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ELECTRON IMPACT IONIZATION AND ELECTRON ATTACHMENT CROSS SECTIONS OF SOME MOLECULES OF ASTROPHYSICAL IMPORTANCE

Milan V. Kurepa
Institute of Physics, P.O. Box 68, 11081 Beograd, Yugoslavia

Abstract Here an insigth is presented into efforts on total ionization and total electron attachment cross section measurements of small molecules of astrophysical interest, as a part of research in the Institute of Physics in Beograd.

1. INTRODUCTION

It was realized a long time ago that molecules do not exist only on Earth but also in atmospheres of other planets and in the interstellar space. To date, more that 60 molecular species have been detected, including some positive ions. Some of these molecular species are very different from what we traditionally call a molecule under normal physical conditions on the surface of Earth. Reviews on the subject, and lists of these molecular species were published by many authors, including Henderson (1972) Turner (1973), Green (1984), Rien (1985), Millar and Williams (1985) and Petrović (1986), part of them given in Table 1.

Table 1. Some molecules found in astrophysical objects, as part of lists given by numerous authors, like Rien (1985), Green (1984) etc.

Number of atoms	2	3	4	5	6
Molecule or Ion	H_2 **CO** CH CN CS C_2 OH NO CH^+ NS SO	H_2O H_2S SO_2 COS HCN HNC HCO HNO	NH_3 H_2CO CH_3 C_2H_2 HNCO C_3O C_3N HNCS	CH_4 SiH_4 CH_2NH HCOOH NH_2CHO	**CH_3OH** CH_3SH CH_3CN

Remark: Molecules for which total ionization cross sections have been measured in the Atomic Collision Physics Laboratory, Institute of Physics, Beograd, some of them published, are given in bold letters.

Particle densities in interstellar objects are much lower (10^2 - 10^5 [at/cm^3]) than on the surface of Earth or/and in laboratory under experimental conditions (10^8 - 10^{19} [at/cm^3]). Nevertheless in binary, or even ternary collisions, many reactions take place, that lead to formation and destruction of rather complex molecular species. Incident particles, as well as products of collisions can be neutral species, positive or negative ions. Apart of that, the composition of particles does change under the influence of radiation and electron impact.

For proper modeling and explanation of possible collision channels under interstellar conditions many data are needed that could be collected in laboratory experiments. Among them the most thoroughly approached are reactions caused by photon or/and electron collisions. As targets, until recently, neutral molecules were used, many of them found in interstellar space, too. Lately, experiments started with species that are traditionally called molecular fragments, such as OH, CH, CH_2, SH, etc. These experiments are more difficult to perform, since one has to prepare the target species not available under normal physical conditions. That includes formation of intense ion beams, mass separation, charge exchange and charged particle removal from the neutral particle beam. Even then, particles considered as targets, are rarely all in their ground state.

Only with rather well known characteristics of a particular particle collision, such as energy exchange, cross sections, angular distributions etc., the modeling of processes in interstellar space could lead to reliable explanations.

2. TOTAL ELECTRON IMPACT IONIZATION CROSS SECTION MEASUREMENTS

The electron impact ionization process was investigated for the first time by Lenard (1903). But, first reliable ionization cross sections for some atoms and molecules were published by Smith (1930). Since then measurements of ionization cross sections have been done in many laboratories around the world. Results of these experiments are collected by a few data centers, mainly to make them available to scientists active in plasma and fusion plasma physics, astrophysics, physical chemistry and radiation physics.

In the Atomic Collision Physics Laboratory of the Institute of Physics in Beograd, the first experimental apparatus for total ionization cross section measurements was constructed as early as 1963. Since then, this apparatus has been redesigned, improved and changed a few times. There were some periods when measurements were very active, and others when due to alterations of the apparatus they almost stopped.

Lately, the newest version of the experimental apparatus was put into operation. This time the targets were mostly small molecules that are formed in collision of protons within the high temperature plasma machines (Tokamak and the like) with walls covered by carbon, as well as those found in interstellar space. Details of the experimental apparatus were published (Kurepa et al. 1974)(Čadež et al. 1983)(Kurepa et al. 1991), while alterations introduced lately will be described in papers that will be reported and/or published shortly (Josifov et al. 1998)(Lukić et al. 1998).

