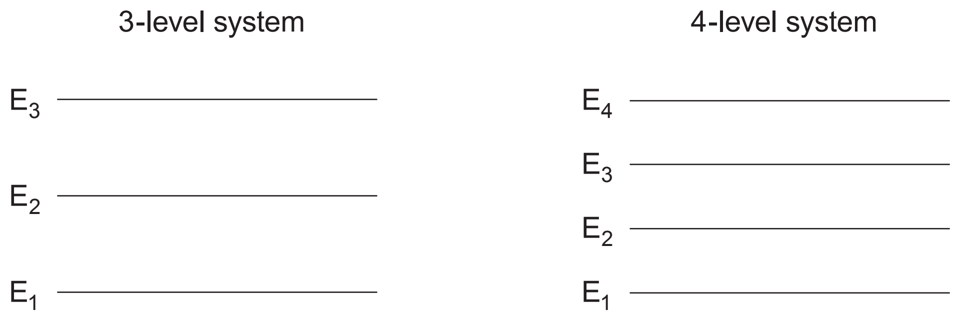
(b) Explain how 3-level and 4-level laser systems work and the advantages of a 4-level system. Refer to the diagrams in your answer. [6 QER]



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4. *(a)* It is possible to distinguish between α, β and γ radiation by their different absorption properties. Explain briefly **one other method** of differentiating between α, β and γ radiation. [3]

Space for diagram

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(b) The half-life of beryllium-7 is 53.1 days. The initial count rate with a beryllium-7 source in position is measured as 3.50 counts per second (cps) and this dropped to 1.50 cps after 84 days.

(i) Show that this final count rate is approximately 0.33 cps higher than would be expected from beryllium alone (approximately 1.17 cps). [3]

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(ii) The discrepancy between the measured count of 1.50 cps and the expected count of 1.17 cps is due to background radiation. Given that the background count rate is a constant 0.50 cps, determine whether the final measured count rate of 1.50 cps is exactly as expected. [4]

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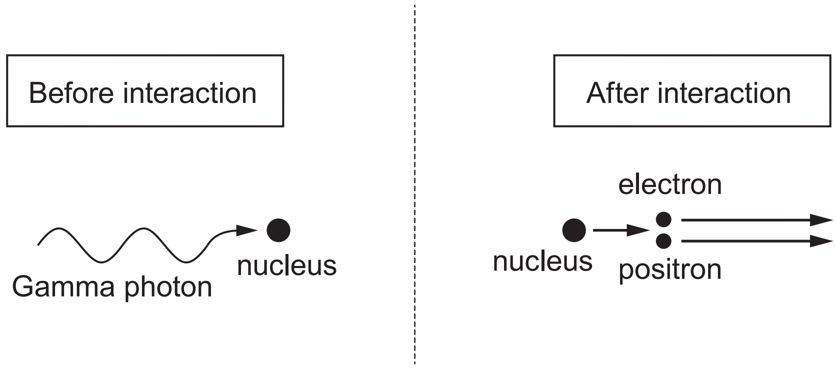
5. The following interaction can take place when a gamma photon encounters a stationary nucleus.



The energy of the gamma photon "creates" a positron-electron pair and the nucleus gains some momentum in the direction of the original gamma photon.

(a) Show that this interaction can only take place if the energy of the gamma photon is greater than 1.02 MeV. [3]

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(b) The actual energy of the incident gamma photon is 1.03 MeV. **Assuming that the kinetic energy of the nucleus after the interaction is negligible**, explain briefly why the kinetic energies of the positron and electron are approximately 0.005 MeV **each**. [2]

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Examiner only

(c) Use the kinetic energies of 0.005 MeV and conservation of momentum to show that the speeds of the positron and electron are $4.2 \times 10^7\,\mathrm{m\,s^{-1}}$ and that the momentum of the nucleus after the collision is $4.7 \times 10^{-22}\,\mathrm{kg\,m\,s^{-1}}$. [4]

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(d) The momentum of the nucleus ($4.7 \times 10^{-22}\,\mathrm{kg\,m\,s^{-1}}$) is essential otherwise conservation of momentum would be impossible. Deduce whether or not the assumption in part *(b)* is valid (the mass of the nucleus is 3.3×10^{-25} kg). [2]

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Examiner only

6. *(a)* The anti-Δ^{++} is an anti-baryon and a first-generation particle which has a charge of $-2e$. Explain why the only possible quark make-up of the anti-Δ^{++} is $\bar{u}\bar{u}\bar{u}$. [1]

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(b) The anti-Δ^{++} has a lifetime of approximately 6×10^{-24} s and decays into a π meson and another anti-baryon. Deduce the quark make-up of the π meson and the anti-baryon and name them. [2]

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(c) State which force is responsible for the decay of the anti-Δ^{++} into a π meson and anti-baryon, giving a reason for your answer. [2]

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(d) In 2011, a highly respected international research collaboration reported that they had measured neutrinos travelling at speeds greater than that of light. This report was met by caution from the scientific community and then the result was disproved. Explain briefly why the result was met with caution and how the results might have been disproved. [3]

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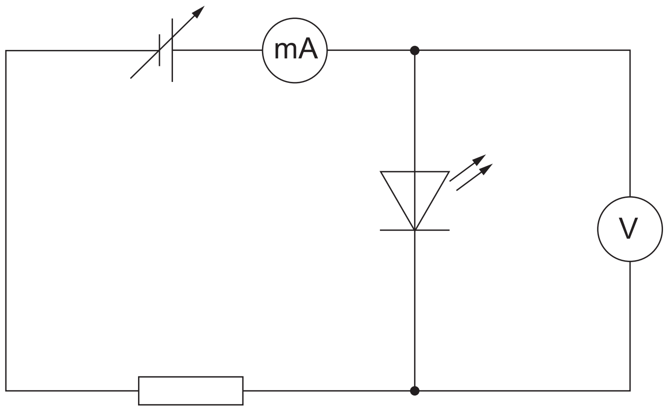
Examiner only

7. *(a)* The following circuit is used to find the pd across an LED when it is switched on.



