EXAMINATION PAPER CONTAINS STUDENT'S ANSW

Please write your 8-digit student number here: ☐☐☐☐☐☐☐☐

The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2009/10

Level I

Thursday 27th May 2010, 13.00-15.00

PHYSICS/ASTROPHYSICS

PHY-10023

Electricity and Stellar Structure

Candidates should attempt ALL of PARTS A and B, and ONE question from PART C and ONE question from PART D.
PARTS A and B should be answered on the exam paper; PART C AND PART D should be answered in the examination booklet which should be attached to the exam paper at the end of the exam with a treasury tag.
PART A yields 16% of the marks, PART B yields 24%, PART C yields 30% and PART D yields 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.

Please do not write in the box below

A		C1		Total
B		C2		
		D1		
		D2		

NOT TO BE REMOVED FROM THE EXAMINATION HALL

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PART A TICK THE BOX BY THE ANSWER YOU JUDGE TO BE CORRECT (MARKS ARE NOT DEDUCTED FOR INCORRECT ANSWERS)

A1 The electrostatic force between two point charges is 8 N. If the separation between these two charges is doubled, the force will be:

☐ 16 N ☐ 4 N ☐ 2 N ☐ 1 N [1]

A2 A 1 m long wire is placed in a 0.1 T magnetic field which is perpendicular to the length of the wire. If the current through the wire is 1 A, the force on the wire is:

☐ 1.0 N ☐ 0.1 N ☐ 1.1 N ☐ 2.0 N [1]

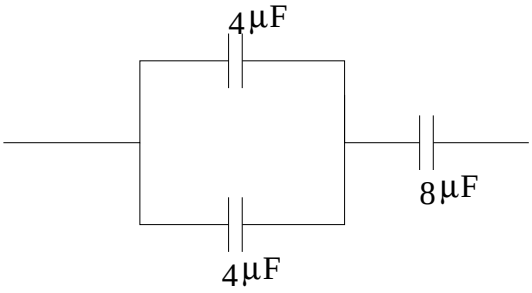
A3 The electric fields at a point due to charges Q_1, Q_2, Q_3 are $10\vec{i}+8\vec{j}$, $-20\vec{i}+16\vec{j}$ and $40\vec{i}-32\vec{j}$ respectively. The electric field at the same point due to all the charges is:

☐ $70\vec{i}+56\vec{j}$ ☐ $-20\vec{i}-32\vec{j}$ ☐ $50\vec{i}+24\vec{j}$ ☐ $30\vec{i}-8\vec{j}$ [1]

A4 An electrical conductor carries 10 coulombs in 5 seconds, the current is:

☐ 10 amps ☐ 2 amps ☐ 0.5 amps ☐ 50 amps [1]

A5 The equivalent capacitance of the following circuit is:



☐ 16 μF ☐ 4 μF ☐ 6 μF ☐ $\frac{8}{5}$ μF [1]

A6 The force acting on charge q moving in a magnetic field $\vec{B}$ with a velocity $\vec{v}$ is:

☐ $q\vec{v}\times\vec{B}$ ☐ qvB ☐ $q\vec{v}.\vec{B}$ ☐ $-qvB$ [1]

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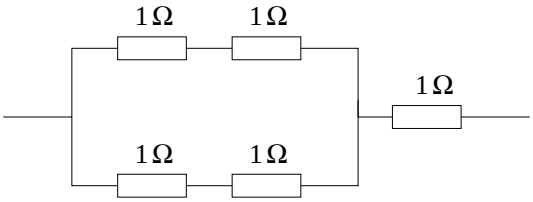
A7 The equivalent resistance of the following circuit is:



☐ 2Ω ☐ 5Ω ☐ 1.25Ω ☐ 3Ω [1]

A8 The density of the charge carriers in an electrical conductor is q Cm^{-3} and the drift velocity is v ms^{-1}. If the area of cross section is A m^2, the current flow through the conductor is given by:

☐ $\frac{q}{v}$ ☐ $\frac{q}{vA}$ ☐ $\frac{v}{q}$ ☐ vAq [1]

A9 The mass of a main sequence star with $L = 500\,000\,L_\odot$ is approximately:

☐ $0.5\,M_\odot$ ☐ $5\,M_\odot$ ☐ $50\,M_\odot$ ☐ $500\,M_\odot$ [1]

A10 How does the gas in the core of stars withstand extremely high pressures?

☐ the gas is cold ☐ the gas is ionised
☐ the gas becomes liquid ☐ the core solidifies [1]

A11 The dynamical and Kelvin-Helmholtz timescales for the Sun are respectively:

☐ 2 000 s and 30×10^6 yr ☐ 2 000 s and 4.5×10^9 yr
☐ 30×10^6 yr and 4.5×10^9 yr ☐ 30×10^6 yr and 2 000 s [1]

A12 Which of the following statements concerning energy stability in the Sun is <u>false</u>?

