NOTES

CONSIDERATIONS REGARDING INTERSTELLAR MOLECULES

ABSTRACT

An attempt has been made to compute the numbers of certain molecules in interstellar space. The results obtained are unfavorable to Saha's identification of one of Merrill's interstellar lines with Na_2. A search for the bands of CH, OH, NH, CN, and C_2 would appear to be promising.

Attention has recently been drawn to the subject of molecules in interstellar space by H. N. Russell,[1] P. Swings,[2] A. S. Eddington,[3] and M. N. Saha,[4] whose aims were essentially the interpretation of new interstellar lines of rather diffuse character, discovered by P. W. Merrill.[5] In the paper by Swings, a tentative identification of two of Merrill's lines with rotatory oscillation bands of CO_2 is suggested; the theoretical width of molecular interstellar bands is calculated and found to be in good agreement with the observations; and finally the importance of the dissociation of molecules in a radiation field is advocated. Later on, Saha published the statement that one of Merrill's bands (λ 6283) was certainly due to the Na_2 molecule (transition $1\Sigma \leftrightarrow 1\Sigma$; $v'' = 0$, $v' = 8$) and that another line (λ 5780) might provisionally be attributed to NaK ($v'' = 0$, $v' = 5$). We do not believe that Saha's identification is correct; actually the experimental and theoretical investigations of the Na_2 spectrum and the determination of the corresponding Franck-Condon diagram by Loomis and Nile[6] and by Loomis and Nusbaum[7] indicate clearly that several other bands of Na_2 ($v'' = 0$ to $v' = 5, 6, 7, 9, 10$) are

[1] *M.N.*, **95**, 635, 1935.

[2] *Ibid.*, **97**, 212, 1937.

[3] *Observatory*, **60**, 99, 1937.

[4] *Nature*, **139**, 840, 1937.

[5] *Pub. A.S.P.*, **46**, 206, 1934; *Ap. J.*, **83**, 126, 1936.

[6] *Phys. Rev.*, **32**, 873, 1928.

[7] *Ibid.*, **40**, 380, 1932.

of the same intensity as $v'' = 0$, $v' = 8$, and, therefore, ought to be present also.

In any case, an estimate of the number of interstellar molecules seems important. If we assume that the density of radiation in the region of molecular absorption leading to dissociation is identical with black-body radiation at temperature T "diluted" by the factor δ, the number of molecules in dissociative equilibrium will be given by the usual formula, except that the numbers of atoms have to be multiplied by $\sqrt{\delta}$ (for diatomic molecules). Indeed, compared with black-body radiation, the number of dissociations in unit time is now reduced by the factor δ, while the number of recombinations is proportional to the product of the numbers of the engaged atoms.

We have, thus, as a first approximation:[8]

$$\frac{n_{AB}}{n_A \cdot n_B} = \frac{G_{AB}}{G_A G_B} \cdot \frac{hr_0^2}{1 - e^{-\frac{h\omega}{kT}}} \cdot \sqrt{\frac{8\pi}{mkT}} \cdot e^{D/kT} \cdot \delta ,$$

where n_A, n_B, and n_{AB} = the numbers of atoms (A and B) and molecules (AB) per cubic centimeter; r_0 = the nuclear distance in the molecule; ω = the fundamental frequency of vibration; D = the heat of dissociation; m = the reduced mass of the molecule [$m = (m_A m_B / m_{AB})$]; G_A, G_B, G_{AB} = statistical weights of the electronic levels concerned.

If we assume $T = 10{,}000°\ K$; $\delta = 2.10^{+14}$; $r_0 = 10^{-8}$cm; $\omega = 2000\ \text{cm}^{-1}$; $m = 10 m_H = 10^{-23}$; $\frac{G_{AB}}{G_A G_B} = 10$, we find for $D = 5$ volts:

$$\frac{n_{AB}}{n_A n_B} = 6.10^{-9} ;$$

for $D = 10$ volts (case of CO):

$$\frac{n_{AB}}{n_A n_B} = 6.10^{-7} ;$$

for $D = 1$ volt (case of Na_2):

$$\frac{n_{AB}}{n_A n_B} = 2.10^{-10} .$$

[8] Cf. S. Rosseland, *Theoretical Astrophysics*, p. 247.