Aled decides that the LED is switched on when a current of 10.0 mA passes through it. He adjusts the variable power supply and records the switching-on pd. He repeats this procedure for different LEDs which emit light of different wavelengths. His results are tabulated below.

(i) **Complete** the table. [2]

Wavelength λ of LED / nm	$\frac{1}{\lambda}$ / m^{-1}	Switching-on pd / V (± 10%)
465	2.15×10^6	2.78 ± 0.28
569	.... $\times 10^6$	2.26 ± ....
660	1.52×10^6	1.91 ± 0.19
820	1.22×10^6	1.47 ± 0.15
890	.... $\times 10^6$	1.44 ± ....
950	1.05×10^6	1.29 ± 0.13

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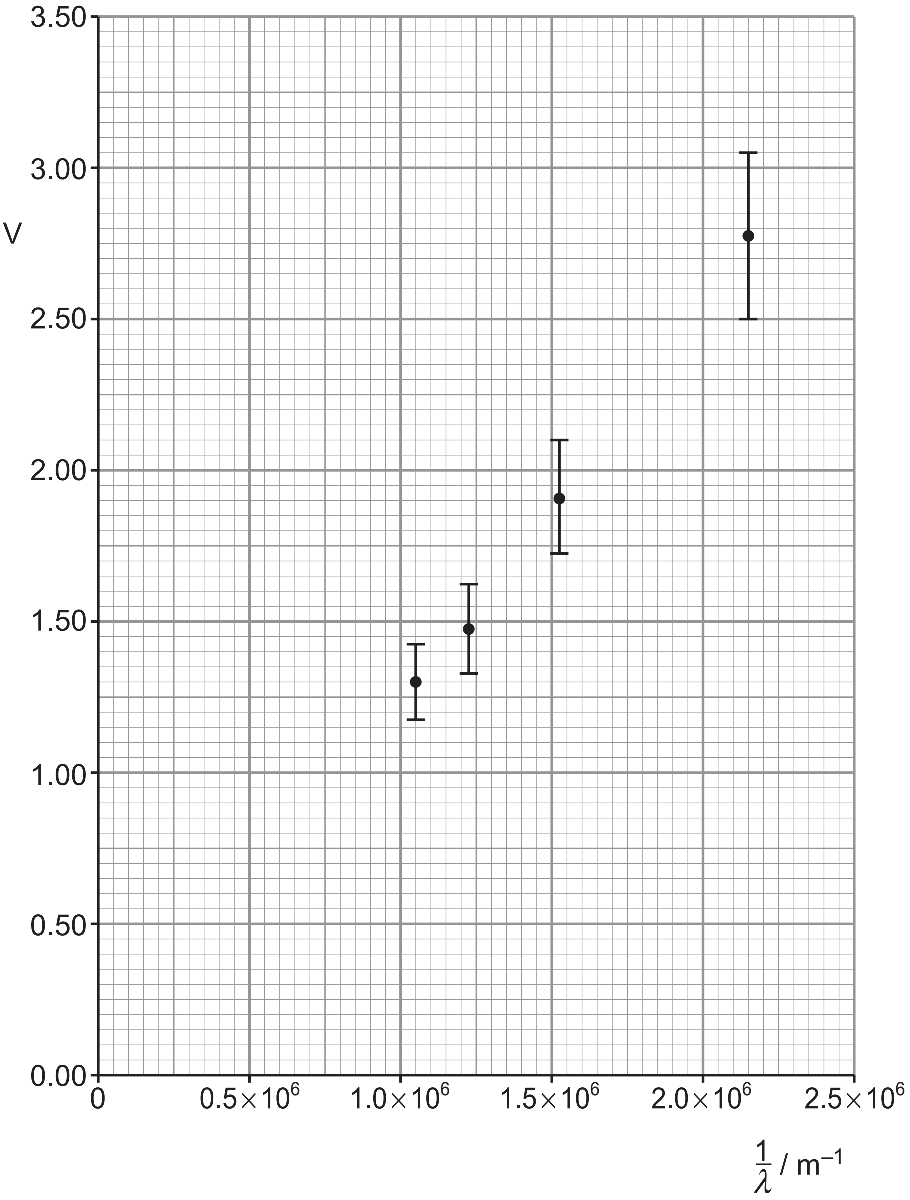
(ii) **Complete** the graph by plotting the **two** missing points whose values you have calculated together with their error bars. [2]

(iii) **Draw** the line of maximum gradient and the line of minimum gradient through the error bars. [2]



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Turn over.

