Tentamen för Rymdfysik I och NV1
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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: 8:00 – 13:00

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. 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. The photosphere (lower atmosphere) is hotter than the core.
   B. The corona (outer atmosphere) is hotter than the photosphere.
   C. Sunspots are hotter than the surrounding plasma.

   1:2. Which statements about the solar wind are correct?

   A. The solar wind is supersonic (i.e. it blows faster than the sound speed in itself).
   B. The solar wind blows out through the solar system in a spiral pattern (as seen in an inertial frame).
   C. The typical solar wind speed at Earth orbit is in the range 200 – 600 km/s.

   1:3. Which statements about rockets are correct?

   A. Rockets work only in an atmosphere, because they need something to push against.
   B. Rockets work only in an atmosphere, because they need oxygen for combustion (förbränning).
   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 geostationary satellite orbit are correct?

   A. The geostationary orbit is popular for communication satellites (except for a sector of the orbit which is always in shadow from the Earth).
   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. Which statements about the Earth's magnetosphere are correct?

A. The radiation belts (van Allen bets) contain trapped energetic protons and electrons.

B. Before it is released, the energy driving a geomagnetic substorm is mainly stored as magnetic energy in the geomagnetic tail.

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).

1:6. Which statements about space weather are correct?

A. X-rays released in a solar flare reach the Earth after about 24 hours.

B. Heating of the Earth's upper atmosphere and ionosphere during a solar storm cause the atmosphere to expand, thereby decreasing the air friction felt by a spacecraft.

C. Increased fluxes of high energy electrons, which can cause radiation problems on spacecraft, can be observed during geomagnetic storms as well as during geomagnetic substorms.

1:7. Which statements about the Earth's ionosphere are correct?

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 slower at F-layer altitudes due to lower densities.

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. Birkeland currents flow along the magnetic field from the magnetic tail into the ionosphere, and then continue through the Earth to close trough the ionosphere at the opposite hemisphere.

1:8. 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, electrons move much faster than protons.

C. In a plasma in perpendicular electric and magnetic fields, the motion of an electron can be seen as the superposition of a steady perpendicular drift and the gyromotion.

1:9. Which statements about other planets are correct?

A. Venus does not have any known magnetic field but a dense atmosphere, and thus has an ionosphere but no magnetosphere.

B. Jupiter's magnetosphere is very large, because the solar wind has lower density than at Earth and the Jovian magnetic field is very strong.

C. When reaching Saturn, the solar wind is so weak that neither Saturn itself nor any of its moon have any significant ionosphere.

1:10. In a homogeneous collisionless plasma in a constant and homogeneous magnetic field $\mathbf{B}$, a current can be generated by:

A. A constant and homogeneous electric field perpendicular to $\mathbf{B}$.

B. A constant and homogeneous gravitational field perpendicular to $\mathbf{B}$.

C. A constant and homogeneous gravitational field parallel to $\mathbf{B}$.

2. Each of the four Cluster spacecraft, orbiting the Earth with apogee close to 20 Earth radii, is approximately a cylinder of radius 1.5 m and height 1 m, with the symmetry axis perpendicular to the direction of the sun. The mantle areas are covered with solar panels, while the top and bottom sides are mainly covered with a thermal blanket. Estimate the equilibrium temperature (in °C) of the satellites, assuming perfect thermal conductivity within the spacecraft and using data from Table 1. Also assume all onboard electrical systems are turned off. (3 p)

	Absorption coefficient	Emission coefficient
Solar panels	0.80	0.90
Thermal blanket	0.20	0.90

Table 1: Some thermal material properties.

