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N(2D) and N(2P) metastable production by electron collisions
in a D.C. glow discharge

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Abstract. — The atomic nitrogen metastable densities of N(2D) and N(2P) have been measured by optical absorption in a continuous glow discharge. Electronic densities have been measured with a microwave resonant cavity. The evolution of N(2D) and N(2P) densities as a function of electronic density allows the estimation of the overall creation coefficient by electronic collisions $C_{eM}^M : e + N_2 \rightarrow e + N(2D, 2P) + N$. This coefficient is of the same order of magnitude for N(2D) and N(2P) and lies between $1.5 \times 10^{-10}$ and $4 \times 10^{-11}$ cm$^3$ s$^{-1}$ for a pressure range between 0.5 and 1.5 torr (tube radius $R = 1$ cm). For currents higher than 20 mA the density of N(2P) is larger than the N(2D) density (approximately a factor of two at 50 mA).

1. Introduction. — Metastable atoms N(2D, 2P) play an important role in the chemistry of upper atmosphere and laboratory plasmas. These states are located 19,233 and 28,839 cm$^{-1}$ (2.38 and 2.58 eV) over the fundamental level N(4S) as shown in figure 1.

In the high atmosphere, these levels produce nitrogen oxides according to the reaction:

$$N(2D, 2P) + O_2 \rightarrow NO + O$$  \hspace{1cm} (1.1)

with

$$K_1(N(2D)) = 6 \times 10^{-12} \text{ cm}^3 \text{ s}^{-1} \ [1]$$
$$K_2(N(2P)) < 2 \times 10^{12} \text{ cm}^3 \text{ s}^{-1} \ [2].$$

The reaction (1.1) is strongly exothermic and produces nitrogen oxides in excited vibrational states [3].

In plasma chemistry, the reaction (1.1) contributes to the synthesis of nitrogen oxides produced by electrical in nitrogen-oxygen mixtures.

The following reactions occur in nitrogen-hydrogen mixtures:

$$N(2D, 2P) + H_2 \rightarrow NH + H \hspace{1cm} (1.2)$$

with $K_3(N(2D)) = 1.7 \times 10^{-12} \text{ cm}^3 \text{ s}^{-1} \ [4]$
$$K_3(N(2P)) < 8 \times 10^{-16} \text{ cm}^3 \text{ s}^{-1} \ [2].$$

N(2D) states are generally more reactive than N(2P) states [4a] as it has been explain by Donovan and Husain [4b]. As a matter of fact, there is no exothermic adiabatic way for the reaction N(2P) + H$_2$ but there is one for the reaction N(2D) + H$_2$ producing NH* + H.

Concentrations of metastable atoms have been previously measured by optical absorption in a low power (\approx 20 W) H.F. flowing afterglow in He-Ar mixtures containing from 0.5 to 4.3 \% of N$_2$ with a total pressure ranging from 7 to 15 torr [1]. In this

(*) Laboratoire associé au C.N.R.S.
Fig. 1. — The first energy levels of nitrogen.

Fig. 2. — Experimental device.

The objective of this study is to determine the electronic excitation coefficients of the $N(2D)$ and $N(2P)$ states. Metastable atom densities have been measured by optical absorption, in the positive column of a continuous electrical discharge in pure nitrogen. Density evolutions of both states $N(2D)$ and $N(2P)$ have been studied as functions of the electron density.

2. Experimental. — Figure 2 shows the whole experimental device. Nitrogen is excited by a continuous glow-discharge in a 2 cm internal diameter, 50 cm long pyrex glass tube closed at both ends with MgF$_2$ windows. The tube is connected to a vacuum tank which permits a stable working pressure. This pressure is measured on the vacuum tank using a Pirani gauge calibrated for pure nitrogen. First the system is baked and pumped by a turbomolecular pump to an ultimate pressure of about $5 \times 10^{-8}$ torr. The nitrogen gas utilized had an impurity level of 50 ppm. The dominant impurity was argon.

At one of the tube’s extremities is the ultra-violet light source. It is a Penning discharge (Damany source from Jobin Yvon) which emits strong atomic nitrogen spectral lines.

The gas temperatures in the light source and in the discharge have been calculated from the intensity of the light emitted. The apparatus profile is asymmetrical with a width of 1.3 A [9]. A sodium salicylate scintillator placed behind the exit slit convert the ultraviolet light to a continuous spectrum around 4 000 Å [10], which is detected with a photomultiplier (RTC 56 UVP).

