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POPULATION DENSITIES OF TRIPLET EXCITED STATES IN A DIFFUSE NITROGEN PLASMA*

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Recently there has been much activity on line emission studies from nitrogen plasmas (1-5), primarily due to their relevance in understanding of upper atmospheric emission. But hitherto there has been little experimental work which investigates the nature of quantitative correlation between the population densities of excited states in laboratory nitrogen plasmas and cross sections of relevant electron impact processes. However, such investigations to be amenable to quantitative correlations with atomic processes, values of plasma parameters must directly be known. This is not available from earlier laboratory plasma experiments. Here we report the results of an experiment in which in situ measurements of electron densities (n_e) and electron temperatures (T_e) were carried out besides vibronic and rotational transition intensities from a nitrogen plasma.

Experiments were conducted at a pressure of 5 microns in a 90 cm long 2.5 cm diameter stainless steel tube and the plasma sustained by electrons injected from one end of the tube, at plasma currents (I_E) of 0.5, 1 and 2 amps. The plasma was immersed in a longitudinal magnetic field ($B=0-700$ gauss). Variation of the magnetic field resulted in a coupled variation of n_e and T_e measured at the centre of the plasma column by means of a Langmuir probe. Results of these measurements are shown in Fig. 1. The radiation from the axial region of the plasma column was taken to a 2.1/6.3 meter spectrograph (first order dispersion 3.4A per mm/1.12A per mm) through a set of angle limiting baffles. Relative intensities from the $N_2 C^3\Pi_u$ state (second positive system SPS) were measured. A typical vibrational temperature T_{vib} plot and vibrational temperatures determined from band head intensities in the n_e, T_e range of the experiment are shown in Fig.2 and Table 1 respectively. For all the SPS bands, T_{vib} increases with increase of B. In general, at a given B, it increases with I_E .

High resolution rotational spectra of SPS vibronic bands (1,0), (0,2) were photographed in 3rd order of the 6.3 meter mode of the spectrograph, and relative intensities

Table 1. Vibrational Temperatures of the $C^3\Pi_u$ state from the (0-2) sequence of the Second Positive System

I_E (amp)	I_B (amp)	0.4	0.8	1.0
0.5		4390±200	4990±300	5625±350
1.0		5660±200	6480±100	6810±100
		1.2	1.6	2.0
0.5		6260±350	6230±350	6600±250
1.0		7450±150	7760±100	8330±250

measured using a microdensitometer. Rotational temperatures of the ground vibrational state at $I_E=1$ amp are shown in Table 2.

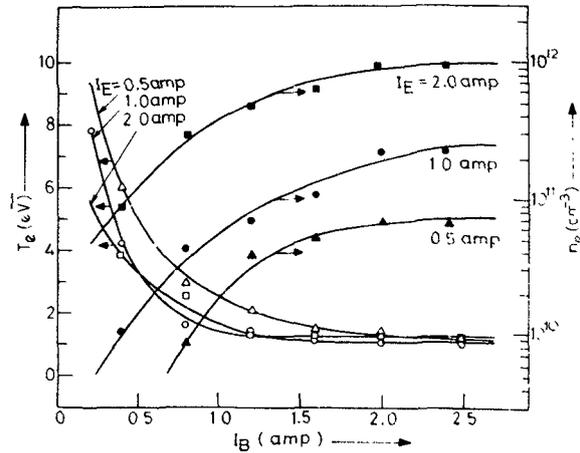


Fig.1 Plasma parameters in the magnetic field (I_B =magnet current; $B=280$ gauss/amp of I_B)

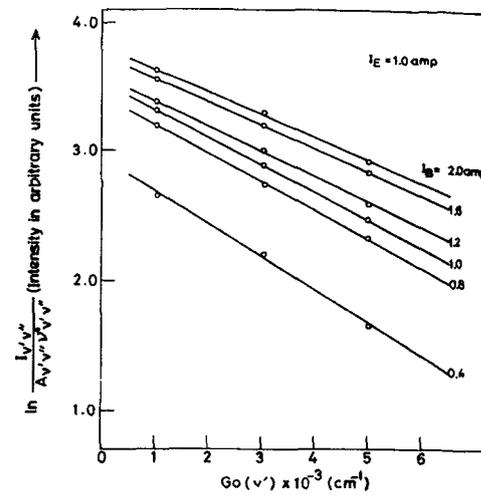


Fig.2. Vibrational temperature plot from the $N_2(O-2)$ band sequence of the Second Positive System

Table 2. Rotational Temperatures of the Ground Vibrational state of $C^3\Pi_u$

I_B (amp)	0.5	1.0	1.5	2.0
R_0	620±20	655±20	680±20	610±20
R_1	615±20	690±20	720±20	600±20
R_2	620±20	695±20	745±20	620±20

In the following sections we show the role of various processes in the total cross section by choosing the example of the B state, and also report results of calculations of population densities of the N₂ triplet excited states.