Examiner only

(b) Conservation of energy applied to an electron and photon involved in the light emitting process of the LED gives:

$$eV = \frac{hc}{\lambda}$$

(i) Use your two lines from *(a)*(iii) to obtain a value for the Planck constant along with its absolute uncertainty to an appropriate number of significant figures. [5]

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(ii) Explain to what extent Aled's data displayed in the graph confirm the relationship. [4]

$$eV = \frac{hc}{\lambda}$$

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Examiner only

(c) Suggest **one** reason why choosing a constant current of 10.0 mA is better than using your eye to detect the emitted radiation for these LEDs. [1]

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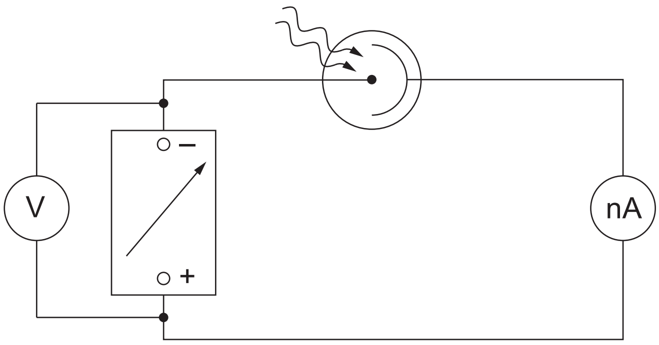
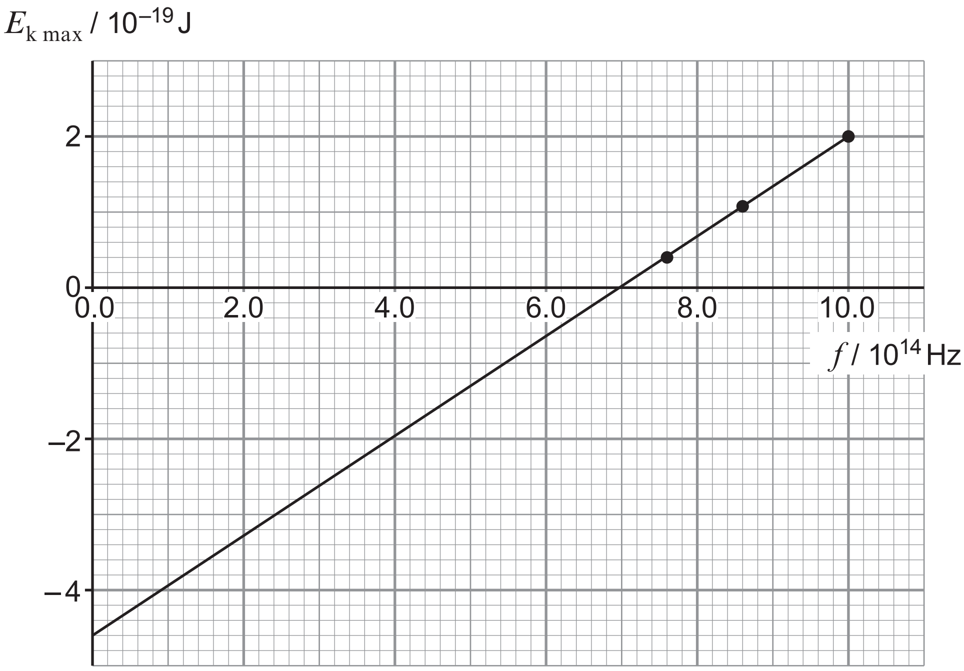
THIS QUESTION CONTINUES ON PAGE 18

(d) The Planck constant can also be determined using the photoelectric effect. Light of various frequencies is incident on a calcium photoelectric cell as shown and the maximum kinetic energy, $E_{\text{k max}}$, of the emitted electrons is determined for each frequency, f.



The following graph is obtained.



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(i) Determine a value for the Planck constant. [2]

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(ii) Determine a value of the work function of calcium and explain why no data points are possible below a frequency of 6.9×10^{14} Hz. [3]

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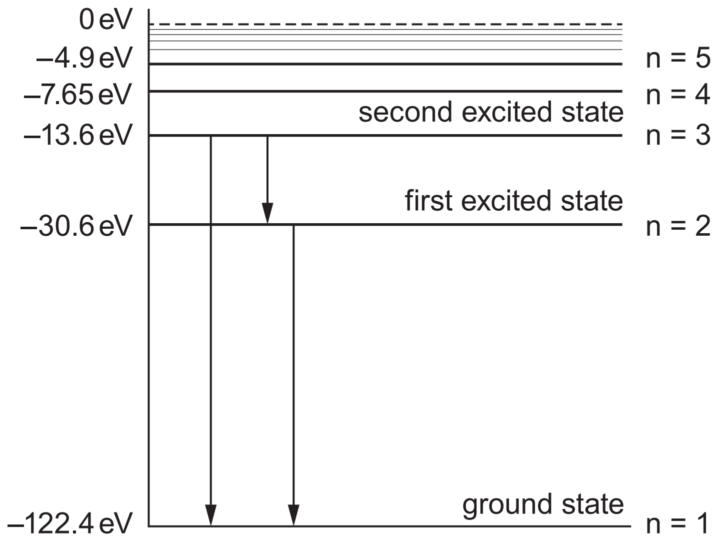
8. The energy levels of a lithium ion are shown.



(a) Calculate the ionisation energy of the lithium ion in joules. [2]

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(b) Calculate the wavelength of the electromagnetic radiation emitted when an electron drops from the second excited state (n = 3) to the first excited state (n = 2) and state the region of the electromagnetic spectrum to which it belongs. [3]

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Examiner only

(c) The emission and absorption spectra of another element are shown below.

