ELECTRON IMPACT EXCITATION OF THE SECOND POSITIVE SYSTEM OF N_2

Marián Danko[1], Juraj Országh[1], Anita Ribar, Jaroslav Kočíšek and Štefan Matejčík[1]

[1]*Department of Experimental Physics, Comenius University, Mlynská dolina F2, 84245 Bratislava, Slovak Republic*

E-mail: matejcik@fmph.uniba.sk

The electron impact excitation of the second positive system of N_2 (2nd PS N_2) have been studied in a new crossed electron/molecular beams apparatus. The excited states C $^3\Pi_u(v')$ (v'=0..4) were excited using electron beam with high energy resolution. The electron induced optical spectra in UV/VIS range (290 – 440 nm), the excitation thresholds of particular vibrational states C $^3\Pi_u(v')$, the emission cross sections of the 2nd PS and the excitation cross sections of the C $^3\Pi_u(v')$ states were measured with high resolution and sensitivity.

1. Introduction

Optical emission spectroscopy (OES) is an important toll to study the properties of the atmospheric pressure plasmas, or discharges. In the case of air the nitrogen molecule plays an important role in OES. The OES yields important information about the plasma and electric discharges, e.g., energy of the electrons, vibrational and rotational temperatures of the gas etc. The second positive system $C\,^3\Pi_u(v') \rightarrow B^3\Pi_g(v'')$ belongs to the most intensive bands in the emission spectrum of the nitrogen, or air. Due to this property the electron impact excitation of the N_2 state $C\,^3\Pi_u(v')$ draws much attention. The upper excited state $C\,^3\Pi_u$ is mainly populated directly by the inelastic scattering of the electrons and in a less extent by the cascading transitions from higher excited states [1].

The process of excitation of the molecules by electron impact and subsequent detection of the photons is often called "electron induced fluorescence" (EIF). The quantity, which describes the efficiency of the EIF process, is called emission cross section. The emission cross sections describes a complex process which consists of the excitation of the molecule into a particular excited state $C\,^3\Pi_u$ and subsequent deexcitation of this state by the photon emission:

$$e(\varepsilon_1) + N_2(X^1\Sigma_g^+) \rightarrow C\,^3\Pi_u(v') + e(\varepsilon_2)$$
$$-C\,^3\Pi_u(v') \rightarrow B^3\Pi_g(v'') + h\nu \quad (1)$$

The emission cross section $\sigma_{v''}^{em}$ is directly measured in the present experiment. On other hand, the excitation cross sections σ_v describes only the first part of the process described by the the emission cross section, the excitation of particular vibrational states of the $C\,^3\Pi_u$. The excitation cross section can be obtained from the measured emission cross sections σ_v^{em} using following relation:

$$\sigma_{v'} = \sigma_{v''}^{em} A_{v',v''} \tau_{v'} \quad (2)$$

where $A_{v',v''}$ is the transition probability and $\tau_{v'}$ is the mean lifetime of level v'. Excitation cross sections can be measure also by inelastic electron scattering techniques.

The emission cross sections, for the various vibrational bands of the second positive systems have been already measured by researchers in several laboratories [1,2,3,4].Up to now there exists only one work, where this excitation has been studied using well defined, high resolution electron beam [2]. In spite of these studies there still exists interest in new data, achieved with high resolution in the electron energy. High resolution experiments may yield more precise values of the threshold energies and also show new phenomena in the excitation cross sections such as resonances. Therefore an accurate knowledge of the excitation cross sections of the $C\,^3\Pi_u(v')$ state is the primary interest for the understanding of several important phenomena in nitrogen.

The emission cross sections for 2nd PS in N_2 have been measured by the detection of the photons from the second positive system in the 290-440 nm spectral range. Excitation functions of several optical lines have been measured and normalized to obtain absolute values of the emission cross sections. The present measurements have been carried out with high electron energy resolution and more accurate electron energy calibration than any previous studies. This has allowed to detect two thresholds in several emission cross sections. Using calibration method (2) we have transformed the emission cross sections into excitation cross sections. Excitations cross sections for the vibrational states (v'=0,1, 2,3 and 4) of $C\,^3\Pi_u(v')$ have been determined in present experiment.

2. Experimental setup

We have used a new crossed electron – molecular beams apparatus - EIFA to study the EIF in N_2 . The apparatus is shown schematically in the Figure 1. It consists of i) electron monochromator producing a collimated beam of electrons, ii) the collision chamber is filled with a target gas, iii) the detection system detecting spectrally analysed photons.

