

## Separation of ions with the same charge to mass ratio from a collision experiment\*

DRAGOLJUB S. BELIĆ<sup>1</sup> and PIERRE DEFRANCE<sup>2</sup>

<sup>1</sup>*Faculty of Physics, P. O. Box 368, YU-11000 Belgrade, Yugoslavia and* <sup>2</sup>*Departement de Physique, Université Catholique de Louvain, 2 Chemin du Cyclotron, B-1348, Louvain-La-Neuve, Belgium*

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Some atomic collision experiments lead to ions having identical  $q/m$  ratio, as well as average velocity, so that standard electric and magnetic analyzers are not able to identify them separately. This situation occurs, for instance, in electron interaction with molecular monocations ( $A_2^+$ ) producing  $A_2^{2+}$  (direct ionization) and  $A^+$  (dissociation or dissociative ionization). Due to the transfer of internal energy to the kinetic energy of the fragments, they usually have a wider angular and energy distribution in the laboratory frame, compared to direct ionization. By use of a specially designed animated crossed beams apparatus, we are able to separate ionization and dissociation fragments. Here the preliminary results of cross sections measurements for electron impact on the nitrogen monocation, producing  $N_2^{2+}$  and  $N^+$  ions, is reported

*Keywords:* ionization, dissociation, molecule, monocation, mass analyzer, cross section, transmission efficiency.

### INTRODUCTION

Electron impact ionization of molecular ions is an important process in astrophysics, the Earth's atmosphere and any laboratory plasma. Its investigation is related to a number of experimental difficulties as a consequence of the more complex structure of molecular ions compared to atomic species. Furthermore, the ionization process is usually followed by dissociation to energetic fragments, which are difficult to collect after collision. In some cases the produced ions have identical charge to mass ratios, as well as average velocity, and cannot be separated. Here recent experimental progress in overcoming some of these difficulties will be reported.

### EXPERIMENT AND TRANSMISSION EFFICIENCY

The measurements were performed using the animated crossed beams technique, in the energy range from the threshold to about 2 keV. The primary ion beam, produced in a small Penning ion source, 1, was accelerated to 4 keV, Fig. 1. The beam was selected by a 30° magnetic analyzer, 3, and crossed at right angles with an animated<sup>1</sup> electron

\* Dedicated to Professor Slobodan Ribnikar on the occasion of his 70<sup>th</sup> birthday

beam, 6. After the collision, the product ions were selected by a  $90^\circ$  magnetic analyzer, 8, focused by a  $90^\circ$  spherical deflector, 10, and detected by a multichannel plate detector, 11. The cross sections were determined by a standard procedure, described elsewhere.<sup>2</sup> The experiments were performed on  $\text{CO}^+$  and  $\text{N}_2^+$  ions.

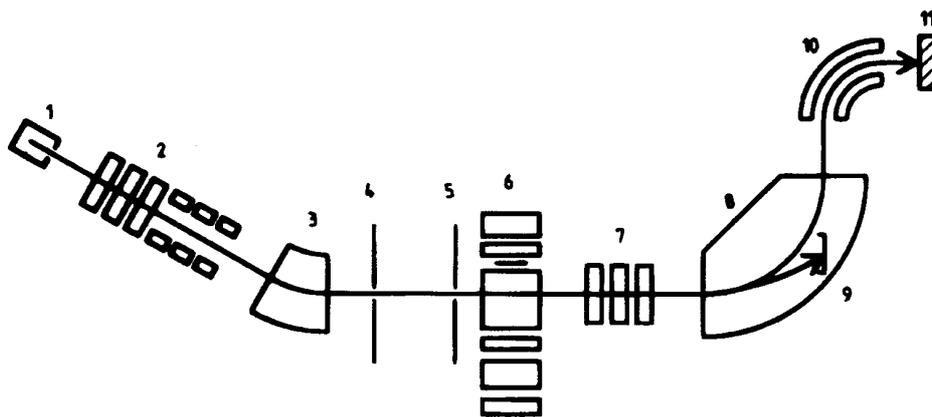


Fig. 1. Experimental set up: 1—ion source, 2—electrostatic lenses, 3—separation magnet, 4,5—apertures, 6—electron gun, 7—deflector, 8—mass spectrometer, 9—Faraday cup, 10—hemispherical deflector, 11—detector.