Part of the apparatus where the interaction of the incident electron beam with the target molecules takes place is presented in Fig.1., the trochoidal electron monochromator as the electron beam source (Stamatović and Schutz 1969) not being shown. Ions, positive in the case of ionizing collisions, or negative in the case of electron attachment, are collected by applying a homogeneous electric field between electrodes of the parallel plate condenser. Further details of the measurement procedure can be found in already published papers.

The main source of error in electron ionization or electron attachment cross section determination comes from the measurement of the target gas pressure. Within the interaction chamber the target gas is at pressures between 10^{-5} [mbar] and 10^{-4} [mbar], while the background pressure is 10^{-7} [mbar]. For more reliable pressure measurements two new generation gauges were used lately. One is the capacitance manometer, the other is the spinning ball manometer, both calibrated by the manufacturer, with the claimed error of ±2 %. Common characteristics of these manometers is that all their parts are at the ambient temperature, so that within the system thermal transpiration does not change the accuracy of the gas pressure measurement. This was, namely, one of the biggest sources of error in most of earlier experiments. Not to be forgotten that in many cases the dissociation of target molecules on the hot filament of the ion gauge changes the composition of the gas and its apparent pressure inside the gauge.

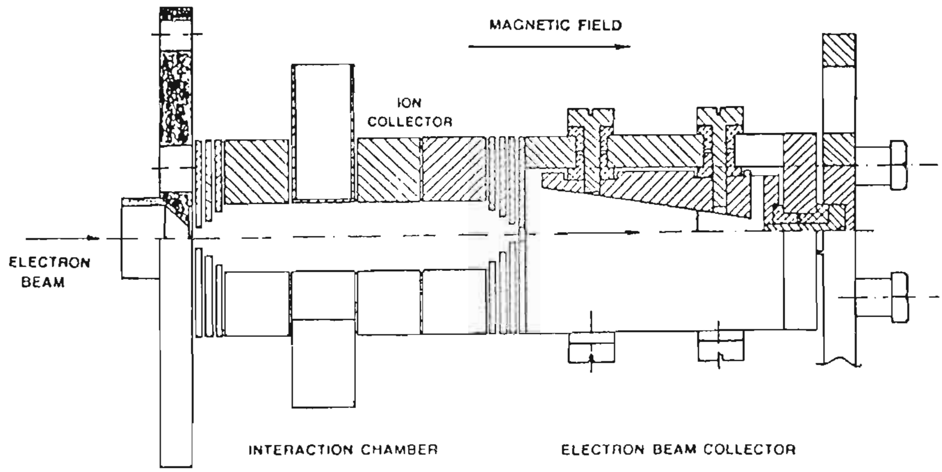

Figure 1. Schematic drawing of the interaction chamber with which the total ionization and total electron attachment cross sections were measured

Some results for molecules of great importance for astrophysical research, of total ionization cross section measurements are listed in Table 2. Already published are cross sections for SO_2 (Čadež et al. 1983) H_2S (Belić and Kurepa 1985) and H_2O (Đurić et al. 1988), while for those investigated lately NH_3 (Đurić et al. 1981)(Josifov 1997), NO_2 (Lukić 1997) COS (Lukić 1997) and C_2H_2 (Đurić et al. 1996)(Josifov et al. 1997) results are not yet published. The agreement of cross sections measured in our experiments with data of other authors is mostly good, sometimes even within the experimental error cited by two or more groups of authors. But, in some cases, the differences are rather big, reaching even 50 %. That is specially the case for the H_2O, H_2S and NH_3 molecules, all containing hydrogen atoms. This is the main reason why for these molecules measurements were repeated in a long period of time.

