# A PENNING MULTIPLY CHARGED HEAVY ION SOURCE TEST FACILITY

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## Summary

An ion source test facility has been constructed at Oak Ridge National Laboratory for making fundamental measurements of the properties of Penning ion sources. The extracted ion energies from the source can be up to 36 x q (keV), where q is the ion charge. Both negative and multiply charged positive ions have been extracted from the source. The facility has high current capabilities for acceleration and for the arc power supply. These low-energy, multiply charged ions are currently being used for measurements of charge exchange cross sections, x-ray production, and electron impact excitation and ionization.


## Introduction

The advance of nuclear research into the field of heavy ions has resulted in an intense effort in producing high charge state ions of all elements in ion sources. In the past, a major portion of ion source development has been done on operating accelerators. In order to accelerate the development of positive ion sources, a test stand has been constructed at Oak Ridge. Two main objectives of the ion source test stand were given prime consideration in the design of the facility. A program of beam diagnostics and atomic physics measurements that operates at ground potential required floating the ion source at high potential. Secondly, adequate separation of the individual charge states for a wide range of charge-to-mass ratios is desired in order to measure the properties of each charge state beam. Construction of the facility was begun in early 1973 and it was used that same year for checking out the rotatable cathode ion source. Extracted beam experiments were started in the fall of 1974.

## Ion Source

The facility is designed to accommodate a variety of Penning type ion sources. Cold cathode ion sources that used 2-5 kW arc power have been operated on the test stand.[1] The present ion source in the test stand is the rotatable cold cathode Penning ion source.[2] This source is designed to increase the operating lifetime of the cathode between source maintenance periods. Its cathode is a disk of tantalum that may be rotated to a new position to strike an arc. A schematic of the ion source is shown in Fig. 1. The plasma collimators may also be rotated and a lifetime-improvement factor of six results. A source that will produce dc extracted ions[3] from solid charge materials is planned.

## Ion Source Analyzer

The ion source test facility is shown in Fig. 2. It is composed of a 30 in. diameter magnet having a 7.5 in. gap. The ion source in the facility is floated from +4 to +36 kV, allowing acceleration of ions up to an energy of 36 x q keV. Atomic physics experiments have operated up to 27 kV. Floating the ion source to high potential necessitates operation of the 75 kW ion source power supply at positive potential. A velocity analyzer using crossed electric and magnetic fields provides substantial m/q dispersion (0.5 in. separation between $^{40}Ar^{9+}$ and $^{40}Ar^{8+}$ at an acceleration voltage of

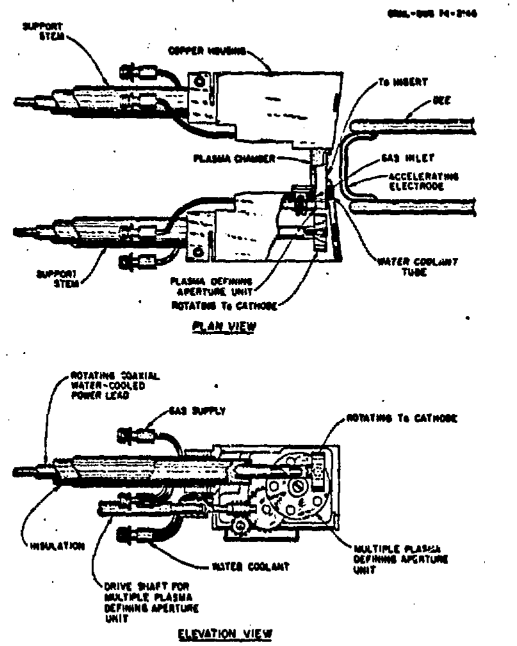


Fig. 1. A schematic view of the rotatable-cathode ion source developed in the ion-source facility. Rotations of the cathodes and plasma defining apertures allow a considerable increase in source lifetime.

10 kV and magnetic field of 4 kG). This combination of electrostatic and magnetic fields deflects the beam by 60° and leads to a focused beam at the deflector plate exit.[4] A variable slit system is provided at this focus point and allows single-charge state selection. The beam enters a region where the field is reduced to less than 50 gauss by magnetic shields.[5] A pair of electrostatic steering plates is mounted in the magnetic shield (Fig. 2) and provides fine tuning in the beam direction. After the ions leave the magnetically shielded region they enter an electrostatic doublet quadrupole lens which focuses the beam onto the desired experimental target at ground potential. The acceleration and electrostatic deflector power supplies are voltage regulated to ~0.01% and are built to withstand large current surges that are characteristic of electrical breakdown of the cold cathode Penning ion source.

