Tentamen för Rymdfysik I
2009-03-18

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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: 14:00 - 19:00

Allowed tools: Mathematics Handbook, Physics Handbook, enclosed tables and formula sheets, calculator. A bilingual dictionary, for example English-Swedish or English-French, may also be used, as may also be own writing paper of special quality for those prefering to write in ink.

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). (1 p/question, 10 p in total)

1:1. Sunspots:

A. A sunspot is a cooler region of the solar corona, typically around 10^5 km above the solar surface.

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

C. As sunspots only live for a few hours, the sunspot number indicates the solar activity level only for short timescales (hours), not its average level over a longer time (weeks or months).

1:2. Solar system plasmas:

A. Because of the decrease of temperature with distance to the sun, the solar wind is in the plasma state only out to a few astronomical units from the sun. Outside of this limit (the heliopause), the solar wind is a neutral gas.

B. Due to the solar wind interaction with a comet, it often develops two tails streaming in different direction, where one tail consists of positive ions, the other of electrons.

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

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 inteplanetary magnetic field decays much slower with distance from the sun, on average as $1/r$ for its tangential components and as $1/r^2$ for its radial component.

C. The concept of ”frozen-in” magnetic field lines applies only to small regions of low temperature, for example sunspots and the nightside ionosphere.

1:4. Earth's magnetosphere:

A. The radiation belts (van Allen bets) contain trapped energetic protons and electrons, corotating with the Earth.

B. Substorms mainly occur when the interplanetary magnetic field has a northward component.

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

1:5. Geomagnetic storms:

A. Geomagnetic storms occur when large perturbations in the solar wind, originating from the sun, hits the magnetosphere.

B. Geomagnetic storms occur when an instability, due to Earth's rotation, releases a part of the plasmasphere into ionosphere.

C. Geomagnetic storms can cause problems for electrical power networks.

1:6. Earth's ionosphere:

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

B. The electron density in the ionosphere is determined by the density of neutral atmospheric gas and the intensity of reflected infrared radiation from the ground.

C. Auroras typically occur at altitudes of 10 – 20 km.

1:7. Spaceflight:

A. The Lagrange points of the Sun-Earth-system are specially suitable for communications satellites, as spacecraft here always stays over the Earth's equator.

B. The only use of planetary swing-by maneouveres is to change the course of your spacecraft without having to use any fuel. As the gravitational field is conservative, there can be no gain of speed during a planetary swing-by.

C. Spacecraft must be designed to withstand heavy vibrations in order to survive a rocket launch.

1:8. Rockets:

A. Rockets are often launched eastward, to gain speed from Earth's rotation.

B. Rockets are often divided into multiple stages so that the amount of useless mass carried at any moment can be reduced.

C. Sounding rockets are small rockets with a limited flight time, never reaching orbit around the Earth, for example used for ionospheric investigations.

1:9. 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 $\mathbf{B}$.

1:10. In the attached printout of the Spaceweather.com web page of yesterday morning, the probability of major solar flares (M or X class) is forecasted to be low. This is consistent with data because:

A. The interplanetary magnetic field is northward directed.

B. There are no sunspots (which are statistically linked to flare activity).

C. The solar wind density is low (only 0.6 cm^{-3}).

2. ESA and NASA are both studying space missions for close investigation of the Sun. It should be no surprise that the main technical issue of such missions is the thermal design.

   ESA's Solar Orbiter is to go as close as 45 RS (solar radii, see attached table of solar properties) to the centre of the Sun, and NASA intends the Solar Probe to reach all down to 10 RS. For these spacecraft to survive, both spacecraft will carry heat shields in front of themselves. If the heat shields were to be circular discs facing the sun, with absorption and emission coefficients of 0.45 and 0.75, respectively, what would be the heat shield equilibrium temperatures on Solar Orbiter and Solar Probe, assuming no heat exchange with the main spacecraft bodies? (3 p)

3. The attached printout of the Spaceweather.com web pages of yesterday morning gives the solar and solar wind conditions at the time. For the data refering to a specific coordinate system, this is the GSE (geocentric solar ecliptic) system, which is a right-handed Cartesian system centred in the Earth with its X-axis pointing to the Sun and Z to ecliptic north (i.e. out of the Earth's plane of motion around the sun).

   (a) From the data given in the left column, estimate the distance from the centre of the Earth to the magnetopause along the Sun-Earth line. (2 p)

   (b) From the data, estimate the Y component of the electric field in the solar wind, as it should be measured on the spacecraft that measured the other solar wind parameters. (2 p)

4. In the following, assume the geomagnetic field is a dipole field with strength 30 μT on the ground at the equator.

   (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 periods in (b) above which are defined for this particle (the third one is undefined because of the particle's zero velocity along the magnetic field). (3 p)

   (c) An electron on a magnetic field line reaching the Earth at a (magnetic) latitude of 60 degreeshas its mirror point at an altitude of 10,000 km (that is, $10 \cdot 10^3$ km). At what geocentric distance does it cross the (magnetic) equatorial plane, and what is its pitch angle there? (4 p)

5. The geostationary satellite orbit is defined by the property that a spacecraft in this orbit stays above the same spot on the Earth all the time.

   (a) Calculate the radius of the geostationary orbit. (2 p)

   (b) Geostationary satellites are sometimes in eclipse (in the shadow of the Earth). Does this happen on every orbit? (2 p)

Lycka till!

