BNL-33473

CONF-830390--3

Two Accel/Decel Experiments: Electron Capture for 6-20 MeV S^{10-16+} on He and Ar and Interference Effects in MO K X-Ray Spectra for 5, 10, and 20 MeV Cl^{16+} on Ar

Brant M. Johnson

Brookhaven National Laboratory

Physics Department, Building 901, Upton, New York 11973, U.S.A.

BNL--33473

DE84 002851

The recent development of four-stage accel-decel operation of the dual MP tandem accelerators at Brookhaven National Laboratory has made it possible to extend atomic collision experiments over an unprecedented range of high charge states and low velocities.[1,2] Briefly, this mode of operation uses the first MP tandem conventionally for two stages of acceleration, then with a negative terminal voltage the second MP tandem provides a third stage of acceleration to high velocity, stripping to high charge state and a final stage of deceleration to low velocity. Details of operation and recent upgrades of the facility were reviewed earlier.[3,4] An overview of present capabilities and the results of two experimental studies using accel-decel beams will be presented here.

Fig. 1 gives a schematic representation of the operational modes of the Brookhaven dual MP tandem facility. The copuled and decoupled configurations are used to produce negative ions at MeV energies (1-stage), positive ions at tens and hundreds of MeV (2- and 3-stage), and highly-stripped positive ions at energies down to a few MeV (4-stage). This versatility provides the opportunity to study atomic-collision phenomena with variable-charge-state projectiles over an extremely wide range of collision energies. Presently, the maximum terminal voltages for V_{MP6} and V_{MP7} are -8 and +12 MV and -11 and +16.5 MV, respectively.

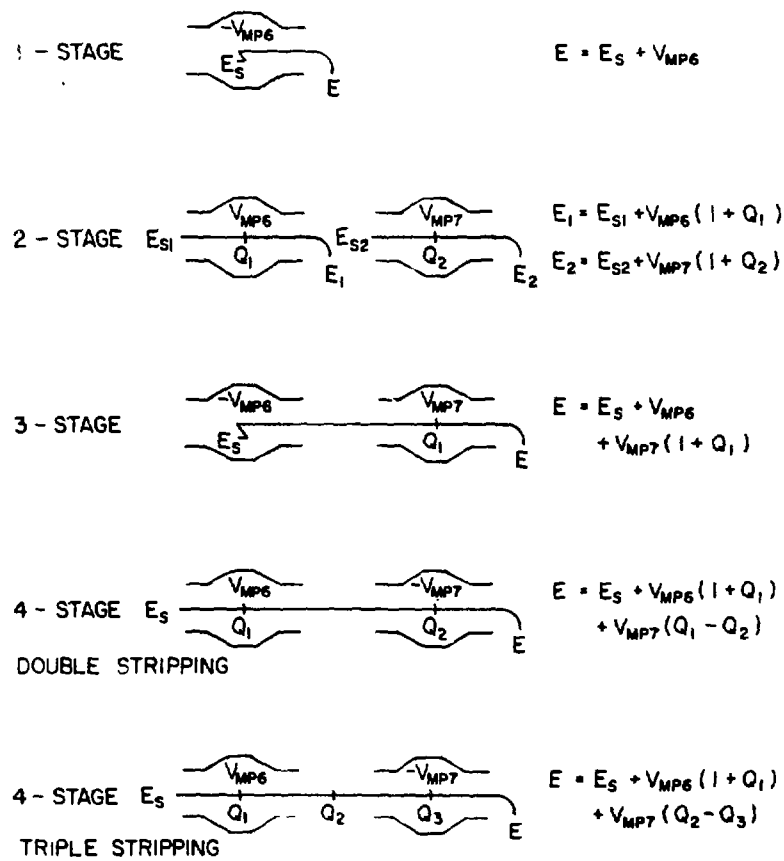

Figure 1. Modes of operation for the Brookhaven dual MP tandem facility.

