Tentamen för Rymdfysik I
2011-10-25

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Answers should be provided in Swedish or English.

Time: 08:00 - 13:00

Allowed tools: Mathematics Handbook (or equivalent), Physics Handbook, enclosed tables and formula sheets, calculator. A bilingual dictionary, for example English-Swedish or English-German, may also be used.

1. Here follows a set of multiple choice questions, where you must find out which statements are correct. For each question (1-1, 1-2 etc), there is only one correct combination of answers, say ”A and C” or ”none”. To score on a question, you need to have exactly the right combination. Any number of alternatives can be correct (0 – 3). Feel free to comment in words if you are uncertain on the interpretation of some alternative or question. (1 p/question, 10 p in total)

   1:1. Solar activity:

   A. Solar flares are huge eruptions from the Sun, emitting large amounts of energetic particles and intense radiation.

   B. The number of sunspots varies with a period for approximately 11 years (or has at least done so for the last 250 years).

   C. The general level of activity follows the same 11 year period as the sunspots.

   1:2. Space plasmas:

   A. A planet with an atmosphere, orbiting a star emitting UV radiation at ionizing wavelengths, will have a magnetosphere.

   B. A comet often develops two tails streaming in different directions, where one tail consists of plasma and the other of dust.

   C. Any sufficiently large volume of a plasma usually contains about equal numbers of positive and negative charges, and thus shows little net charge.

   1:3. Magnetic fields in space:

   A. Plasma parameters like density and temperature typically have stronger gradient in the direction perpendicular to the magnetic field direction than along the same field.

   B. Earth's magnetic field is mainly generated by electric power lines on the Earth's surface.

   C. If the magnetic field is frozen into the plasma, two plasma elements which at one time are on different magnetic field lines will always be so.

   1:4. Solar wind:

A. The electrons generated in the nuclear processes in the sun cause a net negative charge on the sun, repelling electrons from the solar surface and creating the solar wind.

B. If it were not for the ionizing radiation from the sun, the ions and electrons in the solar wind would rapidly recombine.

C. The solar wind sometimes reach as far as Earth orbit, but usually disappears well within the orbit of Venus.

1:5. Earth's ionosphere:

A. The E-layer has much higher electron density at day than at night, because of ionizing radiation from the sun. For the F-layer, the daily variation is not so strong, as the recombination rates are much lower at F-layer altitudes.

B. Due to collissions between particles, the conductivity in the direction perpendicular to the magnetic field is much lower in the ionosphere than in the magnetosphere.

C. The electron density in the Earth's ionosphere is determined by the solar wind intensity and the geomagnetic field strength.

1:6. Spacecraft:

A. Rockets need something to push on, and therefore do not work in vacuum, only inside an atmosphere.

B. The important parameter for launching a rocket is the total impulse (the time integral of the force): a small force applied during a long time is just as efficientfor launching a rocket as a big force during a short time.

C. The basic shape of any satellite orbit is an ellipse, though there can be perturbations resulting from non-ideal effects like the non-spherical distribution ofmass on the Earth, the gravitational influence of the moon, and air friction.

1:7. Aurora:

A. The most common colour of the aurora is red.

B. The auroral light is emitted when atoms (sometimes also molecules and/or ions) in the upper atmosphere de-excite after having been excited by electrons in the keV range coming down along the magnetic field lines from the magnetosphere.

C. The auroral light is mainly emitted at altitudes between 100 and 200 km.

1:8. Motion of charged particles:

A. The orbital magnetic moment of an electron moving in a magnetic field is conserved if the field varies only a little during an electron gyroperiod and inside an electron gyroradius.

B. The radiation belts (van Allen belts) cause severe radiation problems for spacecraft in geostationary orbit.

C. In a dipole-like planetary magnetic field, there are three basic periodicities for motion of charged particles: the gyroperiod, the bounce period (between magnetic mirrors), and the period for completing a full elliptic orbit under the influence of the gravitational force.

1:9. Space weather:

A. Increased solar wind temperatures during magnetospheric substorms can heat the spacecraft to dangerous temperatures.

B. A geomagnetic storm is due to the impact of solar and solar wind disturbances, often caused by solar flares, CMEs, or fast solar wind streams from coronal holes, on the Earth's magnetosphere.