The ion source position with respect to the extractor is adjustable. The ion source to extractor clearance (in-out) and the horizontal alignment (left-right) of the source with respect to the extractor slit are all remotely movable. In addition, the angle of extraction between the ion source and extractor is manually adjustable.

The vacuum system was designed to provide fast pump-down (~1 hour between source changes). The system has two major vacuum regions. The source chamber has a base pressure below 1 x $10^{-6}$ torr and operates at 1 to 5 x $10^{-5}$ torr with source gas. The analyzer region,

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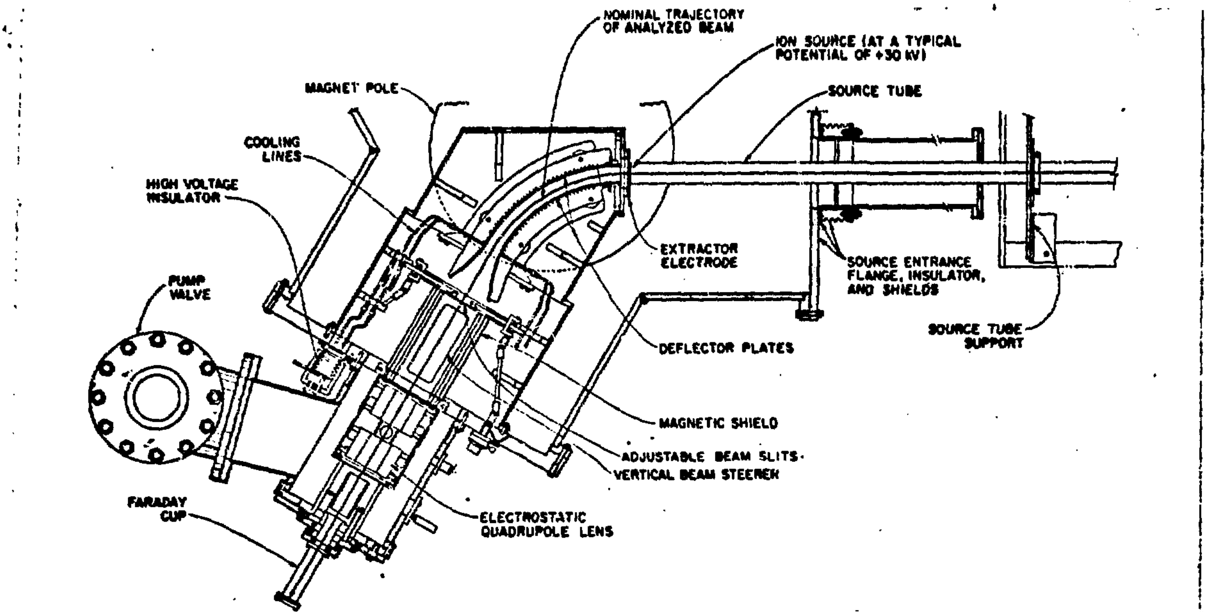


Fig. 2. A schematic view of the ion test facility is shown. Experimental chambers for atomic physics may be connected to the facility instead of the faraday cup.

which is open to the source region through the extraction slit, has a base pressure below 5 x $10^{-7}$ torr and operates at about 1 x $10^{-6}$ torr with source gas.

## Source Test Stand Operation

Various m/q ions have been extracted from the source and have been used to check operating parameters of the facility. Only ions with m/q given by the following expression are expected to emerge from the velocity analyzer.[6]

$$(1)\quad m/q = \frac{H^2}{(4.55)^2}\,\frac{1}{(A + P/2)}\left(\frac{1}{0.0208 + \frac{0.0991P}{(A + P/2)}}\right)^2$$

where m is the mass of the ion in amu units, q is the ion charge state, H is the magnetic field in kG, A is the acceleration voltage in kV, and P is the deflector voltage in kV. The experimental operating curve for 10 kV acceleration and various ion beams is shown in Fig. 3. The experimental data is in excellent agreement with equation (1).