The electron density is measured by the frequency shift of a resonant cavity tuned to the $TM_{020}$ mode [11]. The cavity is excited by a sweep oscillator (Hewlett Packard 692 A).

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The gas temperatures in the light source and in the discharge have been calculated from the intensity
distribution of the rotational spectrum of molecular nitrogen [12]. This rotational structure is observed using a 150 cm focal length monochromator with a resolution of about $5 \times 10^{-2}$ Å at 4 000 Å.

3. Measurement of $\text{N(2D)}$ and $\text{N(2P)}$ concentrations by optical absorption. — Metastable levels concentrations have been determined from light absorption by using the Mitchell and Zemansky [3] method.

Figure 1 shows $\text{N(2D)}$ and $\text{N(2P)}$ levels and radiative transitions which lead to these levels. Transitions coming from upper levels are doublet separated by about 2 Å and each of them (except 1 494.67 Å) exhibits a fine structure.

For an absorption length $L$, the absorption is

$$A_L = 1 - \frac{I_i}{I_0}, \quad (3.1)$$

where $I_0$ and $I_i$ are the incident and transmitted intensities.

Taking into account the fine structure, the absorption is

$$A_L = 1 - \frac{\sum L k_i(\lambda) \exp \left(-L \sum k_i(\lambda)\right)}{\sum L k_i(\lambda) \exp \left(-L \sum k_i(\lambda)\right)}. \quad (3.2)$$

The integration is performed over the whole line profile. The $I$ subscript represents each component of the fine structure.

For each component of the fine structure, the natural broadening is:

$$k_i(\lambda) = k_i(\lambda_0) F_i(\lambda), \quad (3.3)$$

where $\lambda_0$ is the wavelength at the center of the line and $F_i(\lambda)$ represents the Voigt profile which is the convolution of a gaussian profile (Doppler effect) and of a Lorentzian profile (natural broadening).

For each component of the fine structure, the natural broadening is:

$$\Delta \lambda_n = \frac{\lambda_0^2}{2 \pi c} \sum_{m<n} A_{nm}, \quad (3.4)$$

and the relative Doppler broadening

$$\frac{\Delta \lambda_d}{\lambda_d} = 7.16 \times 10^{-7} \left(\frac{T}{M}\right)^{1/2}. \quad (3.5)$$

In these expressions the subscript $m$ refers to the metastable level, and $n$ to a radiative level, $A_{nm}$ the transition probability from level $n$ to $m$, $c$ the speed of the light, $T$ the atomic temperature and $M$ the atomic mass.

The absorption coefficient $k_i(\lambda_0)$ at the center of the line $i$ is given by [13]:

$$k_i(\lambda_0) = \frac{e^2}{4 \pi \varepsilon_0 m_ee^2} 2\sqrt{\pi \ln 2} \frac{\lambda_0^2}{\Delta \lambda_d} n_i f_i. \quad (3.6)$$

In this expression $e$ and $m_e$ are the charge and the mass of the electron, $\varepsilon_0$ the permittivity of vacuum, $f_i$ is the oscillator strength of the component $i$ and $n_i$ the absorbing level density which is equal to the total metastable level density ($3\text{D}$ or $3\text{P}$) balanced by the statistical weights of each component of the fine structure. In MKS units, eq. (3.6) gives:

$$k_i(\lambda_0) = 8.31 \times 10^{-15} \frac{\lambda_0^2}{\Delta \lambda_d} n_i f_i. \quad (3.7)$$

The data used are listed in table I, where the transitions probabilities come from reference [14].

Table I. — Spectroscopic data for N(2D, 2P) absorption lines from [14].

<table>
<thead>
<tr>
<th>$\lambda_{nm}$ (Å)</th>
<th>$A_{nm}$ $(10^{-8} \text{s}^{-1})$</th>
<th>$\sum_{m&lt;n} A_{nm}$ $(10^{-8} \text{s}^{-1})$</th>
<th>$g_m$</th>
<th>$f_{nm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 492.62</td>
<td>5.3</td>
<td>8.03</td>
<td>6</td>
<td>0.12</td>
</tr>
<tr>
<td>1 492.81</td>
<td>0.58</td>
<td>8.03</td>
<td>4</td>
<td>0.019</td>
</tr>
<tr>
<td>1 494.67</td>
<td>5.0</td>
<td>6.95</td>
<td>4</td>
<td>0.084</td>
</tr>
<tr>
<td>1 742.72</td>
<td>0.35</td>
<td>8.03</td>
<td>2</td>
<td>0.032</td>
</tr>
<tr>
<td>1 742.73</td>
<td>1.8</td>
<td>8.03</td>
<td>4</td>
<td>0.082</td>
</tr>
<tr>
<td>1 745.25</td>
<td>1.3</td>
<td>6.95</td>
<td>2</td>
<td>0.052</td>
</tr>
<tr>
<td>1 745.26</td>
<td>0.65</td>
<td>6.95</td>
<td>2</td>
<td>0.082</td>
</tr>
</tbody>
</table>

