GCE PHYSICS

S21-A420QS

Assessment Resource number 24

Options Resource F

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.

Option A – Alternating Currents

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(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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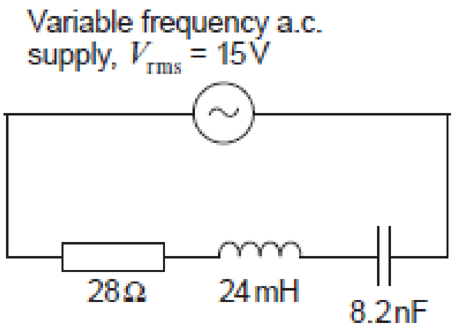
(b) Consider the following RCL circuit.



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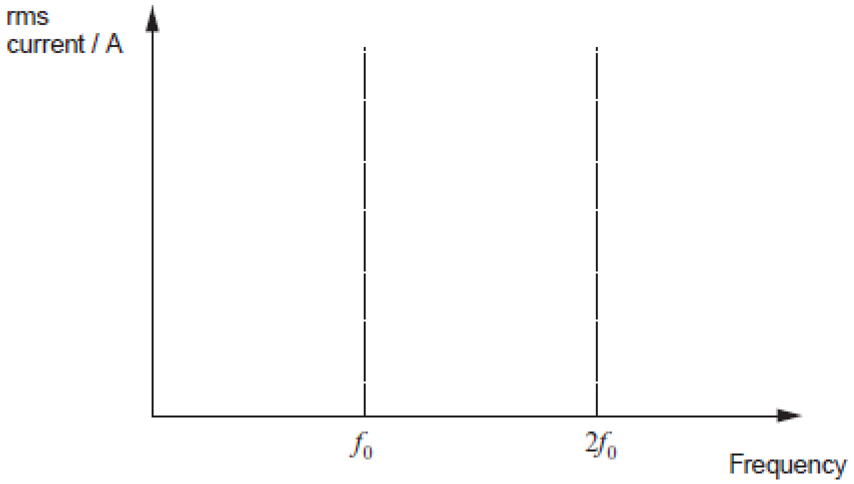
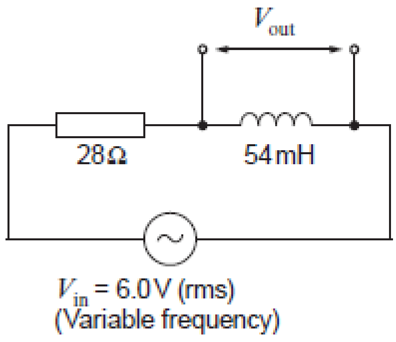
(iv) Sketch a graph of the rms current in the RCL circuit versus applied frequency of the a.c. supply on the axes provided. Label this graph $28\,\Omega$. [3]



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

(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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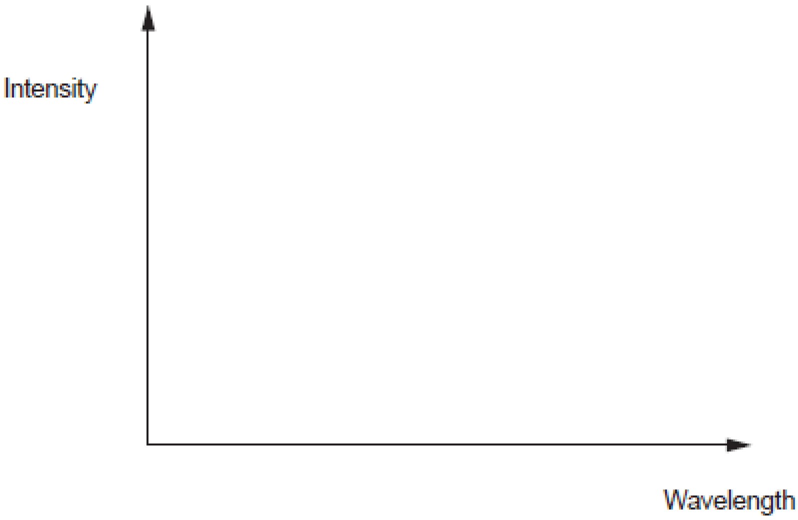
Option B – Medical Physics

