SEMESTER 2 EXAMINATION 2012-2013

SPACE PLASMA PHYSICS

Duration: 120 MINS (2 hours)

This paper contains 7 questions.

Answer **all** questions in **Section A** and **only two** questions in **Section B**.

Section A carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 mins on it.

Section B carries 2/3 of the total marks for the exam paper and you should aim to spend about 80 mins on it.

An outline marking scheme is shown in brackets to the right of each question.

A Sheet of Physical Constants is provided with this examination paper.

Only university approved calculators may be used.

A foreign language translation dictionary (paper version) is permitted provided it contains no notes, additions or annotations.

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Section A

A1. Describe the two processes that ionise a gas to form a plasma. Using the ionisation potential of hydrogen of 13.6 eV, calculate the temperature needed to ionise a hydrogen atom, and the wavelength of radiation required to do likewise. [4]

A2. Show that the magnetic flux, Φ_M, through a particle orbit in a slowly varying magnetic field is independent of time. [4]

A3. Give the equations of balance between the dominant pressures at the nose of the Earth's magnetosphere, illustrating your arguments with a well-labelled diagram. Explain all assumptions and define all terms used. [6]

A4. Explain with the use of a diagram why currents flow in the magnetopause region of the Earth's magnetosphere. Hence explain what effect these currents have on the magnetic field at this boundary between the solar wind and the Earth's field. [6]

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Section B

B1. Consider a plasma with a Boltzmann density distribution, where T is the temperature of both ions and electrons, n_0 is the number density of both ions and electrons, and the ions have a single positive charge.

(a) Describe what happens to the plasma when a test charge q_t is introduced. Write expressions for the number density of both the electrons and ions at equilibrium, explaining any assumptions you make. [3]

(b) Hence show that

$$\nabla^2\phi = \left(\frac{n_0 e^2}{\epsilon_0 k_B T}\right)\phi$$

where ϕ is the shielding potential of the test charge, q_t. Use the Taylor expansion $e^x = 1 + x + ...$ [5]

(c) Given that the solutions in spherical coordinates for ϕ are

$$\phi = \phi_0(r)\, e^{\pm r/\lambda_D} \quad \text{where} \quad \lambda_D = \sqrt{\frac{\epsilon_0 k_B T}{n_0 e^2}},$$

use the boundary conditions for a plasma at $r = \infty$ and r close to zero to show which solution applies to the plasma, and to explain the significance of $\phi_0(r)$ and λ_D. Draw a rough graph showing the variation of potential with r to aid your explanation. [6]

(d) The number densities and temperatures of several plasmas are listed below. (Note that in plasma physics it is standard to give 'temperatures' in eV.) Find λ_D for each, and hence state whether the first plasma criterion is satisfied.

(i) Fusion experiment: $n_0 = 10^{20}$ m^{-3}, $k_B T = 10^4$ eV

(ii) Interplanetary space: $n_0 = 10^6$ m^{-3}, $k_B T = 0.01$ eV

(iii) Solar wind near earth: $n_0 = 10^4$ m^{-3}, $k_B T = 10$ eV [6]

TURN OVER

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B2. (a) What is the important process in magnetohydrodynamics (MHD) which results in the Parker spiral of the heliospheric field? Describe the process in two alternative ways, explaining briefly what determines which description is applicable in different regions. What are the key conditions that must be satisfied for the process to occur? Give the important equations for these conditions. [6]

(b) Using diagrams as required, derive the expression that relates the 'garden hose' angle of the spiral, ψ, to the solar wind velocity, V_{SW}, the angular rotation rate of the Sun, ω_{Sun}, and the radial distance from the centre of the Sun, r. [4]

On rare occasions, exceptionally low values of the solar wind velocity have been measured of 150 km s^{-1}. What is the corresponding value of ψ under these conditions? (Solar rotation period is 25 days.) [4]

(c) The solar wind speed near Earth is $V_{SW} = 350$ km s^{-1} and its number density is 5×10^6 m^{-3}. Estimate the mass loss from the Sun due to the solar wind. Give your answer in kg s^{-1}. [6]

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B3. (a) Particles in the equatorial plane of the Earth's magnetosphere drift under the influence of several forces, which result in a magnetic drift, V_M, and an electric drift, V_E. Write expressions for these forces and explain their origins. [4]

Define what is meant by the L-value or L-shell parameter in the Earth's dipole field. The average magnetic drift velocity can be shown to be proportional to L^2. Derive an expression that gives the proportionality between the electric drift velocity and L in the equatorial plane of a dipole field. [3]

(b) Draw the drift paths of ions in the equatorial plane of the Earth's magnetosphere, using the drift velocities V_M and V_E, showing on your diagram where each has most influence. Hence explain how the ring current forms during a magnetic storm. [5]

(c) Describe with a simple graph how the equatorial magnetic field measured on the ground varies during a magnetic storm, explaining briefly what causes the main changes. [4]

At the main phase of a storm, the equatorial magnetic field changes by 0.4% of its undisturbed value of 5×10^{-5} T. The ring current is measured by spacecraft to be about 6×10^{6} A at this time. Making simplifying assumptions, which you should state explicitly, estimate the L-value of the ring current. Use a diagram to indicate the direction of the ring current and the resulting magnetic disturbance. [4]

END OF PAPER

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