☐ A net outward pressure causes the Sun to contract
☐ Contraction causes the core temperature to rise
☐ Greater core temperature leads to increased energy generation
☐ Too much energy generation leads to a net outward pressure [1]

A13 The main sequence phase of a star ends when:

☐ convection starts
☐ nuclear reactions start in its core
☐ it establishes hydrostatic equilibrium
☐ hydrogen is depleted in its core [1]

/Cont'd

A14 A hot star can have low luminosity if it is:

- ☐ a red giant
- ☐ a white dwarf
- ☐ on the main sequence
- ☐ a protostar

[1]

A15 Convection can be triggered by:

- ☐ radiative equilibrium
- ☐ increased opacity due to partially ionised hydrogen
- ☐ hydrostatic equilibrium
- ☐ mass loss

[1]

A16 The mean free path of a photon inside a star is:

- ☐ directly proportional to the opacity
- ☐ the reciprocal of the Thomson cross-section
- ☐ the average distance between collisions with free electrons
- ☐ the time for a photon to diffuse out of the star

[1]

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PART B Answer all EIGHT questions

B1 Calculate the ratio of the forces due to the gravitational field and an electric field on an electron near the earth's surface. Assume that $\frac{e}{m}$ for an electron is $1.756\times\ 10^{11}$ C kg^{-1}, the electric field is 10^6 V m^{-1} and the gravitational field is 9.8 m s^{-2}. [3]

B2 Sketch the electric field lines for a pair of charges +2q and +q separated by 0.1m. [3]

B3 A 24 μC electric charge is placed at the centre of a cubic box of side 0.6 m. What is the electric flux through one side of the cubic box? [3]

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B4 During a lightning flash, 50 C of electric charge is transferred through a potential difference of 10^6V. Calculate the electrical energy involved in this process. How long could this electrical power be used to light a 100W light bulb? [3]

B5 A $1\,M_\odot$ star has a main sequence lifetime of 10^{10} yr. Estimate the lifetime of a $10\,M_\odot$ star. [3]

B6 Draw a schematic Hertzsprung-Russell diagram, indicating on it the Sun's evolution. Label the axes and the location of the main evolutionary stages. [3]

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B7 Consider a volume of gas displaced upwards inside a star. State the density criteria under which convective instability would occur. [3]

B8 Sirius A is a main sequence star with radius $R = 1.7\,R_\odot$ and luminosity $L = 26\,L_\odot$. Calculate the star's effective temperature and state its approximate spectral type. [3]

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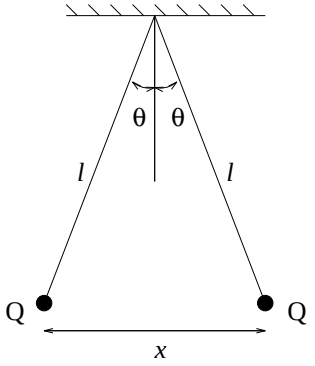
PART C ANSWER ONE OUT OF TWO QUESTIONS

C1 (a) Using Coulomb's or Gauss's law derive an expression for the electric field $\vec{E}$ and the electric potential V at a distance r from a point charge Q. [8]

(b) Two identical conducting balls of mass M are hung from silk threads of length l and carry identical charges Q as shown in figure below. Assume that θ is so small that $\tan\theta \approx \sin\theta$.



i. Sketch a diagram showing the forces acting on either of the balls. [6]

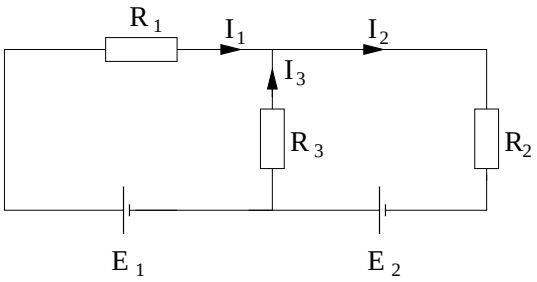
ii. Show that,

$$x = \left[\frac{Q^2 l}{2\pi\epsilon_o M g}\right]^{\frac{1}{3}}$$

where x is the equilibrium separation between the balls. [16]

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

(b) In the circuit diagram shown below, $R_1 = 10\Omega$, $R_2 = 12\Omega$, $R_3 = 4\Omega$, $E_1 = 4V$ and $E_2 = 8V$.



i. calculate the values for I_1, I_2, and I_3; [16]

ii. calculate the power dissipated in R_2; [2]

iii. calculate the power delivered by E_2. [2]

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PART D Answer ONE out of TWO questions

D1 A spherical interstellar gas cloud has a radius R, uniform density, and a total mass M.

(a) Using the hydrostatic equilibrium equation, show that the central pressure of the cloud is given by

$$P_{\rm c} = \frac{3G}{8\pi}\frac{M^2}{R^4}.$$ [14]

(b) Assuming that the cloud consists of a gas of particles of average mass $\overline{m}$ that acts as an ideal gas, derive an expression for the central temperature of this cloud as a function of M and R. [8]

(c) 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. [8]

D2 (a) Show that if there are $n_{\rm e}$ electrons per unit volume, each with a scattering cross-section σ_T, then the mean free path of the photons is

$$l = \frac{1}{n_{\rm e}\sigma_T}.$$ [6]

(b) How is the mean free path related to the opacity of the stellar material? State where in stellar interiors is this opacity mechanism dominant and why. [6]

(c) Explain why the distance travelled, D, after N scatterings is given by

$$D^2 = Nl^2$$

and hence estimate the number of scatterings needed for a photon to diffuse out of a star of radius R. [8]

(d) Consider a star with a radius of $2\,R_\odot$ and an average density $10^5\,{\rm kg\,m^{-3}}$, consisting of ionised hydrogen. Estimate the mean free path and the total diffusion time for a photon inside this star. [10]