The maximum energy obtainable for a given m/q ion is determined by the maximum deflector plate voltage (35 kV), the minimum magnetic field needed to sustain the Penning arc in the high current mode (4 kG), and the acceleration voltage (36 kV). Typical extracted beam currents, which depend upon the ion source slit size and as measured by the acceleration power supply drain current, are approximately 60 mA (~1 cm² slit). Power supply drain currents as high as 300 mA have been observed. Most of this current is believed to be from the ion source. Beams of $C^{5+}$, $O^{6+}$ and $Ar^{8+}$ have been successfully accelerated and charge identified.

## Ion Source Test Facility Experiments

An electrostatic parallel plate analyzer and a gas cell have been installed in the beam line in order to make charge-changing cross section measurements. Fig. 4 is a drawing of this apparatus. The voltage on the electrostatic analyzer is related to ion beam charge states by equation (2).[7]

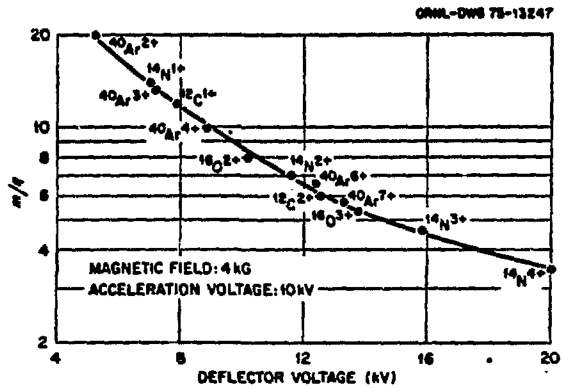


Fig. 3. The analyzer deflector voltage (kV) versus mass-to-charge ratio. The curve is obtained from equation (1) and the points are beams that have been extracted and identified over a period of several months.

$$(2)\quad V_p = (q_i/q_f)\,(0.6)(V_A)$$

where $V_p$ is the analyzer plate voltage, $q_i$ is the incident ion beam charge state, $q_f$ is the final charge state and $V_A$ is the acceleration voltage of the ion beam. An identification of the extracted ion charge state is made by scanning the electrostatic analyzer plate voltage and detecting the charge-transferred peaks. With this information and the known m/q ratio, a positive identification of the ion species can be made. Figure 5 is the analyzer spectrum obtained for $N^{2+}$, $N^{3+}$, $N^{4+}$ and $N^{5+}$ at ~10 kV acceleration voltage. Figure 6 is a spectrum obtained for an $^{40}Ar^{8+}$ beam. Also present is a large contaminant beam of charge state $3^+$. In a like manner, many large peaks of contaminants have been identified with the electrostatic analyzer. Because of our experience in finding and identifying these large contaminant beams, we believe that a system that provides positive identification of the ions charge state is mandatory to achieve reliable test stand data.

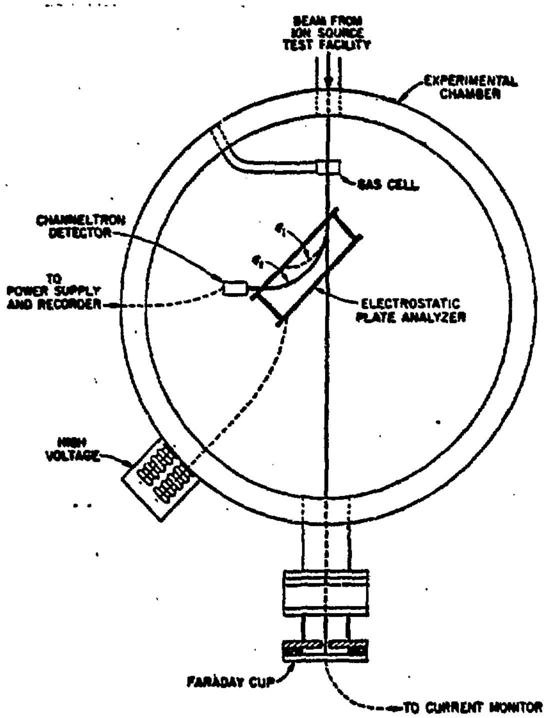


Fig. 4. Experimental apparatus used to identify the charge state of the extracted ion beam from the ion-source test facility. The beam passes through a gas cell and then is analyzed by an electrostatic deflector. The trajectories of the primary beam ($q_i$) and a charge transferred peak ($q_f$) are indicated. A channeltron detector is mounted at the exit of the electrostatic analyzer.