3. The magnetic field strength, B, in the E-region (100 km) above Kiruna is approximately 49 μT. At 5 000 km altitude, the field strength is approximately 9 μT. In order to contribute to the aurora in the E-region, assuming influence only by the static converging geomagnetic field, an electron at 5 000 km height has to be within a certain pitch angle interval.
   (a) Deduce an expression that can be used to estimate this pitch angle interval. (3 p)
   (b) Estimate the pitch angle interval in question. (1 p)
   (c) Give examples of other things that might influence the ability of the electron at 5 000 km height to produce aurora in the E-region. (1 p)

4. A satellite orbits the Earth in a circular eastward equatorial orbit 1 R_E above the ground.
   (a) How long is the orbit period (in hours)? (1 p)
   (b) What do we call the plasma region through which the spacecraft is travelling? What velocity (relative to an inertial frame anchored in the Earth) do you expect the plasma to have here? Give a numerical value, with direction. (2 p)
   (c) If the electric field in the rest frame of the plasma is zero, what is the electric field (magnitude and direction) observed by an instrument on the satellite? The geomagnetic field can be approximated with a dipole field with axis along Earth's rotation axis and strength 30 μT on the ground at the equator. (4 p)

5. In Figure 1, you find solar wind data measured by the ACE spacecraft during the last week (August 10-16, 2004). ACE is in the solar wind, well upstream (towards the sun) from the Earth, but still close enough to measure essentially the same solar wind that reaches the magnetosphere.
   (a) During this week, when did Earth's magnetosphere reach its minimum and maximum size? Select two times and argue why you chose exactly these times. (It is not a problem if you chose a slightly wrong time, as long as your motivation is sound and your choice is at least reasonable) (2 p)
   (b) Estimate the size of the Earth's magnetosphere at these two times, assuming the geomagnetic field to be dipolar with a field strength of 30 μT on the Earth's surface at the equator. (3 p)

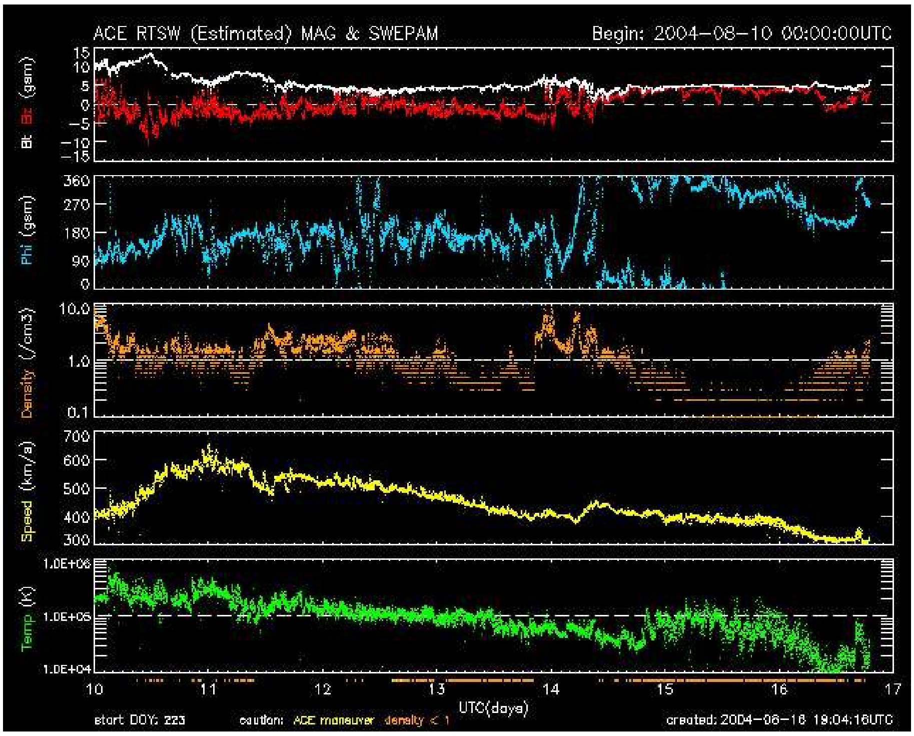

Figure 1: Solar wind data from the Advanced Composition Explorer (ACE) spacecraft. Bt is the interplanetary magnetic field strength (1 gam = 1 nT), Bz its northward component and Phi its direction in the plane perpendicular to the sun-Earth line. Density is the electron number density, Speed the solar wind flow speed, and Temp the electron temperature.

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:

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

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:

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

Conductivities:

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

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:

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

Magnetic force on magnetic dipole:

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

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

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

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:

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