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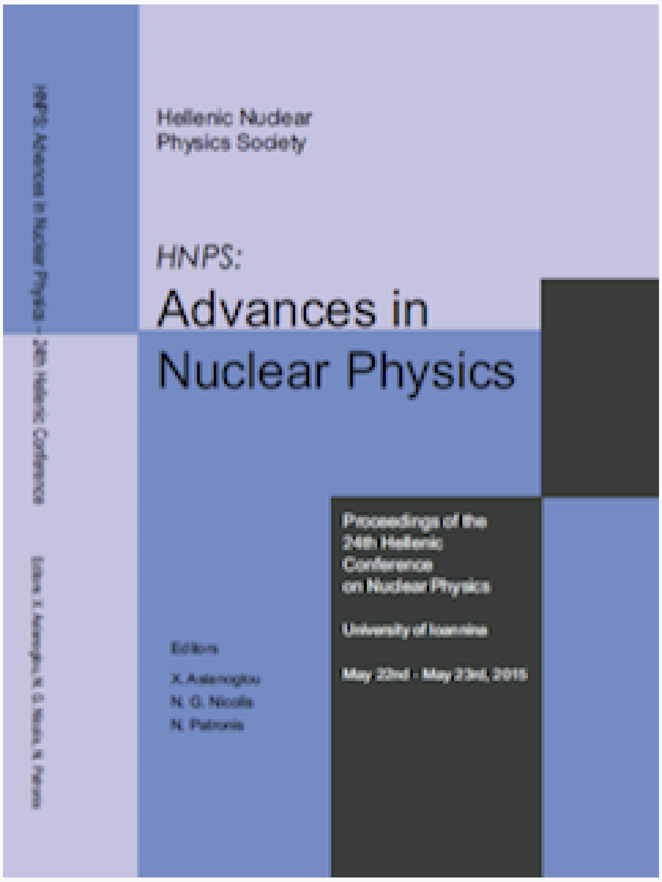

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Atomic Physics at the 5 MV Tandem at Demokritos: the UoC APAPES‡ project

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Abstract. University of Crete (UoC) has initiated the research initiative APAPES funded by THALES‡ that has already set up a new experimental station with a beam line dedicated solely on basic atomic physics research. This new experiment utilizing Zero-degree Auger Projectile Spectroscopy (ZAPS) is located at the 5 MV TANDEM accelerator of the National Center for Scientific Research (NCSR) “Demokritos” in Athens, and has been put together to perform high resolution studies of electrons emitted during ion-atom collisions. The apparatus consists of a Hemispherical Deflector Analyzer (HDA) combined with a 2-dimensional Position Sensitive Detector (PSD) and a doubly-differentially pumped gas cell containing the gas-target.

The goal is to perform a systematic isoelectronic investigation of K-Auger spectra emitted from pre-excited and ground state He-like ions in collisions with gas targets using novel techniques.

So far, various Auger electron spectra produced through collisions of mixed state ($1s^2$, $1s2s\,^3S$) C^{4+} ion beam with various gas targets have been recorded. In addition, detailed simulations using SIMION have also explored the optimal lens voltages and the solid angle correction factors for long-lived metastable states. A terminal gas stripper system is scheduled to be installed in the accelerator, extending its range of available charge states and enabling the production of pure ground state as well as mixed state beams with different metastable fractions, a measurement vital to APAPES.

Here, we report on the progress made up to date on the APAPES project, the description of the apparatus, updated results and plans for the near future.

Keywords Ion-atom collisions, Auger electron spectroscopy, He-like ion beams

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INTRODUCTION

The APAPES initiative establishes in Greece the discipline of Atomic Physics with Accelerators, a field with important contributions to astrophysics, hot plasmas, fusion, accelerator technology as well as fundamental atomic physics of ion-atom collision dynamics, structure and technology. This is accomplished by combining the existing interdisciplinary atomic collisions expertise from three Greek universities, the strong support of distinguished foreign researchers and the high technical ion-beam know-how of the "Demokritos" Tandem accelerator group into a cohesive initiative.

EXPERIMENTAL DETAILS

The experimental setup includes a single stage HDA spectrometer equipped with an injection lens and a 2-dimensional PSD combined with a doubly-differentially pumped gas target. It has been used in previous work at Kansas State Univ. [1], and was transferred to the Athens TANDEM accelerator laboratory. This high-efficiency, high-resolution ZAPS system is ideally suited for use in electron spectroscopy of electrons emitted from weak ion beams, and due to its PSD is also about 15-20 times more efficient than conventional single channel devices (e.g. two-stage parallel plate electron spectrometers [2]). Additionally, the paracentric entry of the HDA [3] is a novel feature adding further high-resolution capability not available to conventional centric HDAs [4, 5]. In Fig. 1 a photograph of the beam line is shown, and in Fig. 2, a schematic of the doubly differentially pumped target gas cell, the HDA, the 4-element input lens and the PSD are shown inside the vacuum chamber.

