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, 2010/11

Level I

Monday 16th May 2011, 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 each of PARTS C and D. PARTS A and B should be answered on the exam paper; PARTS C and 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%, PART D yields 30%.

Please do not write in the box below

A		C1		Total
B		C2		
		D1		
		D2		

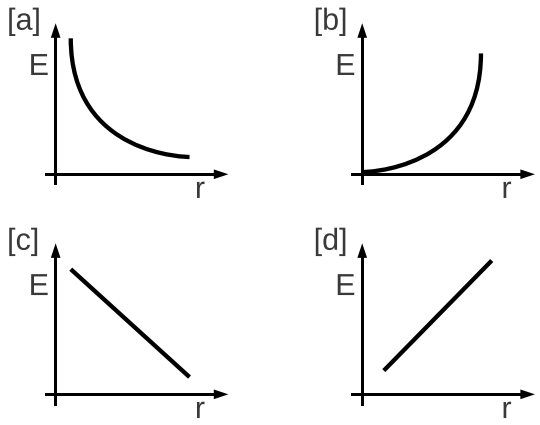
NOT TO BE REMOVED FROM THE EXAMINATION HALL

PART A Tick one box by the answer you judge to be cor
(marks are not deducted for incorrect answers)

A1 The electrostatic force between two point charges is 30 N. If the charge of both charges is tripled, then the force will be:

☐ 3.3 N ☐ 10 N ☐ 90 N ☐ 270 N [1]

A2 Which of the following graphs illustrate the variation of the electrostatic field, E, with distance from a point charge.



☐ a ☐ b
☐ c ☐ d [1]

A3 The electrostatic potentials at a point P due to charges Q_1, Q_2, and Q_3 are +40 V, −10 V and −20 V, respectively. What is the net electrostatic potential at point P?

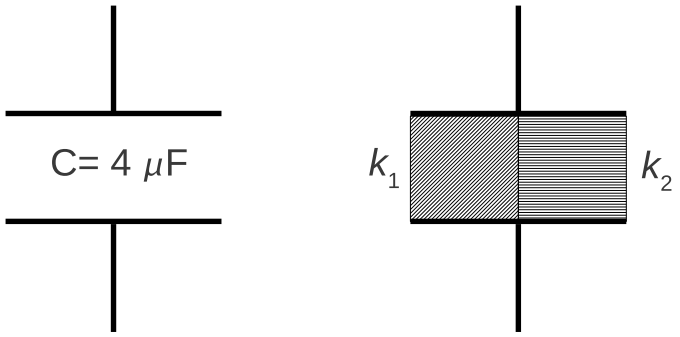
☐ −70 V ☐ −10 V ☐ 10 V ☐ +70 V [1]

A4 What is the electrostatic potential across a distance of 5 m in a uniform electric field, $E = 20\,\mathrm{V/m}$.

☐ 4 V ☐ 20 V ☐ 25 V ☐ 100 V [1]

/Cont'd

A5 The value of the capacitance of the parallel plate capacitor w... the dielectric material is $4\,\mu$F. If the capacitor is filled equally w... two dielectric materials with the dielectric constants k_1 and k_2, the capacitance is:



☐ $\frac{k_1 + k_2}{2k_1k_2}\,\mu$F ☐ $2k_1k_2\,\mu$F ☐ $\frac{2k_1k_2}{k_1 + k_2}\,\mu$F ☐ $2(k_1 + k_2)\,\mu$F [1]

A6 What capacitance would be required to store 5 J at a potential difference of 1000 V across the plates?