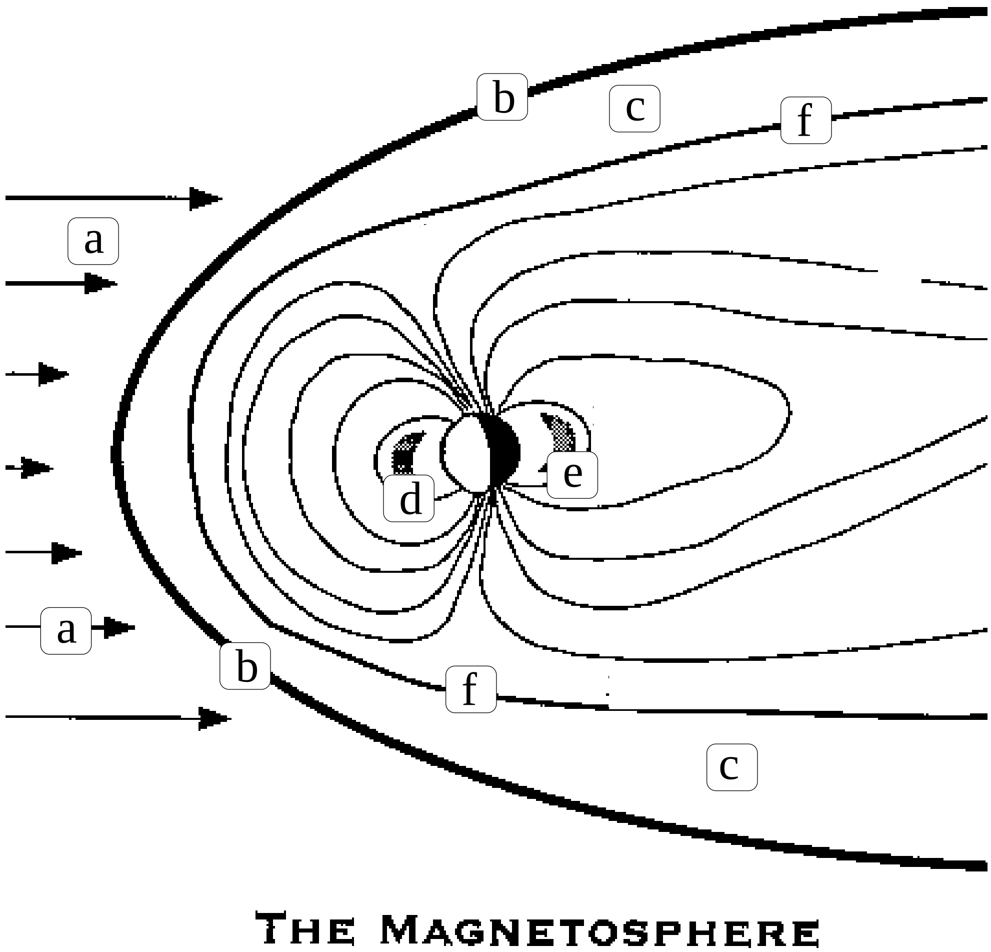

Figure 1:

C. Magnetospheric substorms are driven by reconnection in the solar corona.

1:10. The letters in Figure 1 identify the following regions and boundaries:

A. (b) is the magnetopause
B. (d) and (e) are the radiation belts
C. (f) is the bow shock

2. Consider a box-like spacecraft in the solar wind at 1 AU heliocentric distance. The edges of the box are 2 x 2 x 3 meters, and the 2x2 meter side is directed toward the sun. Assume that the spacecraft has good heat conductivity so that it can be described by a single temperature, and that all surfaces have absorbtion and emission coefficients of 0.6 and 0.3, respectively.

   (a) Calculate the equilibrium temperature of the spacecraft if all electrical systems onboard are turned off so that there is no internal power dissipation. (2 p)

   (b) If the spacecraft moves to 1.4 AU from the Sun, how much power must be generated on board in order to keep it at the same equilibrium temperature? (2 p)

3. An 1 keV electron on a magnetic field line reaching the Earth at a (magnetic) latitude of 60 degrees has a mirror point at an altitude of 10,000 km (that is, $10 \cdot 10^3$ km).

