Construction and Testing of a New Atomic Physics Beam Line at the Western Michigan University Accelerator Laboratory

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ABSTRACT

A new beam line containing a differentially-pumped gas cell and charge state analyzing magnet was constructed for the purpose of measuring a wide variety of atomic inner-shell processes, such as excitation, ionization, and charge transfer. The completed system will be able to measure these individual atomic processes using coincidence techniques. Initial testing of the beam line was performed using 40MeV S^{+7} + Ar collisions to determine the effect of the collimating slit size on the measured x-ray cross sections. These measurements showed that the slit size affects the x-ray cross section by a maximum of ~6% between 4mm² and ≥100mm². X-ray production was measured for 30-60 MeV S^{+13} + Ar collisions to determine the relationship between cross section and beam energy. The results show that the x-ray cross section increases with beam energy. However, the measured cross sections were found to be about four times smaller than expected based on data obtained in another experiment.

Introduction

Several basic inner-shell process over in heavy ion-atom collisions, such as excitation, ionization, and charge transfer. Excitation is the general term for any process where electrons are raised to higher energy levels. Ionization is simply the extension of excitation; the electron is given sufficient energy to remove it from the atom and place it into the continuum. Both excitation and ionization can be experimentally observed by detecting the energy of the emitted photon when the vacancy is filled by another electron. Charge transfer occurs when the projectile ion exchanges electrons with the target atom. The individual charge-changing events can be observed by using either an electric or magnetic field to separate the various charge states of the beam emerging from the target. Particle detectors are positioned behind the field area to collect the individual charge components.

The desire for an apparatus that could measure any of the three atomic processes listed above prompted the design and construction of the differentially-pumped gas cell and beam line system at the Western Michigan University Accelerator Laboratory. The testing of this new equipment was done using S + Ar collisions. Data is presented which examines the effect of beam collimating slit size on the x-ray cross sections. Other data compares the measured x-ray cross section versus beam energy to previous experimental results.[1]

Description of the Beam Line and Gas Cell

The work described below was performed at Western Michigan University using the 6 MV model EN tandem Van De Graaff accelerator. Following the selection of the desired charge state from the accelerator, the beam was collimated with two sets of adjustable slits placed two meters apart. Each unit has four individual micrometer paddles which define the beam in both the horizontal and vertical plane of collima-

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tion. The individual micrometer assembly can be adjusted independently to achieve almost any desired slit area. Both sets of slits are electrically insulated from the surrounding beam pipe so that ion current measurements can be taken.

After collimation with the adjustable slits, the beam strikes a gas target inside a differentially-pumped gas cell. The purpose of the differentially-pumped cell is to maintain a relatively high target gas pressure and to keep this gas from significantly raising the surrounding beam line pressure. This is accomplished in two stages; first, gas which escapes from the target cell through its entrance and exist apertures enters a region pumped by a 4″ diffusion pump. The gas in this region is restricted from entering the beam line by two small apertures. The area of the opening leading to the 4″ diffusion pump is much larger than the corresponding area of the two apertures. Hence, target gas is more likely to escape to the 4″ diffusion pump than through the aperture openings. The small amount of target gas that does escape through the apertures is differentially-pumped a second time using a 6″ diffusion pump and a second set of collimating apertures around the gas cell. The resulting x-rays which are produced in the gas cell are detected with a Si(Li) detector mounted at 90° to the incident beam direction.

At the present time, this is the extent of the completed construction of the beam line, although the remaining components of the apparatus are ready to be installed. Future plans include the installation of a 17.5 kilogauss spectroscopy magnet downstream of the gas cell to separate the emerging beam into charge state components. An array of four surface barrier detectors placed behind the magnet will measure the ion flux which is present in four particular charge states, namely Q-2, Q-1, Q+1, and Q+2 with Q being the incident charge of the ion beam. The detector assembly, in conjunction with the magnet, was designed to charge analyze ions as heavy as bromine with kinetic energies as high as 80 MeV. The addition of the particle detection system described above makes it possible to directly measure charge-changing atomic interactions.

Data Analysis

Initial testing of the beam line was performed using a 40 MeV S^{+7} + Ar reaction to check the alignment of the system and look for the effects of beam collimation and slit scattering on the measured x-ray production cross sections. Additional measurements were made for 30, 40, 48, and 60 MeV S^{+13} + Ar collisions to compare the x-ray cross sections with previous results. A typical spectrum from the Si(Li) detector consists of three distinct peaks: the sulfur K_α, argon K_α, and argon K_β x rays at about 2.30, 2.96, and 3.19 keV respectively.

