SEMESTER 2 EXAMINATION 2013-2014

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.

Section A

A1. Give the magnetic induction equation and use it to explain the magnetic Reynolds number, $R_{\rm M}$. Derive an order of magnitude expression for $R_{\rm M}$, and give the implications, in terms of the resulting plasma behaviour, for (a) a thin current sheet and (b) the tail lobes of the Earth's magnetosphere. [5]

A2. A 5 keV proton is in a magnetic field of 200 nT, which is a typical field value in the middle magnetosphere. Estimate values for the gyroradius and gyroperiod of the proton, assuming that the velocity parallel to the magnetic field is zero. What is the proton's energy after the magnetic field strength has increased slowly to 500 nT? Name and explain the acceleration process taking place. [5]

A3. Estimate, explaining your assumptions, the power incident on the Earth's magnetic field when the solar wind has velocity 700 km/s and ion number density of 10^7 m^{-3}. Assume the magnetosphere viewed from the Sun has a radius of 20 $R_{\rm E}$. Compare your answer with the total power received from electromagnetic radiation, i.e. the total solar irradiance $I = 1.8 \times 10^{17}$ W. Comment on the difference, including a discussion of what happens to the power from the solar wind on average. [5]

A4. Derive an expression for the 'garden hose' angle of the Parker spiral of the solar wind, explaining why the spiral forms. In order to explain all terms, use two well-labelled diagrams, one in the Geocentric Solar Ecliptic (GSE) frame, and one in the frame rotating with the Sun. What happens to the spiral when the solar wind speed increases? [5]

Section B

B1. (a) Give a concise definition of a plasma. [3]

(b) Consider a plasma with an ion gas that is 60% protons and 40% oxygen O^+ ions (16 amu) and with an electron number density of 10^{10} m^{-3}. The bulk flow velocity of the combined ion gas is given by $(1,\ 0,\ 0) \times 10^6$ m/s and that of the electron gas by $(0,\ 2,\ 0) \times 10^6$ m/s.

(i) What is the mean ion mass (in kg)? [2]

(ii) Calculate values for the components of the bulk plasma velocity. [5]

(iii) Calculate values for the components of the current density vector. [3]

(c) Using the definition of pitch angle of a charged particle in a magnetic field, derive a formula which gives the magnetic field density at a point where the particle reverses direction in a dipole field. Explain all assumptions and terms used in the derivation. [5]

An electron is injected into the equatorial plane of the Earth's dipole field at L = 6 with a pitch angle of 45°. The magnetic field strength in this plane is given by

$$B = B_0 \left(\frac{{R_E}^3}{r^3} \right)$$

where $B_0 = 3 \times 10^{-5}$ T. What is the field strength at the point where the particle reverses direction? [2]

TURN OVER

B2.

(a) Give a description of the process known as reconnection or merging, using a well-labelled diagram to include all the main features of the process. [7]

(b) At a time when the solar wind velocity is radial at 500 km/s and the interplanetary magnetic field in the Geocentric Solar Ecliptic (GSE) frame has components (0, 0, -2) nT, the Stern gap, or region of open field lines in interplanetary space, has width $\Delta Y = 8$ R_E (at all values of X). The magnetosphere has a radius of cross section of 25 R_E in the Y plane. What is the voltage across the Stern gap? Calculate the reconnection efficiency. [5]

(c) At time $t = 0$ magnetospheric convection has achieved steady state with conditions given in (b). If each newly opened field line takes 2 hours to traverse the polar cap, calculate the area of the ionospheric polar cap, where the magnetic field $B_i = 5 \times 10^{-5}$ T. [6]

(d) At $t = t_1$ the rate of reconnection at the magnetopause suddenly doubles. How long does it take for the ionospheric polar cap to double in area? [2]

B3. (a) What is the plasma beta? Explain why the solar wind fills the heliosphere with a weak magnetic field. [4]

(b) If the solar wind has the same temperature and velocity at Saturn as at Earth, and the plasma beta at Earth, $\beta_{\mathrm{E}} = 1$, derive an expression for the plasma beta at Saturn, β_{S}, in terms of the ratio $B_{\mathrm{E}}/B_{\mathrm{S}}$, and no other variables, where B_{E} and B_{S} are the magnitudes of the interplanetary magnetic field at Earth and Saturn, respectively. The radius of Saturn's orbit is 9.5 AU. [6]

(c) Explain what determines the maximum radius of the tail of a planet's magnetosphere, in a steady state. What factors can be neglected and why? Hence derive an expression for the magnitude of the magnetic field in the magnetospheric tail lobe under steady state conditions at the maximum radius. [7]

(d) The solar wind has a number density of 3 cm^{-3} and a plasma temperature of 3×10^5 K. When the interplanetary magnetic field has a magnitude of 5 nT, calculate the magnetospheric field of the steady state magnetosphere in the tail lobe at the maximum radius. [3]

END OF PAPER