SHORT COMMUNICATIONS

THE IONOSPHERE OF JUPITER*

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It has been suggested that the radio-frequency emissions from Jupiter are due to plasma oscillations in the planet's ionosphere (e.g. Gardner and Shain 1958). This note shows that, according to standard theory, sufficient ionization may be produced by solar radiation; but it does not attempt to explain the actual cause of the disturbances.

Evidence so far available suggests that the radiation from Jupiter is strongest at frequencies near 20 Mc/s (Gardner and Shain 1958). If this is taken to be the fundamental frequency of a plasma oscillation, then the corresponding electron density is $N = 5 \times 10^6$ cm^{-3}, a value which is seldom approached in the terrestrial ionosphere. Since the intensity of the ionizing radiation is presumably much less than at the Earth, the required electron density will only be attained if the recombination coefficient α is very low. It is suggested that this may be so.

The relevant theory is that of Chapman (1931), who considers the absorption of monochromatic radiation in an isothermal atmosphere. The theory may be expected to give rough quantitative results even if its assumptions are not strictly true.

Let I be the intensity of ionizing radiation incident vertically at the top of the atmosphere and q the rate of production of ionization. Let n be the number density of the ionizable constituent, H its scale height, and A its ionization cross section. Then, at the level of maximum production, under conditions of equilibrium:

$$q = \alpha N^2, \quad \ldots\ldots \quad (1)$$

$$q = I e^{-1}/H, \quad \ldots\ldots \quad (2)$$

$$1 = nAH. \quad \ldots\ldots \quad (3)$$

Also

$$H = kT/mg, \quad \ldots\ldots \quad (4)$$

where k is Boltzmann's constant, T the temperature, g the acceleration due to gravity, and m the mean molecular mass, which may be written as $\mu \times$(mass of hydrogen atom).

A model of the Jovian atmosphere has been proposed by Kuiper (1952). It consists of a troposphere—a region in which the temperature decreases upwards—and an isothermal stratosphere: at the tropopause, which is near the level of the visible clouds, the pressure is of the order of 1 terrestrial atmosphere and the temperature is about 90 °K. The suggested percentage com-

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position by weight of the atmosphere is H_2 63·5, He 35, and heavy gases (CH_4, NH_3, etc.) 1·5, whence $\mu=2\cdot5$. With $g=2600$ cm sec^{-2}, this gives $H\simeq10$ km.*

However, in the terrestrial F region the temperature is much higher than in the stratosphere: the same may be true of Jupiter. Furthermore, the molecular weight may decrease with altitude, for two reasons. Firstly, diffusive separation of gases may occur; and secondly, hydrogen is probably dissociated at great heights in the atmosphere. Thus an alternative estimate of H can be made, in which these possible effects are combined so as to increase H: if $T=300$ °K (say) and $\mu=1$, then $H\simeq100$ km.

Comparison is best made with the F_1 region of the terrestrial ionosphere, in which the maximum rate of ion production occurs: the greater electron density in the F_2 region is due to conditions which may not exist in Jupiter's atmosphere. In the F_1 region, H is about 30 km, and $q=500$ cm^{-3} sec^{-1} for moderate sunspot numbers. Since similar ultraviolet wavelengths are involved in each case, it is reasonable to take

$$I_J/I_E=R_E^2/R_J^2=1/27, \qquad (5)$$

where R is the radius of the planetary orbit and the subscripts E, J refer to the Earth and Jupiter. Use of (1), (2), and (5), with the desired value $N=5\times10^6$ cm^{-3}, shows that if $H_J=10$ km, then $q_J\simeq50$ cm^{-3} sec^{-1} and α must not exceed 2×10^{-12} cm^3 sec^{-1}; but if $H_J=100$ km, then $q_J\simeq5$ cm^{-3} sec^{-1} and $\alpha\leqslant2\times10^{-13}$ cm^3 sec^{-1}. Typical F_1-region values are $N=3\times10^5$ cm^{-3} and $\alpha=5\times10^{-9}$ cm^3 sec^{-1}.