For a triatomic molecule (such as CO_2, assuming the reaction $CO + O$), we get

$$\frac{n_{AB_2}}{n_A n_B^2} = 4 \cdot 10^{-15} .$$

Thus triatomic molecules like CO_2 must be rare compared with diatomic compounds. In the case of Na_2, Eddington has given the maximum value to 10^{-6} atom per cubic centimeter for the density of neutral Na atoms in interstellar space. This would give us

$$n_{Na_2} = 2 \cdot 10^{-22} ,$$

which seems an extremely low value.

On the other hand, most of the H, O, N, and C atoms must be in their neutral state in interstellar space; we may safely assume that for these elements the atomic populations per cubic centimeter are not much smaller than unity, say between 1 and 10^{-3} atom per cubic centimeter. For diatomic compounds, such as H_2, OH, CH, NH, O_2, CO, CN, etc., the numbers of molecules would thus not be much smaller than the numbers of interstellar Ca^+ and Na atoms; but there would be less than 10^{-14} CO_2 molecules per cubic centimeter; this is rather unfavorable to the identification of CO_2. A search for the interstellar bands of CH, OH, NH, CN, and C_2 seems most interesting and promising. An interstellar line observed by Dunham[9] at λ 4300.3 may be due to CH. The only absorption lines of the (0, 0), $^2\Delta \leftarrow {}^2\Pi$ transition of this molecule, starting from the lowest rotational level, are λ 4300.24 and λ 4303.86. The second line could not be observed as a stationary line in an early B star, as it would be blended with λ 4303.82 *O* II. But the first would give an interpretation of the interstellar line observed by Dunham; the corresponding absorbing molecules would all be in their lowest level, in complete analogy with the case of Ti^+ atoms.

We may notice the influence of the adopted values for the temperature, the dilution factor, and the abundances. Actually if the temperature of radiation T_0 and the temperature of matter T_1 are identical, we may apply the formulae of thermodynamic equilibrium with the dilution factor δ and obtain the foregoing formula. If we suppose

[9] Pub. *A.S.P.* **49**, 26, 1937.

$T_1 \neq T_0$, we have to consider separately all the possibilities of transitions to and from the various states of the systems and to examine how these processes balance. But this could not modify substantially the numerical results. It is obvious also that the value of the density of interstellar radiation is rather uncertain. Finally, the problem of relative abundances of atoms in interstellar space is still at its very beginning; it may be that the usual assumption of relative abundances similar to those of the stellar atmospheres is not right.

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NOTE ON THE INTERPRETATION OF UNIDENTIFIED INTERSTELLAR LINES

ABSTRACT

Spectroscopic objections to recent assignments of Merrill's unidentified stationary lines to molecular absorption bands are outlined.

Since the suggestion of the possible molecular origin[1] of Merrill's four interstellar lines,[2] attempts to correlate them with absorption bands of known molecules have been made.[3,4] The resulting identifications are, unfortunately, open to purely spectroscopic criticism, and indeed it seems highly improbable that these lines can be interpreted as molecular bands.

Molecular absorption in the visible spectrum might be formally attributed either to rotation-vibration bands or to electronic bands. In considering the absorption due to the small number of molecules which could conceivably exist in interstellar space, however, bands of the first type must surely be excluded, for the intensities of the high harmonics and combinations which lie in the visible are so extremely small that one could hope to observe such bands only in the relatively dense, cool planetary atmospheres. For this reason alone Swings's[3] identification of the interstellar lines λ 6283.91 and

[1] Russell, *M. N.*, **95**, 635, 1935.

[2] *Pub., A.S.P.*, **46**, 206, 1934; *Ap. J.*, **83**, 826, 1936.

[3] Swings, *M.N.*, **97**, 212, 1937.

[4] Saha, *Nature*, **139**, 840, 1937.