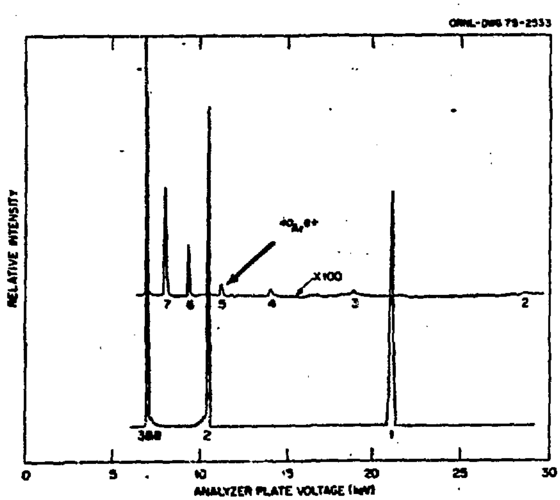


Fig. 6. Charge transfer spectrum obtained for $^{40}Ar^{8+}$. Also present and shown offset on the vertical axis is a charge transfer spectrum of a $3^+$ ion beam. Many high-intensity contaminant beams have been found with the electrostatic analyzer.

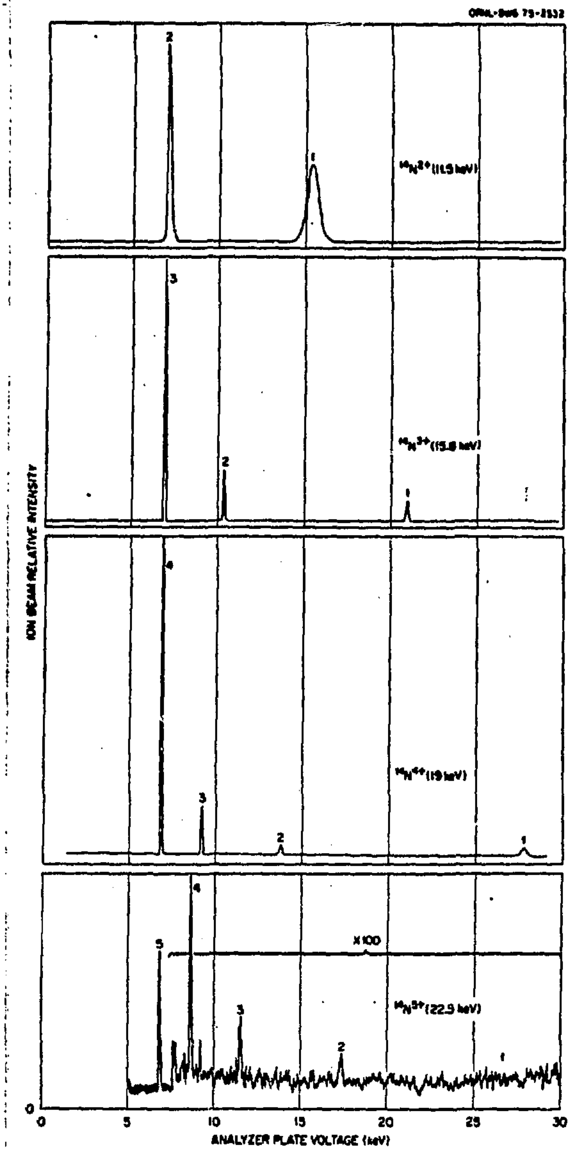


Fig. 5. Charge transfer spectra for $N^{2+}$, $N^{3+}$, $N^{4+}$ and $N^{5+}$ obtained from the ion-source test facility. The lowest voltage peaks are the primary extracted ion beams. The voltage spacings between the following peaks are used to identify the charges of the primary ion beams. The accelerating voltage was ~10 kV, magnetic field 4 kG and the source deflector voltage is given in the parentheses.

The measured energy spread obtained for the extracted ion beam was found to be less than 50 x q (eV) (Fig. 7). This energy spread is the instrumental resolution of our analyzer, and is obtained for all charge states greater than $1^+$. An energy spread measurement by an electrostatic filter lens has confirmed the above measurement and shown an energy spread value of ~30 x q (eV).[8] A filter lens with energy resolution less than 10 x q (eV) is under construction.