Emission spectrum

Absorption spectrum

Explain briefly the processes that give rise to these spectra and why the lines appear at the same wavelengths in the two spectra. [3]

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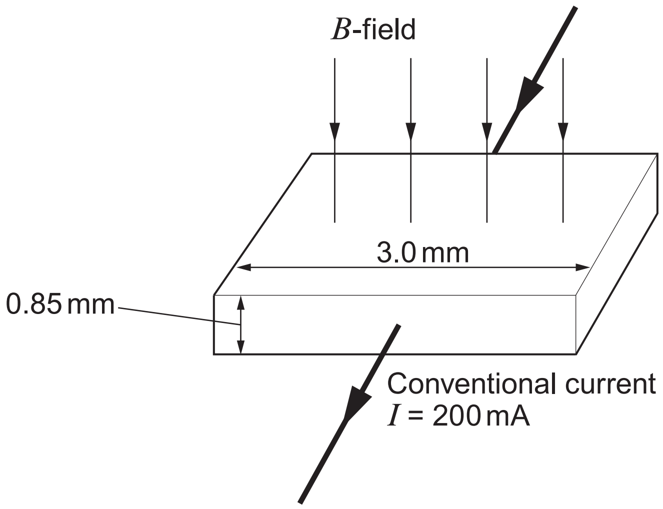
9. *(a)* The silicon chip shown in the diagram is used as a Hall probe with electrons as the charge carriers. Explain how the Hall voltage arises and which face of the chip becomes positively charged. [4]



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(b) The concentration of conduction electrons is $2.4 \times 10^{24}\,\mathrm{m^{-3}}$. Calculate the mean drift velocity of the electrons. [2]

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(c) The Hall voltage, V_H, for this chip can be expressed as:

$$V_H = kB$$

where k is a constant and B is the magnetic flux density. Calculate a value for k and **state its unit**. [3]

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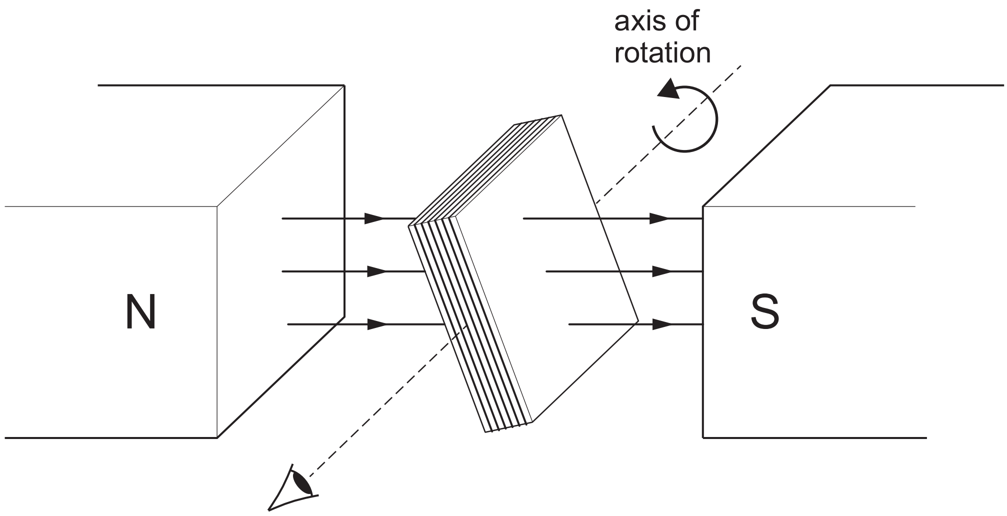
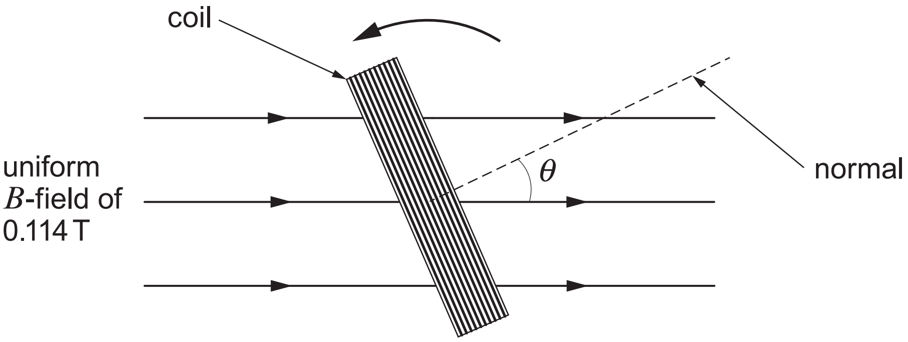
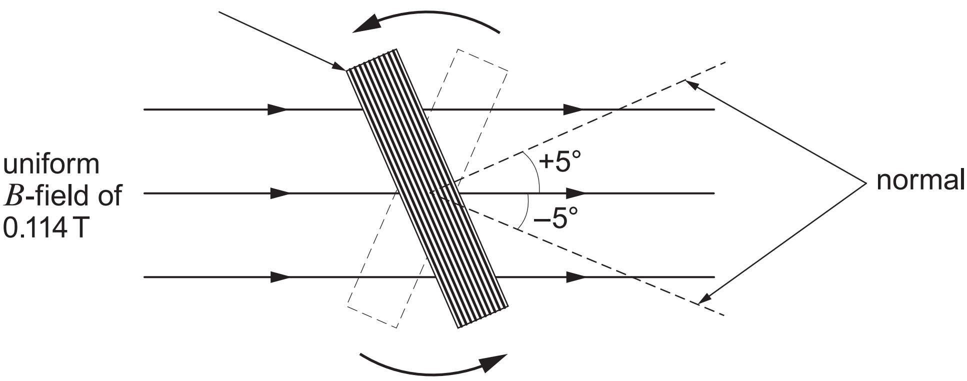
10. A rectangular coil rotates at a constant angular velocity within a uniform magnetic field of 0.114 T. The coil has 270 turns and cross-sectional area 420 cm^2. The diagram below is a simplified 3D diagram of the coil.