The apparatus profile of the V. U. V. monochromator is asymmetrical [9]. We have calculated the convolution product of this profile with the line profile. The whole calculation that relates $A_L$ (eq. (3.2)) to the metastable density is performed numerically for a 50 cm absorption length and for several temperatures of the source and of the discharge.

Source and absorbing media temperatures have been determined from the rotational distribution of the second positive band,

$$[C^3\Pi_g(v = 0) \rightarrow B^3\Pi_u(v = 0)],$$

at 3 371 Å. Usually in glow discharges, the rotational temperature is equal to the discharge temperature. In some cases, collisions between excited nitrogen molecules can disturb the $C^3\Pi_u$ rotational band distribution. For instance Ockim et al. [15] have observed transfers from $N_2(E^3\Sigma^+_u)$ metastable states. This effect is observable on the spectrum of the second positive band only if temperatures are below 300 K. We find $T_R = 500$ K for the Damany source. For discharge pressures ranging between 0.5 and 1.5 torr, the rotational temperature changes from 400 K to 600 K when the discharge current varies from 0.5 to 50 mA.
We have found that, for the same metastable density and for a source temperature of 500 K the change of the calculated absorption \( A_L \) is less than 1\% when the discharge temperature varies from 400 to 600 K. As the accuracy of our absorption measurements is about \( \pm 2\% \), we calculate the absorption for the same temperature of the source and the discharge. Figure 3 shows the variation of metastable densities versus absorption calculated for the strongest lines, for a discharge and source temperature of 500 K.

\[ n_e = 7 \times 10^8 \Delta f \quad (4.1) \]

where \( n_e \) is expressed in cm\(^{-3}\) and \( \Delta f \) in MHz.

The variations of \( n_e \) as function of current intensities are shown on figure 4 for several pressures. We notice that \( n_e \) is proportional to the discharge current up to 20 mA.

4. Experimental results. — 4.1 ELECTRONIC DENSITY. — Electronic density is measured from the frequency shift of a H.F. resonant cavity surrounding the discharge tube. The electrons of the discharge disturb the microwave field which induces a shift of the cavity resonance frequency [11]. The observed electron densities are relatively low (\( \approx 10^9 \) cm\(^{-3}\)). A TM mode has been chosen because the electric field is maximum on the cavity axis. A numerical solution of the electromagnetic field equations gives the relation between the electronic density and the frequency shift. This equation takes into account the dimensions of the cavity and of the discharge tube, the glass thickness and the dielectric constant (\( \varepsilon = 4.45 \) for Pyrex). In our case, for the \( \text{TM}_{020} \) mode, the electronic density \( n_e \) is proportional to the frequency shift \( \Delta f \) if \( n_e \) does not exceed \( 4 \times 10^{10} \) cm\(^{-3}\), so

\[ n_e = 7 \times 10^8 \Delta f \quad (4.1) \]

where \( n_e \) is expressed in cm\(^{-3}\) and \( \Delta f \) in MHz.

4.2 METASTABLE DENSITIES. — The optical absorption has been measured on the most intense lines corresponding to radiative transitions terminating on the metastable states concerned; the 1 492.6 Å line for N\((2D)\) and the 1 742.7 Å line for N\((2P)\). Metastable densities are deduced from the \( A_L \) absorption measurement using the graph of the figure 3.

Figures 5 and 6 present the N\((2D)\) and N\((2P)\) density variations versus discharge current for different pressures. For currents lower than 10 mA the metastable densities increase linearly with the current, and the slope increase with the pressure.
Since the discharge current is related to the electronic density, the metastable densities variations can be expressed as functions of \( n_e \) (Figs. 7 and 8). First, densities of both states increase linearly with \( n_e \) and then lead to a saturation for which the \( \text{N}(2\text{P}) \) level is more populated than the \( \text{N}(2\text{D}) \).