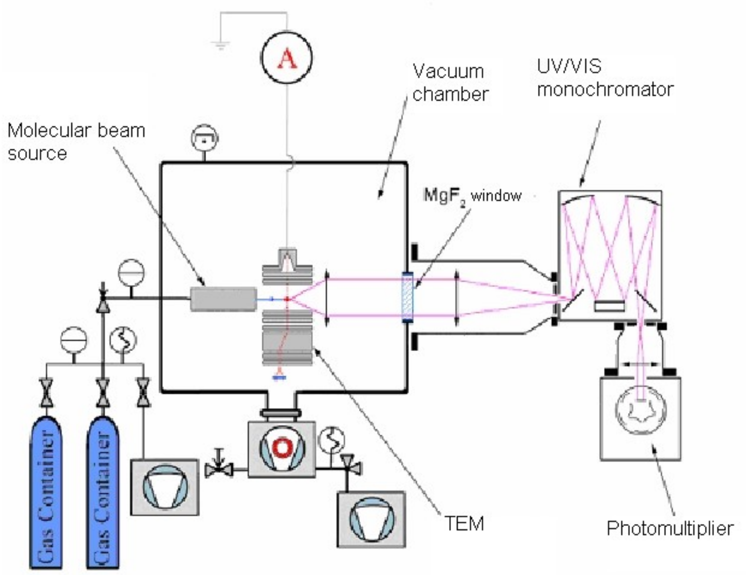

Fig. 1. Experimental setup.

The incident beam with an energy spread of approximately 150 meV and a typical electron current of 90 nA is produced by the trochoidal electron monochromator (TEM). The photons emitted from the collision region are collected by a MgF_2 lens and transmitted via quartz vacuum window outside of the vacuum chamber and refocused by second MgF_2 lens onto the entrance slit of an 0.25 m optical monochromator. The photons are detected at its exit slit by the Hamamatsu H8259 photomultiplier. The photomultiplier works in the photon counting regime and is cooled to -20°C in order to reduce the noise. The magnetic field ($5\mathrm{x}10^{-3}$ T) is produced by a pair of coils which allow for accurate alignment of the direction of the field with respect to the electron spectrometer symmetry axis. The measurements were carried out for pressure range of 1.10^{-4} mbar in the collision region which gave linear dependence between detected photons intensity and target pressure. It was also ensured that the detected photon intensity increased linearly with the electron beam current.

3. Results and discussion

The fluorescence spectrum of the 2nd PS N_2 induced by the electrons with kinetic energy of 14.2 eV is shown in the Figure 2. The (v',v'') transitions of the second positive system have been identified and are indicated in the spectrum. The intensities of the observed transitions enable to estimate the emission cross sections for (v',v'') transitions of 2nd PS as function of the kinetic energy of the electrons. The emission cross sections for selected $C\,^3\Pi_u(v')$ to $B\,^3\Pi_g(v'')$ transitions are presented in the figures 3a and 3b.

The high energy resolution of the electron beam has been used to estimate the thresholds of the excitation cross sections for particular emission bands of 2nd PS of N_2. The excitation by electron impact is an endothermic process, thus there exist thresholds for these reactions. We have analysed the thresholds (Table 1.) in the electron energy range up to 14 eV. In this energy range we have seen two thresholds in each emission cross sections. We have used fitting procedures described in [5] to obtain the values of the threshold. The nature of the first threshold is not satisfactory explained. The second threshold, where more intense emission starts, is assigned to the direct excitation of the $C^3\Pi_u$ state by the electron [4]. Shemansky et al. [4] suggested that the emission below the second threshold has origin in the core excited and Feshbach resonances of N_2^- ($E\ ^1\Sigma_g^+$). These resonances have been measured by Maeau et al [6] and Kurzweg et al [7].

