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STATE-SELECTIVE ELECTRON CAPTURE

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Résumé - Les résultats que nous présentons ont été obtenus dans le cadre du nouveau programme de physique atomique. Ce dernier est basé sur l'utilisation de la source PII ECR d'Argonne construite pour le Tandem-lineaire accélérateur (ATLAS) d'Argonne. Nos premières expériences ont eu pour but d'étudier les états sélectifs de la capture d'électron dans les collisions ion-atome en utilisant la technique spectroscopique d'émission de photon. Nous avons poussé la mesure des sections efficaces à basses énergies (< 15 keV/amu) aux hautes énergies, profitant du fait que la source ECR d'Argonne soit sur une plateforme de 350 keV. Les expériences effectuées comprennent les mesures de O^{6+} et O^{7+} sur des cibles de He et H_2 dans la bande d'énergie 1-105 keV/amu ainsi que les mesures de O^{6+} , O^{5+} et N^{5+} sur des cibles de sodium.

Abstract - We report results from a new atomic physics program using the Argonne PII ECR ion source which is being built as part of the upgrade of the Argonne Tandem-Linear Accelerator (ATLAS). Our initial experiments have been aimed at studying state-selective electron capture in ion-atom collisions using the technique of Photon Emission Spectroscopy. We are extending existing cross section measurements at low energy (< 15 keV/amu) to higher energy taking advantage of the fact that the Argonne source is on a 350-kV high-voltage platform. Experiments have included measurements of capture cross sections for O^{6+} and O^{7+} on He and H_2 targets in the energy range from 1-105 keV/amu. We also present UV spectra obtained in collisions of O^{6+} , O^{5+} and N^{5+} on a sodium target.

1 - INTRODUCTION

We have recently begun an atomic physics program at the Argonne PII ECR Ion Source. This source is part an upgrade to the Argonne Tandem-Linac (ATLAS), and is described in a separate contribution to these proceedings (R. C. Pardo, et al.). One unique feature of the source which results from its use as an injector is that it is on a 350-kV high-voltage platform. This platform allows the beam energy to be tuned over a wide range which gives greater flexibility in the use of the source. In particular, it allows us to explore a greater velocity regime in ion-atom collisions. At the present time, use of the ECR ion source is split between source development and Atomic Physics but once the source begins to be used to inject ATLAS (1989), access to it for atomic physics will be limited to weekends and accelerator down periods. In order to take full advantage of the source in its first year of operation, we built a temporary beam line/1/ and were able to carry out atomic physics experiments shortly after the first beams from the source were available. A permanent beam line will be installed on the accelerator injector line in September 1988.

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2 - ION-ATOM COLLISIONS - GAS TARGET

One important application of ECR ion sources is in the study of ion atom collisions with gas targets. We have studied state-selective electron capture using the technique of photon emission spectroscopy. In particular we have been able to extend measurements which have been made below 10 keV/amu up to 105 keV/amu using the high-voltage platform. Our results are important in extending tests of theoretical calculations to higher energy. In addition,

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measurements in this energy regime are useful to fusion research because collisions between plasma ions and neutral beams in tokamaks involve energies of 40-100 keV/amu. Photon emission following these collisions is used to measure impurity concentrations in the tokamak, study ion transport, and determine ion velocity distributions.

In our experiments, ions produced by the source are analyzed by a 90-degree magnet and directed to the gas cell. For low-energy operation (< 150 keV), the beam energy is determined by the extraction voltage, while for high-energy operation, the beam is extracted at 12 kV and then accelerated after selection of the desired charge state in the analyzing magnet. Charge exchange takes place in a gas cell which consists of a 3.8 cm cube with a 9 mm diameter aperture in the front to allow the beam to enter. Beam current is collected in a Faraday cup attached to the rear of the cell. Photons from a 3 mm region along the beam pass through a 1.6 mm by 17.5 mm slit in the side of the cell and are incident on the entrance slit of a 2.2 m McPherson Model 247 monochrometer. The angle of observation is 90 degrees relative to the beam axis and the spectrometer was set for a grazing angle of 86 degrees. A 600 lines/mm grating was used for wavelengths between 100 Å and 300 Å, while a 300 lines/mm grating was used in the range of 250 Å to 600 Å. The slits are normally set so that the resolution is 5 Å in first order. A channeltron detector located in back of the exit slit was used to detect the photons. The slit-detector assembly was stepped along the Rowland circle in order to measure the spectrum. At each slit position the counts from the channeltron were recorded for a fixed quantity of charge collected at the Faraday cup.