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:

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

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:

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

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:

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

SPACE WEATHER
Current conditions

Solar wind
speed: **384.6** km/sec
density: **0.6** protons/cm^3
explanation | more data
Updated: Today at 1006 UT

X-ray Solar Flares
6-hr max: **A0** 1000 UT Mar17
24-hr: **A0** 1000 UT Mar17
explanation | more data
Updated: Today at: 1000 UT

Daily Sun: 17 Mar 09

The sun is blank--no sunspots. Credit: SOHO/MDI

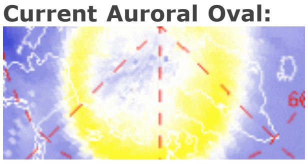
Sunspot number: 0
What is the sunspot number?
Updated 16 Mar. 2009

Far side of the Sun:

This holographic image reveals no sunspots on the far side of the sun. Image credit: SOHO/MDI

Planetary K-index
Now: **Kp= 1** quiet
24-hr max: **Kp= 2** quiet
explanation | more data

Current Auroral Oval:



What's up in Space

March 17, 2009

AURORA ALERT: Did you sleep through the Northern Lights? Next time get a wake-up call: Spaceweather PHONE.

A LITTLE SOLAR ACTIVITY: The sun is in the pits of the deepest solar minimum in almost 100 years. At such a calm time, even a little solar activity is remarkable. Here it is. SOHO recorded the movie on March 16th; it shows a minor CME billowing away from the sun's eastern limb. When the sun is active, we see several such CMEs on a daily basis. Now, the rate is about one per month. That's *very* little solar activity.

RAINBOW PLANET: Something special is happening to Venus. The brightest of all planets is hanging low in the western sky at sunset, and if you look at it with a backyard telescope, you'll see that it is a slender 4% crescent. But that's not the special part.

What's special is, Venus looks like a rainbow:

Sadegh Ghomizadeh took the picture from Tehran, Iran, on March 10th. It shows the view through his 11-inch Celestron. "The seeing was poor, but Venus was still bright and beautiful," he says.

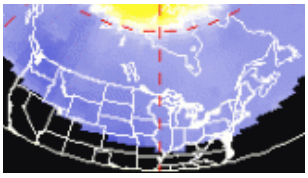
Venus resembles a rainbow because Earth's atmosphere acts like a prism. When Venus is near the horizon, refraction separates the red crescent from the blue. The crescent is so thin, the splitting of colors is obvious. Later this month, Venus will disappear into the glare of the spring sun, so catch the rainbow planet while you can!

more images: from P-M Hedén of Vallentuna, Sweden; from Alan Simpson of Renfrew, Scotland; from Frederic Caron of Victoriaville, Qc, Canada

AURORA BLARNEYALIS: Green auroras over Greenland? It must be St. Patrick's Day. The celebration began last night with this display over Nuuk:

Cool links:

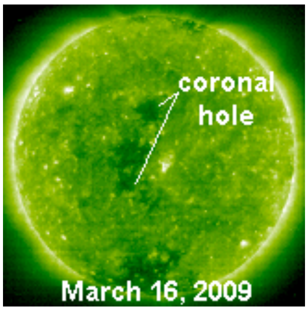
archives
March
17
2009
view



Switch to: Europe, USA, New Zealand, Antarctica
Credit: NOAA/POES
What is the auroral oval?

Interplanetary Mag. Field
B_{total}: **2.2** nT
B_z: **0.9** nT **north**
explanation | more data
Updated: Today at 1007 UT

Coronal Holes:



A solar wind stream flowing from the indicated coronal hole should reach Earth on or about March 20th. Credit: SOHO Extreme UV Telescope

SPACE WEATHER
NOAA Forecasts

Updated at: 2009 Mar 16 2201 UTC

FLARE	0-24 hr	24-48 hr
CLASS M	01 %	01 %
CLASS X	01 %	01 %

Geomagnetic Storms:
Probabilities for significant disturbances in Earth's magnetic field are given for three activity levels: active, minor storm, severe storm

Updated at: 2009 Mar 16 2201 UTC

Mid-latitudes

	0-24 hr	24-48 hr
ACTIVE	05 %	05 %
MINOR	01 %	01 %
SEVERE	01 %	01 %

High latitudes

	0-24 hr	24-48 hr
ACTIVE	10 %	10 %

"They were not the most powerful auroras," says photographer Thomas Bojer Eltorpbut, "but it was such a beautiful display." He took the picture by opening the shutter of his Nikon D3 for 90 seconds at ISO 1600.

More green is in the offing. A solar wind stream is heading for Earth, and it could spark even stronger geomagnetic activity when arrives on or about **March 20th**. Arctic sky watchers should be alert for auroras on the first night of Spring.

Happy St. Patrick's Day!

March 2009 Aurora Gallery
[**previous Marches:** 2008, 2007, 2006, 2005, 2004, 2003, 2002]

Comet Lulin Photo Gallery
[Comet Hunter Telescope: review] [Comet Lulin finder chart]

Explore the Sunspot Cycle

Near-Earth Asteroids

Potentially Hazardous Asteroids (PHAs) are space rocks larger than approximately 100m that can come closer to Earth than 0.05 AU. None of the known PHAs is on a collision course with our planet, although astronomers are finding new ones all the time.

On March 17, 2009 there were **1041** potentially hazardous asteroids.

March 2009 Earth-asteroid encounters:

Asteroid	Date(UT)	Miss Distance	Mag.	Size
2009 DS43	Mar. 1	6.9 LD	18	32 m
2009 DD45	Mar. 2	0.2 LD	11	35 m
2009 DN4	Mar. 3	8.1 LD	21	27 m
2009 EA	Mar. 4	7.4 LD	19	24 m
2009 EW	Mar. 6	0.9 LD	16	23 m
161989 Cacus	Mar. 7	70.5 LD	16	1.7 km
2009 EH1	Mar. 8	1.6 LD	18	12 m
2009 ET	Mar. 9	9.5 LD	21	15 m