This second diagram is a 2D representation of the coil looking along the axis of rotation.



The flux **linkage** of the coil for the angles θ = –5° and θ = +5° is 1.29 Wb turn in each case.



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(a) Show clearly how this value for the flux linkage is obtained. [2]

(b) Explain why the induced emf is zero when $\theta = 0$. [1]

(c) The flux **linkage** of the coil for the angles θ = 85° and θ = 95° are 0.11 Wb turn and –0.11 Wb turn respectively. The coil rotates 10° in a time of 5.8 ms. Calculate the mean induced emf when rotating between θ = 85° and θ = 95°. [2]

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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

11. *(a)* Derive the expression for the resonance frequency, f_0, of a series RCL circuit. [3]

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

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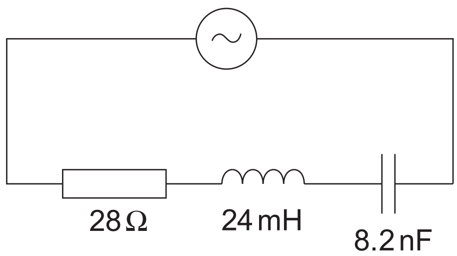
(b) Consider the following RCL circuit.

Variable frequency a.c. supply, V_{rms} = 15 V



(i) Calculate the rms current at the resonance frequency (f_0). [1]

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(ii) Calculate the rms current at twice the resonance frequency ($2f_0$). [4]

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(iii) Calculate the Q factor of the RCL circuit. [2]

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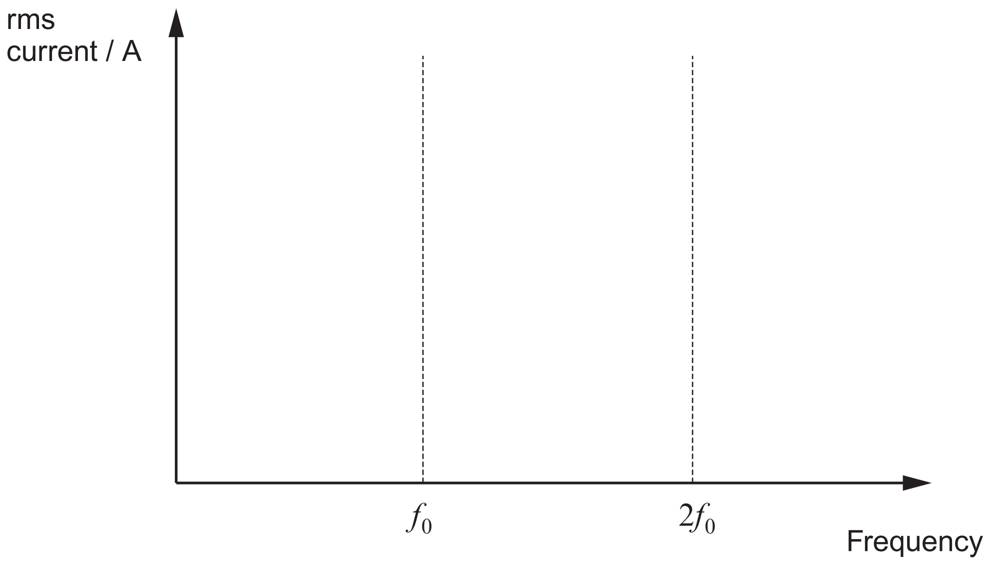
(iv) Sketch a graph of the rms current in the RCL circuit versus applied frequency of the a.c. supply on the axes provided. Label this graph 28 Ω. [3]



(v) The 28 Ω resistor is replaced by a 56 Ω resistor. On the same axes, sketch and label a second graph showing the rms current versus frequency for the new circuit. [2]

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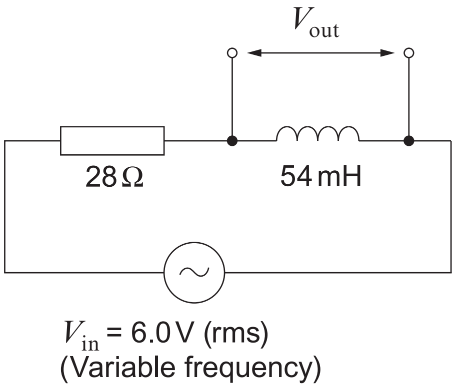
(c) Morgan claims that the rms output pd (V_{out}) in the following circuit is greater than 4.25 V when the frequency is greater than 82.5 Hz but less than 4.25 V below 82.5 Hz. Investigate whether or not Morgan is correct. [5]