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

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(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]

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(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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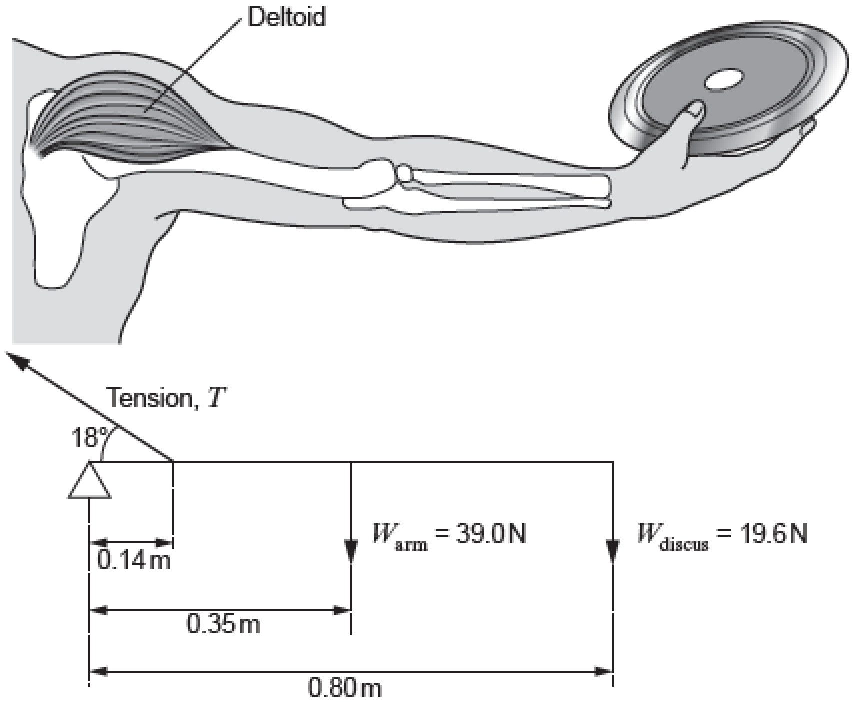
Option C – The Physics of Sports

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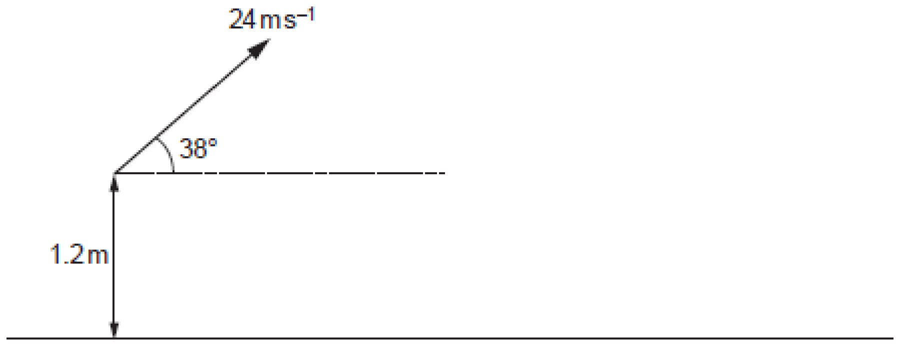
(c) (i) Calculate the maximum height attained by the discus if it is thrown with a velocity of 24 m s^{-1} and an angle of 38° from a height of 1.2 m. *Ignore the effects of air on the motion of the discus.* [4]



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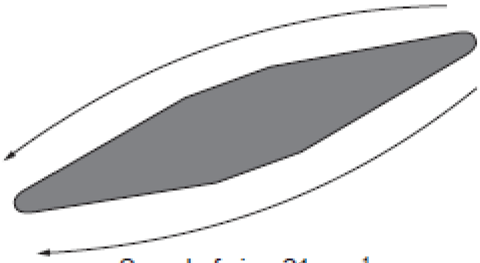
(ii) Taking the effects of air into account, evaluate whether the horizontal distance travelled by the discus will increase, decrease or remain approximately the same. The diagram shows the speed of air relative to the upper and lower surfaces of the discus. The density of air = $1.3\,kg\,m^{-3}$. [5]