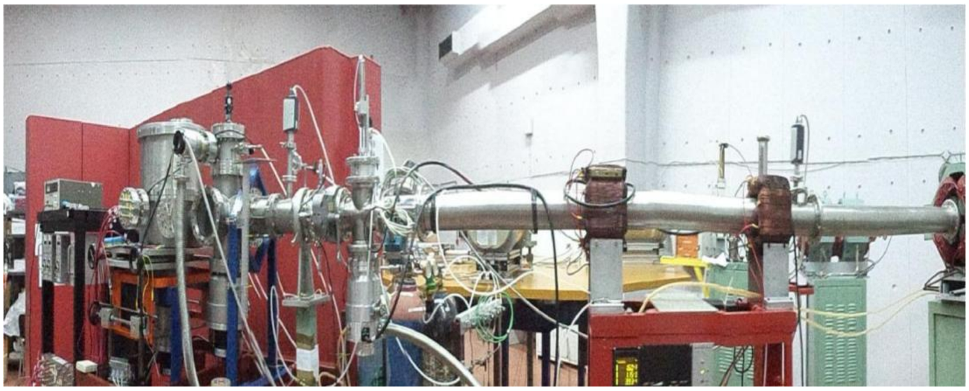

Fig. 1. Panoramic view of the new beam line at the 5 MV Demokritos Tandem.

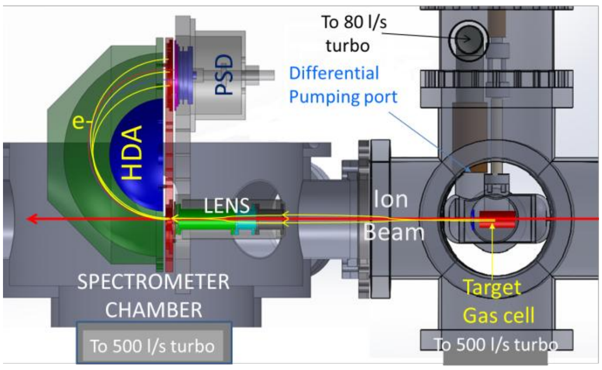

Fig. 2. Schematic view of the doubly-differentially pumped target gas cell, the 4-element input lens, the HDA and the 2-D PSD. Each colour denotes a different electrode that can be independently biased.

ELECTRON ENERGY SPECTRUM

A typical high-resolution KLL Auger spectrum with our new setup using the 5 MV Tandem Van de Graaff accelerator is shown in Fig. 3. A 18 MeV C^{4+} beam was collimated and directed into the doubly-differentially pumped gas cell that contains the Ne target. The gas cell pressure during the measurement was 20 mTorr. The tuning energy W of the analyzer was set at 1525 eV. High resolution was achieved by retarding the electrons using a deceleration factor of F=4. Analysed electrons are recorded and normalized to the incident beam current, which is collected at the Faraday cup. The similarity with previous published works is obvious [9].

