Tentamen för Rymdfysik I
2006-03-10

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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: 9:00 - 14:00

Allowed tools: Mathematics Handbook, Physics Handbook, enclosed formula sheet, calculator. A bilingual dictionary, for example English-Swedish or English-French, 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. If you feel uncertain 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. Which statements about the sun are correct?

A. Sunspots are cooler than the surrounding areas of the sun.

B. The sunspot number anticorrelates with the solar activity: more sunspots means the sun is colder and less active.

C. Solar flares and coronal mass ejections are two examples of solar features that can give space weather disturbances.

1:2. Here is a set of statements about why the temperature in the troposphere decrease with height. Which are correct?

A. The ground is warmer than the air. Therefore more infrared radiation comes from the ground and goes upward than the air radiates down. Air absorbs this upward infrared radiation, and the radiation flux decreases with height. Therefore near the ground absorption is highest, and consequently also the heating of air by infrared radiation.

B. Warm air has more energy content than cold one. Therefore it is heavier and sinks to the bottom.

C. Air is mixed most of the time between heights. Because of the barometric decrease of pressure with height air moving upward expands and cools, while air moving downward is compressed and heated.

1:3. Which statements about rockets are correct?

A. Rockets work only in an atmosphere, because they need something to push against.

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

C. When launching a rocket, burning all the fuel at once saves fuel as compared to burning the same amount of fuel during a longer time.

1:4. Which statements about the Earth's magnetosphere are correct?

A. The magnetosphere disappears at nighttime, because the ionization by solar radiation then stops.

B. Electrical currents flow on the magnetopause, which is the outer boundary of the magnetosphere.

C. Magnetic field lines leaving the Earth at low latitudes (close to the equator) are closed (return back to the Earth without leaving the magnetosphere).

1:5. A scientist named Don Gurnett and his co-workers have observed a layer in the Mars ionosphere with the MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) instrument on board the orbiting Mars Express spacecraft. The layer seems to follow relatively well a Chapman profile. Which of the statements below are probably correct?

A. This is a pure coincidence, as Chapman theory is only applicable for the special circumstances that are fulfilled in the E region of the Earth's ionosphere.

B. This is as expected, a Chapman layer always forms in any kind of ionosphere.

C. This is not unexpected. The Mars atmosphere consists mainly of the CO_2 molecule, and the main ion in the ionosphere is therefore CO_2^+ which can recombine dissociatively, for example $CO_2^+ + e^- \longrightarrow CO + O$. A Chapman layer forms when there is the possibility of dissociative recombination.

1:6. Which statements about the motion of charged particles are correct?

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 or inside an electron gyroradius.

B. In a hydrogen plasma in thermodynamic equilibrium, protons move much faster than electrons.

C. A gravitational field perpendicular to a magnetic field can give rise to electric currents in a plasma.

1:7. Which statements about plasmas are correct?

A. A plasma is a gas of charged particles.

B. Plasmas are usually dominated by electrons. The ions are almost always only a small fraction of the total number of particles.

C. The electric field on large scales in space and time is usually related to the flow velocity and the magnetic field by the relation $\mathbf{E} + \mathbf{v} \times \mathbf{B} = 0$.

1:8. Which statements about temperatures are correct?

A. The equilibrium temperature of an interplanetary spacecraft, travelling between e.g. Earth and Mars, is determined by the temperature of the solar wind plasma (around 10 eV).

B. The equilibrium temperature of an interplanetary spacecraft, travelling between e.g. Earth and Mars, is determined by the balance between absorbtion of solar radiation and emission of thermal radiation.

C. The equilibrium temperature of an interplanetary spacecraft, travelling between e.g. Earth and Mars, is determined by the cosmic microwave background radiation temperature (around 2.7 K).

1:9. Which statements about the aurora are correct?

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. The main reason why auroras are easier to see in Kiruna than in Berlin in winter is that the sky in Kiruna is darker, so that the aurora can easily be detected.

1:10. Which statements about spacecraft are correct?

A. The main reason why spacecraft have to be built to withstand virations is the vibrations from the rocket during launch.

B. Interplanetary probes to Jupiter and beyond have problems using solar cells as the sunlight intensity is small so far out. Instead, they often use electric power generated from radioactive samples.

C. Communication satellites in geostationary orbit are ususally placed a few hundred km above the Earth, so as to be close to the ground stations.