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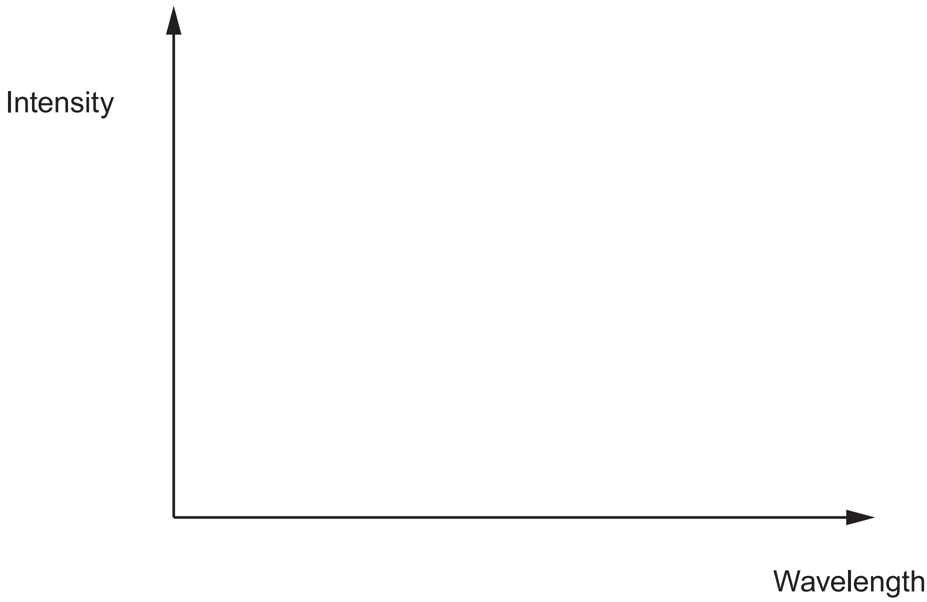
Option B – Medical Physics

12. *(a)* (i) Sketch graphs to show how the intensity of X-rays from an X-ray tube varies with wavelength for a tube operating at two different voltages. Label the main features of the graphs and indicate which curve represents the higher voltage. [4]



(ii) The lower voltage tube operates at 20 kV. Determine the velocity with which the electrons strike the target. [2]

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(iii) Calculate the minimum wavelength of the X-ray photons produced by these electrons. [2]

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(b) (i) Ultrasound can be used to carry out either an amplitude scan (A-scan) or a brightness scan (B-scan). Explain which of these two methods you would use to determine the depth of the tumour. Justify your answer. [2]

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(ii) An ultrasound scan can be used to indicate the thickness of fat on a person's body. Typically fat has a density of $930\,\text{kg}\,\text{m}^{-3}$ and an acoustic impedance of $1.35 \times 10^{6}\,\text{kg}\,\text{m}^{-2}\,\text{s}^{-1}$. If the time delay for the ultrasound pulse is 0.040 ms. Determine the thickness of fat. [3]

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Examiner only

(c) (i) Explain **two** properties of a radioactive isotope used as a tracer in medicine. [2]

(ii) 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 $0.8\,\text{cm}^3$ of blood was taken a few hours later and was found to have an activity of 0.025 Bq. If the half-life of iodine-125 is 60 days, calculate the volume of blood in the patient. State any assumptions you make. [3]

(d) In a magnetic resonance imaging (MRI) scanner a large magnetic field of 1.5 T is used along with short pulses of radio waves. Dr Francis suggests that radio waves of wavelength approximately 5 m would be suitable for this MRI scanner. Determine whether or not Dr Francis is correct. [2]

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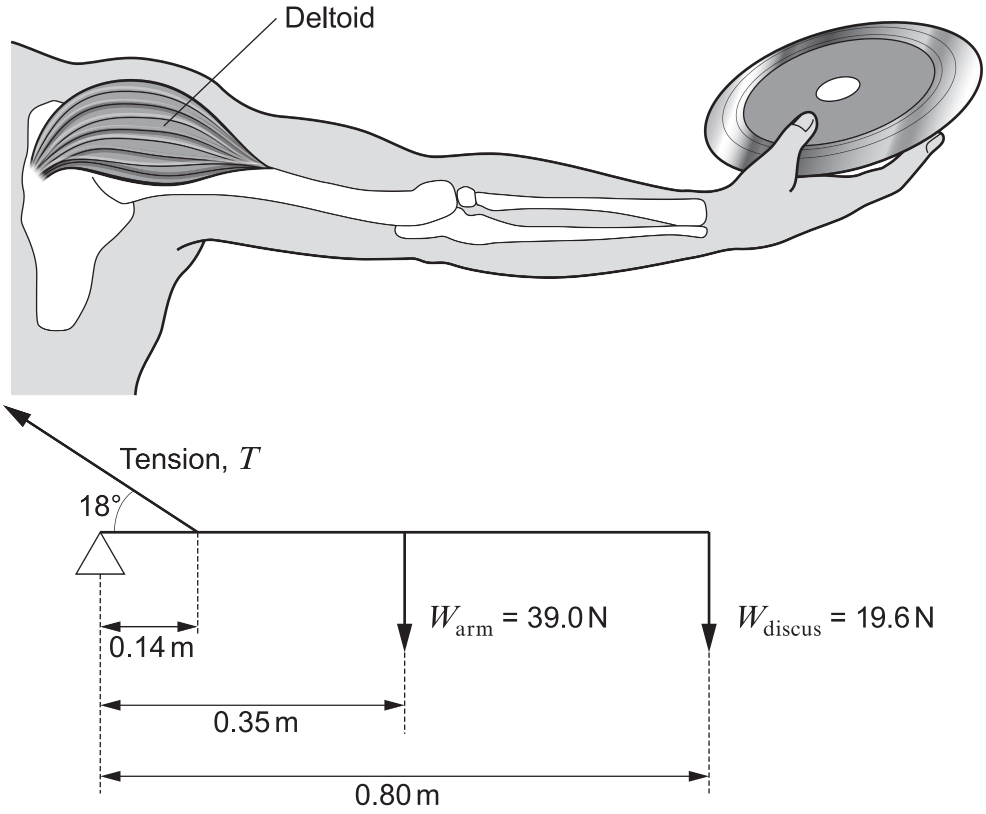
Option C – The Physics of Sports

13. *(a)* The diagram shows the forces acting on an athlete's arm as she holds a discus. Calculate the magnitude of the tension, T, provided by the deltoid muscle. [3]



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(b) (i) Define angular acceleration. [1]

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(ii) When thrown, the discus experiences an angular acceleration. It accelerates from rest to 2.3 revolutions per second in a time of 0.27 s. Calculate the angular acceleration of the discus. [2]

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(iii) Calculate the mean torque applied to the discus of mass 2.0 kg and radius 11 cm.

