Tentamen för Rymdfysik I och NV1
2005-06-13

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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. Any number of alternatives can be correct (0 – 3). (1 p/question, 10 p in total)

1:1. Which statements about rockets are correct?

A. In order to take advantage of the rotation of the Earth, rockets carrying interplanetary spacecraft are preferably launched from bases close to the equator and in an eastward direction.

B. Launching from the equator has the additional advantage that it is possible to put satellites into orbits with any inclination.

C. For a rocket ready for launch, most of the mass is usually fuel, with the rocket structure and the payload only being minor fractions of the total mass.

1:2. Which statements about the geostationary satellite orbit are correct?

A. The geostationary orbit is advantageous for communication satellites as the satellite stays above the same point on the ground all the time.

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

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

1:3. Which statements about the solar wind are correct?

A. The electrons generated in the nuclear processes in the sun cause a net negative charge on the sun, which repels electrons from the surface and create 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. At Earth orbit, the solar wind flow is supersonic.

1:4. Which statements about the interplanetary magnetic field are correct?

A. The interplanetary magnetic field can be well described as a dipole field from the sun, thus decreasing with distance as $1/r^3$.
B. The interplanetary field is mainly due to motion of molten material in the Earth's interior.
C. The direction of the interplanetary field is highly variable, but at Earth orbit, it typically makes an angle of 45° to the direction from the sun.

1:5. Which statements about the Earth's magnetosphere are correct?

A. Magnetospheres are formed because of the interaction of the solar wind with planetary magnetic fields.
B. The magnetotail points away from the sun at midnight and toward the sun approximately 12 hours later.
C. Magnetospheres have rotational symmetry around the sun-Earth line.

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

A. The main reason for why space weather can be a problem for spacecraft is that increased solar wind temperatures can heat the spacecraft to dangerous temperatures.
B. A geomagnetic storm is due to the impact of solar and solar wind disturbances on the Earth's magnetosphere.
C. A geomagnetic substorm is related to the storage and release of magnetic energy in the geomagnetic tail.

1:7. Which statements about ionospheres are correct?

A. The electron density in the Earth's ionosphere is determined by the solar wind intensity and the geomagnetic field strength.
B. Planets and moons with atmospheres also have ionospheres.
C. The lowest ionospheric layers almost disappear at nighttime.

1:8. Which statements about the aurora is correct?

A. The most common colour of the aurora is red.
B. The main cause of aurora are protons emitted from the sun, which hit the Earth's upper ionosphere.
C. The auroral light emissions mainly occur at altitudes between 10 and 20 km.

1:9. 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 and inside an electron gyroradius.
B. The pitch angle is conserved if the field varies only a little during an electron gyroperiod and inside an electron gyroradius.
C. Only the magnetic field can do work on a charged particle, so we can always neglect the gravitational field when considering the motion of protons and electrons around the Earth.

1:10. Which statements about plasmas are correct?

A. 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.
B. Any sufficiently large volume of a plasma usually contains about equal numbers of positive and negative charges, and thus show little net charge.
C. Despite attracting each other electrostatically, a positive ion and a free electron in a plasma cannot generally recombine, unless there is some third particle adjacent to carry away excess energy and angular momentum.

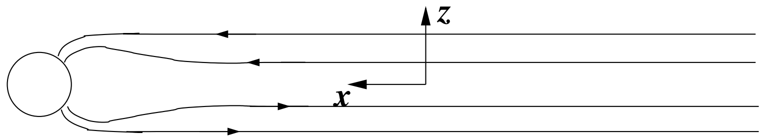

Figure 1: Idealized geometry of the relevant part of the geomagnetic tail (around the origin).

2. Consider the following model of the magnetic field in the central part of the geomagnetic tail:

$$\mathbf{B}(\mathbf{r}) = \begin{cases} -B_0\hat{\mathbf{x}} & , \quad z < -a \\ B_0\,\hat{\mathbf{x}}\,\frac{3\,a^2\,z - z^3}{2\,a^3} & , \quad -a \leq z \leq a \\ B_0\hat{\mathbf{x}} & , \quad z > a \end{cases}$$

where $B_0 = 1$ nT, $a = 2000$ km and the coordinates are defined as in Figure 1.

   (a) Calculate the current density $\mathbf{j}(\mathbf{r})$ and the magnetic force density $\mathbf{j}(\mathbf{r}) \times \mathbf{B}(\mathbf{r})$ (magnitudes and directions as functions of position). Also calculate their numerical values at $z = 0$. (3 p)

   (b) Calculate the temperature field $T(\mathbf{r})$ in equilibrium, assuming the plasma behaves like an ideal gas where the density n is constant, if $T = 10$ eV for $|z| > a$. (2 p)

3. 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 is the temperature range we had to design the sensor for, i.e. what is the lowest and highest temperatures we expect the probe should reach? (3 p)

4. (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 gyroperiod and the drift period (the time it takes for the ion to drift one orbit around the Earth) for this ion. The geomagnetic field may be taken to be a dipole field with strength 30 μT on the ground at the equator. (3 p)

5. 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) The ground trace of Freja for two hours is shown in Figure 2. If the orbital period is 1 h 50 min as said above, why isn't the orbit closed in this plot? (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 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)

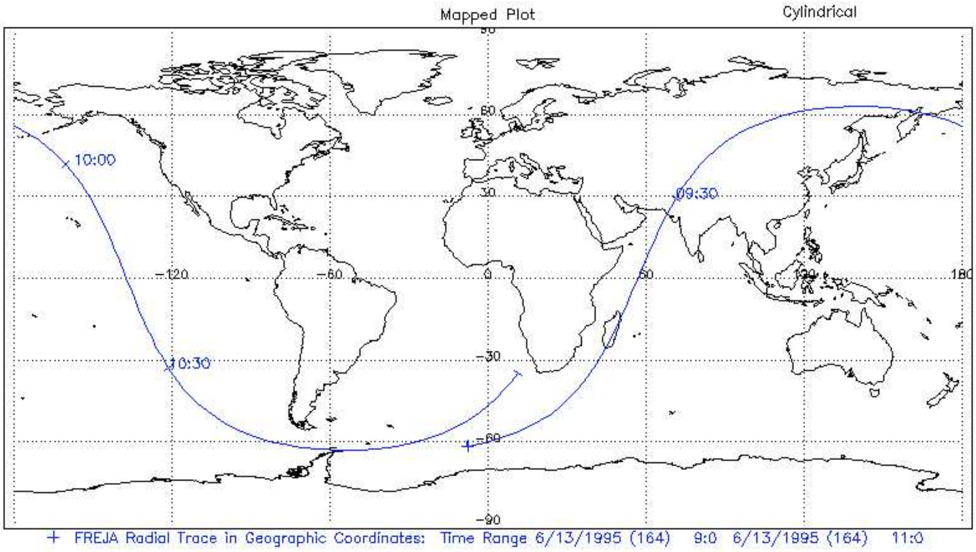

Figure 2: The ground track of Freja between 9:00 and 11:00 UT on June 13, 1995