Typical spectra for measurements of cross sections for collisions of O^{6+} on He are shown in Fig. 1. These were taken with the 300 lines/mm grating. The data of Fig. 1a were taken at a beam energy of 105 keV/amu while that of Fig. 1b were taken at 15 keV/amu. The transitions from $n = 2$ to $n = 3$ are seen in second order. At high energy they are dominated by the 2p-3d transition at 173.1 Å, while at low energy, the lines 2s-3p and 2p-3s are also prominent. An interesting feature of the high energy data is evidence for significant population of $n = 5$.

Fig. 1 - Typical UV spectra taken for collisions of O^{6+} on helium gas. (a) At 105 keV/amu and (b) for 15 keV/amu.

In order to extract cross sections we normalize our data to that of Dijkkamp et al. at 4.5 keV/amu./2/ Because of the short lifetime and relatively low velocity of the ions, the time resolution is limited.

transitions observed. The largest source of uncertainty in these measurements is associated with the fact that the state into which the electron is captured is, in general, aligned. This leads to an angular distribution in the decay and also a polarization of the radiation. The correction factor for the angular distribution/4/ can be as high as 33%. We estimated the polarization dependence of the grating using published optical constants and used this to determine the additional error due to polarization. Typical results for the line emission cross sections for O^{6+} on He are given in Table I.

Table I. Line emission cross sections σ_{em} (10^{-16} cm²) for O^{6+} + He at three of the ten energies where measurements were made. The absolute errors for the lines at 150, 173, 184 and 520 Å are 30%, while for the remainder of the lines the absolute error is greater than 50%. The relative errors are considerably less.

$\lambda(\text{\AA})$	Identification	4.5 keV/amu	42 keV/amu	105 keV/amu
116	2s-4p	0.13	0.57	0.57
130+132	2p-4d; 2p-4s	0.54	1.3	1.0
150	2s-3p	5.2	2.1	1.2
173	2p-3d	4.2	7.3	4.0
184	2p-3s	2.3	0.43	0.24
448	3s-4p	0.03	0.14	--
498	3p-4d	0.16	0.21	0.13
520	3d-4f	1.0	3.0	1.7

We have also obtained data for collisions of O^{6+} on H_2 and O^{7+} on He and we plan to continue in the measurement of cross sections for collisions of highly-stripped oxygen, nitrogen and carbon ions with He, H_2 , and H. The study of collisions between fully-stripped ions and atomic hydrogen is particularly important from a theoretical point of view and these systems are also important in applications to tokamaks. These experiments will require the use of a hydrogen beam target which is currently under development.

3 - SODIUM JET TARGET

Another program which we have begun at the Argonne PII ECR ion source is the study of polarization transfer in collisions of highly- charged ions with an optically-pumped sodium target. In addition to providing a new handle on the dynamics of ion-atom collisions, such studies could lead to the development of beams of ions with a high degree of nuclear or atomic polarization. As the first step in this program, we have developed a sodium jet target. The use of a jet target has the advantage that it is easier to optically pump than a cell because of the reduced Doppler width. In addition, the target is more easily accessible for optical pumping, polarization measurement, observing the resonance fluorescence, and observing the radiation emitted after electron pick-up in ion-atom collisions.

The sodium oven is made up of a reservoir section and nozzle section. The nozzle consists of 9 holes which form a 2 mm by 2 mm array. Each hole is 200 μ m in diameter and 1 mm long. The reservoir contains the charge of sodium metal and is thermally isolated from the nozzle by a thin stainless

tube. Separate heaters are used to maintain the nozzle at 50 degrees C above the reservoir so that the long narrow holes do not clog. The sodium beam is collected on a liquid nitrogen cooled plate opposite to the nozzle. Under normal operation the sodium beam is 5 mm in diameter in the center of the target chamber where the ion beam crosses it.

The first experiments to be performed with the sodium target consisted of measurements of state-selective electron capture. A McPherson 1 m normal incidence monochromator mounted on one side of the target chamber is used to measure photons coming from the interaction region where the ion beam and the sodium beam cross. A typical spectrum of O^{6+} on sodium is shown in Fig. 2. The most prominent features are the 2s-2p and the 4d-5f transitions in Li-like O^{5+} . Capture into higher excited Rydberg states is evidenced by the presence of transitions 4-6, 5-7 and 4-7. In addition to these data we have measured spectra for collisions of O^{5+} and N^{5+} on sodium for several energies in the range 1.8-5 keV/amu.

Fig. 2 - Typical UV spectrum obtained for O^{6+} incident on a sodium beam target.

The optical pumping is being done with a Coherent ring dye laser (CR699) which is housed in an enclosure next to the beam line. We have already used the laser to study the intensity and distribution of the sodium beam. The polarizing laser will interact with the sodium beam just outside of the nozzle where the beam diameter is 3-4 mm. The polarization of the sodium will be determined by measuring the polarization of the fluorescence radiation produced by a probe beam which interacts with the sodium beam after it leaves the pumping region. The polarization of the ion beam will be determined by measuring the polarization of the radiation emitted after electron capture.

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