

RESEARCH NOTE

N₂ VIBRATIONAL DISTRIBUTION IN AURORAE

(Received 8 November 1978)

Abstract—The N₂ vibrational distribution is calculated for a specific IBC Class II aurora using as input, data obtained from coordinated rocket and satellite observations and currently accepted excitation and quenching rates. The results of the calculations indicate no significant vibrational enhancements for this specific aurora nor for “upper limit” estimates for more intense aurorae. We conclude from this study that if significantly larger concentrations of vibrationally excited N₂ molecules exist in the aurora, as recent rocket e.u.v. measurements suggest, current concepts of the sources and sinks of N₂ vibrational excitation will require significant revision.

Recently Erdman *et al.* (1978) and Zipf and McLaughlin (1978) have drawn attention to the fact that the electron impact cross-sections for the excitation of the $c_4^1\Sigma_u^+ \rightarrow X^1\Sigma_g^+$ e.u.v. band system of N₂ is almost as large as that for the 3914 Å (0-0) band of N₂⁺. The above-mentioned band system is readily observable in the laboratory under optically thin conditions in the wavelength range of about 900-1100 Å, however recent auroral observations by Christensen (1976) and Park *et al.* (1977) show a striking dearth of N₂ e.u.v. radiation in this wavelength range. Erdman *et al.* (1978) and Zipf and McLaughlin (1978) suggested that this lack of observable e.u.v. emission is due to entrapment of radiation by an enhanced population of vibrationally excited N₂ (mainly in $v=1$ and 2 levels) corresponding to an equivalent vibrational temperature of several thousand degrees Kelvin.

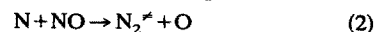
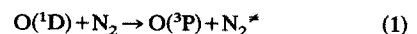
These suggestions, coupled with the knowledge that the auroral ion and minor constituent chemistry is strongly affected by vibrationally excited N₂, make it appropriate to re-evaluate and update our present understanding of N₂ vibrational temperatures in aurorae.

The only direct measurement of the N₂ vibrational distribution in an aurora was made by O’Neil *et al.* (1974) at Fort Churchill, Canada in an IBC class II aurora. They derived the N₂(X¹Σ_g⁺) vibrational temperature by obtaining the $v=0$ and $v=1$ population from the N₂⁺(B²Σ_u⁺) induced luminescence. They concluded that, within their estimated accuracy, they could not detect a vibrational temperature in excess of the estimated kinetic temperature, although they do state that they may have observed an anomalously high $v=2$ population.

The last published and specific calculation of the N₂ vibrational temperature distribution in an aurora is nearly 10 yr old (Walker *et al.*, 1969) and since that time many of the important rate coefficients have been measured

and/or revised and therefore the results need to be re-evaluated. In this brief note we present the results of calculations leading to an upper limit estimate on the auroral N₂ vibrational population since such a limit is sufficient for our present purposes.

Probably the most comprehensive optical, particle and composition measurements in an aurora were carried out in a coordinated rocket (NASA 26.029) and satellite (AE-C) overflight over Fort Churchill by Sharp *et al.* (1978). In this calculation we use the basic data set obtained during these coordinated measurements. Here we do not reproduce the data set in any detail, nor discuss the variety of methods used for obtaining the various composition, emission and flux profiles; the reader is referred to the original paper by Sharp *et al.* 1978. The gas density values used in the calculation are given in Table 1. As we are interested in an upper limit on the N₂ vibrational population we (1) assume the maximum possible production of vibrational excitation in the source reactions, (2) carry out the calculations in terms of the total number of vibrational quanta and (3) scale these data to simulate other auroral conditions. The most important sources of N₂^v in the auroral E-region are:



Laboratory measurements by Slanger and Black (1974) indicate that reaction (1) leads to N₂($v=2$). At E-region altitudes, to all practical purposes, O(¹D) is completely quenched by N₂ via reaction (1), therefore, the number of vibrational quanta produced through this mechanism is simply given by twice the O(¹D) production rate. Rusch *et*

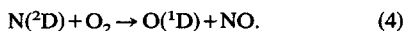
TABLE 1

Altitude (km)	NASA 26.029						“Enhanced” values adopted		
	[N ₂] (cm ⁻³)	[O ₂] (cm ⁻³)	[O] (cm ⁻³)	[NO] (cm ⁻³)	[N(² D)] (cm ⁻³)	[N(⁴ S)] (cm ⁻³)	[NO] (cm ⁻³)	[N(² D)] (cm ⁻³)	[N(⁴ S)] (cm ⁻³)
110	1.5 × 10 ¹²	3.1 × 10 ¹¹	6.1 × 10 ¹⁰	1.0 × 10 ⁹	3.0 × 10 ⁴	3.0 × 10 ⁵	1.3 × 10 ¹⁰	1.5 × 10 ⁷	4.8 × 10 ⁵
130	1.1 × 10 ¹¹	1.5 × 10 ¹⁰	1.2 × 10 ¹⁰	2.0 × 10 ⁸	7.0 × 10 ⁴	3.0 × 10 ⁵	6.2 × 10 ⁸	7.9 × 10 ⁵	2.8 × 10 ⁶
150	3.1 × 10 ¹⁰	3.8 × 10 ⁹	5.0 × 10 ⁹	8.0 × 10 ⁷	1.0 × 10 ⁵	3.4 × 10 ⁵	1.9 × 10 ⁸	1.2 × 10 ⁶	3.3 × 10 ⁶