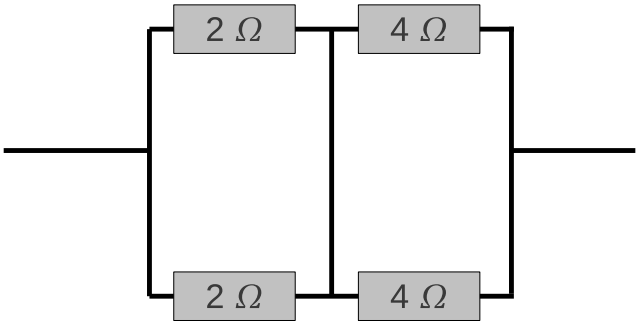
☐ 10^{-2} F ☐ 5×10^{-2} F ☐ 10^{-5} F ☐ 5×10^{-5} F [1]

A7 A transmission line carries a current of 10^3 A from west to east. The earth's magnetic field is horizontal, points to the north, and has a magnitude of 0.5×10^{-4} T. What is the force on one meter of the wire?

☐ 0.05 N ☐ 0.2 N ☐ 50 N ☐ 500 N [1]

/Cont'd

A8 What is the equivalent resistance of the following circuit:



☐ 2.67 Ω ☐ 3 Ω ☐ 6 Ω ☐ 12 Ω [1]

A9 The Sun (effective temperature of 5778 K) is classified as a G-type star. A star with an effective temperature of 30000 K is classified as:

☐ a O-type star
☐ spectral type is independent of temperature
☐ a G-type star
☐ a M-type star [1]

A10 A red giant is:

☐ a molecular cloud that will contract to form a star
☐ the final stage of the Sun's evolution
☐ a star that has exhausted hydrogen in its core and has expanded
☐ a main sequence star more massive than the Sun [1]

A11 Which of these statements is <u>false</u>:

☐ the main sequence is populated by stars of different masses
☐ stars spend the majority of their lifetime in the main sequence
☐ the main sequence is an evolutionary sequence
☐ the main sequence starts when nuclear reactions are ignited [1]

/Cont'd

A12 If the Sun has a mass of $1\,M_\odot$ and a luminosity of $1\,L_\odot$, the lumi
of a $10\,M_\odot$ star is approximately:

☐ $1\,L_\odot$ ☐ $1000\,L_\odot$ ☐ $10\,L_\odot$ ☐ $0.001\,L_\odot$ [1]

A13 During the main sequence phase, a star's energy comes from:

☐ nuclear reactions ☐ chemical reactions
☐ pressure forces ☐ gravitation [1]

A14 Radiative transfer means that energy is transported by

☐ diffusion of photons ☐ bulk motions of gas
☐ collisions of gas particles ☐ all of the above [1]

A15 The mean free path of a photon is

☐ the average distance travelled between collisions with free electrons
☐ the time it takes for a star to collapse
☐ the distance between two photons
☐ directly proportional to the opacity [1]

A16 The hydrostatic equilibrium equation describes

☐ the mass distribution inside the star
☐ the balance between the forces of gravity and pressure
☐ the temperature gradient from the core to the surface
☐ nuclear energy production [1]

/Cont'd

PART B Answer all EIGHT questions

B1 The charge produced by rubbing a block of plastic with a cloth is 32 nC. Calculate the number of electrons that have been transferred in the process. [3]

B2 A proton is accelerated from rest using an electric field, $E = 10^5$ V/m. Calculate the velocity of the proton after it has undergone a displacement of 2 m. [3]

/Cont'd

B3 Sketch the electric potential for a pair of charges −q and −2
separated by 10 cm. [3]

B4 Calculate the magnetic and electric forces and the ratio of the two forces for a particle of charge 3 nC moving at 5000 m/s in the presence of an electric field, E= 10^4 V/m and a magnetic field, B= 2 T (both B and E being perpendicular to the motion of the particle). [3]

/Cont'd

B5 Draw a schematic Hertzsprung-Russell diagram, indicating on it the Sun's evolution. Label the axes, the Sun's position and the location of the main evolutionary stages. [3]

B6 Solar mass stars have luminosities given by $L \propto M^3$. Explain why the main sequence lifetime of these stars varies as M^{-2}. [3]

/Cont'd

B7 Estimate the average electron number density n_e in the interior of the Sun. [3]