Due to the transfer of internal energy to the kinetic energy, the dissociation fragments have a wide energy and angular distribution, in the laboratory frame. After dispersion in the analyzing magnet, the spatial distribution in the dispersion (horizontal) plane is sufficiently large to prevent the total collection of product fragments, due to the limited size of the detector. In fact, the size of the detector is not the actual limiter, but rather the vertical slit placed at the exit of the magnetic analyzer in order to prevent detection of particles scattered from the surfaces and particularly from the edges of the detector. This slit is 8 mm wide (relative to the detector diameter of 25 mm), which is wide enough to ensure total transmission of direct ionization events, either atomic or molecular. This can be confirmed by a careful scan of the analyzing magnetic field, Fig. 2a. The signal count rate or cross section as a function of the magnetic field strength exhibits a wide plateau, which is the usual test for the total collection of ions, systematically performed for all focussing or deflecting ion beam transport elements. At the beginning and end of this profile, the first derivative gives the energy distribution or actual spatial size of the beam, in terms of slit width. For atomic species (or primary beam), this size is usually a few times smaller than the width of the slit. However, for dissociation fragments, the profile of the magnetic scan of the cross section is much wider and does not exhibit a plateau, indicating that the size of the beam was larger than the defining slit, and, thus, that the collection was not complete. Only a fraction of product charged fragments is collected at any beam position and this need to be corrected. The ratio of the collected and the actual number of particles is called the transmission efficiency. Let us refer to the measured cross section as apparent, and determine the real cross section from there.

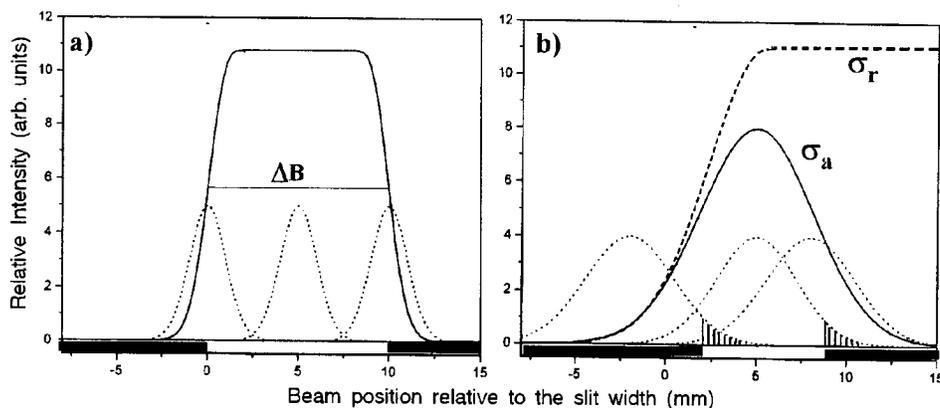


Fig. 2. Signal transmission by: a) wide and b) narrow slit (see text).

Assuming that the change of the magnetic field does not influence the beam size significantly, since the scan occurs at only few % of the expected field value, a steady beam sweeping across the slit from one side to the another, say from left to right, in equal steps, can be imagined. One way to determine the transmission is to choose a beam profile with a few fitting parameters and to integrate the part which passes the slit while moving the beam, until the apparent profile is reproduced. However, another, more elegant and direct procedure is possible. It is related to the way the profile is actually obtained. When the center of the beam reaches the position where its low energy side enters the slit, a signal will start to appear. This will increase until the low energy side reaches the right edge of the slit, where it gets lost, and the profile generally falls off, Fig. 2b. This point is at the distance of 8 mm (slit width) or equivalent in  $\Delta B$  from the first point. From this point, the signal needs to be corrected by the amount which was obtained so far, *i.e.*, increased for the value at  $B - \Delta B$ . Following this procedure the correction to the existence of the right edge can be performed and at the right side it leads to the real signal,  $\sigma_r$ , which would be obtained if there were not a right edge of the slit. A simple formula relates the real signal to the apparent one:

$$\sigma_r(B) = \sigma_a(B) + \sigma_r(B - \Delta B) \quad (1)$$

The maximum at the right side, at the higher magnetic field  $B$ , reaches a plateau which represents the total real signal and the ratio of  $\sigma_a$  at  $B_0$  and this value gives the transmission efficiency. In our previous measurements of asymmetric dissociative ionization<sup>2,3</sup> this efficiency was determined to be 50.0 % for  $C^{2+}$  from  $CO^+$ , 46.6 % for  $O^{2+}$  from  $CO^+$ , 35.8 % for  $N^{2+}$  from  $N_2^+$  and 42.0 % for  $O^{2+}$  from  $O_2^+$ . Another similar experiment has recently been performed on cross section measurements for  $D^+$  production<sup>4</sup> from  $CD^+$ . In this experiment, the analyzing electric field was fixed and the detector was moved with a high precision in the plane of dispersion, from where the total signal was inferred.