2. The European and Japanese space agencies, ESA and JAXA, are planning a two-spacecraft mission to Mercury known as BepiColombo. The Swedish Institute of Space Physics in Uppsala will contribute spherical sensors for the electric field instrument on one of the spacecraft. For our instruments to the outer solar system (Cassini to Saturn and Rosetta to a comet), we have used titanium spheres covered with titanium nitride, TiN, with absorbtion coefficient $\alpha = 0.47$ and emission coefficient $\epsilon = 0.10$. A possible alternative, now under investigation at the Department of Engineering Sciences, is to mix in some aluminium to get a TiAlN surface, for which we may have $\alpha = 0.75$ and $\epsilon = 0.50$. Considering only heating by solar radiation and cooling by radiation from the spheres, what equilibrium temperatures would you expect for the two alternatives (TiN and TiAlN) at Mercury (0.39 AU from the sun)? Which of them would you select for use on BepiColombo? (3 p)

3. Figure 1 shows recent data from the ACE spacecraft, which is observing the solar wind at a point well upstream of the Earth's bow shock, but still so close to the Earth that we can assume the solar wind conditions at ACE and the Earth to be the same.

   (a) During the time period covered in the plot, when do you think the Earth's magnetosphere was largest, and when do you think it was smallest? Motivate your answer. (It isn't a problem if you select slightly wrong times, as long as you have at least a reasonable choice and a good motivation) (2 p)

   (b) Estimate the distance from the magnetopause intersection with the sun-Earth line to the centre of the Earth at 2006-03-06 12:00. (3 p)

   (c) What was the electron number density at the same time as in (b)? Assume that there twelve times as many protons as singly charge helium ions in the solar wind, and that there are no other ion species than these. (2 p)

4. (a) A charged particle moving in a dipole field generally has three characteristic periods of the motion (or three characteristic frequencies, if you so prefer). Which are they? Here you only have to explain their physical meaning, give their usual names and tell why they exist, all in words, not to give any mathematical derivations. (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 in (a) above which are defined for this particle (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)

5. Figure 2 shows a relatively large magnetic disturbance seen with magnetometers in Northern Scandinavia on 1 December 2005 just before midnight. The curve for each magnetometer station shows the deviation from the normal value at that station, with zeros shifted as indicated by the station names at the right edge.

   (a) Estimate the Hall current flowing in the ionosphere from the magnetic field seen at the ground. For simplicity, adopt a single value of -500 nT for the magnitude of the disturbance in nT which is somewhat less than the minimum. Assume that the current flows in an infinitely large sheet in the ionosphere. Use Ampère's law to calculate the current over the sheet, in A/m. (3 p)

   (b) Use the map in Figure 3 to determine the width of the current carrying region. Which stations see the disturbance at the nearly full strength, and where does it decrease considerably? 1 degree in latitude corresponds to 110 km. How many Ampère do then flow in the auroral electrojet on 1 December 2005? (2 p)

Lycka till!