5. Discussion. — 5.1 Balance of Metastable Atoms. — Metastable atoms are created by electronic collisions, radiative cascade from upper excited levels and electron-ion recombination and are destroyed by diffusion to the wall, collisions with the neutrals, electronic collisions and collisions between metastables.

The metastable creation rate by electronic-collisions is

\[
\left( \frac{dn_M}{dt} \right)_{e-c} = n_e n_0 C_M^e \quad (5.1)
\]

where \( n_0 \) is the neutral gas density and \( C_M^e \) the overall creation coefficient by electrons. This coefficient includes the direct and stepwise processes which contribute to populate the nitrogen metastable atoms. \( C_M^e \) is a priori a function of the ratio \( n_e/n_0 \) and of the electron temperature \( T_e \). By analogy with rare gases [20], \( C_M^e \) can be estimated to be of the order of \( 10^{-10} \) to \( 10^{-11} \) cm\(^3\) s\(^{-1}\). As \( n_0 \sim 10^{16} \) cm\(^{-3}\) (at 1 torr) and \( n_e \sim 10^9 \) cm\(^{-3}\) the term (5.1) is of the order of \( 10^{14} \) to \( 10^{15} \) cm\(^{-3}\) s\(^{-1}\).

The electron-ion recombination creation rate is proportional to \( n_e^2 \) and to the recombination coefficient \( \alpha \) :

\[
\left( \frac{dn_M}{dt} \right)_{\text{rec.}} = \alpha n_e^2 . \quad (5.2)
\]

Biondi [19] has shown that the \( \alpha \) coefficient decreases strongly when the electronic temperature \( T_e \) increases : \( \alpha = 2.5 \times 10^{-7} \) cm\(^3\) s\(^{-1}\) at \( T_e = 300 \) K and \( \alpha \sim 2 \times 10^{-8} \) cm\(^3\) s\(^{-1}\) at \( T_e = 10^4 \) K. In a positive column, \( T_e \) is always greater than \( 10^4 \) K. If we suppose that all the electron + N\(_2^+\) ion recombinations lead to atomic nitrogen metastable levels, the term (5.2) is of the order of \( 2 \times 10^{10} \) cm\(^{-3}\) s\(^{-1}\) since \( n_e \sim 10^9 \) cm\(^{-3}\). Consequently the metastable creation due to recombination remains negligible compared with the electronic excitation.

The radiative cascade coming from upper excited levels is taken into account in the electronic creation coefficient \( C_M^e \).
In a positive column the radial distribution of metastables is generally a Bessel function. Since the metastables are destroyed on the tube wall, then the diffusion loss term is:

\[
\left( \frac{dn_m}{dt} \right)_{\text{diff}} = n_M \frac{D_M}{A^2}
\]  

(5.3)

where \(D_M\) is the metastable diffusion coefficient, \(A = (R/2.4)\) is the diffusion length and \(R\) the tube radius.

Destruction rates by neutral and electronic collisions are respectively given by

\[
\left( \frac{dn_M}{dt} \right)_{M^0} = n_M n_0 C_M^0
\]  

(5.4)

\[
\left( \frac{dn_M}{dt} \right)_{M^e} = n_M n_e C_e^e
\]  

(5.5)

where \(C_M^0\) and \(C_e^e\) are respectively destruction coefficients by neutral and electronic collisions.

The metastable-metastable collisions can only give recombination on an excited state of the \(N_2\) molecule, because ionization of nitrogen atom is not energetically possible. This effect has to be considered only at high metastable densities (\(n_M > 10^{11}\) cm\(^{-3}\)).

Under steady-state conditions (for \(n_M < 10^{11}\) cm\(^{-3}\)) where the metastable creation rate is equal to the destruction-rate, then the metastable density is given by:

\[
n_M = \frac{n_e n_0 C_M^e}{A^2 + n_0 C_M^0 + n_e C_e^e}
\]  

(5.6)

5.2 ELECTRONIC CREATION COEFFICIENT. — Experimental curves in figures 7 and 8 indicate that the \(N(2D)\) and \(N(2P)\) densities increase linearly with \(n_e\) at low electronic densities. Since \(n_e\) is low, the electronic destruction term can be neglected in eq. (5.6). This equation can be written:

\[
n_M = \frac{n_0 C_M^e}{A^2 + n_0 C_M^0} = a_M
\]  

(5.7)

where \(a_M\) is a constant given by the slope at the origin of the experimental curve \(n_M\) versus \(n_e\). From this experimental result we deduce, first that, the electronic coefficient \(C_e^e\) is independent of \(n_e\); i.e. that the dissociative excitation of the nitrogen metastable appears to be a direct process or a two steps process with an intermediate state independent of \(n_e\). Second that \(C_e^e\) can be determined from the experimental \(a_M\) values if the destruction frequencies \(D_M/A^2\) and \(n_0 C_M^0\) are evaluated.