The x-ray production cross section can be thought of as the probability of an x ray being produced in the interaction of a projectile ion with the target atom. The total x-ray production cross section is a function of several different parameters which are given below.

$$\sigma_x = \frac{\left(\frac{\triangle F}{\triangle P}\right)}{N\ell\left(\frac{\triangle \Omega}{4\pi}\right)\epsilon}$$

Where: $N = 3.3 \times 10^{13} \frac{\text{atoms}}{\text{microns} \cdot \text{cm}^3}$

ℓ = Target Length
$\Delta\Omega$ = Detector Solid Angle
ϵ = X-Ray Detection Efficiency
$\left(\frac{\Delta F}{\Delta P}\right)$ = Slope of Graph When F is Plotted Versus P

$$F \equiv \frac{N_{x\text{-rays}}}{I_o}$$

And: $N_{x\text{-rays}}$ = Number of X-Rays in Peak
I_o = Incident Ion Flux
P = Gas Cell Pressure (microns)

In order for the above formula for the x-ray production cross section to be valid, it was assumed that the incident sulfur ions have only one interaction with the target gas in the gas cell. This limitation causes the fraction F to be a linear function of the gas cell pressure.

The quantity ϵ in the cross section equation represents the total x-ray detection efficiency. The thin (0.001 inch) beryllium window on the Si(Li) detector attenuates some of the x rays which are produced in the gas cell so the number of detected x-rays is less than the number of x-rays produced in the target.

Discussion

The effect of beam collimation on the x-ray cross sections was studied for 40 MeV S^{+7} + Ar collisions. The results can be found in Table 1. The x-ray production

TABLE 1.
40 MeV S^{+7} + Ar Slit Comparison Data

X-Ray	σ_{4mm^2} ($\times 10^{-20}$ cm^2)	σ_{OPEN} ($\times 10^{-20}$ cm^2)	$\sigma_{OPEN}/\sigma_{4mm^2}$
Sulfur K_α	1.38 ± 0.10	1.30 ± 0.04	0.94 ± 0.08
Argon K_α	0.906 ± 0.096	0.863 ± 0.043	0.95 ± 0.11
Argon K_β	0.114 ± 0.012	0.107 ± 0.005	0.94 ± 0.11

cross section was measured with both a $\geq$ 100 mm^2 and a 4 mm^2 slit opening. Notice that this difference in collimating slit area affects the total x-ray cross section by approximately 6%. This difference is less than the size of the error bars on the x-ray cross section data between a slit area of $\geq$100 mm^2 and 4 mm^2. This data also shows that the cross section for the 4 mm^2 slit opening is consistently larger than the similar measurements taken at $\geq$ 100 mm^2. This systematic increase in x-ray cross section might be caused by slit scattering of the incident sulfur ions.

The results of Table 1 can be compared with data taken by Winters et al. which found the S_{K_α} and Ar_{K_α} x-ray production cross sections to be about 1.30×10^{-20} cm^2 and 0.50×10^{-20} cm^2 respectively, at 16.5 MeV for a S^{+7} + Ar collision.[2] The values of the x-ray cross sections listed in Table 1 are consistent with the Winters et al. data.

Results from the x-ray production cross section measurements for 30-60 MeV S^{+13} + Ar collisions can be found in Table 2. This data shows that the cross section

TABLE 2
30-60 MeV S^{+13} + Ar Energy Comparison Data

Beam Energy (MeV)	$\sigma_{S K_\alpha}$ ($\times 10^{-20}$ cm^2)	$\sigma_{Ar K_\alpha}$ ($\times 10^{-20}$ cm^2)	$\sigma_{Ar K_\beta}$ ($\times 10^{-21}$ cm^2)
30	2.85 ± 0.43	1.77 ± 0.44	2.13 ± 0.30
40	3.11 ± 0.43	2.44 ± 0.35	3.75 ± 0.23
48	3.51 ± 0.38	2.89 ± 0.33	3.93 ± 0.43
60	4.41 ± 0.36	3.24 ± 0.38	4.18 ± 0.55

is steadily increasing over the range of 30-60 MeV for the sulfur K_α, argon K_α, and argon K_β x rays. These results are entirely consistent with other measurements of the x-ray production cross section for S^{+13} + Ar collisions.[1,3]

However, extrapolation of data taken in a similar experiment by Tanis et al. shows that the sulfur K_α and argon K_α x-ray production cross sections, shown in Table 2, are between three to five times smaller than previously measured values for these x-ray cross sections.[1] At the present time there is no adequate explanation for these large differences in the x-ray production cross section. Further measurements should be taken between 30 and 160 MeV to resolve this question.

Literature Cited

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