JOURNAL OF GEOPHYSICAL RESEARCH VOLUME 66, No. 8 AUGUST 1961

Electron Densities in the Outer Ionosphere Deduced from Nose Whistlers

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An attempt was recently made by *Pope* [1961] to determine the electron density in the exosphere by using nose whistlers. The deduced densities are lower by factors of 5 or more than densities deduced by *Smith* [1960*a*] and by *Smith and Helliwell* [1960], who also used nose whistler data. The discrepancies are even more surprising since Smith had also used, as part of his data, the same data used and previously exhibited in a technical report by *Pope* [1959].

In the following discussion, all figure and equation numbers refer to the paper by *Pope* [1961].

The right-hand side of equation 2 is too large by a factor of 2. Apparently the term 1/2, which appears in the group refractive index formula, was omitted. The same error appears in the unnumbered equation below Figure 2, which presumably makes the time-delay correction factor too large by a factor of 2. In any event, a time-delay correction of

$$t = 4/f^{1/2}$$

is closer to the dispersion one would expect for a double passage through the regular ionospheric layers at night.

The factor of 2 has been reinserted into equation 6. The resulting curves shown in Figures 2, 3, and 4 appear to be correct. Let us compute the electron density from nose whistler spectrograms, assuming a $1/R^3$ distribution. Examination of the nose whistler trains shown in Figure 5 reveals an outstanding nose whistler at 1235 UT, March 19, 1959, with a nose frequency of 5 kc and a time delay to the nose of approximately 2.55 seconds. An additional 0.05 seconds should be added to this figure to account for the propagation time of the causative atmospheric. An additional time of $8/(5000)^{1/2} = 0.11$ seconds (using Pope's correction factor) can be subtracted to account for the propagation through the lower layers, giving $t_n = 2.49$ seconds. The nose frequency can be shifted downward by 200 cycles (again using Pope's numbers) to give $f_n = 4{,}800$ cps. Applying the graph in Figure 3 to the above data, we deduce that the latitude of the field line, θ_0, for this nose whistler component is 61°, and, furthermore, $t_n/K_2 = 1.8 \times 10^{-2}$. The dipole field line passing through the earth's surface at 61° magnetic latitude reaches a maximum distance of 4.26 earth radii from the center of the earth. The value of K_2 deduced from the above measurements is

$$K_2 = \frac{t_n}{1.8 \times 10^{-2}} = 1.38 \times 10^2$$

The electron density at 4.26 earth radii is found by using equation 4:

$$N = K_2^2 R^{-3} = \frac{1.91 \times 10^4}{77.4}$$
$$= 246 \text{ electrons/cc}$$

This is to be compared with the value of 51/cc taken from the graph on Figure 7 for the same data point, the same distance, and the same distribution. It appears that some errors have been made in the calculations. Similar errors occur in the calculations for other assumed distributions. After making suitable corrections, the electron densities deduced from the data shown by Pope are reasonably close to those deduced by *Smith* [1960*a*] and by *Allcock* [1959].

Smith [1960*a*] has examined 22 nose whistlers and nose whistler trains received from a number of different stations at different times. He concludes that the gyro-frequency model (electron density proportional to gyro frequency, or approximately $1/R^3$) fits the data somewhat better than the so-called Johnson model presented in Pope's paper. The data are not absolutely conclusive, however, since each nose whistler can give only integrated density along one set of field lines. It is clear from the data that the density of the ionization in the outer ionosphere cannot be expressed in terms of a simple smoothly varying model, even at one time. In one instance a minimum ionization variation across the field lines of at least 40 per cent was noted. It might also be noted that there are two Johnson models of the outer ionosphere. The older model [*Johnson,* 1959], an approximate form of which was used by Pope, has been discarded by Johnson on theoretical grounds in favor of a model [*Johnson,* 1960] similar to that discussed by *Dungey* [1954].

One of Pope's stated assumptions, that the whistler follows the magnetic field lines, and an unstated assumption, that the wave normals are aligned with the magnetic field, deserve further comment. On the basis of theoretical and experimental evidence, it appears quite likely that whistlers propagate in field-aligned ducts of enhanced ionization in the outer ionosphere [*Smith,* 1960*a,b; Helliwell,* 1959; *Smith, Helliwell, and Yabroff,* 1960]. Furthermore, even though the wave normals of whistler energy trapped in these ducts may vary considerably, the average group velocity is given fairly accurately by assuming that the wave normals are aligned with the magnetic field [*Smith,* 1960*a*]. There is, however, a high frequency cutoff at one-half the gyro frequency associated with this mode of propagation. A detailed account of these results will appear shortly.

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(Received April 6, 1961.)