In search for explanation why these differences do appear, a new apparatus was constructed recently in the Institute of Physics, that is intended to measure angular and energy distributions of positive ions formed in dissociative ionization and/or negative ions from dissociative attachment processes. Already the first results in H_2 (Popović and Čadež 1993) and in H_2, H_2O and CH_4 (Kurepa et al., 1997) showed two important properties of H^+ ions. Firstly, there is a wide energy distribution, with ions of kinetic energy as high as 10 [eV], and secondly, the angular distribution of ions is, as a rule, not isotropic. The consequence to total ionization measurements can be serious. High kinetic energy ions could escape collection in the parallel condenser interaction chamber, partly those emitted in the forward and backward directions, and partly those emitted side- ways within the gap between the condenser electrodes. Although in experiments a special

Table 2. Total ionization cross sections of some molecules, in units of 10^{-20} [m^2]

Electron energy, in [eV]	**H_2O**	**H_2S**	**SO_2**	COS	NO_2	NH_3	C_2H_2
12	-	0,376	-	-	0,009	0,124	0,072
14	0,025	0.878	0,481	0,036	0,035	0.269	0,53
16	-	1,58	0,848	0,546	0,088	0,479	1,01
18	-	2,29	1,23	1,28	0,175	0,764	1,45
20	0,290	3,01	1,63	2,19	0,440	1,06	1,84
22	-	3,73	2,04	2,95	0,607	1,36	2,19
24	-	4,14	2,40	3,56	0,788	1,60	2,52
26	-	4,52	2,75	4,32	0,976	1,82	2,80
28	-	4,83	3,06	4,96	1,17	2,08	3,06
30	0,965	5,06	3,31	5,83	1,35	2,31	3,29
32	-	5,25	3,58	6,18	1,57	2,49	3,50
34	-	5,39	3,78	6,48	1,74	2,68	3,69
36	-	5,52	3,98	6,77	1,91	2,84	3,85
38	-	5,62	4,15	6,94	2,07	3,00	4,01
40	1,46	5,71	4,34	7,14	2,22	3,13	4,15
45	1,62	-	-	-	-	3,41	-
50	1,76	6,08	4,92	7,90	2,83	3,64	4,59
55	-	-	-	-	-	3,85	-
60	-	6,22	5,38	8,38	3,25	3,95	4,82
65	1,91	-	-	-	-	4,13	-
70	-	6,22	5,67	8,64	3,51	4,20	4,90
75	-	-	-	-	-	4,24	-
80	2,05	6,18	5.87	8,68	3,67	4,31	4,90
85	-	-	-	-	-	4,33	-
90	2,06	6,08	5,96	8,63	3,76	4,32	4,85
95	-	-	-	-	-	-	-
100	2,06	5,98	5,99	8,45	3,80	4,34	4,76
125	2,00	-	5,87	7,98	2,76	-	-
150	1,92	-	5,68	7,48	3,64	-	4,21
175	1,82	-	5,43	7,05	3,50	-	-
200	1,72	-	5,15	6,59	3,34	-	3,70

Remark: Bold are given molecules for which final cross sections values have been published. For others, final evaluation is completed and manuscripts are in phase of preparation for publishing.

calibration procedure is obligatory, that requires total collection of ions by increasing the electric field strength, a loss of high kinetic energy ions of the order of 2 - 5 % could be expected. Thus, that is a possible explanation for differences in cross sections obtained by different experimental groups. Special tests are under way to prove this hypotheses.

3. TOTAL ELECTRON ATTACHMENT CROSS SECTIONS

Electron attachment is a process in which the incident electron is resonantly attached to the molecule and a negative ion and a neutral fragments are formed after the decay of the negative and excited parent molecular ions. Processes of electron attachment do happen with electrons of rather low energy, usually nor exceeding 10 [eV].

Total electron attachment cross sections, i.e. without the analysis which negative ion is formed, were measured with the parallel plate interaction chamber, shown in Fig 1., too. These cross sections are, as a rule, lower than the total ionization cross sections by 2 - 3 orders of magnitude. In the experiment this has a consequence that electrometers that can determine ion current of the order of 10^{-15} [A] to 10^{11} [A] are needed. They are more difficult to calibrate absolutely, and in their use more often surface leakages do appear, making the experiment much more difficult to perform properly.