SEPARATION OF IONS WITH THE SAME  $Q/M$  RATIO

In the case of electron impact on homonuclear diatomic molecular monocation, such as  $N_2^+$  and  $O_2^+$ , different particles with the same  $q/m$  ratio can be produced. For instance, for  $N_2^+$ , the following reactions, among the others, are possible:



where the first represents simple ionization, the second is dissociation and the last one is dissociative ionization. Here, preliminary results of cross sections measurements for electron impact on the nitrogen monocation, producing  $N_2^{2+}$  and  $N^+$  ions, are reported. Both  $N^+$  and  $N_2^{2+}$  ions have the same ratio of  $q/m = 1/14$ .

From our previous experience on dissociative ionization<sup>2,3</sup> we have learned that, due to the transfer of internal energy into the fragments kinetic energy in the laboratory frame, the fragments have a wide energy distribution. However, the energy of the product dication from simple ionization remains unchanged. Thus, by an energy analysis, the products can be separated. For this reason, a scan of the mass analyzer magnetic field, simultaneously measuring the apparent cross section, was made. The result is shown in Fig. 3.

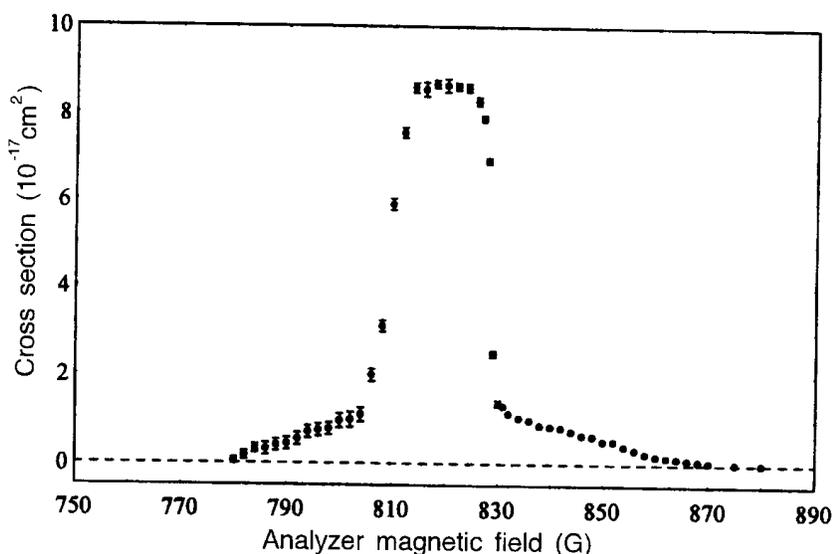


Fig. 3. Apparent cross section *versus* analyzer magnetic field for  $N_2^+$ .

The apparent cross section exhibits two contributions. The lower wide contribution is from  $N^+$  ions, which have a larger energy distribution due to their

dissociation origin. The upper narrow distribution corresponds to simple ionization, since its FWHM is the same as that of the primary beam. By the simple numerical procedure discussed above, the cross sections for simple ionization were estimated to be  $6.5 \times 10^{-17} \text{ cm}^2$  and for  $\text{N}^+$  production  $5.3 \times 10^{-17} \text{ cm}^2$ , at an energy of 150 eV. This is only the first preliminary result and some discrepancies with previous measurements<sup>5,6</sup> need to be resolved.

By a careful analysis of the curve shown in Fig. 3, three existing contributions can in fact be identified, corresponding to processes (2a), (2b) and (2c). Their forms are shown in Fig. 4. Curve 3 represents dissociative ionization. Curve 2 is the fit and 2' represents dissociation (2b). Curve 1 is again the fit and 1' represents the net contribution of direct ionization process.