TABLE 2

Altitude (km)	Rate of N ₂ ⁶ Quenching by O(³ P)(s ⁻¹)	NASA 26.029				"Enhanced" conditions					
		N ₂ ⁶ production rates				Equi- valent vibra- tional temper- ature T ₀ (K)	N ₂ ⁶ production rates				Equi- valent vibra- tional temper- ature T ₀ (K)
		P ₁ (N ₂ ^v) (cm ⁻³ s ⁻¹)	P ₂ (N ₂ ^v) (cm ⁻³ s ⁻¹)	P ₃ (N ₂ ^v) (cm ⁻³ s ⁻¹)	n(N ₂ ^v) (cm ⁻³)		P ₁ (N ₂ ^v) (cm ⁻³ s ⁻¹)	P ₂ (N ₂ ^v) (cm ⁻³ s ⁻¹)	P ₃ (N ₂ ^v) (cm ⁻³ s ⁻¹)	n(N ₂ ^v) (cm ⁻³)	
110	6.7 × 10 ⁻⁵	1.1 × 10 ⁵	4.2 × 10 ⁴	1.9 × 10 ⁵	5.1 × 10 ⁹	590	5.4 × 10 ⁵	1.3 × 10 ⁶	1.9 × 10 ⁶	5.7 × 10 ¹⁰	1000
130	1.6 × 10 ⁻⁴	1.3 × 10 ⁴	1.1 × 10 ⁴	2.3 × 10 ⁴	3.0 × 10 ⁹	570	1.4 × 10 ⁵	3.5 × 10 ⁵	2.3 × 10 ⁵	4.6 × 10 ⁹	1100
150	1.4 × 10 ⁻⁴	4.6 × 10 ³	5.7 × 10 ³	9.5 × 10 ³	1.4 × 10 ⁸	~T _{gms}	5.5 × 10 ⁴	1.5 × 10 ⁵	9.5 × 10 ⁴	2.1 × 10 ⁹	1250

al. (1978), using the data from the coordinated measurements mentioned earlier, have concluded that the major source of O(¹D) in the E-region during an aurora is the reaction



Assuming unit efficiency for this reaction and using the N(²D) density calculated by Rusch *et al.* (1978) we obtain the production rate of N₂ vibrational quanta, P₁(N₂^v), given in Table 2.

The work of Morgan *et al.* (1962) indicates that reaction (2) leads to a N₂ vibrational population peaked near *v* = 5. Assuming that all reactions lead to *v* = 5 and using the density estimates of Sharp *et al.* (1978) given in Table 1, we derive the production rates of vibrational quanta due to this process, P₂(N₂^v), given in Table 2. Finally we consider production due to direct electron impact excitation. The electron impact excitation cross-section given by Schulz (1964) is folded with the measured low energy (*E* ≤ 30 eV) electron flux (Sharp *et al.*, 1978) leading to the rate, P₃(N₂^v), given in Table 2.

The major loss mechanism of N₂ vibrational quanta in the altitude range under consideration is quenching by ground state atomic oxygen, O(³P). McNeal *et al.* (1974) measured this rate at kinetic temperatures representative of lower thermosphere conditions. Using kinetic temperatures and atomic oxygen values derived by Sharp *et al.* (1978) [see Table 1] for the aurora under consideration, we obtained the loss rates shown in Table 2. We should note here that the atomic oxygen density in the specific aurora under consideration may have been unusually low (e.g. [O]_{110km} = 1.6 × 10¹⁰ cm⁻³), resulting in a low quenching rate. This fact, coupled with our neglect of other possible quenching mechanisms (e.g. CO₂, thermal electrons) is in line with our interest in obtaining an upper limit on the vibrational population.

Finally in order to be sure that our conclusions are not based on an unusual and/or low intensity aurora, we scaled up our source terms to values which would be expected in an aurora with a 3914 Å emission rate of 50 kR. As the measured aurora (Sharp *et al.*, 1978) was a factor of ten less intense we (1) scaled the low energy flux responsible for direct impact excitation by a factor of ten and (2) assumed a tenfold increase in the N(²D) production rate and calculated the resulting odd nitrogen {N(²D), N(⁴S), NO} chemical equilibrium population in order to calculate the enhanced source terms due to reactions (1)

and (2). The results of these scaled up calculations are also shown in Table 2.

A detailed calculation, considering anharmonicity, vibration-vibration exchange, etc. is necessary in order to determine the actual non-Boltzmann vibrational distribution in an aurora, while the vibrational temperature values given in Table 2 are obtained by assuming that the calculated vibrational quanta are distributed according to a Boltzmann distribution. Nevertheless, the crude calculations presented here are sufficient to provide us with an upper bound estimate on the N₂ vibrational distribution. Our results show that significantly enhanced vibrational temperatures of several thousand degrees are clearly inconsistent with presently accepted source reactions and reaction rates. Therefore, the lack of observable N₂ e.u.v. emissions are either not due to entrapment by enhanced vibrational population or we are unaware of a significant auroral source of N₂ vibrational quanta and/or some of the presently accepted rates for the sources and sinks are significantly wrong.

Acknowledgements—The authors wish to express their appreciation to Drs. W. E. Sharp and D. W. Rusch for many helpful discussions. The work presented here was supported by NASA Grants NSG 5282 and NGR23-005-015.

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