THE NEGATIVE ION PROJECT AT CRYRING

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Introduction

Negative ions are interesting from a fundamental point of view. In such loosely bound systems the normally dominant Coulomb interaction is suppressed and the interelectronic interaction becomes greater than the interaction of each electron with the rest of the system. Under such conditions the independent particle model, that adequately describes atomic structure under normal conditions, breaks down. Experimental studies of negative ions can therefore serve as a probe of the electron correlation effect and hence be used to test theoretical models in order to get better understanding of atomic and molecular processes.

Most information on the structure of negative ions have been obtain by studying the photodetachment process, in which the outermost electron is emitted due to the absorption of a photon. Pioneering experiments were carried out by Branscomb in the 1950's, but it was Lineberger and co-workers in the 1970's [1] that performed the first systematic studies. By using neutral particle detection and electron spectroscopy they managed to determine the ground state configuration of most atomic and some molecular negative ions. In more recent years, the combination of photodetachment and resonance ionisation spectroscopy has been shown to be a powerful tool for studies of bound as well as continuum states [2-3]. Studies of interaction between negative ions and electrons, on the other hand, have been carried out by Tisone and Branscomb [4-5], by Dance, Harrison and Rundel [6] and later by Peart, Walton and Dolder [7]. Later, after the storage ring technology came into operation, a number of studies were performed by Andersen and collaborators [8] using the storage ring ASTRID (Aarhus University - Denmark).

Technical development

The negative ions project at CRYRING was initiated in the spring of 1999. As a first test the existing MINIS ion source was used to produce F^- ions. After the successful injection into the ring, a new, dedicated ion source was purchased and installed by the Manne Siegbahn Laboratory. It is a Cesium Sputter Ion Source manufactured by Peabody Scientific [9]. In this source positive Cesium ions are accelerated towards a cooled solid

target. The Cesium vapour in the source forms a few monolayers on the cathode. Atoms and molecules sputtered from the target will then, with a rather high probability, capture electrons from the Cesium atoms and hence be emitted as negative ions. By a proper choice of the cathode material almost any atomic and many molecular ions can be produced. This source is now routinely in operation and it has, for instance, been used to produce S^-, CN^-, C_4^- and Cl^- ions.

Results

Electron impact detachment of halogen negative ions

The properties of a plasma is strongly dependent on whether the negative charge is in the form of highly mobile electrons or slowly moving negative ions. In order to correctly model a plasma, it is therefore important to know the cross section for collision processes involving negative ions. The destruction of negative ions due to electron impact is then one of the most important processes. One example of an application where this process is of importance is in plasma etching in semi-conductor industry where halogens often are used as an active reactant. Another example is in excimer lasers where metastable excimer molecules are formed by attaching a neutral halogen atom to an excited noble gas atom. If the halogen is in the negative charge state it will not be able to participate in the laser action. Modelling of such lasers therefore requires accurate values of cross sections for production and destruction of negative halogen ions.

In our first experiment on negative ions at CRYRING, we studied one such process, namely electron detachment of F^-. The result from that work has now been published in the European Journal of Physics D [10]. We have further conducted an experiment where we studied electron impact detachment of Cl^-[11].

Detachment and dissociation of molecular negative ions

For molecular negative ions, the situation is different, in comparison with atomic ions. In this case, not only detachment but also dissociation will occur. This opens up a whole range of possible decay channels. As an example, the first molecular anion we studied, CN^-, will be discussed. In this experiment, CN^- ions stored in the ring collided with electrons in the electron cooler. Neutral fragments caused by detachment and/or dissociation processes were detected with a surface barrier detector placed 3.5 meters downstream to the interaction region. Positive fragments were detected with another, similar detector placed on the trajectory for positive ions, i. e. on a path bending out of the ring.

The so-called grid technique was further applied in order to distinguish the detachment channel

$$CN^- + e^- \rightarrow CN + 2e^-$$

from the detachment and dissociation channel

$$CN^- + e^- \rightarrow C + N + 2e^- .$$

In total, 8 different decay channels where investigated. Our main conclusion from this experiment is that the pure detachment channel completely dominates over all other energetically allowed channels [12].

Later, we applied the same technique to study the C_4^- ion [13], and more recently also to the Cl_2^- ion[14].

Photodetachment studies

It is now generally believed that there are no bound excited states in atomic negative ions with opposite parity with respect to the ground state. This means that it is not possible to induce allowed optical transitions between states in negative ions in order to gain information about their internal structure. For many ions it is, on the other hand, still unclear whether or not bound excited states with the same parity as the ground state exist. We have now embarked a program where we investigate how the unique properties of the storage ring can be used to investigate the internal structure of negative ions. As a proof of principle experiment we have studied the S^- ion. This ion has two bound excited states with binding energies of 2.08 and 2.02 eV. We will investigate if the population, during the storage, can be transferred between the two states. By using laser light with a photon energy of 2.07 eV we have shown that ions in the upper state can be detached while leaving the ground state ions unaffected. With the storage times of 10 seconds we managed to diminish the population of the upper state to only a few percent of the initial level. As a second step we now intend to investigate if it is possible to repopulate the upper state through electron impact. This is a resonance phenomenon that would yield

information about the energy of the upper state. This method will allow us to map out the existence of excited states in many atomic negative ions. For these experiments a new detector situated in the section of the ring where laser light can be introduced both co- and counter propagating with respect to the ion beam direction has been installed in the CRYRING storage ring.

Conclusion and outlook

This project has now come to the stage where the technical problems associated with producing, injecting and accelerating negative ions into CRYRING have been solved. Electron impact experiments can now routinely be performed and photodetachment studies are under development.

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