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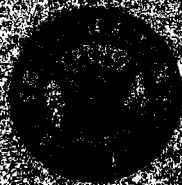
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CONDUCTIVITY FORMULAS FOR THE DISTURBED IONOSPHERE

Introduction

Formulas for the perpendicular DC ionospheric plasma conductivities have been presented previously by numerous authors.^{1,2,3,4,5} Use of these published formulas under normal ionospheric conditions for the E and F regions leads to accurate, reliable results. However, under certain extreme conditions (i.e., a high altitude nuclear explosion) these approximate formulas can lead to inaccurate and even unphysical results for the conductivities.

In this memo report we present a new set of exact formulas which do not suffer these deficiencies. They yield accurate and usable results under the most extreme circumstances of plasma and neutral densities and temperatures. We therefore recommend use of the formulas presented here for extreme or unusual ionospheric conditions.

Derivation

We begin with the electron and ion momentum equations considering only the Lorentz term and frictional terms

$$-\frac{e}{m_e} (\vec{E} + \vec{v}_e \times \vec{B}) = \nu_{en} \vec{v}_e + \nu_{ei} (\vec{v}_e - \vec{v}_i) \quad (1)$$

$$\frac{e}{m_i} (\vec{E} + \vec{v}_i \times \vec{B}) = \nu_{in} \vec{v}_i + \nu_{ie} (\vec{v}_i - \vec{v}_e). \quad (2)$$

Here $\vec{B}$ is the magnetic induction and $\vec{E}$ the electric field strength; $\vec{v}_e$ and $\vec{v}_i$ are the electron and ion velocities; m_e and m_i are the electron and ion mass; e is the electron charge; and ν_{en} , ν_{ei} , and ν_{ie} are the electron-neutral, the ion-neutral, the electron-ion, and the ion-electron collision frequencies.

We eliminate from (1) and (2) the cross product terms between the velocities and the magnetic induction resulting in

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$$\begin{aligned}
[(v_{en} + v_{ei})^2 - v_{ei}^2 + \Omega_e^2] \vec{v}_e &= -v_{en}\Omega_e \frac{\vec{E}}{|B|} + \Omega_e^2 \frac{\vec{E} \times \vec{B}}{B^2} \\
&- \frac{m_i}{m_e} v_{ei} (v_{in} - \frac{m_e}{m_i} v_{en}) \vec{v}_i
\end{aligned} \tag{3}$$

$$\begin{aligned}
[(v_{in} + v_{ie})^2 - v_{ie}^2 + \Omega_i^2] \vec{v}_i &= v_i = v_{in}\Omega_i \frac{\vec{E}}{|B|} + \Omega_i^2 \frac{\vec{E} \times \vec{B}}{B^2} \\
&+ \frac{m_e}{m_i} v_{ei} (v_{in} - \frac{m_e}{m_i} v_{en}) \vec{v}_e
\end{aligned} \tag{4}$$

where $\Omega_e = eB/m_e$, $\Omega_i = eB/m_i$, and $v_{ie} = (m_e/m_i) v_{ei}$ have been used.

We next solve (3) and (4) for $\vec{v}_e$ and $\vec{v}_i$ explicitly which yields

$$\begin{aligned}
(d_i d_e + c^2) \vec{v}_e &= - (d_i a_e + \frac{m_i}{m_e} c a_i) \frac{\vec{E}}{|B|} \\
&+ (d_i b_e - \frac{m_i}{m_e} c b_i) \frac{\vec{E} \times \vec{B}}{B^2}
\end{aligned} \tag{5}$$

$$\begin{aligned}
(d_e d_i + c^2) \vec{v}_i &= (d_e a_i - \frac{m_e}{m_i} c a_e) \frac{\vec{E}}{|B|} \\
&+ (d_e b_i + \frac{m_e}{m_i} c b_e) \frac{\vec{E} \times \vec{B}}{B^2} .
\end{aligned} \tag{6}$$

In (5) and (6) we have defined

$$a_i = v_{in}\Omega_i, \quad a_e = v_{en}\Omega_e,$$

$$b_i = \Omega_i^2, \quad b_e = \Omega_e^2,$$

$$c = v_{ei} (v_{in} - \frac{m_e}{m_i} v_{en}),$$

$$d_i = (v_{in} + v_{ie})^2 - v_{ie}^2 + \Omega_i^2, \quad d_e = (v_{en} + v_{ei})^2 - v_{ei}^2 + \Omega_e^2.$$

Use of equations (5) and (6) in $\vec{j} = ne (\vec{v}_i - \vec{v}_e)$ now yields the Pederson and Hall conductivities.

We write

$$\vec{j} = \sigma_p \vec{E} + \sigma_h \frac{\vec{E} \times \vec{B}}{|\vec{B}|} \quad (7)$$

where

$$\sigma_p = \frac{ne}{|\vec{B}|} \frac{d_e a_i + d_i a_e + c \left(\frac{m_i}{m_e} a_i - \frac{m_e}{m_i} a_e \right)}{d_i d_e + c^2}, \quad (8)$$

$$\sigma_h = \frac{ne}{|\vec{B}|} \frac{d_e b_i - d_i b_e + 2c(b_e b_i)^{1/2}}{d_i d_e + c^2}, \quad (9)$$

and n is the plasma number density.

The conductivity formulas presented above are considerably more complicated than those previously published in the literature. For instance, the formulas of Völk and Haerendel⁴ ignore the effects of collisions between ions and electrons which can be of considerable importance for very high plasma densities. Similarly, Francis and Perkins⁵ while including electron-ion collisions in the electron momentum equation, ignore their effect on the ion momentum equation. The result of these types of simplifications is either incorrect or even unphysical conductivities for the ionosphere under extreme plasma conditions. The exact formulas presented above do not suffer these difficulties.

Summary

In the preceding section we have presented the derivation of exact formulas for the perpendicular DC ionospheric conductivity. These formulas are usable and present accurate results under the most extreme of ionospheric conditions, a high altitude nuclear explosion. We therefore recom-

mend their use in computations for unusual or extreme ionospheric conditions.

Collision frequencies for use in the equations can generally be found in the standard reference texts on the ionosphere and aeronomy^{3,6}.

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