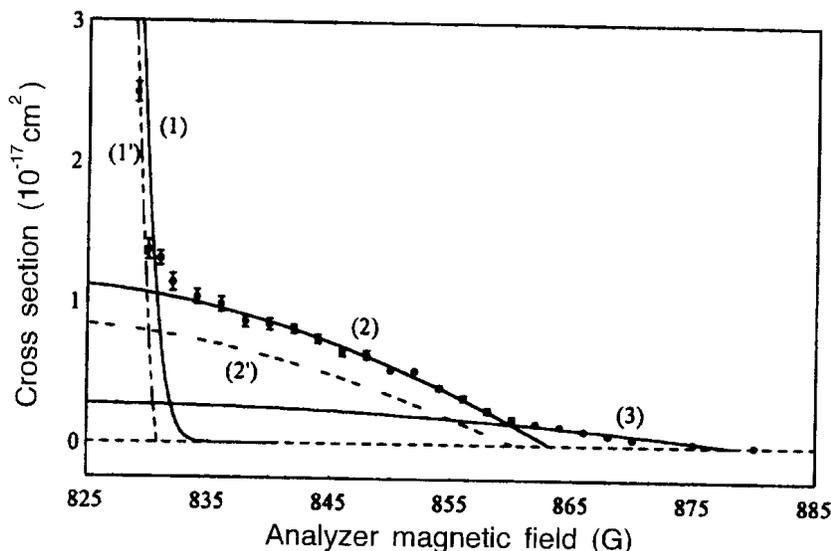


Fig. 4. Separated contributions to the apparent cross sections.

This procedure was performed for various electron energies in order to determine the behavior of the cross section with energy. Also, systematic cross sections measurements were performed for fixed selected magnetic field values, *e.g.* at the cross section maximum of Fig. 3, as well as for some selected values to the left and right of the maximum. From all these measurements, after corrections to the transmission functions, absolute cross sections for various processes were inferred, in the energy range from the threshold to 2 keV. The cross section for direct ionization has a threshold energy of 30 eV, and maximum value of  $5.8 \times 10^{-17} \text{ cm}^2$  at 120 eV. The cross section for dissociative ionization has the same value of the threshold energy and its maximum of  $2 \times 10^{-17} \text{ cm}^2$  lies at 100 eV. The cross section for dissociative excitation or dissociation has a threshold energy of 9 eV and a maximum of  $8 \times 10^{-17} \text{ cm}^2$  at 28 eV.

The cross sections for asymmetric dissociative ionization were also measured. This process refers to dissociative ionization leading to the fragments  $N^{2+} + N$ . The cross sections for this process were measured using the same experimental device and have already been published.<sup>2</sup> In this case the measurements are relatively simple, since the product  $N^{2+}$  ions do not interfere with any other fragments. The cross sections for this process are one order of magnitude lower than the cross sections for the other processes.

To the best of our knowledge, no other measurements or theoretical predictions have been published, which can be directly compared with our results.

## ИЗВОД

РАЗДВАЈАЊЕ ЈОНА ИСТОГ ОДНОСА МАСЕ И НАЕЛЕКТРИСАЊА  
ИЗ СУДАРНОГ ЕКСПЕРИМЕНТАДРАГОЉУБ С. БЕЛИЋ И PIERRE DEFRANCE<sup>o</sup>

Физички факултет, Струденџски тирџ 16, 11000 Београд, Југославија и \*Departement de Physique, Universite Catholique de Louvain, Chemin du Cyclotron 2, B-1348, Louvain-La-Neuve, Belgija

У неким атомским сударним експериментима настају јони са идентичним односом масе и наелектрисања,  $m/q$ , као и средњом брзином, тако да их је стандардним електричним и магнетним анализаторима немогуће посебно идентификовати. Таква ситуација се јавља, на пример, при интеракцији електрона са молекулским монокатјоном ( $A_2^+$ ) при чему настају  $A_2^{2+}$  (из директне јонизације) и  $A^+$  (из дисоцијације или дисоцијативне јонизације). Услед трансфера унутрашње енергије у кинетичку енергију фрагмената, ови обично имају широку енергијску и угаону дистрибуцију у лабораторијском систему, у односу на продукте директне јонизације. Коришћењем посебно конструисаног експерименталног уређаја, омогућено је раздвајање продуката јонизације и фрагмената дисоцијације. Овде су саопштени прелиминарни резултати мерења ефективних пресека за интеракцију електрона са монокатјоном азота, уз продукцију  $N_2^{2+}$  и  $N^+$  јона.

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