# UNIVERSITY OF OSLO

## Faculty of Mathematics and Natural Sciences

**Exam in** **FYS3610 Space Physics**
**Day of exam:** **08. October 2014**
**Exam hours:** **3 hours**
**This examination paper consists of 3 page(s).**
**Appendices:** **1**
**Permitted materials:** **pocket calculator**

*Make sure that your copy of this examination paper is complete before answering.*

**PROBLEM 1 (10 points)**

a) Sketch the height variation of temperature in the Earth's atmosphere from sea level to 150 km. Name all regions and boundary layers! Explain in general terms the physical mechanisms responsible for this structure. (3 points)

b) Under what circumstances can an atmosphere be considered adiabatic? In which of the following two cases is an atmosphere unstable with respect to the convective instability:
   a. $\frac{\partial\rho}{\partial z} < \left.\frac{\partial\rho}{\partial z}\right|_{ad}$ or
   b. $\frac{\partial\rho}{\partial z} > \left.\frac{\partial\rho}{\partial z}\right|_{ad}$

   Draw a sketch to justify your answer! (2 points)

c) Sketch the altitude profile of the electron density below 500 km both for the dayside and the nightside. (2 points)

d) What controls the electron density at a certain altitude? What are the main processes involved? How can they explain the difference in the day- and nightside electron profile? (3 points)

**PROBLEM 2 (12 points)**

a) Sketch the magnetosphere! Pay special attention to the different regions and boundary layers – give their names. (3 points)

b) Briefly describe the interaction between the solar wind and the dayside terrestrial magnetic field – exclude effects due to reconnection. (3 points)

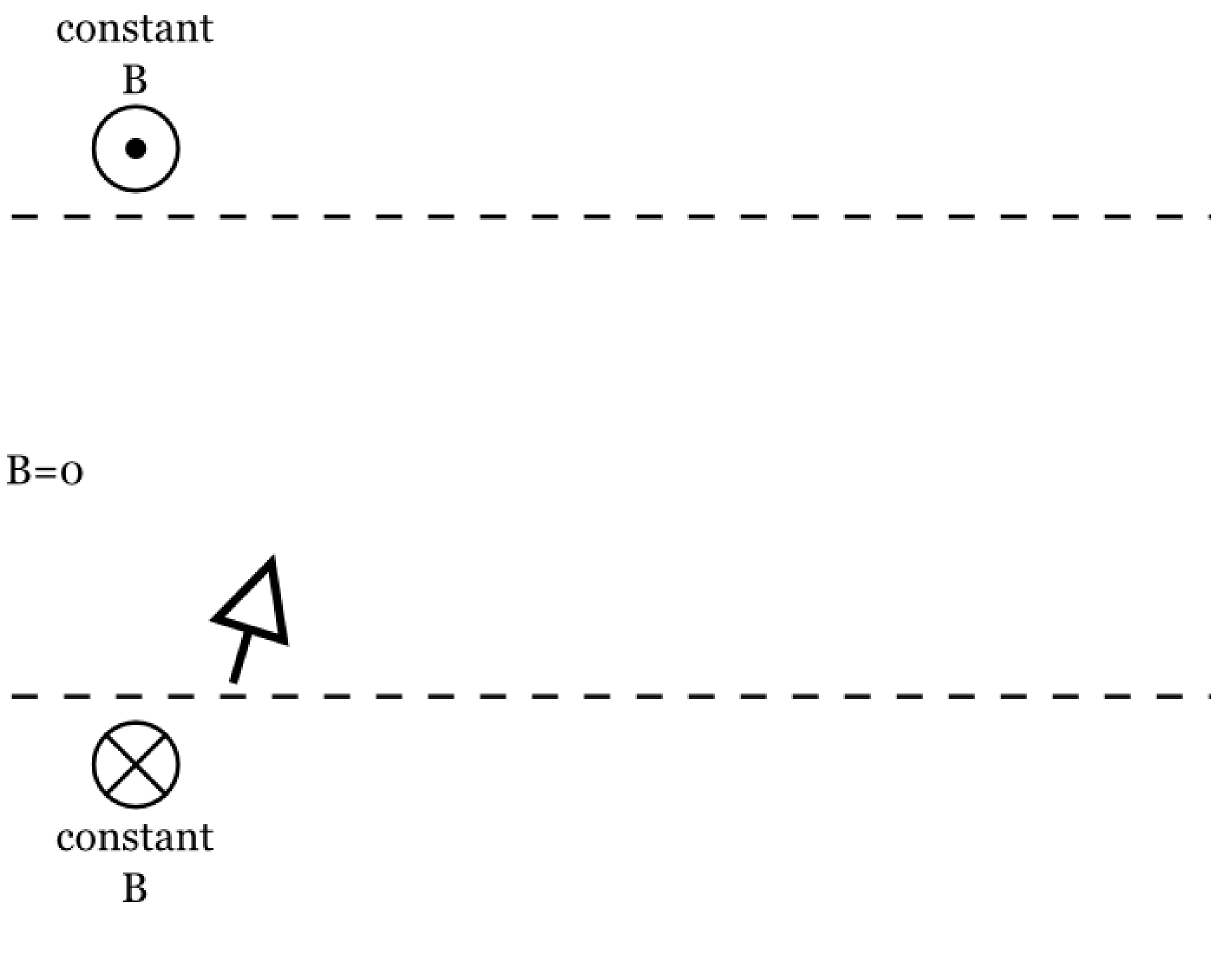
c) What controls the stand-off distance of the dayside boundary layers? Give typical values for the stand-off distances. (2 points)