An excellent example of the need for widely variable beam energies

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

and charge states can be found in the study of single-electron-capture (SEC). Universal scaling laws such as those reported by Knudsen et al.[5] are in reasonable agreement with the data from various laboratories for many different projectiles, charge states, and collision energies. Systematic discrepancies are apparent, however, and varying uncertainties in the compiled data cause non-statistical fluctuations which inhibit further theoretical progress. What is needed are systematic measurements of SEC cross sections over extended ranges of beam energy with a single-charge-state projectile.

The feasibility of using four-stage accel-decel to produce high - charge - state, low-velocity projectiles for SEC studies was recently demonstrated.[6] Total- and single - electron - capture cross sections were measured for S^{10-16+} at 20 MeV, for S^{12+} at 12 MeV, and for S^{13+} at 6, 8, and 10 MeV. The SEC results are plotted in Fig. 2 in terms of the semi-empirical model of Knudsen et al.[5] The magnitude of the S^{q+} + Ar and the trend of the S^{q+} + He data are well represented by the model.

The study of quasimolecular or molecular-orbital (MO) x rays can also be enhanced by employing accel-decel beams.[7] Primarily due to collision broadening

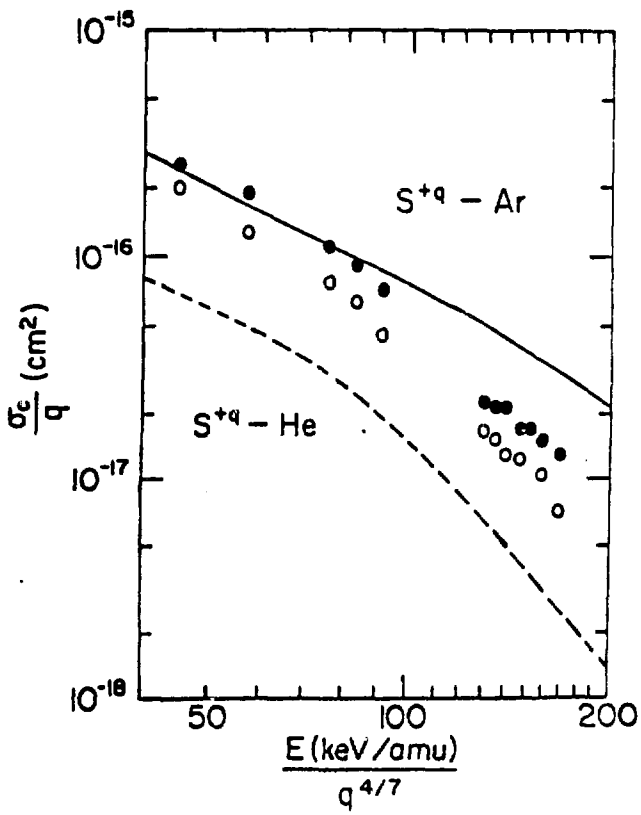

Figure 2. Single-electron - capture cross sections plotted in the reduced form of Knudsen et al.[5]

