Multiple capture contributions in charge exchange induced x-ray spectra and their relevance to astrophysical applications

S. Otranto and R. E. Olson

Citation: AIP Conf. Proc. 1525, 55 (2013); doi: 10.1063/1.4802289
View online: http://dx.doi.org/10.1063/1.4802289
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1525&Issue=1
Published by the American Institute of Physics.

Additional information on AIP Conf. Proc.
Journal Homepage: http://proceedings.aip.org/
Journal Information: http://proceedings.aip.org/about/about_the_proceedings
Top downloads: http://proceedings.aip.org/dbt/most_downloaded.jsp?KEY=APCPCS
Information for Authors: http://proceedings.aip.org/authors/information_for_authors
Multiple Capture Contributions In Charge Exchange Induced X-ray Spectra And Their Relevance To Astrophysical Applications

S. Otranto\textsuperscript{1} and R. E. Olson\textsuperscript{2}

\textsuperscript{1}IFISUR and Departamento de Física, Universidad Nacional del Sur, 8000 Bahía Blanca, Argentina.
\textsuperscript{2}Physics Department, Missouri University of Science and Technology, Rolla MO 65409, USA.

Abstract. In this work, we present theoretical line emission cross sections for Ar\textsuperscript{18+} and Ne\textsuperscript{10+} colliding on Ar for impact energies in the range 5 eV/amu-10 keV/amu which covers typical EBIT-traps as well as Solar Wind energies. The present analysis is performed by means of a 5-body classical trajectory Monte Carlo (CTMC) model which allows us to model the multiple capture contribution to the X-ray line emission spectra. Our results are contrasted to recent capture and line emission data from Berlin-EBIT, NIST and the University of Nevada Reno.

Keywords: X-ray emission, charge exchange, multiple capture.

PACS: 34.70.+e, 32.30.Rj, 32.70.Fw, 95.30.Ky

INTRODUCTION

During the last few years, many efforts were devoted towards a better understanding of line emission cross sections which follow charge exchange processes between highly charged ions and different atomic and molecular species. This interest has been strongly influenced by the fortuitous discovery of the cometary X-ray emission by the German satellite ROSAT in 1996 [1,2]. Although many different mechanisms were initially proposed to describe the X-ray emission, the data provided by ROSAT had low resolution (about 300eV) that didn’t give any further clue on its physical origin. It was only a few years later, in the year 2000, and after the Chandra X-ray Observatory was put in orbit and produced X-ray images of an improved resolution of about 100eV, that the charge exchange mechanism was finally recognized as the major contributor to the cometary X-ray emission. Astrophysicists soon realized, with the information at hand, that all the ingredients needed to predict such emission were available since 1968: the properties of the cometary coma, the solar wind velocity and its heavy ion content, the average cross sections of charge transfer reaction (at the total cross section level, not state-selective) and the energies released in the subsequent recombination. A rough estimate for the X-ray luminosity of a comet in those days would have led $10^9$ W, what would have easily identified comets as a new type of X-rays sources 30 years before ROSAT’s discovery [3].

In any case, soon after the discovery charge exchange was also found to be responsible for X-ray emissions originating in planetary atmospheres as well as in the geocorona and the heliosphere. In recent years, search for evidence of charge-exchange induced X-ray emission from outside the heliosphere has taken place including as potential targets the interstellar medium, as well as stars and galaxies [4-6].

In view of the next generation of X-ray microcalorimeter spectrometers to be put in orbit in the ASTRO-H mission (4-7 eV resolution) or the International X-ray Observatory (2.5 eV resolution), high resolution data are expected to be collected in the next few years. Accurate line emission cross sections (theoretical and experimental from Earth-based laboratories) will then be needed in order to exploit the astrophysical data at their maximum.

Earth based-laboratories have carried on experiments based on linear accelerators together with Ge or SiLi detectors (JPL) [7,8], EBIT-traps (LLNL [9,10], NIST [11] and Berlin-EBIT [12]) and COLTRIMS devices together with Ge detectors (UNR) [13]. Collision chambers with extraction lines have the drawback that photons arising from transitions involving metastable states like O\textsuperscript{6+}(2\Sigma)
DOUBLE CAPTURE

INHERENTLY PROVIDES MULTI-CROSSING LANDAU-ZENNER (MCLZ) MODEL [14, 15], OF THE PUBLISHED STUDIES WERE PERFORMED WITHIN THE RANGE AT EARTH-BASED LABORATORIES. IN THIS SENSE, AN EXACT REPLICAS OF THE ASTROPHYSICAL CONDITIONS IS STILL OUT OF RANGE OF ABOUT 1 keV/amu. IN THIS SENSE, AN EXACT REPLICA OF THE ASTROPHYSICAL CONDITIONS IS STILL OUT OF RANGE OF ABOUT 1 keV/amu.

The electron with the greater n_s is considered to autoionize with zero energy. Conserving energy, the inner electron falls to a deeper n value and its l value is modified by preserving the orbital eccentricity.