The moment of inertia is given by the equation $I = \frac{mr^2}{2}$. [3]

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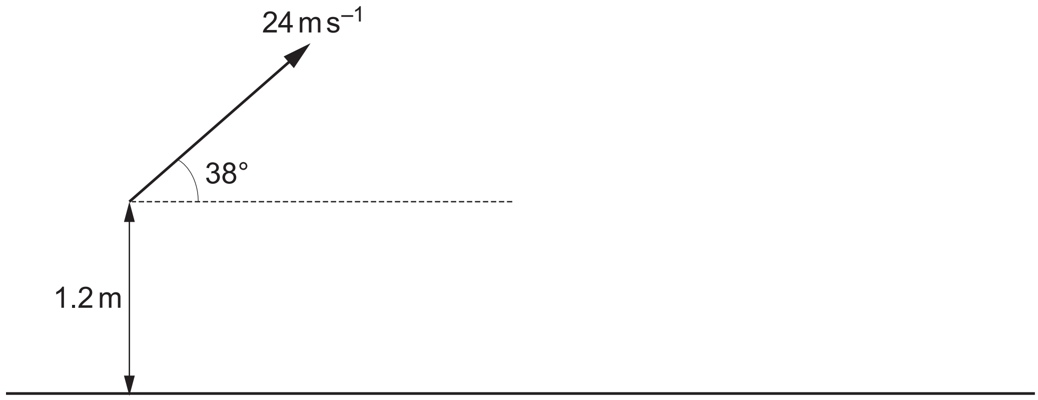
Examiner only

(c) (i) Calculate the maximum height attained by the discus if it is thrown with a velocity of 24 m s^{-1} and an angle of 38° from a height of 1.2 m. *Ignore the effects of air on the motion of the discus.* [4]



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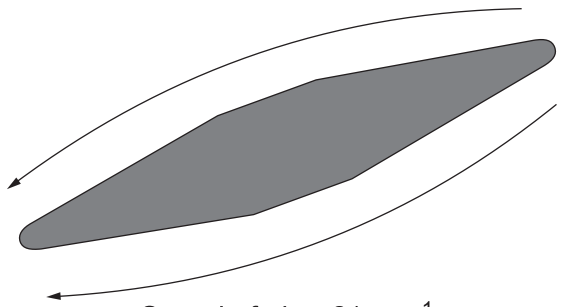
(ii) Taking the effects of air into account, evaluate whether the horizontal distance travelled by the discus will increase, decrease or remain approximately the same. The diagram shows the speed of air relative to the upper and lower surfaces of the discus. The density of air = 1.3 kg m^{-3}. [5]



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(iii) A wind tunnel is used to examine the motion of the discus in a wind speed of 20 m s^{-1}. Calculate the factor by which the drag force increases if the speed of the wind is increased to 30 m s^{-1} and all other factors are kept constant. [2]

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Examiner only

Option D – Energy and the Environment

14. *(a)* (i) Solar energy resources are considered to be renewable resources. State what is meant by a *renewable energy resource*. [1]

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(ii) The proton-proton chain is a set of reactions that take place in our Sun and can be summarised in the following equation.

$$4\,{}^{1}_{1}\mathrm{H} + 2\,{}^{0}_{-1}\mathrm{e} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\nu_e$$

Use data to show that the percentage mass loss is approximately 0.7%. [2]

Mass of ${}^{1}_{1}\mathrm{H}$ = 1.007 28 u   Mass of ${}^{4}_{2}\mathrm{He}$ = 4.001 51 u

Mass of ${}^{0}_{-1}\mathrm{e}$ = 0.000 55 u   Mass of ν_e = 0.000 00 u

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(iii) The Sun can be assumed to have come to the end of its life when it has lost 0.7 % of its mass to radiated energy. Estimate the lifetime of the Sun in years. Take the mass of the Sun to be 2.0×10^{30} kg and assume it to have a constant power output of 3.8×10^{26} W. [2]

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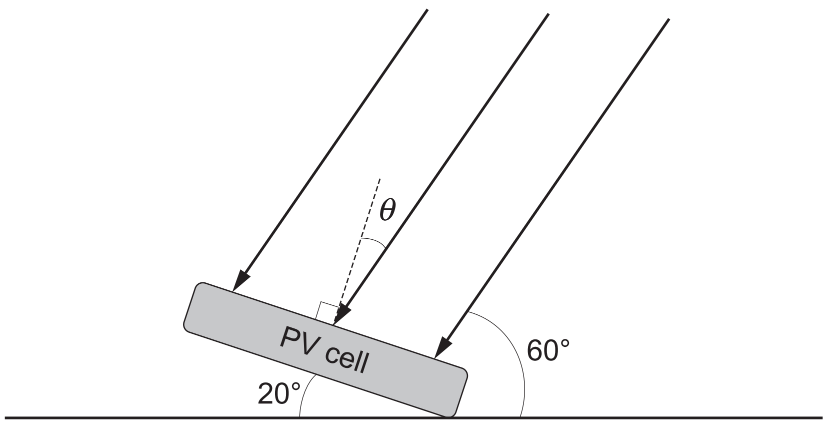
Examiner only

(b) The power output, P, from a photovoltaic (PV) cell of surface area, A, can be calculated using the equation:

$$P = \mu A I \cos\theta$$

where μ is the conversion efficiency of the cell, I is the intensity of solar radiation and θ is the angle between the normal and the incident sunlight.