d) How is the interplanetary magnetic field formed? Sketch large-scale structure of interplanetary magnetic field as seen from the top and the side. (4 points)

**PROBLEM 3 (13 points)**

Assume a charged particle moves in a constant magnetic field with no electric field.

a) Write down the general equation of motion for a charged particle for this situation. Name all the parameters. (2 points)
b) Assume that the magnetic field is aligned along the $z$-direction and that the charged particle is moving only in the $(x, y)$-direction. Solve the coupled differential equations and derive the expression for the gyrofrequency. (4 points)
c) Sketch the resulting trajectories for positively and negatively charged particles. (2 points)
d) Now assume an electric field in the $y$-direction is added. Sketch the resulting trajectory for positive particles. (2 points)
e) Imagine a central region with no magnetic field which is embedded between two regions of equal but opposite magnetic field (see below). Complete the trajectory for a positive and a negative particle in such a situation. The initial position and velocity is indicated by the arrow. Can you think of a location within the magnetosphere where such a trajectory is possible? (3 points)



**PROBLEM 4 (10 points)**

The power $P$ radiated by an accelerated particle is given by Larmor's formula

$$P = \frac{1}{6\pi\epsilon_0}\frac{q^2}{m^2c^3}\left(\frac{dp}{dt}\right)^2$$

where $\epsilon_0$ is the permittivity of free space, $q$ is the particle's charge, $m$ is the particle's mass, $c$ is the speed of light, and $dp/dt$ is the change in the particle's momentum $p = mv$.

a) Derive – in the non-relativistic limit (the mass of the particle is constant) – the radiated power when the acceleration is provided by the Lorentz-force. (2 points)

b) The power radiated will be at the expense of the particle's kinetic energy $E_{kin}$ such that $P = -dE_{kin}/dt$. Insert your result from a) and solve the resulting differential equation by separation of variables. (4 points)

c) In b) you found a time constant of the energy loss of $= 6\pi\epsilon_0 m^3c^3/q^4B^2$ . Use this result to estimate the time scale of energy loss for protons when located in
   a. the magnetosphere ($B \approx 200\text{nT}$).
   b. a fusion reactor ($B \approx 1\text{T}$).
   c. a neutron star ($B \approx 10^8\text{T}$). (3 points)

d) What consequences does that have for fusion reactors in which one tries to fuse protons? (1 point)

**APPENDIX**

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|---|---|
| Permittivity of free space | $\epsilon_0 = 8.85 \times 10^{-12}$ F/m |
| Electron charge | $q_e = 1.60 \times 10^{-19}$ C |
| Proton mass | $m_e = 1.67 \times 10^{-27}$ kg |
| Speed of light | $c = 2.99 \times 10^8$ m/s |