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ATOMIC PHYSICS AT THE ARGONNE PII ECR ION SOURCE

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ABSTRACT

An atomic physics beam line has been set up at the Argonne PII ECR Ion Source. The source is on a 350-kV high-voltage platform which is a unique feature of particular interest in work on atomic collisions. We describe our planned experimental program which includes: measurement of state-selective electron-capture cross sections, studies of doubly-excited states, precision spectroscopy of few-electron ions, tests of quantum electrodynamics, and studies of polarization transfer using optically pumped polarized alkali targets. The first experiments will be measurements of cross sections for electron capture into specific nl subshells in ion-atom collisions. Our method is to observe the characteristic radiation emitted after capture using a VUV spectrometer. Initial data from these experiments are presented.

INTRODUCTION

The electron cyclotron resonance (ECR) ion source is an important new tool for Atomic Physics which produces intense beams of slow, highly-charged ions. Such beams allow precision measurements uncomplicated by Doppler problems, and in addition, the collisions of slow ions with gas targets allow selective population of excited states which provides a technique for obtaining clean spectra.[1] For example, the identification of doubly-excited states is considerably simpler for spectra obtained from atom-ion collisions involving slow, highly-charged ions than it is for spectra obtained from beam foil spectroscopy.[2] In addition, the rapid development of the ECR ion source has allowed the flowering of "second generation" ion-atom collision experiments[3] whereby, in addition to total cross sections, the n, nl, and nlm distributions of captured electrons are determined by photon spectroscopy, electron spectroscopy or by translational energy spectroscopy. All of these techniques are difficult and require long integration times and intense beams. Other methods for obtaining slow, highly-charged ions include the recoil ion method and the accel/decel technique, both of which depend on the availability of costly accelerator beams. Because of the difficulty of obtaining beam time on the large heavy-ion accelerators, low-statistics experiments are not generally practical.

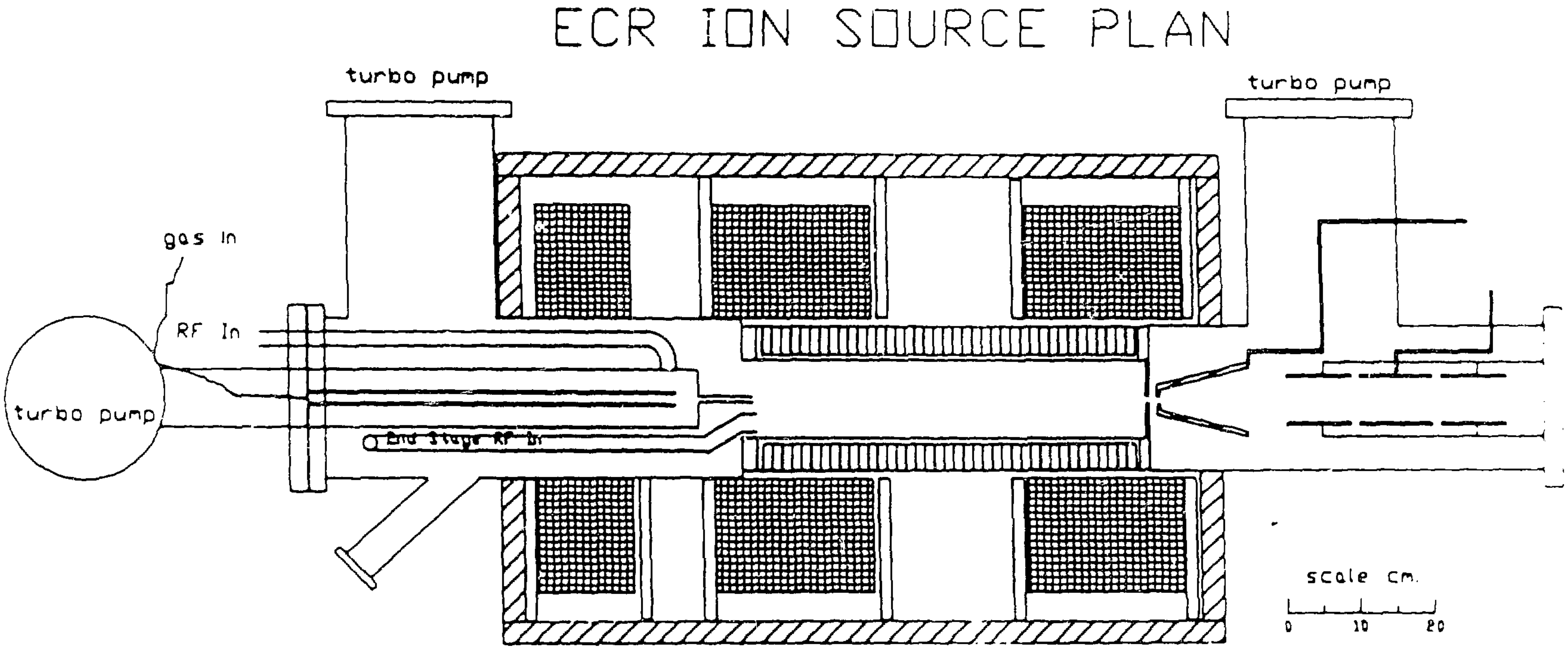
Our atomic physics program will make use of the ECR ion source which is being built as part of the positive-ion injector for the Argonne Tandem Linac (ATLAS). The most unique feature of this source, from the atomic physics point of view, is that it will be on a high-voltage platform. This will allow us greater flexibility for experiments because ot the greater dynamic range of beam energies that will be available for experiments. Some of the experiments we are pursuing will take advantage of this capability. The first atomic physics data, which was obtained the week before this conference, utilized the high-voltage platform to obtain information on state-selective electron capture by $^{16}O^{6+}$ on a helium target at 666 keV. The best opportunity for doing atomic physics using this source will occur in the next year when the source will be operational but will not yet be required for injecting the linac. Once the source begins to be used as an injector, atomic physics will be carried out only when the linac is shutdown.