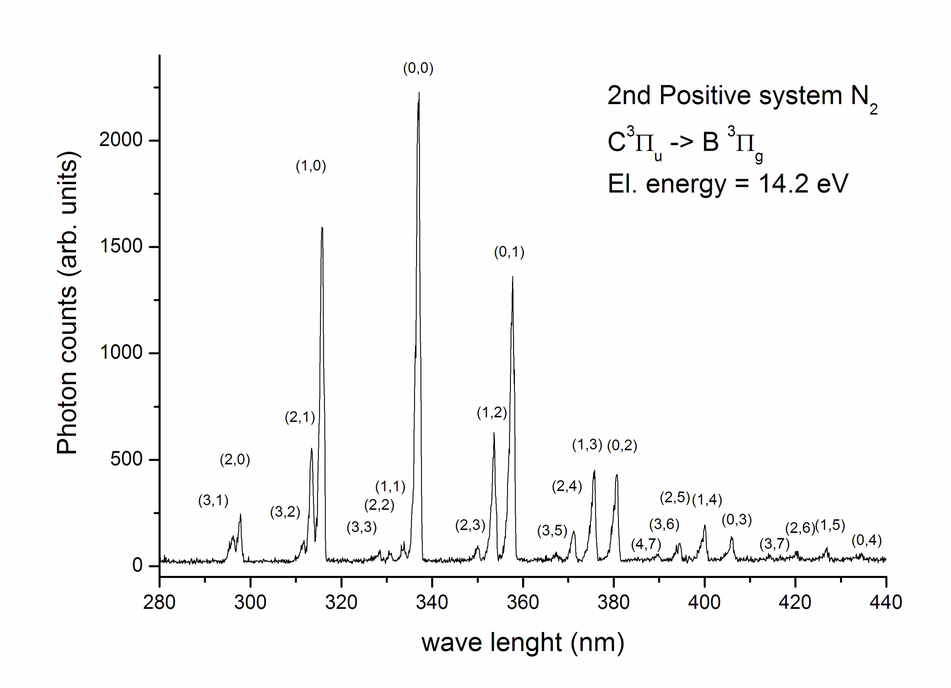

Fig. 2. The fluorescence spectrum of nitrogen 2nd positive system induced by electrons with kinetic energy of 14.2 eV.

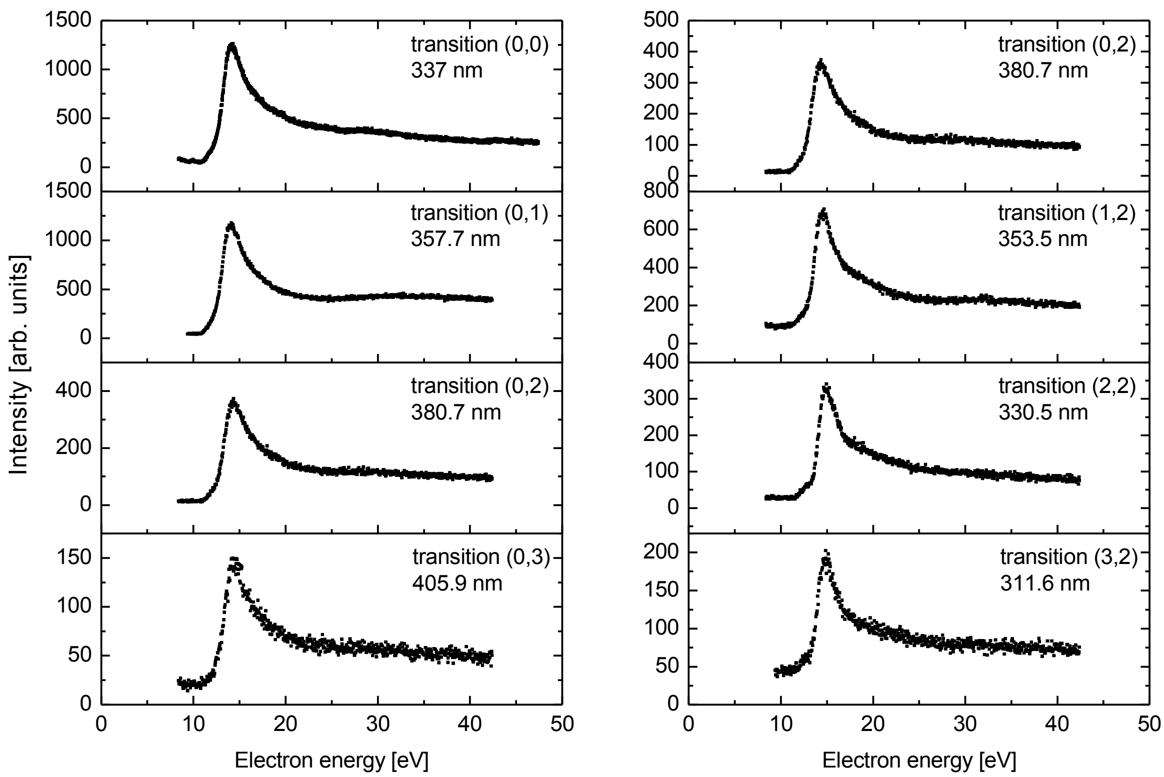

Fig. 3a and 3b. The emission cross sections for selected transitions of the 2nd PS of N_2.

