A Qualitative Explanation of the Diurnal Variation of Chorus

N. BRICE[1]

Radioscience Laboratory, Stanford University, Stanford, California

Diurnal variation of chorus. One of the most regular and consistent features of the very low frequency (VLF) emissions known as chorus is the diurnal variation of occurrence. *Storey* [1953] noted that chorus occurrence peaked at dawn at Cambridge; later *Allcock* [1957] and *Pope* [1957] showed that the diurnal peak varied almost linearly with geomagnetic latitude, being near dawn at the lower latitudes and near noon at the high latitudes. Attempts have been made to reduce the scatter in the data by measuring the peak occurrence in auroral time [*Brice and Ungstrup,* 1963]. No satisfactory explanation of these observations has been presented to date, and in this work we will be concerned only with the general observation that chorus peaks between dawn and noon.

The transverse resonance plasma instability. Recently *Brice* [1963] and *Bell and Buneman* [1964] suggested a nonconvective transverse resonance plasma instability for electrons as a mechanism for the generation of VLF emissions. *Sudan* [1963] considered an anisotropic Maxwellian electron velocity distribution in a magnetic field and found that an instability existed if the transverse temperature exceeded the longitudinal temperature. *Bell and Buneman* [1964] considered a cold ambient plasma and a beam of gyrating electrons and found that the instability existed if the electrons in the beam had sufficient average transverse velocity. Guthart (private communication) finds a similar result for two Gaussian velocity distributions, one with and one without a longitudinal drift velocity. It is apparent that, in general, the existence of this instability requires an adequate transverse temperature of the electrons, and that for inadequate transverse temperatures Landau damping will dominate and no growing waves will be found. It is expected that, if emissions are generated by this instability, the generation is most probable at or near the top of the magnetic field line along which the emissions propagate. It is therefore of interest to examine mechanisms which might produce anisotropic electron distributions in the vicinity of the equatorial plane at geocentric distances of a few earth radii.

Production of required electron velocity distributions. It is apparent that energetic electrons with very small pitch angles in the equatorial plane will have mirror points in or below the lower ionosphere, and these electrons will rapidly be lost by collisions near their mirror points. The existence of this 'loss cone' of pitch angles would provide a favorable temperature asymmetry in an otherwise isotropic distribution, since the particles lost are those with large longitudinal and small transverse velocities in the region of interest. While collisions, in general, tend to restore isotropy, small angle collisions giving rise to 'random walk' effects in the particle pitch angles would ensure that few particles were observed with pitch angles slightly greater than that defining the limit of the loss cone. This effect would tend to enhance the anisotropy in pitch angles and hence temperature.

Trapped energetic electrons will drift with respect to the earth because of gradients in the magnetic field, but let us ignore this effect for the moment and consider the plasma as frozen to the magnetic field. It is now accepted that the earth's magnetic field is compressed on the day side of the earth by the solar wind as *Parker* [1958] suggested, so that the magnetic field strength at a given field line is stronger on the day side of the earth than the night side. Thus, as the earth rotates, there will be an increase in magnetic field strength at a given field line on the morning side of the earth and a corresponding decrease on the evening side. For adiabatic compression of the field, the par-

[1] Now at Carleton University, Ottawa, Ontario, Canada.

ticles move with the field and the ratio of transverse energy to magnetic field strength remains constant [*Spitzer*, 1956]. Thus as the magnetic field is compressed on the morning side, the average transverse energy of the trapped particles is increased. It is suggested that this increase in the transverse energy gives rise to the plasma instability mentioned above and hence the generation of VLF emissions. This anisotropy will be offset in part by the drift of trapped particles around the earth (mentioned above), and, in part, by collisions. In addition, *Brice* [1964] has shown that during the generation of emissions by this mechanism, some of the transverse kinetic energy of the electrons is converted to longitudinal kinetic energy and some to electromagnetic radiation. Both these effects will tend to reduce the anisotropy in the medium. It can therefore be suggested that the rate at which emissions are generated depends on the rate at which the magnetic field is being compressed. This concept has been likened to the 'toothpaste tube' effect. The squeezing of a tube of flux in the equatorial plane produces a temperature anisotropy which gives rise to the generation of emissions. These emissions are squirted out the end of the tube of flux and are observed on the ground, the rate of emission generation depending on the compression on the tube. It should be pointed out, in passing, that, as emission of electromagnetic signals by this mechanism tends to reduce the temperature anisotropy, absorption of these waves will have the opposite effect.