In the second section of this contribution, we will describe our experimental facilities including the atomic physics beam line which has been set up next to the source. We will then briefly outline the experimental program that we plan to carry out using this source. In the final section, we will describe in more detail our program for measurements of state-selective electron capture and present the first atomic physics data obtained from the ion source.

THE ARGONNE PII ECR ION SOURCE

The Argonne PII ECR ion source is shown schematically in Fig. 1. The source is described in a separate contribution[4] to these proceedings. The high-voltage platform which will operate at voltage up to 350 kV is shown schematically in Fig. 2. The difficulty of delivering power to the the platform and removing excess heat requires a system which is as power efficient as possible. The total power required for the source and beam transport elements will be approximately 80 kW. Of this amount approximately 50 kW will be dissipated into a fluid cooling system. In order to maintain a voltage stability of better than one part in 10^4 on the platform, we require low leakage currents through the cooling system. Therefore, we will need to employ a two-stage cooling system which uses a high resistivity fluid between ground and the platform and uses water for cooling the magnets.

The Atomic Physics beam line which has been installed on the ATLAS ECR ion source is shown in Fig. 3. The experimental equipment that is available includes normal and grazing incidence monochronometers, a ring dye laser, Si(Li) detectors, an electron spectrometer, charge-state analyzers and various gas targets. Data acquisition and analysis will be done with an on-line microvax computer system.


ECR ION SOURCE PLAN
turbo pump
turbo pump
gas in
RF In
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scale cm.
0
10
20