Events for which |n_s-n_i|>1 are treated as double radiative decay and the decay routes of both electrons are explicitly considered,

\[
Ar^{18^+} + Ar \rightarrow Ar^{16^+}(n_1 l_1, n_2 l_2) + Ar^{2+} \\
\rightarrow Ar^{17^+}(nl) + e + Ar^{2+} \\
\rightarrow Ar^{17^+}(1s) + h\nu_1 + e + Ar^{2+}
\]

(1)

As a distinctive feature, we notice that the successive decay of both electrons lead to a shoulder located on the low energy side of the dominant Ar^{17+}(2p 1s) transition.

For three electron capture, we noticed that most of our events correspond to two electrons capture with nearly equal n values while the third one is bound to a deeper n value. The following scheme has been assumed: the two outer electrons autoionize with zero energy while the third one falls to a deeper n level preserving its orbital eccentricity:

\[
Ar^{18^+} + Ar \rightarrow Ar^{16^+}(n_1 l_1, n_2 l_2, n_3 l_3) + Ar^{3+} \\
\rightarrow Ar^{17^+}(nl) + e_1 + e_2 + Ar^{3+} \\
\rightarrow Ar^{17^+}(1s) + h\nu_1 + e_1 + e_2 + Ar^{3+}
\]

(2)

In all cases the line emission cross sections have been calculated as in ref. [18].

RESULTS

In Figure 1 we benchmark our theoretical results with the data obtained by Ali et al [13] at the University of Nevada Reno for the single capture channel (SCX) in 4.54 keV/amu Ne^{10+} + Ar collisions by using a COLTRIMS device including two position-sensitive detectors. From their analysis, relative n-state selective cross sections are obtained by fitting their energy gain or Q-value spectrum. The CTMC results shown have been convoluted by means of Gaussian functions for which we have set the FWHM in 12eV, a value at which we found the best agreement with the energy widths of the data. Nevertheless, we note that the present experimental spectrum exhibits a shoulder.
In Figure 2, our CTMC line emission cross sections are compared to the NIST data for 4 keV/amu Ne\(^{10+}\) + Ar as published by Tawara et al. [11]. In their study, these authors employed the EBIT-trap as an ion source and performed the collision process in a separate chamber (i.e. extraction mode). The separate theoretical contributions of the SCX and the different multiple capture channels are explicitly shown. From our treatment, it can be seen that autoionizing double and triple capture mainly enhance the higher Ly lines, while double radiative decay gives rise to the typical shoulder found at lower energies of the Ly-\(\alpha\) peak. Although the reported resolution is of 130 eV at 4.50 keV, at the present emission energies (600 eV-1400 eV) we had to increase the resolution to 160 eV in our theoretical convolution procedure in order to properly reproduce the data.

In Figure 3, we show similar data for 4 keV/amu Ar\(^{18+}\) + Ar collisions. Again the agreement obtained with the data is very good and clearly highlights the low energy shoulder on the Ly-\(\alpha\) peak which we ascribe to radiative double decay. In this case we used the reported FWHM of 130 eV in the theoretical convolution procedure.

Finally in Figure 4 we show line emission cross sections for 18 eV/amu Ar\(^{18+}\) + Ar collisions performed with the Berlin-EBIT in both extraction and magnetic trapping modes [12]. In their analysis, Allen et al. [12] showed that at typical EBIT energies their magnetic trapping results are in agreement with those from LLNL [9, 10] while at Solar Wind energies their results are in agreement with the extracted beam results from NIST [11]. Clear discrepancies among these two techniques are evident from the experimental spectra shown which were collected at the same nominal collision energy. We notice that the present CTMC results are in agreement with the extraction mode results. Further attempts to reconcile the two sets of data by theoretical exploration included sensitivity tests on the collision energy and the existence of possible electric fields in the trap. However, those explorations did not clarify the
differing experimental results. In the magnetic trapping mode, in order to isolate the Ar$^{17+}$ spectrum from those arising from other charge states of Ar, in particular that of Ar$^{16+}$, the corresponding spectra are manually subtracted. It is then not clear how the contribution coming from radiative double capture by Ar$^{18+}$ is accounted for in the magnetic trapping mode, since those photons would be associated to the final Ar$^{16+}$ ionic state. This suggests that events corresponding to radiative double capture should be present in the extraction mode spectra but not in the magnetic trapping mode, leading for the latter a larger relative contribution arising from the higher Ly-lines.

We have introduced a 5-body CTMC model which allows for an explicit modeling of the multiple capture contribution to the charge exchange X-ray spectra. This contribution has been so far, and at best, grossly estimated for certain collision systems. A full description and understanding of the multiple capture contribution for different collision systems of interest is still out of reach.

We have showed that our line emission cross sections are in very good agreement with line emission cross sections from Berlin-EBIT and NIST, both obtained with EBIT-traps in the extraction mode.

More data for these collision systems would be welcome, in particular concerning the magnetic trapping mode-extraction mode discrepancies which so far have remained elusive from the experimental side. Such major differences present a large uncertainty if EBIT cross sections are used to de-convolute astrophysical data.

**CONCLUSIONS**

In view of the recent experimental advances in terms of microcalorimeter spectrometers and the planned missions to put more sophisticated X-ray observatories in orbit, the need of accurate line emission cross sections (either theoretical or experimental) is imperative.

**ACKNOWLEDGMENTS**

Work at UNS supported by Grants No. PGI24/F049 and No. PIP 112-2008001-02760 of CONICET (Argentina).

**REFERENCES**