GEOMETRIC CORRECTIONS DUE TO INHOMOGENEOUS FIELD IN THE MAGNETOSPHERIC DOUBLE CURRENT LAYER

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Plane parallel models for a magnetospheric double layer resp. current layer [1-2] were described earlier by us as well as geometric corrections due to cylindrical or spherical geometry for perpendicular incidence of the solar wind [3]. Here oblique incidence is considered as well as a slope for the magnetic field.

1. INTRODUCTION: MDL and MDCL

When the solar wind impinges on the magnetosphere a charge separation takes place due to the difference in gyration radii of the electrons and ions [1-3]. Thus a double layer (DL) is created. In fact due to the (relativistic) $\bar{E} \times \bar{B}$ drift opposite electron and ion currents flow parallel to each other, so that a double current layer (DCL) is generated, creating a very strong magnetic field between the two layers and thus balancing practically their electrostatic attraction. The two magnetospheric models (MDL and MDCL) are somewhat extreme and give rather different results. Obviously the MDCL model is more appropriate, but due to some approximations it exagerates some results. An improved model uses a triple current layer. See also the accompanying paper [4] for a more detailed account and a sketch.

We first improve further on the geometrical corrections calculated in ref. [3] by incorporating now the oblique incidence of the solar wind. Again we compare a plane square magnetospheric surface of side $10R_E$ (10 Earth radii) with a cylindrical and a spherical sector, having however the same surface for their cross-section.

Secondly we investigate the influence of the slope of the magnetic field for the solar wind particles entering the magnetosphere.

2. PLANE-PARALLEL LAYERS

We first suppose that the solar wind (y-direction) impinges perpendicularly on the plane square magnetosphere. $\bar{B}_E$, the magnetic induction of the Earth, is in the z-direction. The $\bar{E} \times \bar{B}$ drift determines the x-direction. See fig. 1 of ref. [4].

2.1. MDL model. We first note our previous results:

$$n_e(x) = (2\varepsilon n_s B_E x/e)^{1/2} = 10^6\sqrt{x}\,(m^{-2}) \qquad (1)$$

$$E_y(x) = e\, n_e(x)/\varepsilon = 2\; 10^{-7}\sqrt{x}\,(V/m) \qquad (2)$$

$$En_{tot,sq} = \frac{1}{2}\, edB_E n_s (10R_E)^3 = 6.6\; 10^{13}\,(J) \qquad (3)$$

Here $n_e(x)$ is the surface density of the electrons (or ions in the parallel layer). n_s is the electron or ion flux of the solar wind (about 10^{12} ions/m^2s). v_s is the velocity of the solar wind particles. ε is the per-

mittivity ($\epsilon_o = 8.86\ 10^{-12}$F/m).
E_y is the electric field (opposite to the y-axis) due to the charge separation. $En_{tot,sq}$ is the total energy associated with the square MDL. The ion charge is e. We have here $m_i v_s = e r_i B_E$ with r_i the ion gyration radius. We have $r_i \approx d$, the thickness of the layer ($r_i \approx 300$ km if $v_s = 300$ km/s and $B_E = 10^{-8}$T).

2.2. MDCL model. Here we obtained, using dashes to distinguish from the MDL model:

$$n_e'(x) = n_s x/c = \frac{1}{3}\ 10^4 x (m^{-2}) \quad (4)$$

$$E_y'(x) = e n_e(x)/\epsilon \approx 6.10^{-5} x (V/m) \quad (5)$$

$$En'_{tot,sq} = \frac{e^2 n_s^2 d}{6 \epsilon c^2} (10R_E)^4 = 2\ 10^{14} (J) \quad (6)$$

The resulting numerical values are too large by an order of magnitude in comparison with some observations. The reasons were explained in ref. [3]. It may be added that $10R_E$ is a somewhat large value.

