ELECTRON SCATTERING ON NEGATIVE IONS IN A STORAGE RING

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In this paper we present the results from electron scattering experiments performed at the heavy ion storage ring CRYRING at the Manne Siegbahn Laboratory in Stockholm. We have studied the cross sections for single, double and triple detachment of Cl^- in the energy range 0 eV to 100 eV. We have also studied electron scattering on C_4^- ions in the energy range 0 eV to 30 eV. The neutral particles from the detachment process were detected, and the different branching ratios were investigated. In particular, we searched for a resonance in the cross section due to the formation of a doubly charged C_4^{2-}ion.

1 Introduction

The structure of negative ions differs significantly from their positive and neutral counter- parts. This difference stems from the difference in the binding potential experienced by the outermost electron. In negative ions, the extra electron feels a short range induced dipole force instead of a long range coulomb force as for neutral and positively charged systems. Another difference is the charge states of the final products in an ionization / detachment process. In the electron impact induce single electron detachment the final state consists of a neutral atom and two outgoing electrons. This is in contrast to electrons escaping from a positively charged core in the ionization processes. Studies of electron scattering on negative ions started in the early seventies, with experiments done by Tisone and Branscomb[1, 2], Dance *et al*[3] and Peart *et al*[4]. A major advance in electron scattering experiments came with the advent of the heavy ion storage ring. Cross sections could be studied down to zero relative collision energies with a very high energy resolution. Andersen *et al*[5, 6] began a systematic study of light atomic and diatomic anions of the first row elements. In particular, they search for resonances in the threshold region due to doubly charged anions. In 1998 we started a research program at the Manne Siegbahn Laboratory, MSL, in Stockholm, Sweden. In a first experiment we studied electron impact single detachment on the F^- ion[7]. In the present paper we describe electron scattering experiments on Cl^- and C_4^- ·

2 Experiment

The experiments are performed at the magnetic heavy ion storage ring CRYRING. Negative ions are produced in a Cs sputter ion source with an extraction voltage of 40 keV. After injection into the ring, the ions are accelerated to a maximum energy of 2

MeV and 2.7 MeV for the experiments on C_4^- and Cl^-, respectively. The ion storage lifetime due to collisions with residual gas is 1.2 s for C_4^- and 2.3 s for Cl^-. In one section of the ring the ions are merged with a collinear electron beam that has the same velocity as the ions in order to achieve phase space cooling. The electrons have an anisotropic Maxwell - Boltzmann distribution, with longitudinal and transverse electron temperatures of 0.1 meV and 1 meV, respectively. After about 2 s the voltage on the electron gun in the cooler is changed in order to give the electrons the desired collision energy. This energy, in the center of mass frame, E_{cm}, is given by

$$E_{cm} = \left(\sqrt{E_e} - \sqrt{E_{cool}}\right)^2, \tag{1}$$

where E_e is the average electron energy in the laboratory frame given by the voltage on the gun and E_{cool} the energy of the electrons at cooling conditions. In the case of Cl^-, we studied the processes

$$\begin{aligned} Cl^- + e^- \rightarrow\ & Cl + 2e^- \\ & Cl^+ + 3e^- \\ & Cl^{2+} + 4e^- \end{aligned} \tag{2}$$

by detecting the Cl, Cl^+ or Cl^{2+} ions. Since these products all are in different charge states, they will leave the orbit of the ring on different trajectories, and they can then easily be separated by using three separate surface barrier detectors. In the case of C_4^-, we only detected neutral fragments. We then use the so called grid technique to distinguish between channels with the same number of neutral C - atoms:

$$\begin{aligned} C_4^- + e^- \rightarrow\ & C_4 + 2e^- \\ & C_3 + C + 2e^- \\ & 2C_2 + 2e^- \\ & C_2 + 2C + 2e^- \\ & 4C + 2e^- \end{aligned} \tag{3}$$

For all measurements, a scintillator is used for normalization purposes by detecting neutralized particles due to collisions with the rest gas (in another section of the ring). The ion current was measured absolutely with a AC pick-up current transformer.