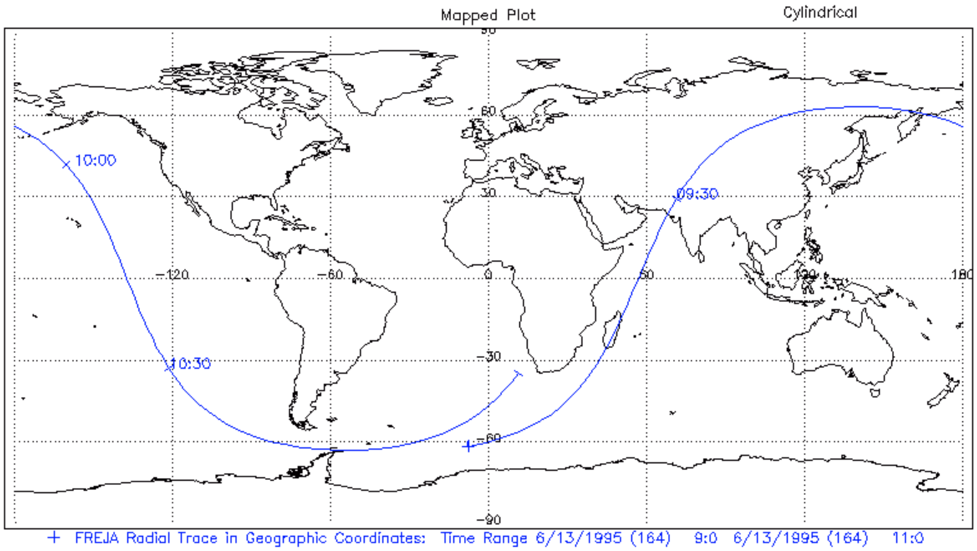

Figure 2: The ground track of Freja between 9:00 and 11:00 UT on June 13, 1995

(a) At what geocentric distance does it cross the (magnetic) equatorial plane? (2 p)

(b) Calculate the pitch angle of this electron at the mirror point and in the equatorial plane. (2 p)

(c) Calculate its gyroradius at the mirror point and in the equatorial plane (2 p).

(d) Calculate how far the electron drifts due to the magnetic gradient drift during one gyroperiod, at the mirror point an in the equatorial plane. (This distance is known as the "drift step") (2 p).

4. The Swedish-German Freja satellite was launched in October 1992 into a near-circular, eastward orbit around the Earth, with inclination $63°$ and orbital period 1 h 50 min. For the calculations here, we assume the geomagnetic field to be a dipole field of strength 30 μT on the ground at the equator, with dipole axis parallel to the Earth's spin axis.

   (a) Calculate Freja's speed and altitude (height above the Earth). (2 p)

   (b) What is the strongest magnetic field (in μT) you expect the magnetometer onboard Freja should measure? In addition, mark on the map in Figure 2 where in the orbit this maximal value is seen. (2 p)

5. For October 22, 2011, at 22:54 UT, the web site http://www.spaceweather.com listed the following current space weather conditions:

   - Solar wind speed: 298.0 km/s
   - Solar wind density: 0.2 protons/cm^{-3}
   - Interplanetary magnetic field (GSE coordinates):
     - B_{total}: 6.2 nT
     - B_z: 1.4 nT north

(a) Given these solar wind conditions, estimate the distance from the centre of the Earth to the magnetopause on the dayside. (2 p)

(b) What limits can you put on the electric field strength measured by a satellite out in the solar wind but still quite close to the Earth? Note which assumptions you made to arrive at these limits. (2 p)

The Earth's magnetic field may be approximated by a dipole field with the strength 30 μT on the ground at the equator.

Lycka till!

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Space Physics Formulas:
Complement to Physics Handbook

Charge density in plasma with charge particle species s:

$$\rho = \sum_s q_s n_s$$

Current density:

$$\mathbf{j} = \sum_s q_s n_s \mathbf{v_s}$$

Galilean transformations:

$$\mathbf{E}' = \mathbf{E} + \mathbf{v} \times \mathbf{B}, \qquad \mathbf{B}' = \mathbf{B}$$

Dipole magnetic field:

$$\mathbf{B}(r,\theta) = -B_0 \left(\frac{R_0}{r}\right)^3 \left(2\hat{\mathbf{r}}\cos\theta + \hat{\theta}\sin\theta\right)$$

Dipole field lines:

$$r/\sin^2\theta = \mathrm{const.}$$

Magnetic field energy density and pressure:

$$w_B = p_B = \frac{B^2}{2\mu_0}$$

Equation of motion of neutral gas:

$$\rho_{\mathrm{m}} \frac{d\mathbf{v}}{dt} = -\nabla p + \text{other forces}$$

Equation of motion of gas of charged particles:

$$mn\frac{d\mathbf{v}}{dt} = nq(\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \nabla p + \text{other forces}$$

