

PHOTOIONIZATION OF IONS IN A TRAP: A NEW TOOL TO EVALUATE PLASMA PHYSICS. FIRST RESULTS IN THE CASE OF Xe⁺

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The “Fourth State of Matter”, often called plasma, differs from the solid, liquid and gas state by its significant number of electrically charged particles which affect its electrical properties and behaviour. Besides being inherent in our daily lives through many aspects, plasmas make up more than 99 percent of the visible universe.

An ordinary gas is electrically “neutral”. Indeed, in each atom the positive charges of the nucleus are balanced by an equal number of negatively charged electrons. A gas turns into plasma when insertion of heat or of other energy can induce the release of some or all electrons from a significant number of atoms, so that the electrical characteristics of the gas are macroscopically affected. Atoms being left with a positive charge, the detached negative electrons are free to move about and both atoms and the resulting electrically charged gas are said to be “ionized.”

Atomic spectroscopy is a powerful tool for characterizing plasma properties such as their thermodynamic state and transport. The determination of the populations and degree of ionization of species inside the plasma requires knowledge of the production rates (cross sections) for many atomic processes. Beyond their fundamental interest, photoionization of ions is particularly important for such different fields as astrophysics, planetary sciences and, more generally, all applications of energetic plasmas (food processing, waste disposal, fusion research, X-ray laser, electronic etching or implantation). Photoabsorption cross sections are fundamental information

needed for the description of radiation transfer, the main way for energy to diffuse inside the plasma.

The main obstacle to experimental studies in this field is the difficulty to produce clean targets of multiply-charged ions with density high enough to compensate for both the relatively low flux of the available XUV photon sources and the low value of photoionization cross sections. One technique allowing for the measurement of absolute photoionization cross sections on a large variety of ion samples was implemented during the 80's in Daresbury [1]. It consists in merging two beams: one of mass-selected ions and one of energy-selected synchrotron radiation. The major limitation of this method is that the ionic target is often composed of a mixture of ions in different excited states, as the time of flight of the ions between the source and the interaction region is very short (typically a few μsec). The determination of the population of ions in the different states present in the target usually requires theoretical data.

We propose [2] a new method to measure the photoionization cross sections of the pure ground level of ionic species: *store ions in a trap and wait for a time long enough for excited states to radiatively decay to the ground state before their irradiation*. To this purpose, we installed the MICRA [3] (Mobile Ion Cyclotron Resonance Analyzer) Penning ion trap on the low energy branch of the Gas Phase Beam-Line, in order to analyze the change of the photoion population as a function of photon energy.

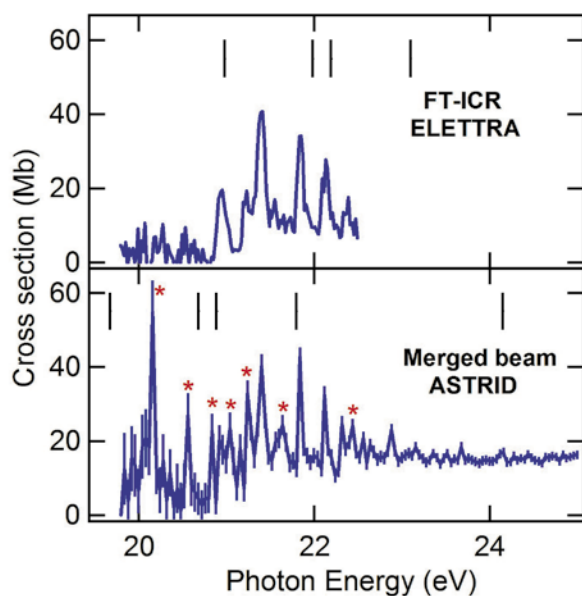
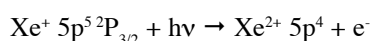


Figure 1. Variation of the photoionization cross sections of Xe^+ ion (blue lines). Upper panel: with ion trap result; lower panel: the merged beam experiment. The vertical bars give the position of the various ionization thresholds for ions in the ground and metastable levels. The asterisks correspond to transitions from the metastable level.

The target ions are first produced by electron ionization of Xe atoms, producing the Xe^+ ions in both fundamental $^2\text{P}_{3/2}$ and metastable $^2\text{P}_{1/2}$ state. After a 1 s delay for relaxation, the Xe^+ ions are irradiated for 1.3 s and the mass spectrum of ions in the trap is recorded. The resulting photoionization (Xe^{2+} signal) spectrum is shown as the thick curve on the upper panel of Figure 1. The spectrum clearly shows a rise of the signal at 20.9 eV, the energy of the first threshold for the direct photoionization process:



The positions of the thresholds for the various terms of the $\text{Xe}^{2+} 5p^4$ configuration are shown as vertical bars. Above the continua produced by process (1), prominent lines are observed. In our spectrum, the absence of signal below 20.9 eV demonstrates that the ions in the trap are in the ground level at the moment of the irradiation.

The measurement was reproduced using the merged beam experiment at ASTRID [4]. The spectrum obtained is shown in the lower

panel of Figure 1. In addition to the previously observed lines, new ones, marked with an asterisk, appear. The most intense is below 20.9 eV and reveals an overwhelming contribution of Xe^+ ions in metastable levels.

This work shows that an ion trap coupled to synchrotron radiation allows for the measurement of a pure ionic population. Further developments are foreseen, since the possibility of doing in-cell chemistry with mass selected ions opens new opportunities for studies in fields including spectroscopic and dynamic studies on molecular or cluster ions, multiply charged molecular ions, bio molecules, etc.

References

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