The vacuum tank maintains the pressure \(P\) constant in the tube. So the nitrogen molecular density \(n_0\) varies with gas temperature \(T\) following the perfect gas law: \(n_0 = P/kT\).

The destruction rate \(C_M^0\) have been measured by different authors for both levels \(N(2D)\) and \(N(2P)\). Those values are collected in table II. There is a good agreement for \(N(2D)\) but for \(N(2P)\), \(C_M^0(2P)\) is ranging from \(10^{-16}\) to \(6 \times 10^{-14}\) cm\(^3\) s\(^{-1}\). The most recent values have been selected:

\[
C_M^0(2D) = 1.8 \times 10^{-14}\text{ cm}^3\text{ s}^{-1}\quad [16]
\]

\[
C_M^0(2P) = 1 \text{ to } 3 \times 10^{-16}\text{ cm}^3\text{ s}^{-1}\quad [17].
\]

Table II. — Neutral quenching coefficients for \(N(2D, 2P)\):

<table>
<thead>
<tr>
<th>(C_M^0(2D)) (cm(^3) s(^{-1}))</th>
<th>(C_M^0(2P)) (cm(^3) s(^{-1}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\leq 6 \times 10^{-15})</td>
<td>(&lt; 3 \times 10^{-19})</td>
<td>[23]</td>
</tr>
<tr>
<td>(1.6 - 2 \times 10^{-14})</td>
<td>(6 \times 10^{-14})</td>
<td>[1]</td>
</tr>
<tr>
<td>(1.5 \times 10^{-14})</td>
<td>(10^{-16})</td>
<td>[24]</td>
</tr>
<tr>
<td>(1.8 \times 10^{-14})</td>
<td>(1 - 3 \times 10^{-16})</td>
<td>[16]</td>
</tr>
</tbody>
</table>

The diffusion coefficient of atomic nitrogen in molecular nitrogen \(D(N, N_2)\) has been measured [18]:

\[D(N, N_2) = 221 \text{ cm}^2\text{ s}^{-1} \text{ torr} \text{ at } 280 \text{ K where } P\]

is the gas pressure. Because diffusion coefficients \(D_M(2D, N_2)\) and \(D_M(2P, N_2)\) are not known, we have used the \(D(N, N_2)\) value. The product \(DP\) (diffusion coefficient \(\times\) pressure) is proportional to \(T^{3/2}\) [18]. At \(T = 500 \text{ K}\), the diffusion coefficients chosen are:

\[D_M(2D, N_2) = D_M(2P, N_2) = 527 \text{ cm}^2\text{ s}^{-1}\text{ torr}.
\]

In the table III are reported, for different pressures, the estimated value of \(D_M/A^2\), \(n_0 C_M^0\), the measured \(a_M(2D)\) and \(a_M(2P)\) slopes and the deduced \(C_e^{2D}\) and \(C_e^{2P}\) coefficients. The diffusion frequency \(D_M/A^2\) an the quenching frequency of \(N(2D)\) are respectively of the order of \(3 \times 10^3\) s\(^{-1}\) and \(3 \times 10^2\) s\(^{-1}\).

The quenching rate of \(N(2P)\) is two order of magnitude smaller than the \(N(2D)\). The quenching of \(N(2P)\) by \(N_2\) molecules is negligible with respect to the diffusion. We found that \(C_e^{2P}\) and \(C_e^{2P}\) are of the same order of magnitude and decrease from \(1.5 \times 10^{-10}\) to \(4 \times 10^{-11}\) cm\(^3\) s\(^{-1}\) when the pressure increases from 0.5 to 1.5 torr.

The experimental determinations of \(C_e^{2D}\) and \(C_e^{2P}\) are very sensitive to the neutral gas temperature, because they are calculated from eq. (5.7) where \(n_0\) and \(D_M\) are functions of \(T\). For instance, we have seen that

\[C_e^{2P} = a_M(2P) \frac{D_M/A^2}{n_0}.
\]
For a fixed pressure we measure the slope $a_M(2P)$, we see that the deduced coefficient is a function of $T^{3/2}$. The temperature $T$ is measured with an accuracy of ± 50 K, that gives an error of about ± 30 % on $T^{3/2}$. The accuracy of the $a_M$ measurement is about 20 %. The determination of the coefficients $C_e^{2D}$ and $C_e^{2P}$ is made with an accuracy of about 50 %.