The total cross section of the B³Π_g is shown in Fig.3 for the vibrational levels v=0-11 with electron energy as a parameter. The cross sections are evaluated using the method from (6) and using the processes: electron impact excitation X¹Σ_g⁺(v=0)→B³Π_g(v=0-11), cascade processes C³Π_u→B³Π_g, B¹Σ_u⁻→B³Π_g, W³Δ_u→B³Π_g, and A³Σ_u⁺→B³Π_g intersystem cascade. One notes a strong dependence of the cross section on the electron energy for the lower vibrational states, unlike the higher ones. Enhanced population densities are observed beyond the v=9 level. Direct electron impact excitation from the ground state, C³Π_u→B³Π_g, as well as B¹Σ_u⁻→B³Π_g contribution decrease with increasing vibrational quantum number of the B³Π_g state, and W³Δ_u→B³Π_g contribution is negligible. It is the A³Σ_u⁺→B³Π_g intersystem cascading which increases with the vibrational quantum number of the B³Π_g state and accounts for increased population densities of the B³Π_g vibrational states beyond v=9. Fig.4 shows the partial contributions of the various processes to the B³Π_g v=2 state, the state which has the highest Franck-Condon factor with respect to the ground state.

The collisional-radiative model used in calculation of population densities of triplet states involves the following: the ground vibrational state v=0 of the X¹Σ_g⁺ state, vibrational levels 0-11 of A³Σ_u⁺, v=0-12 of B³Π_g, v=0-7 of W³Δ_u, v=0-12 of B¹Σ_u⁻ and v=0-3 of C³Π_u. The following electron impact processes are considered: X¹Σ_g⁺→A³Σ_u⁺, B³Π_g, C³Π_u, W³Δ_u, B¹Σ_u⁻, radiative transitions C³Π_u→B³Π_g, B³Π_g→A³Σ_u⁺, B¹Σ_u⁻→B³Π_g, W³Δ_u→B³Π_g, and A³Σ_u⁺→X¹Σ_g⁺ besides intersystem cascades B³Π_g→B¹Σ_u⁻, A³Σ_u⁺→B³Π_g, B³Π_g→W³Δ_u. The total electron impact cross sections are from (7), the method of obtaining vibrational cross sections from electronic state cross sections is from (6), and the Franck-Condon factors of various states are from (6,8,9), and transition probabilities from (10-12). The population densities calculated numerically using steady state condition, Maxwellian velocity distribution of electrons, and a constraint that the sum of population densities of all the states is equal to 1.6 x 10¹⁴ cm⁻³, are shown in Fig.5. It will be noted that the C state vibrational levels do not thermalize, in variance with experimental results.

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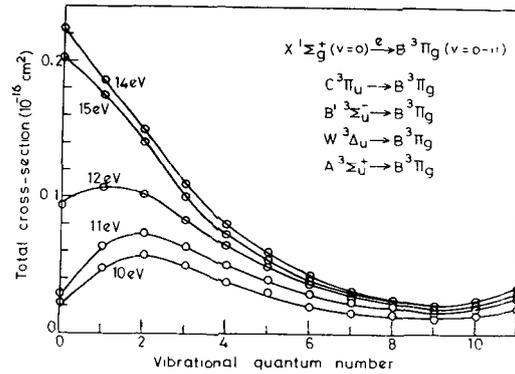


Fig.3 Total cross section of B³Π_g

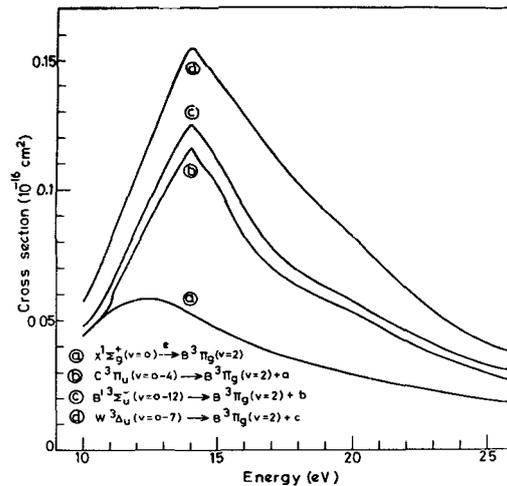


Fig.4 Partial contributions to B³Π_g (v=2)

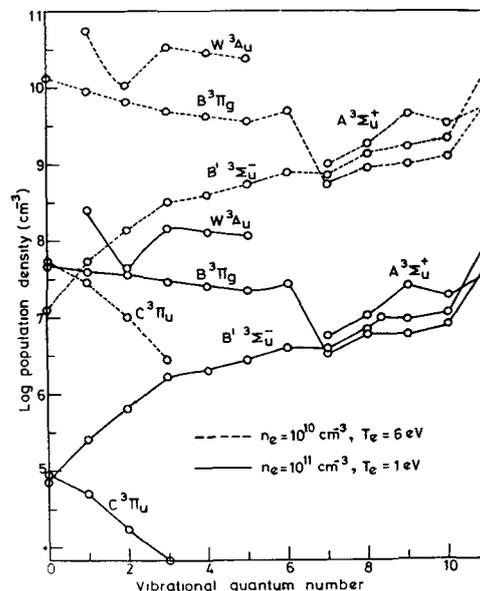


Fig.5 Population densities of N₂ triplet states for total particle density 1.6 x 10¹⁴ cm⁻³

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