First Test of Photoionization of Multi-charged Ions and PHOton Beam Ion Source (PHOBIS) with the RIKEN EBIS (REBIS)

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Photoionization of multi-charged ions (PMI), besides being of fundamental interest, is important in various plasma applications such as fusion plasmas and astrophysical plasmas. The relevance is to radiation transport through the plasmas, for instance X-rays can carry energy out of a fusion plasma. Theoretically, numerous works have been published on PMI,that includes: isonuclear, isoionic, double photo-ionization of He like ions, and photoionization of highly excited multi-charged ions, just to name a few. The ex-perimental publication list for PMI is short, due to the difficulties in obtaining a high density ion target, high flux x-ray sources and the small cross-sections involved in the PMI process.

To overcome the difficulties associated with measurements of PMI, ions produced and trapped inside an Electron Beam Ion Source (EBIS)[1] and undulator radiation from a synchrotron radiation facility as the photon source will be used. EBIS produced ions trapped inside the source were chosen as the ion target because of the potentially high density of ions confined inside the EBIS in an ultra-high vacuum. Densities from 10^6 to 10^{10} ions/cm^3 are obtainable. Undulator radiation, due to its low emittance (parallel beam), is well suited for the long cylindrical shape of the ion target in the EBIS. Thus, a long interaction region can be employed, in the case of REBIS, about 25 cm. Detailed descriptions of REBIS have been given elsewhere[2] and will not be discussed here.

The basic principles of EBIS operation are as follows: an electron beam is injected into a solenoidal magnetic field, the increasing magnetic field compresses the electron beam to high densities. Upon exiting the magnetic field the electrons are defocussed and collected. Multiply charged ions are created inside the compressed electron beam by successive electron impact ionization of an injected gas. The ions are confined in the EBIS axially by a potential well created by applied potentials to drift tubes in the solenoid, and radially by the space charge of the electron beam. The presence of the space charge of the electron beam is what allows the high densities of ions. We designed an electron gun that has a hole in the cathode to allow for passage of synchrotron radiation along the axis. As an ion source, REBIS can produce Ar^{16+} ions.

Photoionized ions are created in the following way: the ion target is first created by the electron beam. After preparation of the desired ion target, synchrotron radiation is allowed to pass through REBIS to photoionize the ion target, after which the photon beam is blocked, the end potential of the potential well is lowered which allows the ions to exit the REBIS and be charge state analyzed. By carefully measuring the ratio of the photoionized ion rate to the ion target number, an absolute cross section can be obtained.

The first test beam time was held on the BL2-B undulator (unmonochromatized) beam line at the Photon Factory, but photoionized ions were not detected. Problems with the target ion charge state distribution and the ion detection system caused the non-result. Currently, im-provements in the apparatus are being performed. The real usefulness of this experiment can be realized when SPring-8 comes online. Because of the high flux and brightness of SPring-8, a monochromater can be employed, making the measurements more differential and results simpler to interpret.

Also of interest in ion source development is the PHOton Beam Ion Source(PHOBIS) concept. For PHOBIS, synchrotron radiation replaces the electron beam as the ionizing means, and ions are extracted from the source for low energy atomic physics experiments. The advantage of PHOBIS over other low energy ion sources is the potentially low energy spread of the extracted ions because of the low recoil energy associated with photoionization.

Unmonochromatized undulator radiation spectrum was used to produce the first PHOBIS. The first harmonic, the most intense peak of the spectrum, is in the region of the Ar 2p shell ionization energy of

247.9 eV. Ions were extracted from PHOBIS in a continuous mode. The extracted charge state distribution can be seen in Fig. 1. Fig. 2 is a bar plot of the % abundance of the experimental charge distribution along with a calculation of the expected distribution from single photoionization of the LI, LII,III, MI or MII,III shells The calculated charge state distribution was estimated from the convolution of the photoionization cross-sections with the photon flux as a function of photon energy, and the probability of removing n electrons due to Auger cascade and electron shake-off for a given LI, LII,III or M shell initial vacancy. The experimental charge state distribution is skewed towards the higher charge states as compared to the calculat-ed distribution. Successive ionization by photons to produce this charge state distribution is unlikely because in the continuous extraction mode the ions spend little time in PHOBIS, on the order of 20 msec. Also,the cross section for 2p photoionization is larger than that for 2s photoionization at all photon energies in the undulator spectrum , excluding the possibility of the higher harmonics in the undulator radiation producing more 2s initial vacancies and therefore to which produce higher charge states. We believe the discrepancy between the experimental and calculated values for the charge distribution was caused by the single hit TAC effect. This effect causes the detection efficiency for high charge states to be larger than that for low charge states when the counting rate is high, since the high charge states can stop the TAC before the low charge states can reach the Ceratron.

REFERENCES

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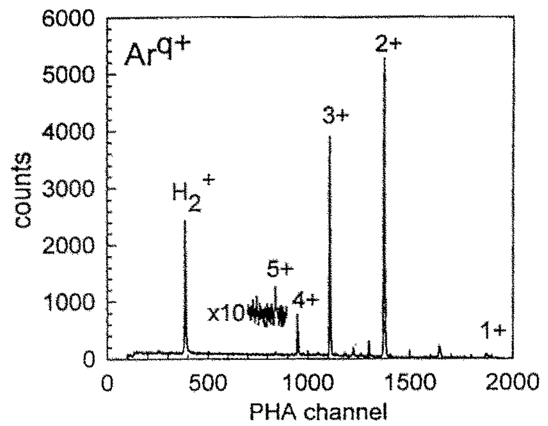

Fig.1 Time of flight spectrum of Ar ions from PHOBIS.

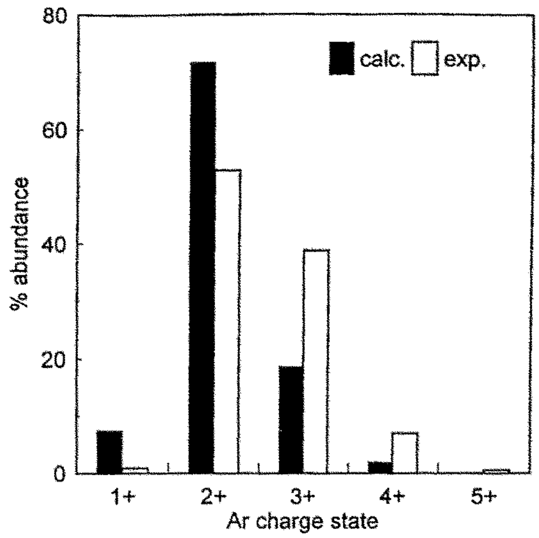

Fig.2 Bar graph of the experimental(exp.) and calculat-ed(calc.) values for the % abundance of the charge state distribution.