Publ. Astron. Obs. Belgrade No. 102 (2022), 215 - 218 *Contributed Paper*

DETECTION OF FAST NITROGEN AND OXYGEN ATOMS VIA EMISSION SPECTROSCOPY

B. M. OBRADOVIĆ[1], N. CVETANOVIĆ[2], I. B. KRSTIĆ[1] and M. M. KURAICA[1]

[1]*University of Belgrade, Faculty of Physics, 11001 Belgrade, Serbia*

[2]*University of Belgrade, Faculty of Transport and Traffic Engineering,*
11000 Belgrade, Serbia
E-mail nikola@ff.bg.ac.rs

Abstract. Fast atoms are generated in charge exchange reactions of ions with the molecular gas both in laboratory and astrophysical plasma. In hydrogen, they are observed in the emission spectra via Excessive line broadening. In this study, we have used a special configuration of the electrode system, to obtain energetic atoms in plasma of diatomic gases. Emission spectroscopy was used to detect the N and O fast atoms and measure their velocity. Energy analysis was performed to obtain atoms' distributions and evaluate the mean energy of atoms. This was compared to the potential energy available from the electric field. The field acceleration model, previously established for hydrogen, was extended to nitrogen and oxygen.

1. INTRODUCTION

Fast atoms are produced both in astrophysical and laboratory plasma. Exited atoms are detected in spectra with unusually high energies for heavy particles - of the order of keV. In molecular hydrogen, the process is well described via the charge exchange reaction. Specifically, the so-called field acceleration model (FAM), describes the process in which atomic and molecular ions accelerating in the electric field reach high energies, due to the low cross section for the asymmetric process (Phelps, 2011, 2009) . After the charge exchange collision occurs, a fast neutral atom is formed preserving the momentum and kinetic energy of the ion. The fast atom can then be excited in the collisions with the surrounding gas.

The Doppler shifted radiation of fast atoms, shows a distorted far wing of the line, the so-called Excessive line broadening (Cvetanović et al., 2005) of the order of ~nm. The phenomenon of excessive Doppler broadening and corresponding fast atoms was examined experimentality in detail in several types of laboratory plasma, see the references in (Cvetanović et al., 2011).

As noted above, the effect of detecting fast atoms via Doppler shift can be valid for any molecular plasma. However due to the low mass of the emitters, only hydrogen

Excessive broadening can be easily detected. In the literature, the effect was obtained so far exclusively in hydrogen plasma with exception of one paper in nitrogen (Wang et al., 2000). Here results are obtained in nitrogen and oxygen plasma.

In hydrogen discharge, three types of ions are formed H^+, H_2^+, H_3^+. The fast nitrogen and oxygen atoms are produced via similar mechanisms but mostly from the atomic ion collision with slow molecule (Phelps, 1991; Stebbings et al., 1963). In all cases, the fast atom is excited mostly through the process of collisions with molecular gas. The spontaneous emission then gives Doppler shifted radiation by $\Delta\lambda$.

2. EXPERIMENTAL SETUP

The experimental setup consists of a hollow cathode discharge chamber, gas control and pressure system, power supply and the optical detection system. The detailed scheme can be found in Ref. (Cvetanović et al., 2011), though a different spectrometer is used in this experiment. A gas flow of about 300 cm^3/min of nitrogen or oxygen was sustained at a selected pressure. by means of a needle valve and a two-stage mechanical vacuum pump. To run the discharge, a 0–2.5 kV voltage stabilized power supply is used. The discharge image was projected by a lens to the entrance slit of 1-m monochromator. At the exit of the monochromator, radiation was detected using a two-dimensional ICCD camera. The instrumental profile half-width was measured to be FWHM=0.035 nm.

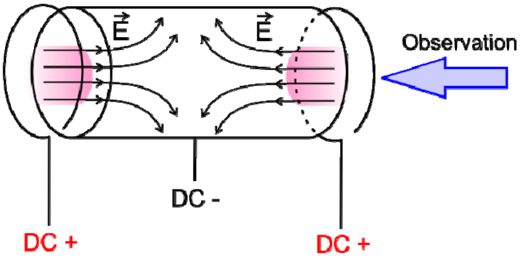

Figure 1: Schematics of the hollow-cathode discharge. The sheath electric field is shown.

The plasma reactor itself is a hollow-cathode discharge, with a cylindrical cathode and a round wire anode set further from the cathode cylinder, see Fig. 1. Both anode and cathode have the diameter of 10 mm. The distance between the edge of the cathode cylinder and the anode wire is 3 mm. Below the pressure of 1 mbar the discharge operates in the so-called low-pressure regime. Namely, at pressure below 1 mbar, the negative glow is notably extracted from the cathode cylinder, so the sheath (or cathode fall) fills the gap to the anode ring thus making the electric field vector coincide with the central axis of the cathode cylinder (Fig 1). To sustain this field configuration the applied discharge voltage must be increased.