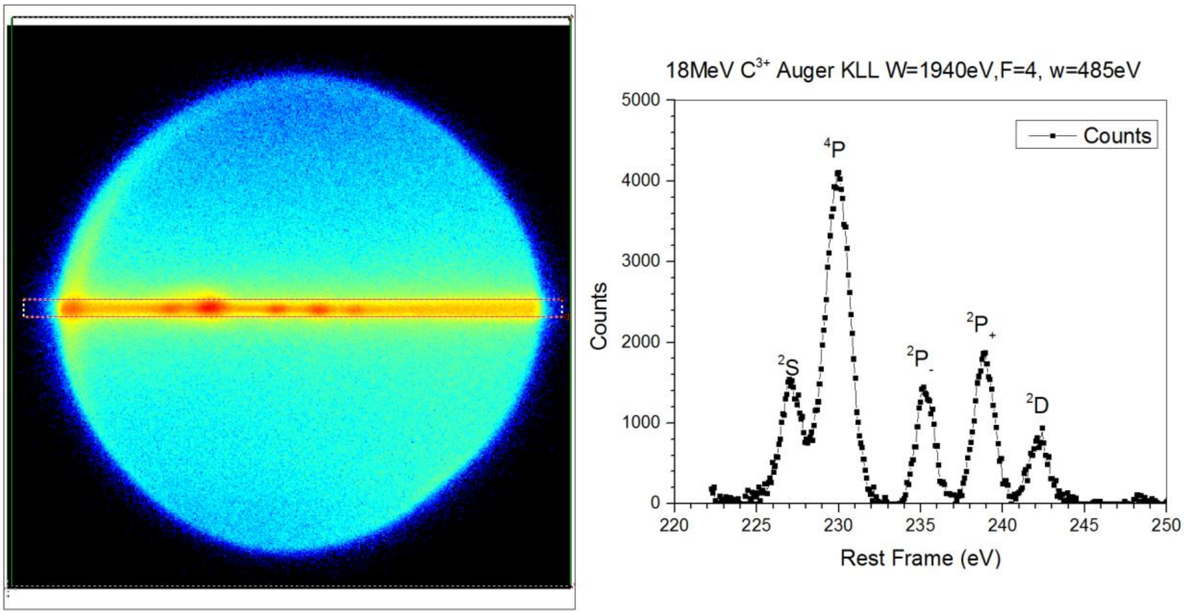

Fig. 3. (a) 2-D PSD Image, (b) Projection of the PSD image within the selected region shown in (a). The ^4P line is seen to be broadened. Its considerably longer life-time makes it decays closer to the spectrometer with increased angular acceptance and therefore kinematic broadening.

ELECTRON CAPTURE

The various 1s2s2*l* lines observed in the Auger electron spectra in Fig. 3 result from various electron transfer processes of a target electron to one of the possible (1s2s2*l*) states available to a He-like ion. In the past, we have presented calculations for fluorine He-like beams. With the use of the well known COWAN Hartree-Fock package [6] the relevant $F^{6+}(1s2snl\ ^{2,4}L_J)$ Li-like energy levels, including dipole and Auger transition rates for principal quantum numbers $2 \le n \le 5$ and l=0, n-1 were calculated [7]. In Fig. 4 the energy level scheme along with the corresponding transition rates is shown. Basic quantum mechanics requires the spin coupling of a 2p electron to the 1s2s ^3S state yielding 1s2s2p ^4P quartet and 1s2s2p ^2P doublet states to be in the ratio of 2:1, i.e. $R=\sigma(1s2s2p\ ^4P)/\sigma(1s2s2p\ ^2P)= 2$. However, it has been documented in the literature that the values of R extracted from the spectra are much larger having values of $R\sim 6$-9 [7-10]. Our intention is to provide a more thorough understanding of cascade feeding of the 1s2s2p ^4P metastable states produced by electron capture in collisions of He-like ions with gas targets and further elucidate their role in the non-statistical production of 1s2s2p states by electron capture, recently a field of conflicting interpretations awaiting further resolution.

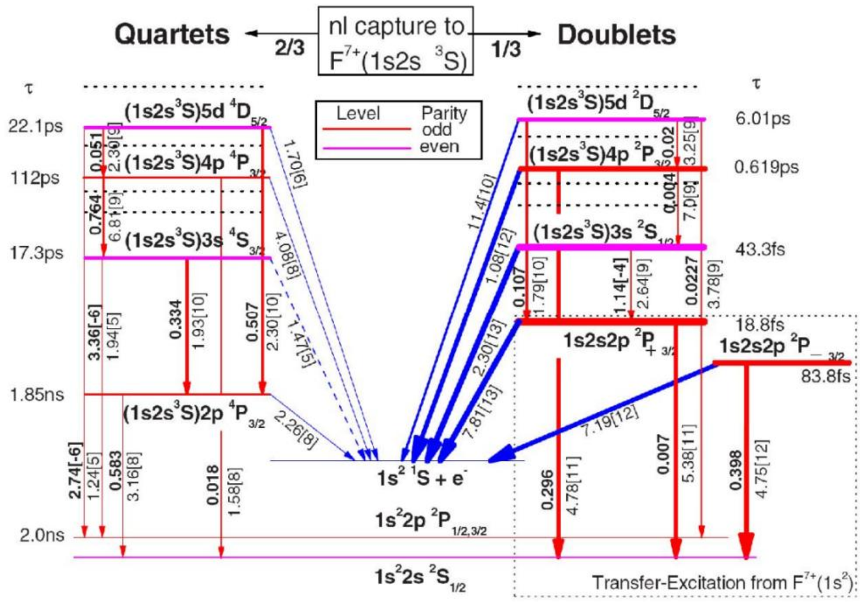

Fig. 4. Li-like quartet and doublet F^{6+} 1s2snl energy level scheme (not to scale) resulting from single electron nl capture to F^{7+} 1s2s ^3S. Only a few representative levels are indicated for clarity. Arrows represent transitions with widths roughly proportional to their strength radiative E1 (dipole) vertical red lines and Auger slanted blue lines. Rates in s^{-1} are given to the right of the arrows the quantity in square brackets indicates power of 10, while radiative transition branching ratios are given in bold to their left. Also indicated are total lifetimes and dashed arrows for Coulomb forbidden transitions (from Ref. [7]).

FUTURE DEVELOPMENTS

Future developments on the beam line include the upgrade of the TANDEM's accelerator to also include a recirculating gas stripper system in the accelerator terminal, along with a post-stripping stage, for both gas and foil stripping. These, along with the placement of a number of beam profile monitors will allow for better control of the beam both as to its transmission as well as to the composition of the mixed state.

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