The altitude of the ionized region in the Jovian atmosphere may be estimated by means of equation (3). For the principal gases of the Earth's atmosphere the ionization cross section A is 10^{-17} or 10^{-18} cm^2: similar values are probably appropriate to the Jovian situation, and with a scale height H of 10 or 100 km, the equation gives n as 10^{10} to 10^{12} cm^{-3} (similar to that in the F_1 region). At the tropopause of Kuiper's model, the number density is of order 10^{20} cm^{-3}. Thus between the tropopause and the ionosphere the number density decreases by a factor of about 10^9, corresponding to a difference in altitude of $9 \ln 10=21$ scale heights, or a few hundred kilometres. The ionosphere thus lies well above the level of the visible clouds.

The recombination processes operative in the terrestrial ionosphere have been discussed by Bates and Massey (1946, 1948). They are:

(i) Radiative recombination: coefficient about 10^{-12} cm^3 sec^{-1}.

(ii) Dissociative recombination (involving molecular ions); coefficient 10^{-8} or 10^{-9} cm^3 sec^{-1}.

The latter process is important either if the ionizable gas is composed of diatomic or polyatomic molecules, or if monatomic ions can transfer their charge to a molecular constituent. No other recombination process is likely to be more rapid than (i).

* Kuiper proposes an alternative composition, with helium as the predominant constituent and $\mu=3\cdot3$: the adoption of this model makes no substantial difference to the subsequent discussion.

The coefficients quoted are rough values, applicable to conditions in the Earth's atmosphere, and it is plausible that for the constituents of Jupiter's atmosphere they will be of similar magnitude. Then, if process (i) alone occurs, the required electron density seems feasible; but if process (ii) is operative, it does not—so it is necessary to consider whether any constituent gas is likely to give rise to molecular ions in the ionosphere.

It may be estimated that hydrogen will be dissociated above the level at which $n \sim 10^{13}$ cm^{-3}, a few scale heights below the level of the ionosphere. The principal constituent of the ionosphere is thus atomic hydrogen, and molecular hydrogen will be comparatively rare. Although H_2 molecules will absorb a small proportion of the ionizing radiation, and the resulting H_2^+ ions can recombine dissociatively, most of the radiation is available for the production of H^+ ions. Since the ionization potential of H_2 exceeds that of H, there can be no formation of H_2^+ ions by transfer of charge from the H^+ ions. Moreover, the pressure is probably too low to permit the formation of He_2^+ ions, and CH_4 and NH_3 are likely to be dissociated well below the ionosphere. Consequently, the H^+ ions cannot recombine by a dissociative process.

The essential difference between the two ionospheres, therefore, is that whereas in the terrestrial F region the principal ion (O^+) can react with neutral molecules to form molecular ions, the H^+ ions in the Jovian ionosphere can only recombine by the radiative process. Provided electrons are not removed too quickly by diffusion, and rough calculation suggests that they are not, the values $\mu=1$, $T=100$ °K, $\alpha=10^{-12}$ cm^3 sec^{-1} yield $N \simeq 4\times10^6$ cm^{-3}, which is satisfactory.

The ionization will be removed by recombination in a time of order $\alpha N \sim 10^5$ or 10^6 sec. This is longer than the rotation period of Jupiter ($3\cdot6\times10^4$ sec), so the electron density will show little diurnal variation.

The above considerations suggest that Jupiter may possess an ionosphere with a critical frequency of order 20 Mc/s, and that it lies a few hundred kilometres above the level of the visible clouds. However, the correlation between the radio-frequency activity and the planet's rotation period (Shain 1956) implies that the sources of excitation are fixed with respect to the cloud system. Possibly surface or atmospheric phenomena cause disturbances in the overlying ionosphere.

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References

Bates, D. R., and Massey, H. S. W. (1946).—*Proc. Roy. Soc.* A **187**: 261.
Bates, D. R., and Massey, H. S. W. (1948).—*Proc. Roy. Soc.* A **192**: 1.
Chapman, S. (1931).—*Proc. Phys. Soc. Lond.* **43**: 26.
Gardner, F. F., and Shain, C. A. (1958).—*Aust. J. Phys.* **11**: 55.
Kuiper, G. P. (1952).—"The Atmospheres of the Earth and Planets." 2nd Ed. Ch. XII. (Univ. Chicago Press.)
Shain, C. A. (1956).—*Aust. J. Phys.* **9**: 61.