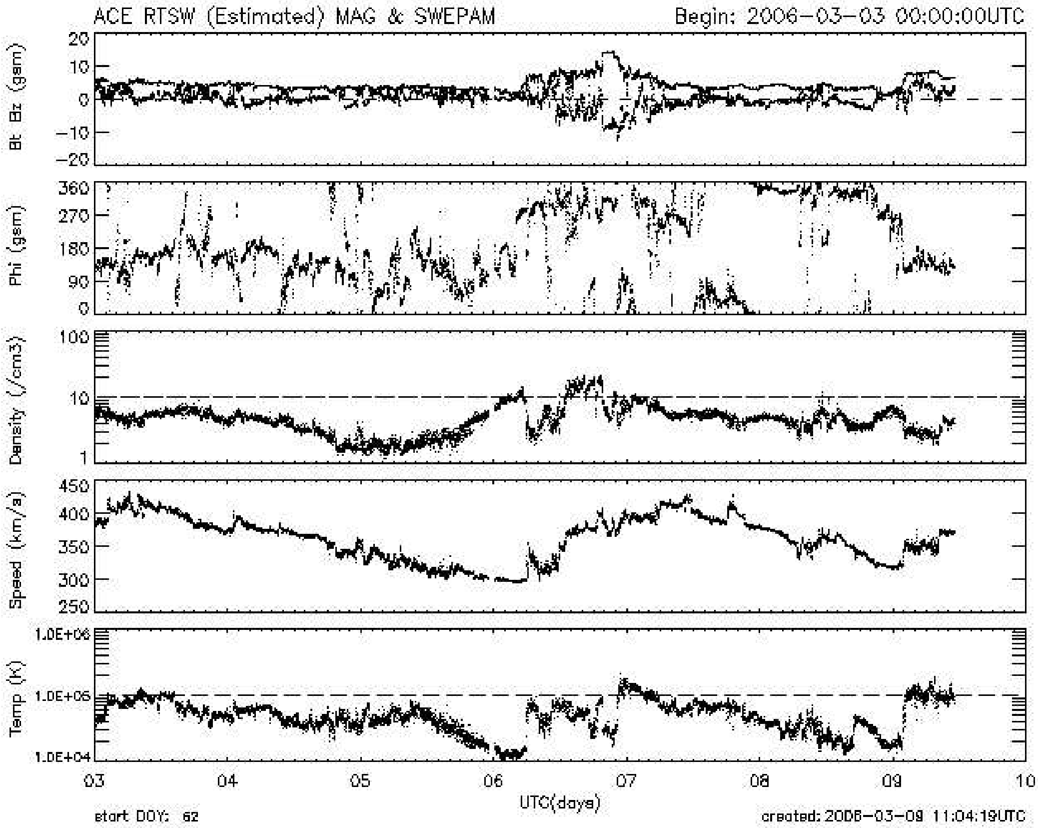

Figure 1: ACE data from the last days. On the x-axis, the number "04" denotes the time 00:00 on March 4, so each small tic mark is 2 hours. From top to bottom, the panels show: (i) Interplanetary magnetic field (IMF) in nT (total strength and ecliptic z component), (ii) angle between IMF and direction to sun, (iii) proton number density in cm^{-3}, (iv) solar wind speed in km/s, and (v) proton temperature in K.