The results can be compared to those found for argon [20] for $n_0 R < 10^{16}$ cm$^{-2}$.

$$C_e(3P_d) = 2 \left( \pm 0.7 \right) \times 10^{-11} \text{ cm}^3 \text{s}^{-1}$$

$$C_e(3P_o) = 3 \left( \pm 1 \right) \times 10^{-12} \text{ cm}^3 \text{s}^{-1}$$

For $n_0 R < 10^{16}$ cm$^{-2}$, in the Maxwell distribution approximation for the electron energy, the electronic temperatures are of the order of 2 eV in argon and nitrogen. Argon and atomic nitrogen metastable levels are located about 12 eV above the ground level ($N_2(X, 1\Sigma_g^+)$ for nitrogen).

Although excitation conditions are nearly the same in the two gases, we found that electronic-creation coefficient $C_e^{2D}$ and $C_e^{2P}$ in nitrogen are greater than those of metastable argon.

We can also notice that the exchange

$$N(1D) \approx N(1P)$$

by electron collisions can be neglected. With this exchange process, the $N(1D)$ electron collisions creation term is:

$$\frac{d n(1D)}{dt} = n_e(n_0 C_e^{1p} + n(3P) C_{1p}^{2D}) \ldots (5.8)$$

By analogy with rare gas, for instance helium [21] for which the two metastable levels are separated by 0.8 eV, the exchange coefficient would be

$$C_{1p}^{2D} \approx 10^{-6} - 10^{-7} \text{ cm}^3 \text{s}^{-1}$$

The product $n(3P) C_{1p}^{2D}$ is of the order of $10^3$ to $10^4 \text{ s}^{-1}$ and can be neglected when compared with $n_0 C_e^{1p} \approx 10^6 \text{ s}^{-1}$.

Figures 7 and 8 show that for electron densities $n_e > 10^9 \text{ cm}^{-3}$ the metastable densities are nearly saturated. This effect can be described by the eq. (5.6) when the electronic collisions are the dominant loss term. Then the saturated metastable densities $n_M$ could be written:

$$n_M = n_0 C_e^{1p} C_M^{1M}$$

The ratio $C_M^{1M}/C_e^{1M}$ of the electronic coefficients could be deduced from the $n_M$ and $n_0$ measurements. But, in this high electron density range the variation of each coefficient with $n_e$ remains unknown. Metastable-metastable collisions may become efficient in this nearly saturated range where $n_M > 10^{11} \text{ cm}^{-3}$, then eq. (5.9) would not be valid. Furthermore, the relative contribution of direct and stepwise process must be studied accurately in this high electron and metastable densities range before calculating the $C_e^{1M}$ coefficient.

6. Conclusion.—We have determined the $N(2D, 2P)$ metastable atomic concentration in a $N_2$ glow discharge ($R = 1$ cm) for current intensities $2 < I < 50$ mA and pressures $0.5 < p < 1.5$ torr. In the range $10 < I < 50$ mA, the atoms concentration $N(2P)$ is higher than that of $N(2D)$. Lin-Kaufman [1] and Foner-Hudson [5] have found opposite results in mixtures of rare gas-nitrogen at higher pressures. In the present pure $N_2$ discharges, the electrons collisions are efficient processes to excite and dissociate molecular nitrogen. Consequently, the following reaction has to be taken into account in the production of $N(2P)$ states [2, 22] :

$$N_2(A, 1\Sigma_u^+) + N \rightarrow N_2(X, 1\Sigma_g^+) + N(2P) \ldots (6.1)$$

with

$$\kappa_N = 5 \times 10^{-11} \text{ cm}^3 \text{s}^{-1} \text{ at } 300 \text{ K} \ldots [22]$$
At low electronic densities (\(n_e < 2 \times 10^8 \text{ cm}^{-3}\)), the \(N(2D, 2P)\) densities increase linearly with \(n_e\). We deduce from this variation that the electronic creation coefficients of the atomic metastable states \(C_{2D}^+\) and \(C_{2P}^+\) are independent of the electronic density. The values obtained for the two coefficients are on the same order of magnitude and decrease as the pressure increase.

References