Diagram not to scale



A factory decides to install rooftop PV cells at an angle of 20° to the horizontal. At midday when the Sun's elevation is 60° the solar radiation incident upon the surface of the Earth has an intensity of 600 W m^{-2}. An individual PV cell has a conversion efficiency of 20 % and is found to produce a power output of 150 W.

(i) Show that the area of the PV cell is approximately 1.3 m^2. [2]

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(ii) The factory roof covers an area of 3.6×10^4 m^2 and the factory owner plans for the installation to produce a mean power output of 4.0 MW. It is suggested that the company should install 27 500 of these PV cells. Discuss whether or not you believe this to be suitable. [3]

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(c) (i) Describe what is meant by the *enrichment* of uranium and explain why it is necessary. [2]

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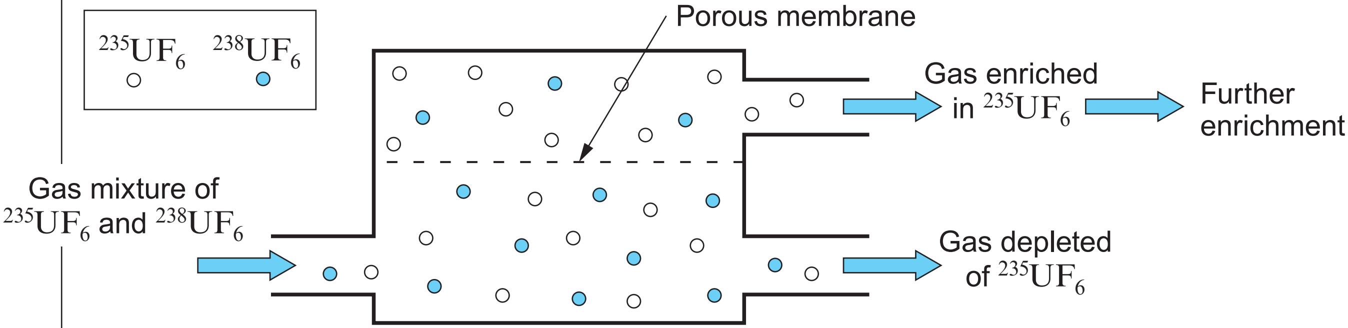
(ii) Gaseous diffusion was one of the original methods used to enrich uranium fuel. Uranium hexafluoride gas composing of $^{235}UF_6$ and $^{238}UF_6$ moves from a region of high pressure to a region of low pressure through a porous membrane. The lighter and faster $^{235}UF_6$ molecules diffuse through the membrane at a greater rate.

The first stage of the enrichment process is shown below.



During this stage, the mixture is enriched by a factor that can be calculated using:

$$\text{enrichment factor} = \sqrt{\frac{\text{molar mass of } ^{238}UF_6}{\text{molar mass of } ^{235}UF_6}}$$

Use the equation and data below to show that the uranium hexafluoride gas would need to complete more than 450 stages if it is to increase the concentration of uranium-235 from 0.7% to 5%. [3]

Molar mass of $^{235}UF_6$ = 349 g mol^{-1}

Molar mass of $^{238}UF_6$ = 352 g mol^{-1}

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(iii) State an alternative method for the enrichment of uranium. [1]

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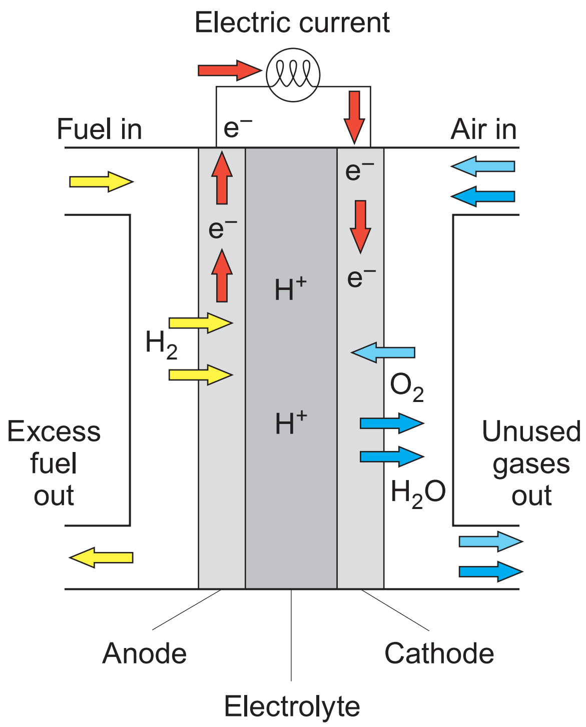
(d) A method of reducing CO_2 emissions involves the use of fuel cells to power cars. The basic layout for a *proton exchange membrane fuel cell* is shown in the diagram below.



(i) Describe the purpose of the electrolyte and state the waste product from the reaction. [2]

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(ii) In order for the fuel cell to be considered to have no CO_2 emissions, the sourcing of the hydrogen fuel must be considered. Two possible sources are:

- Electrolysis of water – where electrical energy is used to split water molecules to create hydrogen and oxygen;
- Reforming fossil fuels – where steam at high temperature is reacted with a fossil fuel to separate the hydrogen from the carbon in a hydrocarbon.

Discuss their likely impact on CO_2 emissions. [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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