MHD equation of motion:

$$\rho_{\mathrm{m}} \frac{d\mathbf{v}}{dt} = \mathbf{j} \times \mathbf{B} - \nabla p + \text{other forces}$$

Equation of continuity:

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{v}) = Q - L$$

Equation of state for ideal gas:

$$p = nKT$$

Condition for ”frozen-in” magnetic field:

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = 0$$

Ohm’s law:

$$\mathbf{j} = \begin{pmatrix} \sigma_{\mathrm{P}} & \sigma_{\mathrm{H}} & 0 \\ -\sigma_{\mathrm{H}} & \sigma_{\mathrm{P}} & 0 \\ 0 & 0 & \sigma_{\parallel} \end{pmatrix} \begin{pmatrix} E_x \\ E_y \\ E_{\parallel} \end{pmatrix}$$

Conductivities:

$$\begin{aligned}\sigma_{\mathrm{P}} &= \frac{ne}{B}\left(\frac{\omega_{\mathrm{ci}}\nu_{\mathrm{i}}}{\omega_{\mathrm{ci}}^2+\nu_{\mathrm{i}}^2}+\frac{\omega_{\mathrm{ce}}\nu_{\mathrm{e}}}{\omega_{\mathrm{ce}}^2+\nu_{\mathrm{e}}^2}\right)\\ \sigma_{\mathrm{H}} &= \frac{ne}{B}\left(\frac{\omega_{\mathrm{ci}}^2}{\omega_{\mathrm{ci}}^2+\nu_{\mathrm{i}}^2}-\frac{\omega_{\mathrm{ce}}^2}{\omega_{\mathrm{ce}}^2+\nu_{\mathrm{e}}^2}\right)\\ \sigma_{\parallel} &= ne^2\left(\frac{1}{m_{\mathrm{i}}\nu_{\mathrm{i}}}+\frac{1}{m_{\mathrm{e}}\nu_{\mathrm{e}}}\right)\end{aligned}$$

Cyclotron frequency (gyrofrequency):

$$f_{\mathrm{c}} = \omega_{\mathrm{c}}/(2\pi) = \frac{1}{2\pi}\frac{qB}{m}$$

Magnetic moment of charged particle gyrating in magnetic field:

$$\mu = \frac{1}{2}mv_{\perp}^2/B$$

Magnetic force on magnetic dipole:

$$\mathbf{F}_B = -\mu\nabla B$$

Drift motion due to general force $\mathbf{F}$:

$$\mathbf{v_F} = \frac{\mathbf{F}\times\mathbf{B}}{qB^2}$$

Pitch angle:

$$\tan\alpha = v_{\perp}/v_{\parallel}$$

Electrostatic potential from charge Q in a plasma:

$$\Phi(r) = \frac{Q}{4\pi\epsilon_0}\frac{e^{-r/\lambda_{\mathrm{D}}}}{r}$$

Debye length:

$$\lambda_{\mathrm{D}} = \sqrt{\frac{\epsilon_0 KT}{ne^2}}$$

Plasma frequency:

$$f_{\mathrm{p}} = \omega_{\mathrm{p}}/(2\pi) = \frac{1}{2\pi}\sqrt{\frac{ne^2}{\epsilon_0 m_{\mathrm{e}}}}$$

Rocket thrust:

$$T = v_{\mathrm{e}}\frac{\mathrm{d}m}{\mathrm{d}t}$$

Specific impulse:

$$I_{\mathrm{sp}} = \frac{\int T\,\mathrm{d}t}{m_{\mathrm{fuel}}g} = v_{\mathrm{e}}/g$$

The rocket equation:

$$\Delta v = -gt_{\mathrm{burn}} + v_{\mathrm{e}}\ln\left(1+\frac{m_{\mathrm{fuel}}}{m_{\mathrm{payload+structure}}}\right)$$

Emitted thermal radiation power:

$$P_{\mathrm{e}} = \varepsilon\sigma A_{\mathrm{e}}T^4$$

Absorbed solar radiation power:

$$P_{\mathrm{a}} = \alpha A_{\mathrm{a}} I_{\mathrm{rad}}$$

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