KEELE UNIVERSITY

LEVEL 1 EXAMINATIONS, 2009

(PRINCIPAL COURSE)

Tuesday 26th May, 16:00–18:00

ASTROPHYSICS

PHY-10005

ELECTROMAGNETISM AND STELLAR STRUCTURE

Candidates should attempt ALL of PARTS A, A2, B and B2 and ONE question from PART C and ONE question from PART D. PARTS A and B should be answered on the exam paper; PARTS C and D should be answered in an answer book which should be attached to the exam paper at the end of the exam with a treasury tag.

The total marks available in each section are PART A: 16%, PART B: 24%, PART C: 30% and PART D: 30%. You are advised to divide your time in roughly these proportions.

Figures in brackets [ ] denote the marks allocated to the various parts of each question. Tables of physical and mathematical data may be obtained from the invigilator.

Student Number .....

A1		C1		Total
A2		C2		
B1		D1		
B2		D2		

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PART A TICK THE SQUARE BRACKET BY THE ANSWER YOU JUDGE TO BE CORRECT. MARKS FOR INCORRECT ANSWERS WILL NOT BE DEDUCTED.

A1. Two charges q_1 and q_2 are separated by a distance r. The electrostatic force between these two charges is given by:

[ ] $\frac{kq_1q_2}{r^2}$

[ ] $\frac{k(q_1+q_2)}{r}$

[ ] $\frac{kq_1{}^2q_2}{r^2}$

[ ] $\frac{k(q_1+q_2)^2}{r^2}$ [1]

A2. The force on an electric charge q due to an electric field is F. The strength of the electric field is given by:

[ ] qF

[ ] $\frac{q}{F}$

[ ] $\frac{F}{q}$

[ ] F [1]

A3. The electrostatic potentials at a point due to charges Q_1, Q_2, Q_3 are -20V, +10V and +30V respectively. The potential at the same point due to all the charges is:

[ ] 60 V

[ ] -20 V

[ ] 40 V

[ ] 20 V [1]

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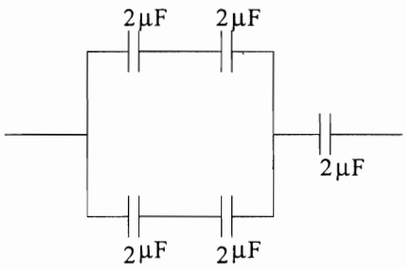
A4. The equivalent capacitance of the following circuit is:



[ ] 10 μF

[ ] 1 μF

[ ] 4 μF

[ ] 3 μF [1]

A5. An electrical conductor carries a charge q coulombs in t seconds, the current is given by:

[ ] q amps

[ ] $\frac{q}{t}$ amps

[ ] $\frac{t}{q}$ amps

[ ] qt amps [1]

A6. The current due to a DC voltage V across a resistance R is I. The electrical power dissipated by the resistor R is:

[ ] VR

[ ] IR

[ ] I^2R

[ ] $\frac{V}{R}$ [1]

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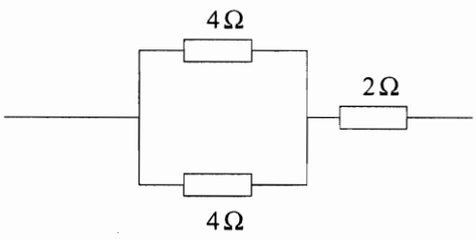
A7. The equivalent resistance of the following circuit is:



[ ] 10 Ω

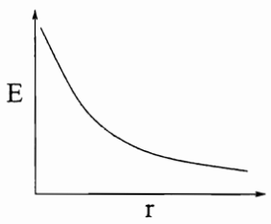
[ ] 4 Ω

[ ] 6 Ω

[ ] 1 Ω [1]

A8. Which of the following graphs illustrate the variation of electric field with distance from a point charge.

[ ]



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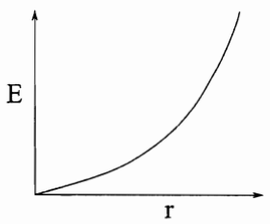

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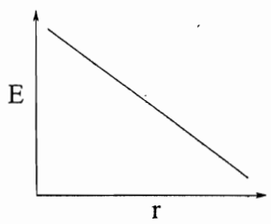

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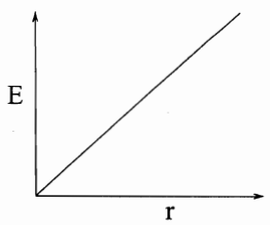

[1]

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PART B Attempt ALL questions

B1. A charged oil drop of mass 3.2×10^{-6} kg falling vertically against a 10^{14} Vm^{-1} uniform electric field reaches a constant velocity. How many electrons are on the oil drop? (For an electron $e = 1.6 \times 10^{-19}$C. Assume that the acceleration due to gravity is 10.0ms^{-2}.) [3]

B2. Calculate the ratio of the electric force to gravitational force between the electron and the proton in a hydrogen atom. ($q_e = -1.6 \times 10^{-19}$ C, $q_p = 1.6 \times 10^{-19}$ C, $m_e = 9.11 \times 10^{-31}$ kg, $m_p = 1.67 \times 10^{-27}$ kg, $\frac{1}{4\pi\epsilon_o} = 8.99 \times 10^9$ Nm^2C^{-2} and the gravitational constant $G = 6.67 \times 10^{-11}$ $\text{Nm}^2\text{kg}^{-2}$) [3]

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B3. An infinitely long thin wire has a linear charge density 0.5 Cm^{-1}. What is the electric field at 0.1m away from the wire in the direction perpendicular to the length of the wire? [3]