B8 Betelgeuse is a red giant star with a surface temperature of 3500 K and a radius of 1000 $R_\odot$. Calculate Betelgeuse's luminosity. [3]

/Cont'd

PART C Answer ONE out of TWO questions

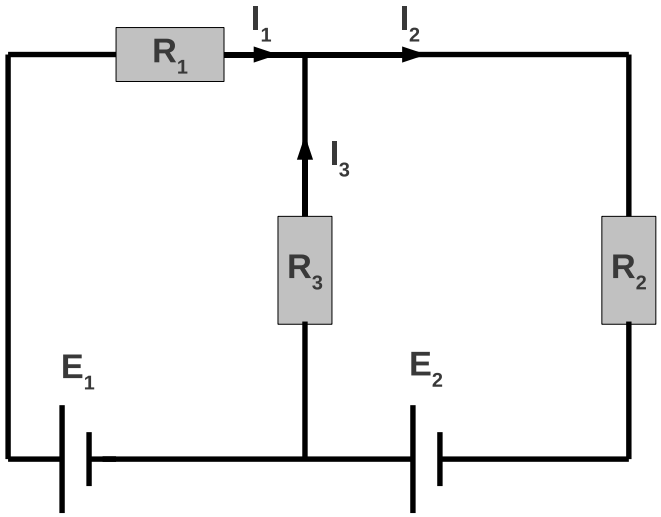
C1 (a) State and explain Gauss's law. [5]

(b) An infinite line of charge has a uniform charge per unit length, λ. Find the electric field at a perpendicular distance r from the line. [10]

(c) An infinite flat sheet of charge has a uniform charge per unit area, σ. Find the electric field at a perpendicular distance r from the sheet. [15]

C2 (a) State and explain Kirchhoff's rules for an electric circuit. [10]

(b) In the circuit diagram below, $I_1 = 3\,\text{A}$, $I_2 = 2\,\text{A}$, $E_1 = 10\,\text{V}$, $E_2 = 5\,\text{V}$, and $R_1 = 2\,\Omega$.



i. Calculate the power delivered by E_2. [2]

ii. Calculate the values for R_2 and R_3. [18]

/Cont'd

PART D Answer ONE out of TWO questions

D1 Consider a spherical interstellar gas cloud which has a radius R, uniform density $\overline{\rho}$ and a total mass M.

(a) Starting from the gravitational potential energy of a thin shell (radius r, thickness δr and mass δM) show that the total potential energy of the cloud is given by:

$$E_{\mathrm{G}} = -\frac{3}{5}\frac{GM^2}{R}. \qquad [14]$$

(b) If the gas behaves like an ideal isothermal gas and the particles in the gas have a mean mass $\overline{m}$, show that the total thermal energy of the cloud is given by:

$$E_{\mathrm{Th}} = \frac{3}{2}\frac{k_{\mathrm{B}}}{\overline{m}}MT. \qquad [6]$$

(c) What is the necessary condition for the gravitational collapse of a molecular cloud? [2]

(d) Derive an expression in terms of T, R and $\overline{m}$ for the critical mass above which the interstellar cloud will collapse into a star. Hence find an expression in terms of T, M and $\overline{m}$ for the critical density. [8]

/Cont'd

D2 The general form of the virial theorem is

$$3\int_0^V P(r)dV = -E_{\rm G}.$$

(a) Assuming the gas is ideal, show that this expression is equivalent to

$$E_{\rm Th} = -\frac{1}{2}E_{\rm G}. \qquad [10]$$

(b) Explain the implications of the virial theorem for a contracting star. [8]

(c) The gravitational potential energy of a star of uniform density is given by

$$E_{\rm G} = -\frac{3}{5}\frac{GM^2}{R}.$$

Explain the meaning and derive an expression for the Kelvin-Helmholtz timescale, for a uniform density star. [6]

(d) By considering the total energy of the star, explain what happens when the temperature rises enough to ignite nuclear reactions. How would the Sun evolve if nuclear reactions were to suddenly stop? [6]