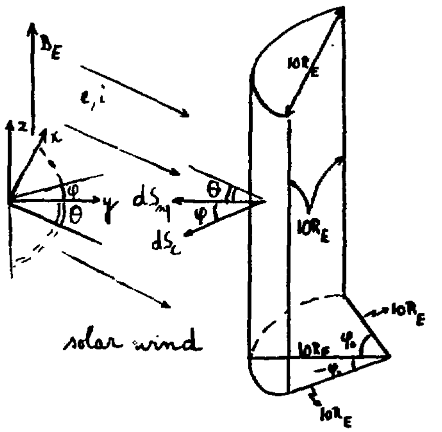
If one consideres oblique incidence e.g. an angle φ with the y-axis in the (x,y) plane and an angle θ with the y-axis in the (z,y) plane the results (1)-(6) have to be changed as follows:

n_s becomes $n_s \cos\theta \cos\varphi$
d becomes $d \cos\theta \cos\varphi$

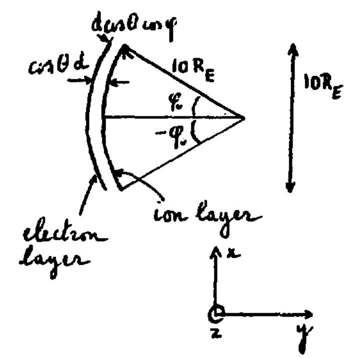
Thus the total energy is just multiplied by $\cos^2\theta \cos^2\varphi$ for the MDL model and by $\cos^3\theta \cos^3\varphi$ for the MDCL model.

3. CYLINDRICAL LAYERS

We replace the two plane-parallel square layers (one for the electrons and one for the ions)by two cylindrical sector layers, parallelly displaced over the distance $d\cos\theta$. In fact the velocity orthogonal to $\bar{B}$ is $v_s \cos\theta$, yielding $r_i \cos\theta$ as gyration radius (both independent of φ). The effective thickness is reduced from d to $d \cos\theta \cos\varphi$. The axes of the cylinders are parallel to the z-axis ($\bar{B}_E \parallel \bar{B}_{ind}$). See fig. 1.



a. Side view of cylindrical sector.



b. Top view of the cylindrical MDL or MDCL (not on scale: $d \ll R_E$)

Fig. 1

$\bar{E}$ is now a radial vector. $\bar{E}(\varphi)$ replaces $\bar{E}(x)$ of the square model. A surface element is now replaced by $dS_c = dS_{sq}\cos\theta/\cos\varphi$ and the impinging solar flux is now $n_s\cos\theta\cos\varphi$. Instead of dx we get $10R_E d\varphi$, with $-\varphi_o \leq \varphi \leq \varphi_o$; here $\sin\varphi_o = 5R_E/10R_E = 1/2$, hence $\varphi_o = \pi/6$. The full calculation yields no correction for the φ-dependence. We finally obtain that n_s is replaced by $n_s\cos\theta$ and that the distance between the two layers $\rightarrow d\cos\theta$. The influence on both models can then be read at once from formulae (1)-(6) with n_s and d multiplied by $\cos\theta$. For the MDL model this reduces En_{tot} by a factor $\cos^2\theta$, which for $\theta = 23°$ (which is about the maximum value) amounts to a factor 0.85. For the MDCL model En_{tot} is reduced by a factor $\cos^3\theta$, amounting to 0.78 for $\theta = 23°$.

4. SPHERICAL LAYERS

In view of the spherical symmetry one has only one possible situation. We are thus reduced to the cases considered earlier [3]. For En_{tot} we obtained 22% increase for the MDL model and 38% increase for the MDCL model with respect to the corresponding values for the square with perpendicular incidence.

Clearly the spherical approximation will break down when the axis Sun-Earth would be close to the axis of the magnetic field. Although this is not the case in the system Sun-Earth, it may be relevant for other planets (Uranus?) and in other planetary systems.

5. SLOPE OF MAGNETIC FIELD

We consider only a linear field gradient or a combination of such ones in the y-direction. The corresponding $\bar{B} \times \nabla B$ drift turns out to be small as compared to the $\bar{E} \times \bar{B}$ drift and is not very important. However the influence on the relative thicknesses of electron and ion layers is sometimes relevant. In fact various cases can occur according to whether the slope extends beyond r_i (before B reaching a constant value) or just beyond r_e. In the latter case the thickness of the electron layer can be increased strongly, while the ion layer stays at about the same place. Moreover, due to the strong induced field ($B_{ind} \gg B_E$) behind the electron layer, the thickness of the ion layer is further reduced corresponding to another relative increase of the thickness of the electron layer. This is an additional effect contributing in making the layers diffuse as also resulted from the damping considered in the accompanying paper [4]. Details, concerning perpendicular and oblique incidence, will be given at the conference as well as the effects due to the influence of the velocity distribution.

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