Tentamen för Rymdfysik I
2008-04-02

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Please write your **name** on **all** papers, and on the first page your **address, e-mail** and **phone number** as well. Answers may of course be given in Swedish or English, according to your own preference.

Time: 08:00 - 13:00

Allowed tools: Mathematics Handbook, Physics Handbook, enclosed formula sheet, 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 B” or ”none”. To score on a question, you need to have exactly the right combination. You are welcome to add comments to your answers. Any number of alternatives can be correct (0 – 3). (1 p/question, 10 p in total)

1:1. Solar activity:

A. The activity of the sun varies in an 11-year cycle. If taking into account the magnetic polarity of the sun, the period is 22 years.

B. The intensity of visible light changes very little during a solar cycle.

C. The sunspot number correlates with other forms of solar activity: more sunspots means the sun is more active also in other ways.

1:2. Rockets and propulsion:

A. For rocket launches from Earth, the only important parameter is the total impulse of the rocket, $\int F, \mathrm{d}t$, not the force F itself.

B. Rockets are often launched eastwards to take advantage of the rotation of the Earth.

C. Launch sites at low latitudes cannot easily launch satellites into polar orbits (inclination $\sim 90°$).

1:3. Magnetic fields in space:

A. The magnetic field from a source in vaccuum decreases with distance at least as fast as $1/r^3$.

B. The magnetic pressure arises because of the random motion of magnetized particles.

C. A frozen-in magnetic field is always static and cannot change in time.

1:4. Satellite orbits:

A. The geostationary orbit is popular for communication satellites.

B. The geostationary orbit has a radius approximately six times the radius of the Earth.

C. The geostationary orbit is possible due to a balance between the gravitational pull of the earth and the moon.

1:5. Plasmas:

A. A plasma is a gas of charged particles.

B. The magnetic pressure is $B^2/(2\mu_0)$, without any reference to any plasma parameter: hence, magnetic pressure gradients are equally important for a neutral gas and a plasma.

C. The magnetic field in the frame of reference of the plasma is close to zero (for processes on sufficiently large scales in time and space).

1:6. Ionosphere:

A. The electron density in the dayside ionosphere is determined by the solar UV intensity and the Earth's atmospheric density.

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

C. Field-aligned currents can flow along the magnetic field from the magnetic tail into the ionosphere, flow perpendicular to $\mathbf{B}$ in the ionosphere, and then flow up along the magnetic field lines back into another part of the magnetosphere.

1:7. Magnetosphere. The letters below refer to labels in Figure 1.

A. The solar wind (a) abruptly slows down at the bow shock (b) to become a more turbulent flow in the magnetosheath (c).

B. The dayside (d) and nightside (e) radiation belts are two distinct banana-shaped regions filled mainly with electrons and ions, respectively, and separated by empty regions around the dawn and dusk directions.

C. The magnetopause (f) separates the shocked solar wind plasma in the magnetosheath from the more tenous plasma in the magnetosphere.

1:8. Radiation in space:

A. Radiation in space can degrade solar panels and cause problems for spacecraft electronics.

B. There are two radiation belts around the Earth: an inner belt (mainly of ions) and and outer belt (mainly of electrons).

C. The radiation belts around Jupiter are much weaker than those around the Earth because of the greater distance from the Sun.

1:9. Aurora:

A. The aurora is mainly caused by electrons from the sun, hitting the Earth's atmosphere at the poles.

B. The aurora is mainly caused by electrons accelerated inside the Earth's magnetosphere in regions where field-aligned currents flow.

C. Auroral arcs are ususally elongated in the east-west direction.

1:10. Space weather:

A. Geomagnetic storms can lead to strong electric currents in large conductive structures on Earth, like power grids and pipelines.

B. Geomagnetic storms usually cause bad weather on Earth.

C. Solar flares and other energetic solar events can cause heating and expansion of the Earth's atmosphere, leading to increased drag on low-altitude spacecraft shortening their lifetime in orbit.