Additional feature of our electrode system is that it has two wire anodes on each side of the cathode cylinder. This construction of the discharge electrodes enabled engaging either one of the anodes or both, if required. Effectively, this changes the direction of the field in respect to the detector i.e., direction of observation, see Fig. 1. This enabled observation of very small Doppler shift of the moving particles since the change of the field direction creates asymmetry of the measured spectral line.

3. RESULTS

It was determined that reduction of pressure extends the mean free path of the ions thereby creating faster atoms. Low pressure was chosen in here in order to maximize the shift in the spectrum. The nitrogen spectrum was measured for two groups of lines: 818-825 nm and the NI ($3p^4D \rightarrow 3s^4P$) triplet transition at 868 nm. The asymmetric broadening is ≈0.2 nm but it can still be observed since the asymmetry of each spectral line changes from "red" to "blue" with the electric field reversal. To obtain the velocities of the emitting N atoms, transition NI ($3p^4P \rightarrow 3s^4P$) at 822 nm is chosen and recorded at lower pressure, see Figure 2. It can be seen that in the case of nitrogen the maximum velocity reached is ≈100 km/s.

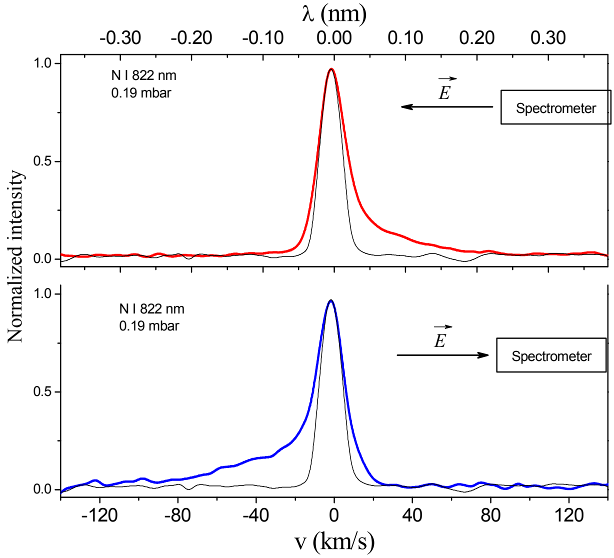

Figure 2: Nitrogen NI ($3p^4P \rightarrow 3s^4P$) 822 nm shown in the velocity scale. The instrumental profile is shown for comparison. Conditions: U=1300 V, p=0.19 mbar, I=1.2 mA.

Detecting fast atoms in oxygen plasma is even more difficult due to the even larger atom mass (M(O)=16). The spectrum of the notable OI 777 nm triplet for two field directions is shown in Figure. 3. The spectrum measured from the Geisler tube, with line profiles close to instrumental profile, is shown to clearly note the small asymmetry in the line profile. The spectral observation of oxygen fast atom in a discharge was not published so far. Again, the difficulty lies in very small Doppler shift. The spectral line in the velocity scale is shown in Fig.8.

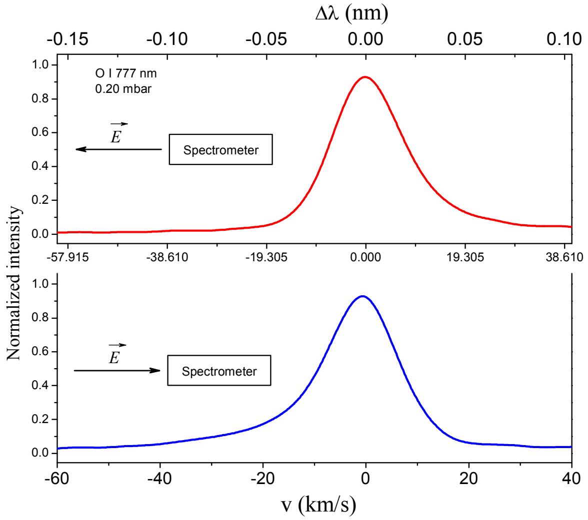

Figure 3: Oxygen triplet OI ($3p^5P \rightarrow 3s^5S$) 777.4 nm shown in the velocity scale. Conditions: U=1000 V, p=0.17 mbar, I=0.7 mA.

Using variable transformation, energy distribution of atoms can be obtained. The mean kinetic energy was calculated at 252 eV for nitrogen and 145 eV for oxygen atoms. The maximum kinetic energy for both gases corresponds to about ~80% of the available potential energy from the electric field, respectively.

Therefore, the detection of fast atoms in nitrogen and oxygen discharge was successfully demonstrated. Energy analysis can be performed and the FAM model can be well extended to these gases.

References

Cvetanović, N., Kuraica, M.M., Konjević, N., 2005. J. Appl. Phys. 97, 033302.
Cvetanović, N., Obradović, B.M., Kuraica, M.M., 2011.. J. Appl. Phys. 110, 073306.
Phelps, A. V., 2011.: Plasma Sources Sci. Technol. 20, 043001.
Phelps, A. V., 2009.: Model. Phys. Rev. E 79, 066401.
Phelps, A. V., 1991:. J. Phys. Chem. Ref. Data.
Stebbings, R.F., Turner, B.R., Smith, A.C.H., 1963.: J. Chem. Phys. 38, 2277–2279.