It is of interest to determine at what time the rate of compression of the magnetic field by the solar wind is greatest. *Hones* [1963, Figure 2] has presented loci of given field lines and contours of constant magnetic field strength from which some estimate of the compression can be obtained. It is seen that the rate of compression is zero at noon and midnight, as expected, and is negligible between midnight and dawn for geocentric distances of interest. Thus almost all the compression occurs between dawn and noon, providing an explanation of the predominance in the occurrence of chorus during these hours.

Energy considerations. Hones [1963] noted that particles will be energized on the morning side and de-energized on the evening side. While the prime concern of this work is the production of anisotropy, it is also of interest to compare the rate at which energy can be pumped into the kinetic energy of the particles by magnetic field compression with that observed in VLF emissions. Consider a tube of flux at about 5 earth radii containing one energetic electron per ten cubic centimeters, with an average energy of 10 kev. Let us suppose that two-thirds of the electron kinetic energy is contained in the transverse velocity and that the field is compressed one per cent per hour.

Then the rate of increase of transverse kinetic energy per unit area for the energetic electrons in a ten-thousand-kilometer length of the tube is found to be of the order of 2.10^7 kev/m^2 sec. The cross-sectional area of the tube is smaller at the surface of the earth by a factor of about 30 for the regions of interest, so that, if all this energy were converted to VLF emissions, the energy in the emissions would be 6.10^8 kev/m^2 sec, or about 10^{-7} watt/m^2. This is a few orders of magnitude greater than that observed in chorus (which is of the order of 10^{-13} watt m^{-2} (cps)$^{-1}$ or less), so that only a small fraction of the increase in transverse kinetic energy need be converted to electromagnetic energy to explain the observed intensities of the VLF emissions considered here.

Summary. It is suggested that the VLF emissions called chorus are generated by the transverse resonance plasma instability for electrons and that the production of this instability requires anisotropy in the electron velocity distribution. Phenomena which might give rise to the required anisotropy are considered. It is suggested that the compression of the outer magnetosphere by the solar wind would assist in producing the anisotropy. While no attempt is made to explain the systematic shift in the time of maximum chorus occurrence with latitude, it is shown that the compression of the magnetosphere leads to an explanation of the observation that chorus is generally observed between dawn and noon. A conservative estimate of the rate of increase in transverse energy of energetic electrons arising from this compression is found to be orders of magnitude greater than that required to explain the energies observed in chorus.

Acknowledgments. I acknowledge helpful advice and criticism from Dr. R. A. Helliwell and his co-workers of the Radioscience Laboratory at Stanford.

This work was supported by the United States Air Force Office of Scientific Research under grant AFOSR 63-370.

REFERENCES

Allcock, G. McK., A study of the audio-frequency radio phenomenon known as 'dawn chorus,' *Australian J. Phys., 10*(2), 286–298, 1957.

Bell, T. F., and O. Buneman, Plasma instability in the whistler mode caused by a gyrating electron stream, *Phys. Rev., 133*(5A), 25–26, March 2, 1964.

Brice, N. M., An explanation of triggered VLF emissions, *J. Geophys. Res., 68*(15), 4626–4628, August 1, 1963.

Brice, N. M., Fundamentals of generation mechanisms very low frequency emissions, *J. Geophys. Res., 69*(21), November 1, 1964.

Brice, N. M., and E. Ungstrup, Use of 'local mean auroral time' for very-low-frequency emissions, *Nature, 198*(4883), 874, June 1, 1963.

Hones, E. W., Motions of charged particles trapped in the earth's magnetosphere, *J. Geophys. Res., 68,* 1209–1219, March 1, 1963.

Parker, E. N., Interaction of the solar winds with the geomagnetic field, *Phys. Fluids, 1,* 171, 1958.

Pope, J. H., Diurnal variation in the occurrence of 'dawn chorus,' *Nature, 180,* 433, August 31, 1957.

Spitzer, L., *Physics of Fully Ionized Gases,* Interscience Publishers, New York, 1956.

Storey, L. R. O., An investigation of whistling atmospherics, *Phil. Trans. Roy. Soc. London, A, 246,* 113–141, 1953.

Sudan, R. N., Plasma electromagnetic instabilities, *Phys. Fluids, 6,* 57–61, 1963.

(Received June 25, 1964;
revised July 28, 1964.)