B4. The internal resistance of a galvanometer is 0.5Ω and has a full-scale deflection for a current of 10mA. Sketch a circuit to show how the instrument should be modified to measure up to 500mA. [3]

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PART C Answer ONE question from this section

C1. (a) State and explain Gauss's law describing the flux through a closed surface containing a number of electric charges. [8]

(b) A spherically symmetric distribution of charge has a charge density ρ given as follows:

$$\rho = \rho_o \qquad r \leq R,$$

$$\rho = 0 \qquad r > R,$$

where $\rho_o = \dfrac{3Q}{4\pi R^3}$ is a constant.

i. What is the total charge contained in the charge distribution ? [6]

ii. Obtain an expression for the electric field in the region $r \leq R$. [12]

iii. Show that, for the region defined by $r > R$, the electric field is identical to that produced by a point charge Q. [4]

C2. (a) State and explain Kirchhoff's current and voltage laws for electric circuits. [10]

(b) In the following circuit diagram shown in figure 1, $R_1 = 40\Omega$, $R_2 = 60\Omega$, $R_3 = 20\Omega$, $R_4 = 10\Omega$, $E_1 = 20$ V and $E_2 = 40$ V.

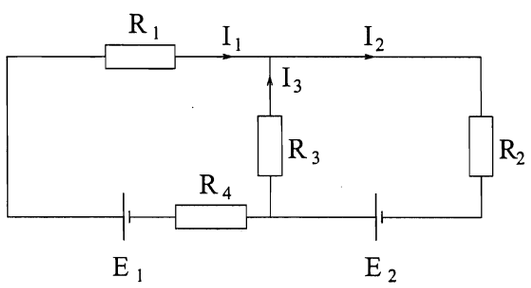

Figure 1:

i. What are values of the currents I_1, I_2, and I_3 ? [16]

ii. What is the power dissipated in R_2? [2]

iii. What is the power delivered by E_2? [2]

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PART A2 TICK THE BOX BY THE ANSWER YOU JUDGE TO BE CORRECT

A9 Stars typically range in mass from:

☐ 10^{29}–10^{32} kg ☐ 10^{14}–10^{18} kg ☐ 10^{24}–10^{27} kg ☐ 10^{32}–10^{35} kg [1]

A10 If a planet orbiting 1×10^{11} m from a star receives 300 W m^{-2} of radiation, the star's luminosity is:

☐ 3×10^{25} W ☐ 4×10^{25} W ☐ 7×10^{25} W ☐ 9×10^{25} W [1]

A11 Stars are composed mostly of:

☐ hydrogen ☐ helium ☐ carbon ☐ oxygen [1]

A12 The thermal or Kelvin–Helmholtz timescale for the Sun is about:

☐ 2000 s ☐ 28 days ☐ 30×10^6 yrs ☐ 4.5×10^9 yrs [1]

A13 The virial theorem relates a star's thermal energy to its:

☐ mass ☐ nuclear reactions
☐ gravitational energy ☐ lifetime [1]

A14 The average mass of a particle in the Sun is roughly:

☐ $4m_p$ ☐ m_p ☐ $m_p + m_e$ ☐ $\frac{1}{2}m_p$ [1]

A15 In the Sun, the pressure is proportional to:

☐ ρT ☐ $\rho^2 T$ ☐ $\frac{3}{2}kT$ ☐ $\bar{m}T$ [1]

A16 The main sequence phase of a star ends when:

☐ convection starts
☐ it enters the Hayashi forbidden zone
☐ it establishes hydrostatic equilibrium
☐ hydrogen is depleted in its core [1]

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PART B2 ANSWER ALL QUESTIONS

B5 What is the luminosity of a star with a radius 3×10^8 m and a surface temperature of 4000 K? [3]

B6 A star of 1 $M_\odot$ has a main-sequence lifetime of 10^{10} yrs. Estimate the lifetime of a 10-$M_\odot$ star. [3]

B7 Why is there a maximum mass for a star? [3]

B8 Explain why a white dwarf is far dimmer than a red giant despite being hotter. [3]

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PART D ANSWER ONE QUESTION FROM THIS SECTION

D1. A spherical interstellar gas cloud has a radius R, uniform density, and a total mass M. By considering the gravitational potential energy of a thin shell show that the total potential energy of the cloud is given by

$$U = -\frac{3}{5}\frac{GM^2}{R}.$$ [15]

Assuming that the cloud has a temperature T and consists of particles with an average mass $\bar{m}$, find the total thermal energy of the cloud in terms of T and M. [6]

If the cloud consists of 10 $M_\odot$ of molecular hydrogen (H_2), and has a radius of 4×10^{15} m and a temperature of 25 K, will the cloud collapse into a star? Justify your answer. [5]

What other processes might inhibit collapse into a star? [4]

[$M_\odot = 2 \times 10^{30}$ kg.]

D2. Produce an argument showing that if there are n electrons per unit volume, each scattering photons with a cross-section σ_T, then the mean free path of the photons is

$$l = \frac{1}{n\sigma_T}.$$ [8]

Find an order of magnitude estimate for n in the Sun and hence, given that $\sigma_T = 6.6 \times 10^{-29}\,\mathrm{m}^2$, estimate l. [7]

Explain why the resulting distance travelled, D, after $\mathcal{N}$ scatterings is given by

$$D^2 = \mathcal{N}l^2$$

and hence estimate the number of scatterings D needed for a photon created in the Sun's centre to emerge from its surface. [8]

Hence estimate the total time a photon will take to emerge from the Sun's centre and comment on whether the solar photons will be a good indicator of conditions in the solar centre. [7]

[$R_\odot = 7 \times 10^8$ m; $M_\odot = 2 \times 10^{30}$ kg; proton mass $= 1.67 \times 10^{-27}$ kg.]