3 Data Analysis

The experimental electron impact rate coefficient for a given centre-of-mass energy is given by

$$\langle v_{rel}\sigma \rangle = R_B \frac{C}{n_e l} \frac{N_{signal}(t)}{N_{bg}(t)}, \tag{4}$$

where v_{rel} is the relative velocity between the ions and the electrons, R_B is the destruction rate due to the rest gas collisions in the cooler, C is the circumference of the ring, n_e is the electron density in the cooler and l is the length of the interaction region. N_{signal} is the number of counts in the detector arising from the electron scattering process at a certain time t. This time corresponds to a certain collision energy and is the

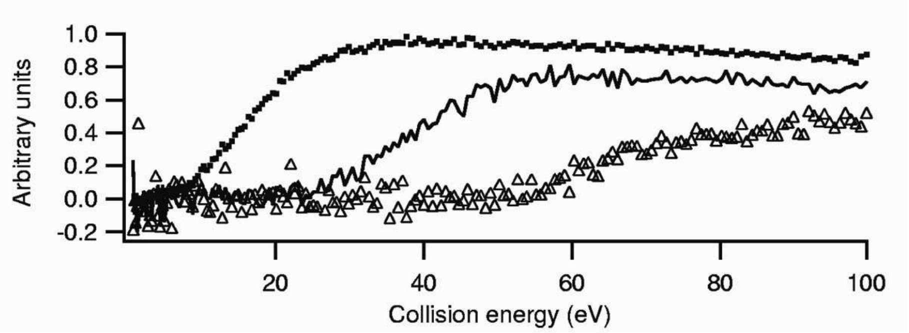

Figure 1. Relative cross section for electron scattering on Cl^-. The squares show single detachment, the sold line represents double detachment and the triangles show triple detachment. The double and triple detachment curves have been multiplied by a factor of 5 and 50, respectively.

number of reaction products from collision with residual gas ions measured with the scintillator.

The measured rate coefficient $\langle v_{rel}\sigma \rangle$ has to be deconvoluted with the electron velocity distribution. In the case of C_4^- and Cl^-, where the reaction thresholds are larger than 5 eV, the velocity distribution of the electrons is negligible.

In the analysis, two corrections have been made in order to obtain the correct cross sections. First, the space charge effect caused by the electron beam has to be treated. Second, the toroïdal effect has to be incorporated in the analysis. This effect is caused by the change in the collision energy in the sections where the electron beam is bent in and out of the ion beam.

4 Results and Discussion

4.1 Cl^- Measurements

The results for single, double and triple detachment processes in the energy range 0 eV to 100 eV are shown in figure 1. No resonance structure was observed in this energy range. The single detachment threshold was observed at around 10 eV, and the corresponding thresholds for double and triple detachment were observed at 28 eV and 50 eV, respectively. These values are determined by fitting the data using the over – the - barrier model described by Andersen *et al*[6]. One can see that different threshold laws are involved in the detachments processes since they involve different final states. At the time of this experiment absolute cross section measurements could not be performed, but such measurements will take place during an experiment in the near future.

4.2 C_4^- Measurements

Carbon clusters have been studied thoroughly in recent years, both experimentally and theoretically. The C_4^- ion exists in at least four different isomeric states; one linear, one tennis-racket shaped, and two rhombus shaped forms. We cannot distinguish between these isomers in our experiment, but previous measurements have shown that mainly linear clusters are produced in a Cs sputter ion source. The aim of this experiment was to study the branching ratios between the different detachment processes and to search for resonances in the cross section due to doubly charge C_4^{2-} ions.

In this experiment we have measured the total detachment cross section for the production of neutral carbon fragments. The cross sections for pure detachment, leading to the production of C_4 molecules, and for detachment plus dissociation leading to $C_3 + C$, $2C_2$ and $C_2 + 2C$ production were measured. Decay channels which include one ionic fragment, which show up at the same energy as a single C, C_2 or C_3 molecule, were too small to be detected in the present experiment. The flux into any such channel was less than 1 % of the total flux. Decay channels that include only ionic fragments cannot be detected with the present experimental arrangement. Among the four decay channels observed, pure detachment is the dominating one. At 15 eV it constitutes 87 % of the total flux. The cross section curve for this process shows the same qualitative behaviour as the single detachment curve of Cl^-: It rises monotonically from the threshold at 6 eV, and reaches a plateau value of 2×10^{-16} cm^2 at 20 eV. The thresholds for the other three channels were observed at 10.5 eV for the $C_3 + C$ channel, at 12.5 eV for the C_2 molecules and at 13.4 eV for the channel producing two carbon atoms and one C_2 molecule. Based on these observations, it must be concluded that the outermost electron in C_4^- is situated outside a rather inert C_4 molecule.

In the pure detachment channel we also observe a small structure situated just above the threshold. We attribute this to the formation of a doubly charged negative ion C_4^{2-} formed by the capture of the incoming electron. The energy of this resonance is higher than the ground state of the C_4 molecule. This doubly charged ion will therefore rapidly decay via the emission of two electrons. By fitting a Lorentzian function to this resonance structure we obtain a width that corresponds to a lifetime of only 0.7 fs. The scattering in the data in this energy range is, however, rather large and the amplitude of the resonance is comparable in size of the background level. This issue will be further discussed in a forthcoming paper.

Acknowledgments

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