The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2012/13

Level I

Thursday 23rd May 2013, 09:30 - 11:30

PHYSICS/ASTROPHYSICS

PHY-10023

ELECTRICITY & STELLAR STRUCTURE

Candidates should attempt ALL of PART A and ONE question from each of PARTS B and C.

PART A yields 40% of the marks, PART B yields 30%, PART C yields 30%

NOT TO BE REMOVED FROM THE EXAMINATION HALL

PART A Answer all TEN questions

A1 Calculate the ratio of the electric force to the gravitational force between an electron and a proton in a hydrogen atom. [4]

A2 What is the work done by an external force in order to bring a $+1\mu$C test charge from infinity to a distance of 10 cm from a point charge of $+50\mu$C? [4]

A3 Two 8μF capacitors are connected in parallel to a 12 V battery. What is the combined capacitance and how much work is done by the battery to charge both capacitors? [4]

A4 A 24 μC electric charge is placed at the centre of a cubic box. What is the electric flux through one side of the cubic box? [4]

A5 A charge of 0.5 C flows through a resistor of $R = 50\Omega$ in 5 seconds. How much energy is dissipated in the resistor? [4]

A6 Draw a schematic Hertzsprung-Russell diagram, indicating on it the Sun's evolution. Label the Sun's position and identify the main evolutionary stages. [4]

A7 Explain briefly what is meant by convective transport in stellar interiors. In which region of the Sun's interior is convective transport dominant? [4]

A8 Sirius A is a main sequence star with radius $R = 1.7R_\odot$ and luminosity $L = 26L_\odot$. Calculate the star's effective temperature and state its approximate spectral type.

A9 Show that the main-sequence timescale for a solar-type star of mass M and luminosity L is:

$$t_{\rm MS} = 7 \times 10^{-4} c^2 \frac{M}{L}.$$ [4]

A10 Explain briefly why the gas in the core of the Sun behaves as an ideal gas, despite being subject to extremely high pressures. [4]

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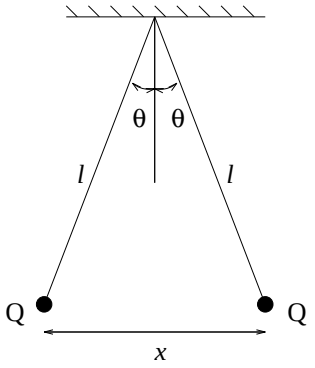
PART B Answer ONE out of TWO questions

B1 (a) Using either 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. [6]

(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. [12]

iii. If the threads are of 1 m length and hang at an angle of 5 degrees to the vertical, while the mass of each ball is 0.1 kg, calculate the charge on each ball. [6]

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B2 (a) State and explain Gauss's law concerning electric fields a charges. [6]

(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 within the charge distribution? [3]

ii. Derive an expression for the electric field where $r \leq R$. [12]

iii. Show that, for the region defined by $r > R$, the electric field is identical to that produced by a point charge Q. [3]

iv. Sketch how the magnitude of the electric field varies with radius. [6]

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PART C Answer ONE out of TWO questions

C1 Consider a spherical interstellar gas cloud which has a radius R, uniform density $\overline{\rho}$ and a total mass M.

(a) 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 as an ideal gas at temperature T, 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) 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. [10]

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C2 The general form of the virial theorem is

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

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

$$E_{\rm Th} = -\frac{1}{2}E_{\rm G}.$$

where $E_{\rm G}$ and $E_{\rm Th}$ are respectively the total gravitational potential energy and the total thermal energy of a star. [12]

(b) 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 this star. [6]

(c) Explain the implications of the virial theorem for the formation of stars. [6]

(d) By considering its total energy, explain why the onset of nuclear reactions leads to the end of the contraction stage of a star. [6]