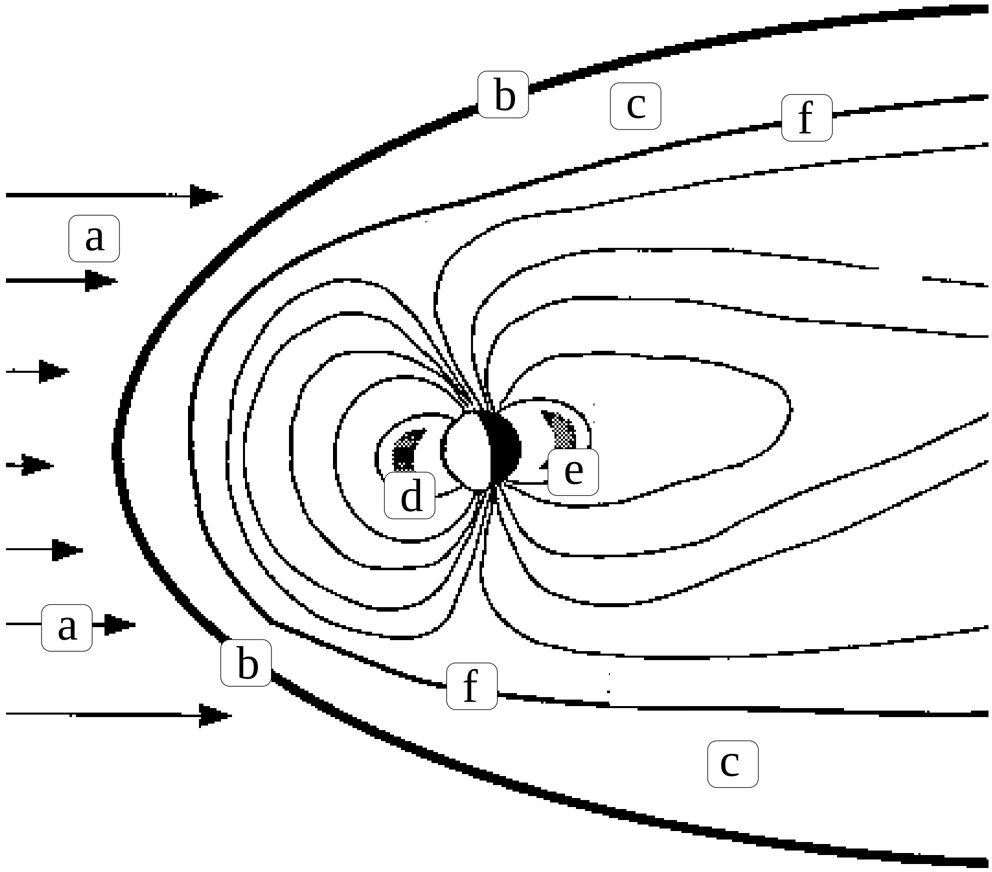

Figure 1:

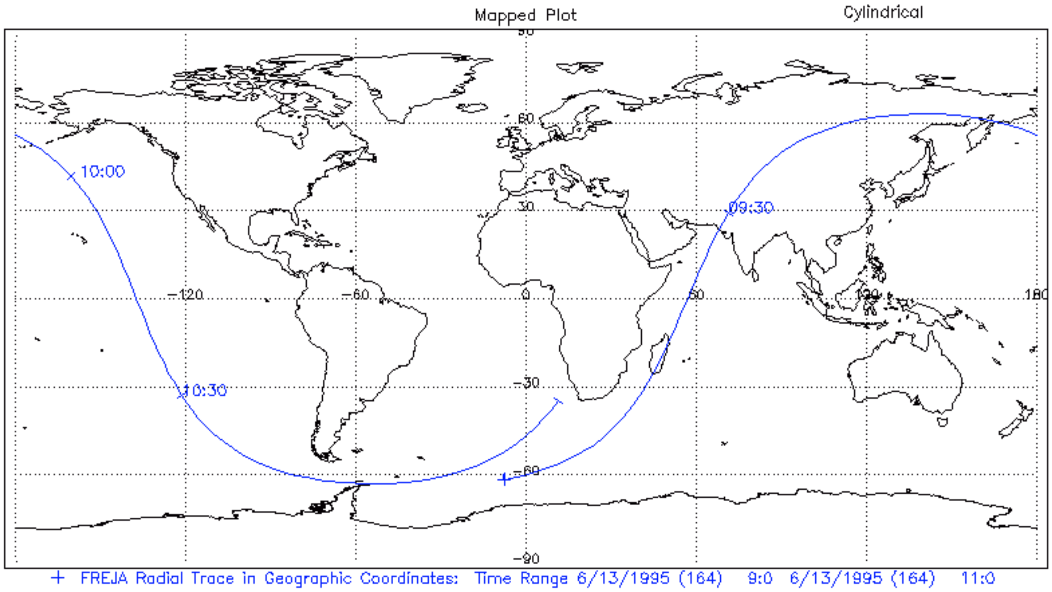

Figure 2: The ground track of Freja between 9:00 and 11:00 UT on June 13, 1995

2. The sensor of our instrument (a kind of space weather station known as a Langmuir probe) on the Cassini spacecraft, now orbiting Saturn, is a sphere ($r = 25$ mm) covered with titanium nitride, with absorption coeffiecient 0.47 and emission coefficient 0.10. Since its launch in 1997, Cassini has been as close to the sun as Venus (0.72 AU) and as far out as Saturn (9.54 AU). What temperature range did we have to design the sensor for, i.e. what were the lowest and highest temperatures we expected the probe should reach? (3 p)

3. (a) Show that the kinetic energy of a charged particle moving in a magnetic field, which is constant in time but may vary in space, is constant. (2 p)

   (b) Consider an oxygen ion (O^+) with a kinetic energy of 10 keV and no velocity along the magnetic field, moving in the equatorial plane at a distance of 3 R_E from the center of the Earth. Calculate the two characteristic frequencies defined for this particle (the third one is undefined because of the particle's zero velocity along the magnetic field). The geomagnetic field may be taken to be a dipole field with strength 30 μT on the ground at the equator. (3 p)

4. The Swedish-German Freja satellite was launched in October 1992 into a near-circular, eastward orbit around the Earth, 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) The ground trace of Freja for two hours is shown in Figure 2. What is Freja's inclination? How did you get that result? (1 p)

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

   (c) 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 (or in a copy of that map) where in the orbit this maximal value is seen. (2 p)

   (d) Assume the plasma to be co-rotating with the Earth, and the electric field in the plasma to be zero. What is the value and direction of the electric field measured by the Freja electric field instrument at the point(s) of maximum magnetic field strength? (2 p)

5. Figure 3 shows 48 hours of data from the ACE spacecraft, situated in the solar wind upstream of the Earth. Time is given as the day number in the year, so that 297.0 means 00:00 in October 24 and 298.5 is 12:00 in October 25. Magnetic field data are given in the GSE coordinate system, where x points to the sun, z points to ecliptic north, and y completes the triad. From top to bottom, the plots show solar wind speed v in km/s, solar wind proton number density n in cm^{-3}, magnetic field magnitude B in nT, and the z component of the magnetic field, B_z, in nT. ($\hat{\mathbf{y}} = \hat{\mathbf{z}} \times \hat{\mathbf{x}}$).

   (a) What do you think of the solar wind conditions shown in the figure? Is there some remarkable features in the data? Any uncommon values of the measured parameters? What would you think the space weather around Earth was like during these days? Are geomagnetic substorms or storms likely during some periods? (2 p)

   (b) Estimate the stand-off distance, i.e. the distance from the magnetopause to the center of the Earth along the sun-Earth line, at times 297.50 and 296.74 (the time of the density peak). (3 p)

   You may assume that the geomagnetic field is described by a dipole field all the way out to the magnetopause, with a magnetic field strength on Earth at the equator of 30 μT, and that all solar wind ions are protons.

Lycka till!

