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Remarks on the Electrical Conductivity of the Ionosphere

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Abstract

In the previous paper [1] on the ionospheric conductivity, it is assumed that the ratio of the concentration of negative ions to that of electrons varies only with height. Considering the equilibrium between electrons and negative ions, the ratio is given by a function of the electron concentration as well as height. The results given in the previous paper are remarkably affected by the high value of this ratio, especially in the night hours. The numerical results are shown as the functions of the electron concentration in the figures.

1 The Ratio of the Concentration of Negative Ions to that of Electrons

Considering the various reactions among electrons, negative ions, positive ions and neutral particles, whose concentrations are \( N, n_-, n_+ \) and \( n \), respectively, we have

\[
\frac{dn_-}{dt} = \beta n N - \mu n_+ - \gamma n_- n - \alpha_i n_+n_-, \tag{1}
\]

and, in the equilibrium,

\[
\lambda = \frac{n_-}{N} = \frac{\beta n}{\gamma n - \mu + \alpha_i n_+}, \tag{2}
\]

in which \( \beta, \gamma, \mu \) and \( \alpha_i \) denote the coefficients of attachment, collisional detachment, photo-detachment, and mutual neutralization, respectively. Remembering that 

\[
n_+ = (1+\lambda)N \text{ and } \lambda > 0,
\]

we have

\[
\lambda = \frac{-2 \gamma n_+ \mu + \alpha_i N + \sqrt{4 \gamma n_+ \mu + \alpha_i N} + 4 \alpha_i \beta N n}}{2 \alpha_i N}.
\]

Among the various processes of attachment or collisional detachment, it is sufficient to consider only the reactions concerned with the oxygen atoms. Then, \( n \) may be regarded as the concentration of atomic oxygen. According to the study of Bates and Massey[2], \( \beta \) is the function of the temperature and is estimated to be \( 4.2 \times 10^{-11} \text{ T}^{-1} \text{ cm}^3 \text{ sec}^{-1} \). They also estimated \( \mu \) to be 0.34/negative ion/sec. In the ionosphere, as it is likely that there are not many particles of very high energy, only the associative detachment of oxygen is taken into account. Then, the rate coefficient, \( \gamma \), is \( 10^{-16} \text{ cm}^3 \text{ sec}^{-1} \) in accordance with Massey[3]. According to Bates and Massey[2], the three body collision,

\[
O^- + O^+ + M \rightarrow O + O + M,
\]

can be neglected in comparison with the process,
Fig. 1 The ratio of concentration of negative ions to that of electrons at various altitudes.
the rate coefficient, $\alpha_{ti}$, of which is $10^{-7}$ cm$^3$·sec$^{-1}$.

With these values, the ratios of the concentrations of negative ions to those of electrons are calculated for various values of electron density at the selected altitudes, and the results are shown in Fig. 1. In dark hours, the photo-detachment process may be absent. The curves for night-hours are drawn obliquely. It is seen that the ratio, $\lambda$, increases with the decrease of the electron density, especially in the dark hours.

2 Electrical Conductivity

In the estimation of the electrical conductivity, the results in the F region where
$\lambda < 10^{-4}$ are not much affected by the changes in $\lambda$. But in the E region, where the conductivity reaches its maximum value, the results for night-hours may be largely different from those for day-hours. In this additional remark, the differences are examined at each step of the calculations.

Assuming the changes in $\lambda$ with electron density as shown above, the frequency of

\[ \text{Collision frequency of an ion} \]

\[ \text{Electron density} \]

Fig. 3 Frequencies of the total collisions of ions of the both signs.
Fig. 4  Integrated conductivity for $\sigma_{xx}$. 

Maximum electron density

- Day
- Night
collisions of an electron with positive or negative ions are computed by using the Eqs. (23) and (24) in the previous paper[1]. On account of the comparatively large value of $v_e$, the total collisional frequency of an electron is not largely affected by the changes in $\lambda$. It is seen from Fig. 2 that the values for night-hours are slightly higher than those for day-hours. In the case of ions, the results shown in Fig. 3 are more agreeable to Fig. 6 in [1], and only a little difference is found between the values for day and for night.

According to Eq. (2) in [1], the transverse conductivity, $\sigma_\perp$, is much affected by the changes in $\lambda$ on account of the large contributions from the ions of the both signs. And the essential differences, especially in the E region, are found between the values for day-hours and for dark-hours. On the other hand, the longitudinal conductivity, $\sigma_\parallel$, differs slightly from the result shown in Fig. 2 in [1], because the contributions from both ions are negligible in comparison with the electronic contribution to $\sigma_\parallel$.

In the case of the Hall conductivity, $\sigma_z$, the results are almost the same as those
given in [1]. Consequently, \( \sigma_{xx} \) and \( \sigma_{yy} \) given by Eqs.(39) and (41) in [1] must be modified in accordance with \( \sigma_1 \). And the values for night-hours are essentially different from those for day-time especially in the E region.

After drawing the curves for \( \sigma_{xx}, \sigma_{xy}, \) and \( \sigma_{yy} \), and assuming the same vertical distribution of electron density as in [1], the integrated conductivities, \( \Sigma \sigma_{xx}, \Sigma \sigma_{yy} \)
and $\Sigma \sigma_{yy}$, are computed, and the renewed results expressed in e.m.u. are shown in Figs. 4, 5 and 6. In these figures, the values for dark hours are drawn by dashed and dotted lines. It is obvious that, in the night, $\Sigma \sigma_{xx}$ and $\Sigma \sigma_{yy}$ decrease more slowly than the electron density.

In the same manner as described in the former paper [1], the longitudinal
Fig. 8 Diurnal variation of $\Sigma \sigma_{xy}$

Fig. 9 Diurnal variation of $\Sigma \sigma_{yy}$
distributions of the conductivities, or the diurnal variations are derived from the above figures. The results are given in Figs. 7, 8 and 9. It is noted that the conductivities during night are significantly high in comparison with the former results (Figs. 17, 18 and 19 in [1]).

The vertical distributions of the conductivities are shown in Fig. 10 for the noon values at the co-latitude of 60°. The curve for $\sigma_{xy}$ at the equator is also drawn in the figure by the broken line.

3 Concluding Remarks

It is concluded that, in general, the conductivity during the night is not so reduced as expected from the simple consideration made in the previous paper [1]. And it
must be mentioned that, in [1], the curves for $5^h$ in Fig. 16 and the values for $5^h$ and $21^h$ in Table 1 should be omitted. One of the most important results is that the conductivity in the equatorial belt is enhanced only during the sunlit hours.

It is additionally noted that the model of the atmosphere above 220 km adopted in the present computation is in accordance with the paper [4], which is slightly different from that assumed in [1].

**Reference**