All molecules, listed in Table 2, that were investigated for their total ionization cross sections, have also electron attachment processes. So far, we measured and published data for H_2O (Đurić et al. 1988), H_2S (Belić and Kurepa, 1985), and SO_2 (Čadež et al., 1983), while values for NH_3 have been determined and reported (Đurić et al. 1981), but not published so far. The total electron attachment cross section curves for these four molecules are presented in Fig. 2. For the remaining three molecules NO_2, C_2H_2 and COS some preliminary investigations of other authors do exist for formation of various negative ions in electron attachment processes, but the results are not consistent, and no attempt to measure cross sections is kown to the author. Here, too, careful analysis of negative ion energy and angular distributions are needed in order to give a full description of the particular attachment process.

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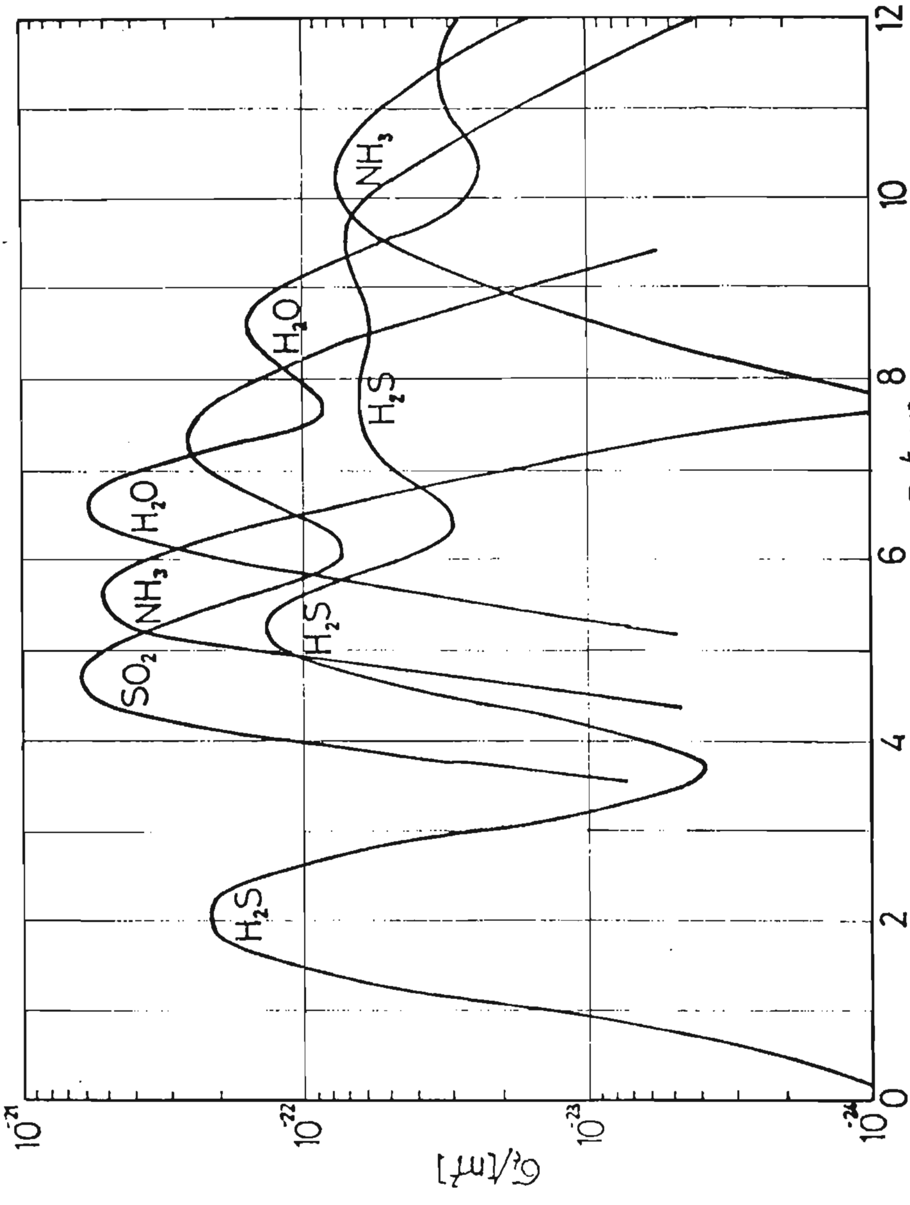

Figure 2. Total electron attachment cross sections of some molecules measured with the apparatus shown in Fig. 1., and published in journals

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