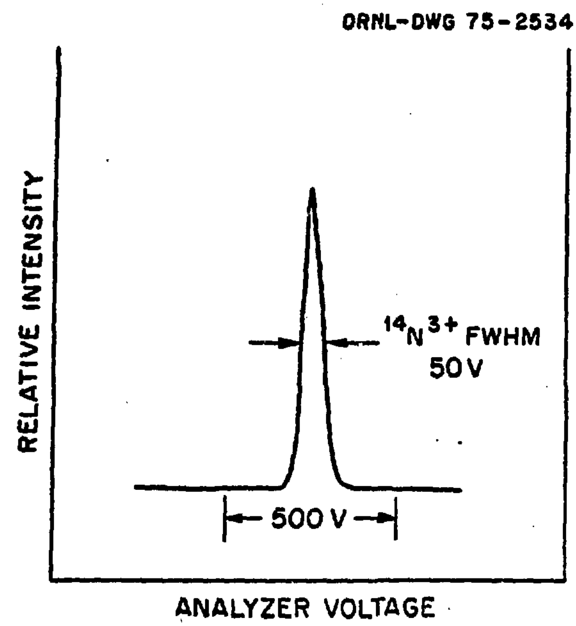


Fig. 7. Measured energy spread of $N^{3+}$ beam extracted from the ion-source test facility. The FWHM is less than 50 V, the resolving limit of the electrostatic analyzer. For higher charge states, the energy spread is also less than 50 V.

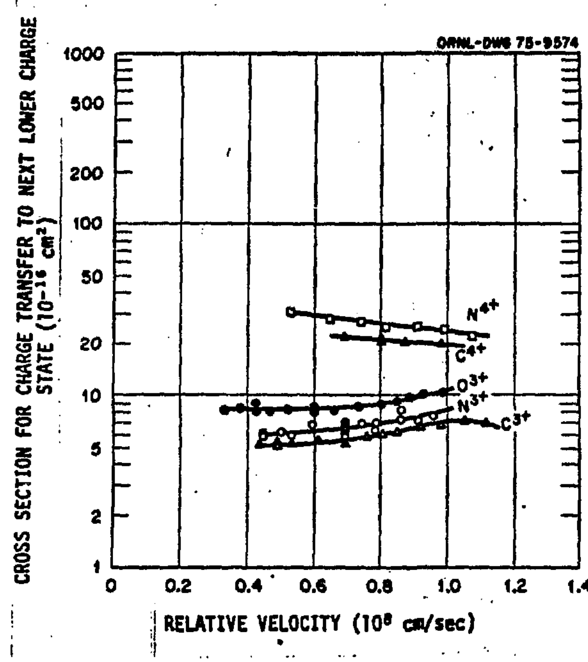


Fig. 8. The charge transfer cross sections for C, N, O and for initial charge states of 3 and 4 at various velocities and colliding with molecular hydrogen. The multiple points on the $N^{3+}$ is an indication of the experimental reproducibility including considerable change in experiment geometry.

## Atomic Physics Experiments

Various atomic physics experiments have been performed with the extracted beam of the ion source test facility. An example of the data obtained in a charge transfer cross section measurement is shown in Fig. 8. The various cross section curves are single electron transfer for C, N, O in charge states 3 and 4 interacting with molecular hydrogen. In addition to the charge exchange measurements, experiments on x-ray production and electron impact excitation and ionization are underway.

## Conclusion

A Penning ion source test stand has been built and is now in operation at Oak Ridge. A program of ion source research, charge exchange cross-section measurements, electron impact excitation and ionization, and x-ray production of high charge states at low energy are in progress.

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## References

1. E. D. Hudson, et al., IEEE Trans. Nucl. Sci. NS-18, No. 3 (1971) 113.
2. M. L. Mallory and E. D. Hudson, IEEE Trans. Nucl. Sci. NS-22, No. 3 (1975) 1669.
3. E. D. Hudson, et al., "Production of Positive Ion Beams from Solids", Proceedings of this Conference.
4. W. E. Millett, Phys. Rev. 74 (1948) 1058.
5. D. Kleppner, et al., Phys. Rev. 138 (1965) A972.
6. C. M. Jones, private communication.
7. G. A. Harrower, Rev. Sci. Instr. 26, No. 9 (1955) 850.
8. P. M. Koch, private communication.