Table 1. The threshold energies of emission cross sections for (v', v'') transitions in 2nd PS N_2

v', v''	1st threshold (eV)	2nd threshold (eV)
0.0	10.60±0.12	11.74±0.1
0,1	10.60±0.1	12,20±0.1
0,2	10.66±0.1	12.20±0.1
0,3	10.72±0.1	11.98±0.1
1,1	11.28±0.1	13.10±0.1
1,2	10.90±0.1	12.49±0.1
2,2	11.27±0.1	13.11±0.1
3,2	11.03±0.1	12.99±0.2
3,3	11.18±0.1	13.10±0.2

The data in the Table 1 indicate that there exist differences in the threshold energies of particular vibrational states of $C\,^3\Pi_u$. This is in contrast to former work by Fons [3], who stated that there is no difference in threshold for these states. However, his experiment suffered of weak resolution in the electron energy.

The excitation cross section of the strongest emission band of the 2nd PS $C\,^3\Pi_u(v'=0)$ to $B\,^3\Pi_g(v''=0)$ (337 nm) is presented in the Figure 4. The excitation cross section has been measured in the energy region from threshold to 80 eV and it has been normalised to the absolute emission cross section at its maximum at 14.1 eV. The electron energy range and the absolute value of the cross section have been calibrated to cross section measured by Zubek [2]. Excitation cross sections of additional transition lines of the 2nd PS of the N_2 have been measured.

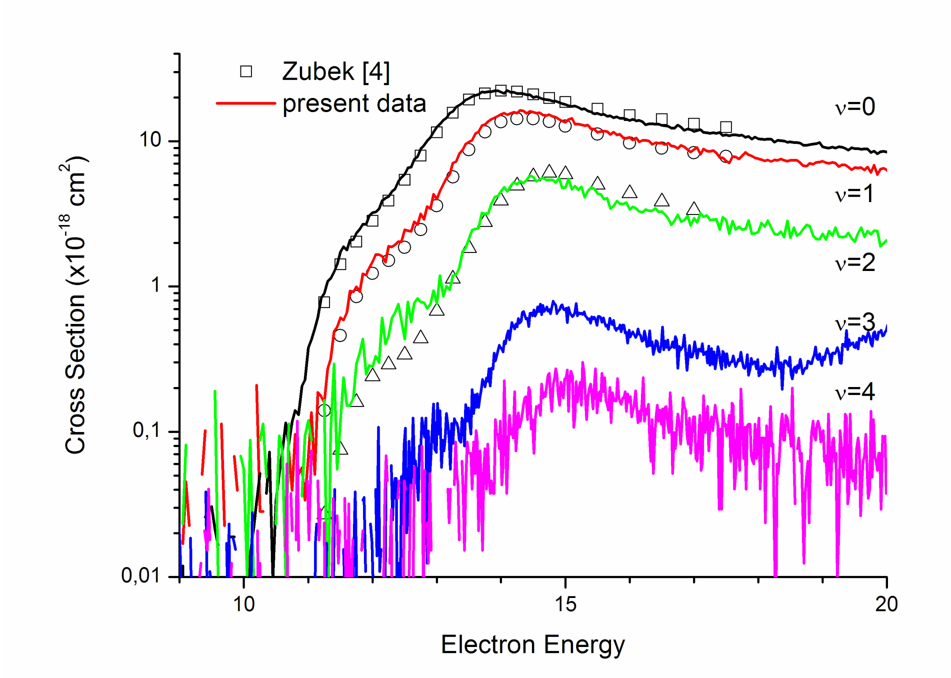

Fig. 4. Excitation cross section of the $C\,^3\Pi_u(v'=0,1,2,3,4)$ N_2 and its comparison with the data of Zubek [2].

4. Conclusions

We have studied the process of EIF in N_2 for 2nd PS. We have measured high resolution emission spectra, emission cross sections and determined excitation cross sections for the excited states $C\,^3\Pi_u$ ($v'=0..4$) of N_2. We have determined the threshold energies in emission cross sections for particular bands of the 2nd PS of N_2.

5. Acknowledgment

This work was supported the Slovak Research and Development Agency, project Nr. APVV-0365-07 and LPP-0143-06. In addition this work was supported by Association EURATOM-CU. The content of the publication is the sole responsibility of its publishers and it does not necessarily represent the views of the EU Commission or its services.

6. References

[1] M. Shaw and J. Campos, J. Quont. Speetrosc. Radiat. Transfer 30 (1983) 73
[2] M. Zubek, J. Phys. B: At, Mol. Opt. Phys., 27 (1994) 573
[3] J.T. Fons, Phys. Rev. A, 53 (1996) 2239
[4] D.E. Shemansky, J.M. Ajello, I. Kanik, Astrophys. J., 452(1995) 472
[5] M. Stano, S. Matejcik, J.D. Skalny and T. D. Märk, J. Phys. B: At. Mol. Opt. Phys. , 36 (2003) 261