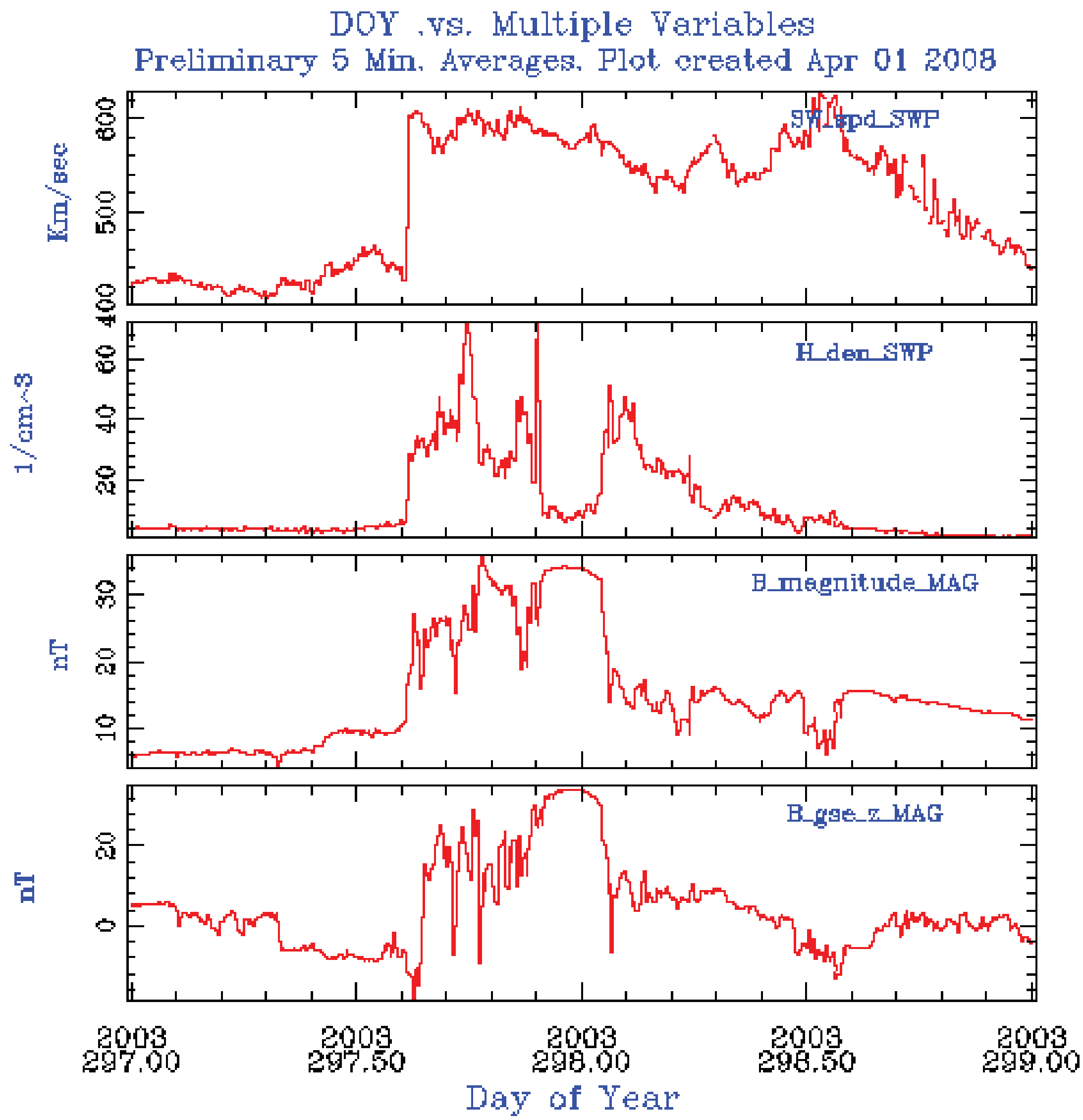

Figure 3: Magnetic field and solar wind data from ACE.

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:

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

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:

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

Magnetic field energy density and pressure:

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

Equation of motion of neutral gas:

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

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:

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

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:

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

Conductivities:

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

Cyclotron frequency (gyrofrequency):

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

Magnetic moment of charged particle gyrating in magnetic field:

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

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:

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

Emitted thermal radiation power:

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

Absorbed solar radiation power:

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