Figure 1

ECR HIGH VOLTAGE PLATFORM

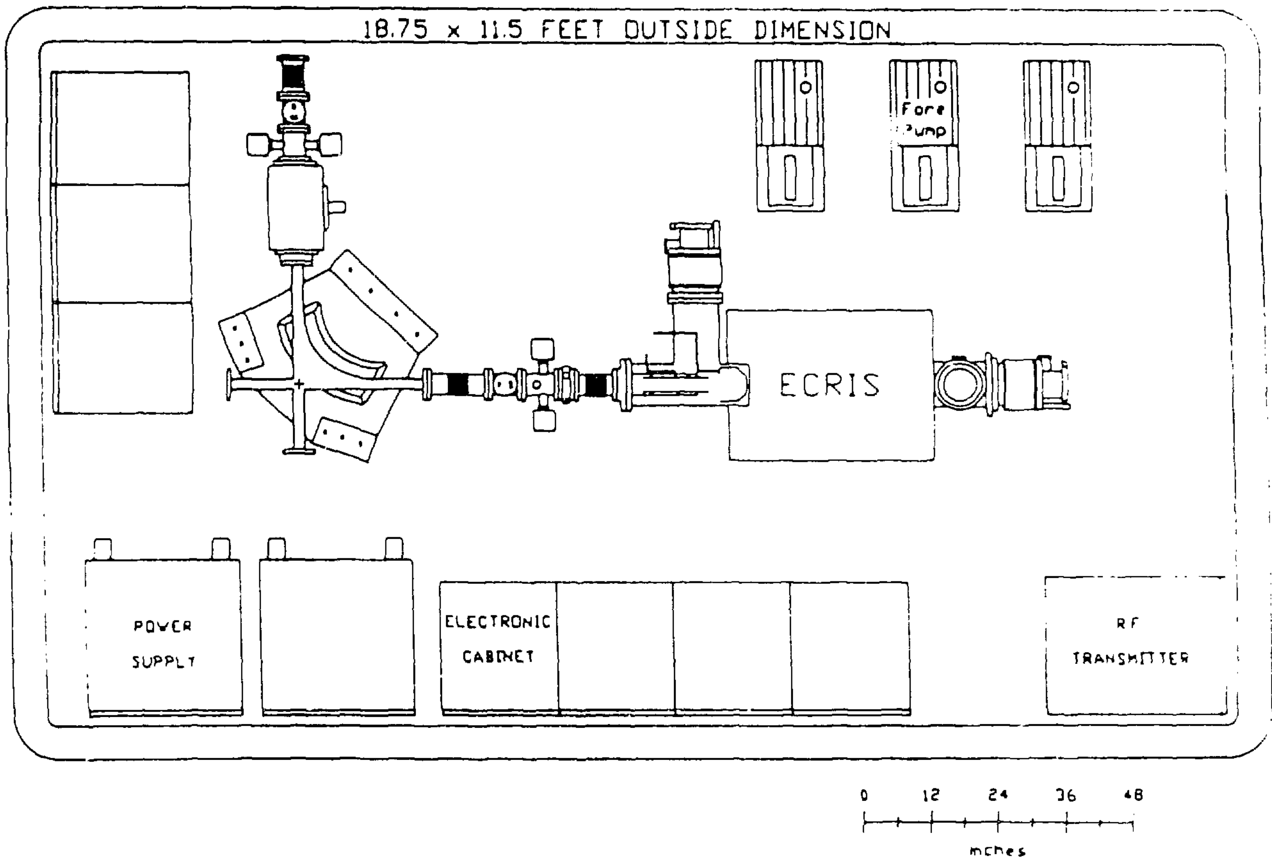

Figure 2

ATOMIC PHYSICS ECR SOURCE BEAM LINE LAYOUT

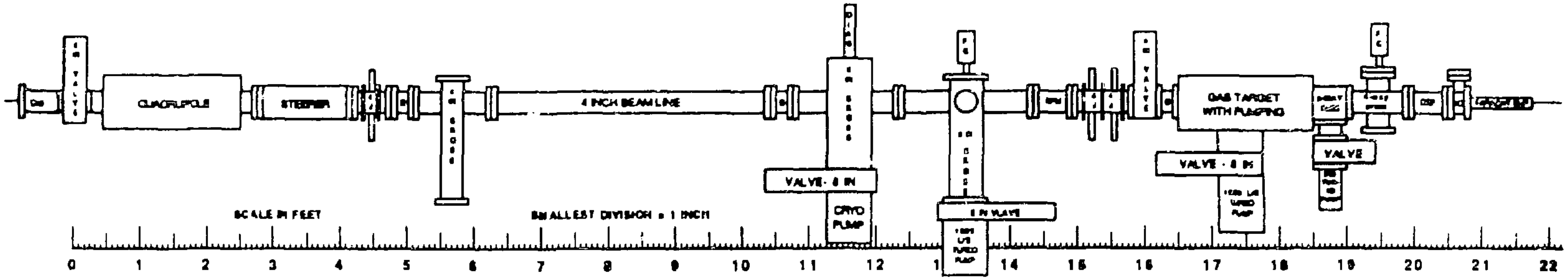

Figure 3

ATOMIC PHYSICS PROGRAM

A. Atomic Structure and Tests of QED

An important component of our atomic physics program will be precision measurements of the n=2 transitions in 2- and 3-electron atoms. The reduced Doppler effect compared with the most accurate beam-foil measurements can lead to wavelength measurements of a few parts in 10^6, a factor of 10 better than has been done to date. Such measurements will provide precision tests of QED and many-body calculational techniques. We also plan to study the Lamb shift in one-electron ions using both the laser resonance technique,[5] and the quenching anisotropy method.[6] Another test of relativistic quantum mechanics will be measurements of the lifetime of the 2S state in one-electron ions. Other experiments in this program will include measurement of metastable transitions and transition probabilities in ions with outer shells of $2p^k$, $3p^k$, and $3d^m$ electrons (k=1-5 and m=1-9). We will also study multiply-excited states in the lithium and sodium isoelectronic sequences.