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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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Option D – Energy and the Environment

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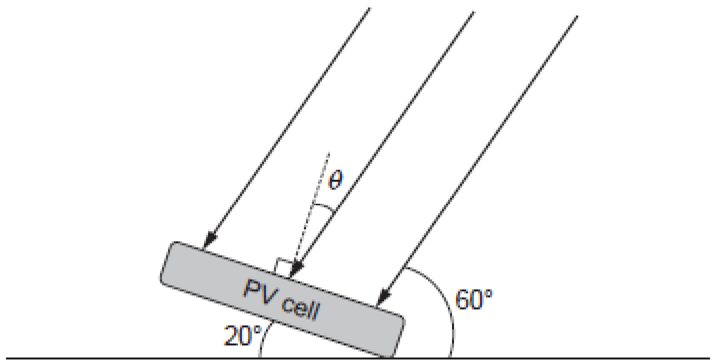
(b) The power output, P, from a photovoltaic (PV) cell of surface area, A, can be calculated using the equation:

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

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 $3.6 \times 10^4\,m^2$ 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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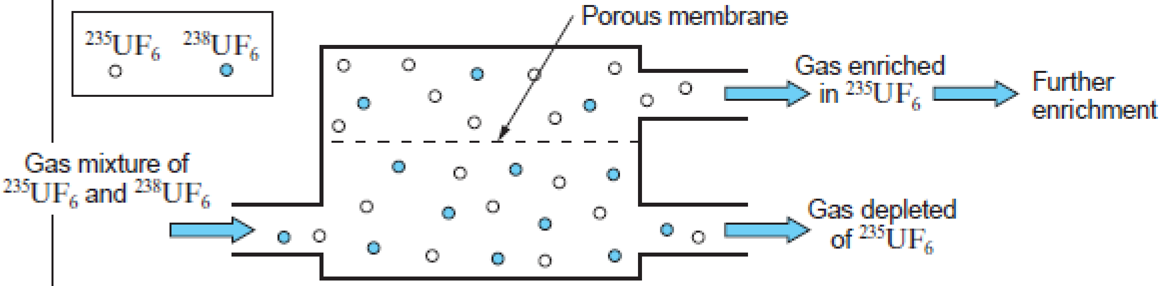
(ii) Gaseous diffusion was one of the original methods used to enrich uranium fuel. Uranium hexafluoride gas composing of $^{235}UF_6$ and $^{238}UF_6$ moves from a region of high pressure to a region of low pressure through a porous membrane. The lighter and faster $^{235}UF_6$ molecules diffuse through 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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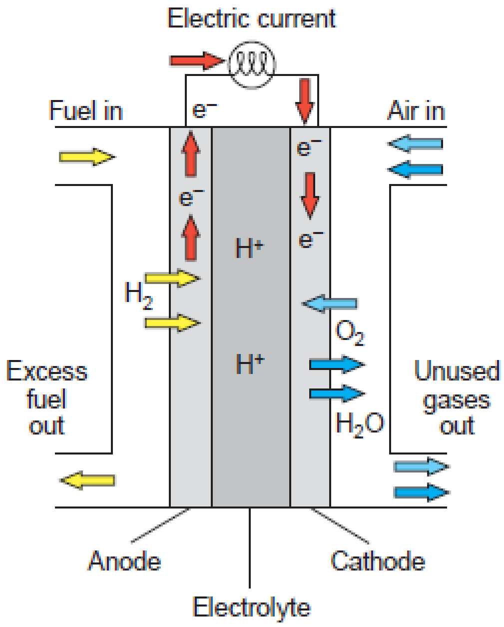
(d) A method of reducing CO_2 emissions involves the use of fuel cells to power cars. The basic layout for a *proton exchange membrane fuel cell* is shown in the diagram below.



(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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