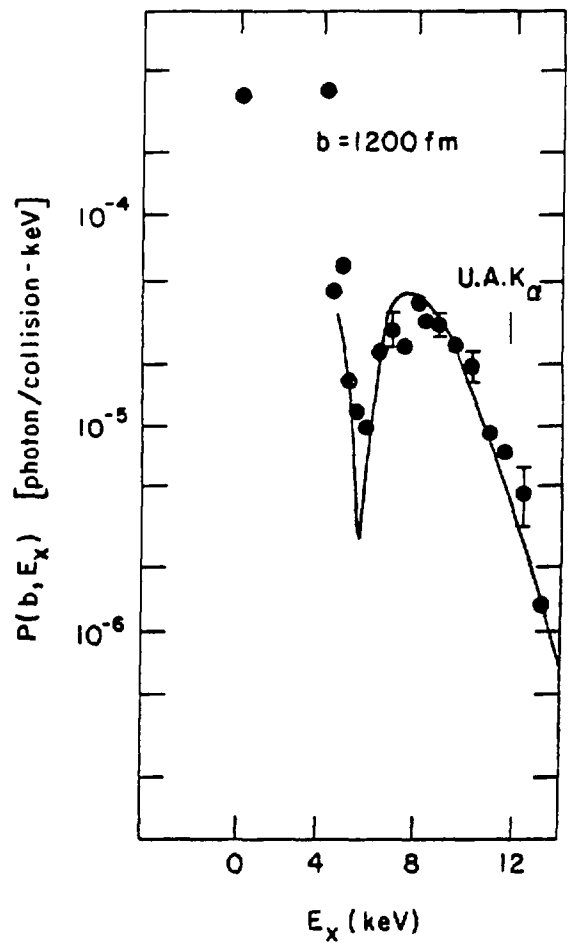

Figure 3. Energy dependence of K x rays for Cl^{16+} + Ar collisions at 10 MeV. The solid curve is the calculation by Anholt.[10]

at high velocities, previously observed MO K x-ray spectra exhibited a structureless shape, essentially independent of impact parameter.[8] Mererly using slower projectiles to reduce collision broadening is not sufficient to overcome this problem, because the probability to both form and fill a K-shell vacancy would be too low to provide adequate coincidence counting rates. The solution is to use a low-velocity one-electron projectile, such as Cl^{16+}, with a large probability of bringing a $1s\sigma$ vacancy into the collision. Under these conditions, the K vacancy does not have to be formed, only filled; the decay rate of $1s\sigma$ vacancies is increased due to the longer collision time; the collision broadening is reduced; and the adiabaticity condition[9] is better fullfilled. In addition, since the $1s\sigma$ vacancy can decay either on the way in or on the way out of the collision, inteference effects should be observable.

The impact-parameter dependence of MO K x-ray production in Cl^{16+} + Ar collisions has recently been measured at 20, 10 , and 5 MeV. Fig. 3 shows the x-ray energy spectrum recorded at an impact parameter of 1200 fm for a collision energy of 10 MeV.[7] The peak near 8 keV is well reproduced by dynamical calculations of Anholt.[10] The structure in the calculated curve arises from the interference between the $1s\sigma$ decay amplitudes in the incoming and outgoing parts of the trajectory. These experiments, which have recently been extended to 5 and 20 MeV, mark the first demonstration that quasimolecular x-ray spectroscopy is possible, and reveal the potential for quantitative studies of transient molecular orbitals formed during ion-atom collisions.

This research is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Chemical Sciences, under Contract No. DE-AC02-76CH00016.

References

1. B.M. Johnson, K.W. Jones, and M. Meron, IEEE Trans. on Nucl. Sci. NS-30, to be published (April, 1983).

2. K.W. Jones, B.M. Johnson, M. Meron, Wang Da-Hai, P. Thieberger, J. Barrette, R. Schuch, H. Schmidt-Böcking, I. Tserruya, and T.H. Kruse, Phys. Scripta, to be published.

3. P. Thieberger, J. Barrette, B.M. Johnson, K.W. Jones, M. Meron, and H.E. Wegner, IEEE Trans. on Nucl. Sci. NS-30, to be published (April, 1983).

4. J. Barrette and P. Thieberger, IEEE Conference record, IEEE 81CH1639-4 (1981) 202.

5. H. Knudsen, H.K. Haugen, and P. Hvelplund, Phys. Rev. A23 (1981) 597.

6. J. Barrette, B.M. Johnson, K.W. Jones, R. Schuch, I. Tserruya, and T.H. Kruse, "Proc. XII ICPEAC," Gatlinburg, Tennessee, July 15-21, 1981, Ed. by S. Datz, (Oak Ridge, Tennessee, 1981) Vol. I., p. 716.

7. I. Tserruya, R. Schuch, H. Schmidt-Böcking, J. Barrette, Wang Da-Hai, B.M. Johnson, M. Meron, and K.W. Jones, Phys. Rev. Lett.

8. I. Tserruya, H. Schmidt-Böcking, R. Schule, K. Bethge, R. Schuch, and H.J. Specht, Phys. Rev. Lett. 36 (1976) 1451.

9. M. Barat and W. Lichten, Phys. Rev. A6 (1972) 211.

10. R. Anholt, Nucl. Instrum. and Meth. 198 (1982) 567; private communication.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.