B. Polarized Target

We will obtain (electron) polarized heavy-ion beams via ion-atom collisions in an optically-pumped alkali target. This technique has been used to obtain polarized hydrogen atomic beams in the first stage of newly developed polarized H^- ion sources at Lampf, Triumf, and KEK. The technique has been suggested for use with heavier ions,[7] but no experiments have been done to date. An ability to selectively populate final states of the ion will be essential to the optimization of the polarization transfer. The flexibility afforded by the high-voltage platform of our ECR ion source is thus essential. The motivation for this work includes the following experiments which would require spin polarized heavy ion beams:

(1) Study of Weak Interactions by searching for parity nonconservation in an electron-spin polarized heavy ions (this is of fundamental interest as a test of unified theories of the weak and electromagnetic interactions).

(2) Measurement of the electron magnetic moment in the field of a highly-charged nucleus.

(3) Study of polarization transfer in atomic collisions -- provides a new handle on the detailed dynamics of atomic collisions.

(4) Nuclear Polarization -- The hyperfine interaction will transfer polarization from the polarized electron to the nucleus, thus providing a means for obtaining nuclear polarization of heavy ions.

C. ECR Source Velocity Profiles

We will use laser/fast-ion beam techniques[8] to measure the ion velocity distributions of the beam from the ECR ion source. The technique requires singly-charged ions because of the lack of resonances in more highly charged ions at wavelengths accessible to dye lasers, but more highly charged ions could be studied following charge exchange. Present knowledge of ion velocity distributions is very fragmentary.

D. Quasi-Molecular X-ray Interference

The quasi-molecular orbitals which are formed when a one-electron ion is incident on a target gas atom are difficult to study because they give rise to an X-ray continuum rather than discrete lines. A method for studying these orbitals has been devised which is based on the observation of the interference between X-rays formed at two different times which are symmetrically before and after the time of closest approach of the two nuclei.[9,10] We will use this technique to study quasimolecules at our ECR ion source. The high-voltage platform will be an asset in this work because we will have the capability to adjust the velocity to obtain optimum conditions for observing the interference patterns.

E. Atomic Collisions

Our program to study atomic collisions will involve studies of state-selective electron capture and measurements of cross sections for double electron capture. The state-selective electron capture will be studied using the technique of Photon Emission Spectroscopy. The focus of our program will be to extend existing measurements to higher energy. The motivation and first data from this effort are discussed in the next section.

STATE-SELECTIVE ELECTRON CAPTURE -- FIRST DATA

Most of the existing data on electron capture in ion-atom collisions are measurements of total cross sections. There is only a small amount of data on n distributions and even less on nl and nlm distributions. Theoretical calculations determine nlm distributions but these are normally averaged over to get total cross sections in order to compare with experiments. Measurements of subshell capture cross sections provide a better test of theoretical calculations. Recently, some subshell cross sections for collisions between atoms and highly-charged ions have been measured at lower energy (<15 kev/amu) using ECR ion sources.[11,12] We will extend the measurements to intermediate energy using the 350 kV platform. In addition to their importance in testing theoretical calculations, measurements in this energy regime are useful to fusion research because collisions between plasma ions and neutral beams in tokamaks involve energies of 40-150 keV. Photon emissions following these collisions are used to measure impurity concentrations, study ion transport, and determine ion-velocity distributions.

For our first experiment with state-selective electron capture we are measuring the cross sections for capture by O^{6+} incident on a He gas target. The target is a differentially pumped chamber with a 3 mm diameter hole on the the beam inlet side. The beam passing through the target is monitored with a Faraday cup located inside the gas target. A 1 mm X 10 mm slit in the side of the target transmits light to the entrance slit of a 2.2 meter grazing-incidence spectrometer. A channeltron detector measures the light which passes through the exit slit of the spectrometer. The spectrum is measured by moving the detector along the Rowland circle using a stepping motor. Figure 4 shows the first data obtained in this experiment which was taken with a 666 keV beam of O^{6+}. Each channel corresponds to a fixed quantity of charge collected on the Faraday cup. The lines at 150 Å, 173 Å, and 184 Å indicate capture into n=3 of Li-like O^{5+}, while the lines at 116 Å and 130 Å arise from capture into n=4. Note that the n=3 levels dominate the spectrum and capture into the 3d level is highly favored. Interpretation of these spectra in terms of cross sections requires absolute intensity calibration of the spectrometer. One must also consider cascades from higher excited states. Another consideration is the effect of the alignment of the ion and the polarization dependence of the spectrometer. These factors will require a series of calibration experiments before cross sections can be determined. The complete experiment will consist of a series of runs at different beam energies which will allow a determination of the velocity dependence of the collision. We will carry out similar experiments with other charge states and other targets. A