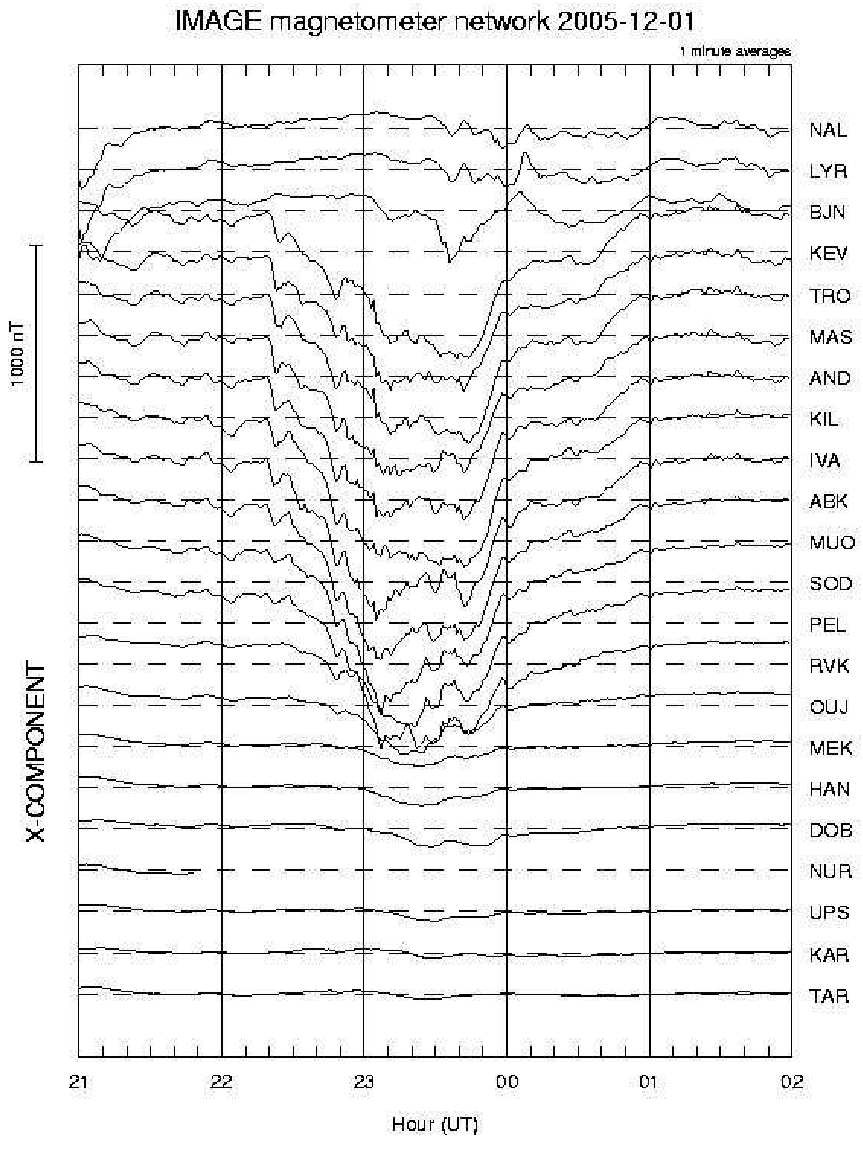

Figure 2: Data from the IMAGE magnetometer network for December 1, 2005.

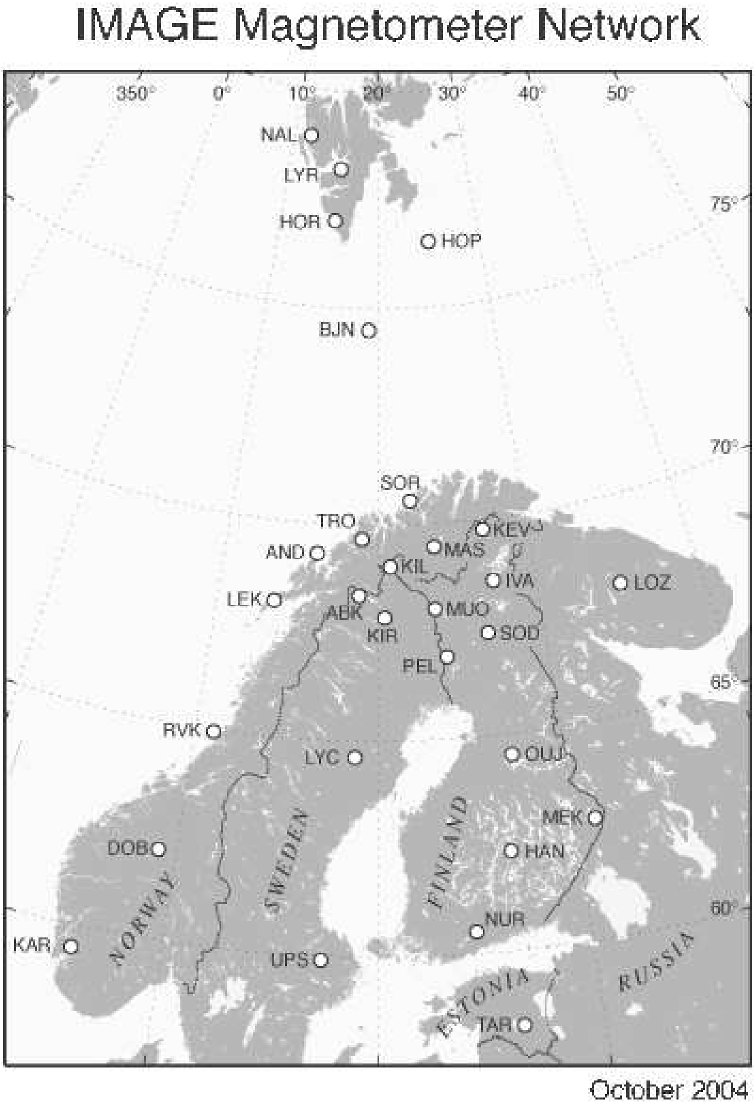

Figure 3: The IMAGE magnetometer network.

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:

$$\mathbf{j} = \begin{pmatrix} \sigma_\text{P} & \sigma_\text{H} & 0 \\ -\sigma_\text{H} & \sigma_\text{P} & 0 \\ 0 & 0 & \sigma_\parallel \end{pmatrix} \begin{pmatrix} E_\perp \\ 0 \\ E_\parallel \end{pmatrix}$$

Conductivities:

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

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 $\mathbf{F}$:

$$\mathbf{v}_\mathbf{F} = \frac{\mathbf{F} \times \mathbf{B}}{q B^2}$$

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:

$$\lambda_\mathrm{D} = \sqrt{\frac{\epsilon_0 K T}{n e^2}}$$

Plasma frequency:

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

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:

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