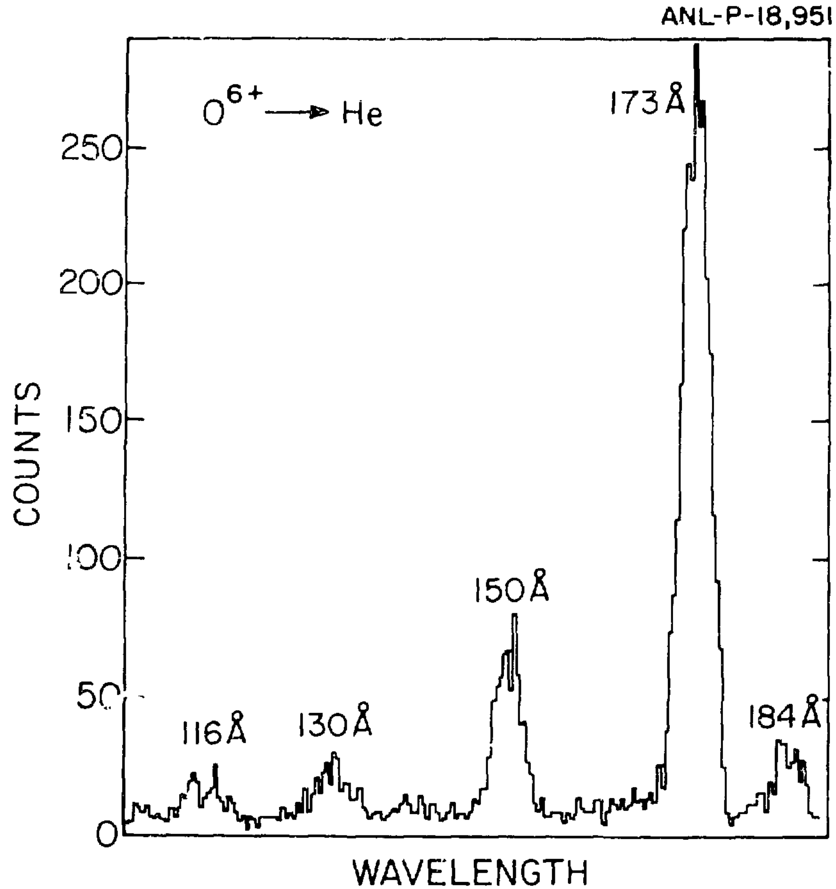

Figure 4 UV Spectrum obtained from O^{6+} incident on He gas. The lines correspond to transitions in lithium-like O^{5+} as follows: 4p-2s 116 Å 4d-2p and 4s-2p 130 Å, 3p-2s 150 Å, 3d-2p 173 Å, 3s-2p 184 Å.

particularly interesting case is that of fully stripped projectiles incident on a hydrogen target. This is a simple system for testing theoretical calculations and is also of importance for fusion plasma diagnostics. In order to do these measurements we are developing plans for a dissociated hydrogen beam target.

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REFERENCES

1. T. Bouchama, M. Druetta and S. Martin, in Proceedings of the International Conference on Spectroscopy and Highly-Ionized Atoms, Lisle Illinois, 1987.

2. T. Bouchama, A. Denis, J. Desesquelles, M. Druetta, M. Farizon, S. Martin, in Proceedings of the International Conference on Spectroscopy and Highly-Ionized Atoms, Lisle Illinois, 1987.

3. R. K. Janev and H. Winter, Physics Reports 117, 265 (1985).

4. R. Pardo, P. J. Billiquist and F. J. Lynch, Proceedings of the International Conference on ECR Ion Sources and Their Applications, East Lansing, Michigan, 1987.

5. H. W. Kugel and C. E. Murnick, Rep. Prog. Phys. 40, 297 (1977).

6. G. W. F. Drake, S. P. Goldman, and Q. ban Wijngaarden, Phys. Rev. A20, 1299 (1979).

7. L. W. Anderson, Nucl. Instrum. and Meth. 167, 363 (1979).

8. L. Young, B. Childs, H. G. Berry, C. Kurtz, and T. Dinneen, Phys. Rev A36, 2149 (1987).

9. J. Serruya et al., Phys. Rev. Lett. 50, 30 (1983).

10. H. Schmidt-Bocking et al., Nucl. Instrum. and Meths. B10/11, 69 (1985).

11. S. Bliman, M. Bonnefoy, J.J. Bonnet, S. Dousson, A. Fleury, D. Hitz and B. Jacquot, Physica Scripta, T3 63 (1983).

12. D. Dijkkamp, D. Ciric, E. Vlieg, A. de Boer, F. J. de Heer, J. Phys B18, 4763 (1985).