X-ray Emission due to Charge Exchange from Highly-Charged Multielectron Fe Ions

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Abstract

In astrophysical environments where highly-ionized plasma interact with cold neutral gas, the observed X-ray emission may be due to a variety of atomic processes. About two decades ago, charge exchange due to ion-neutral collisions was found to dominate the X-ray emission from comets. Within the past decade, charge exchange induced X-ray emission has been inferred to be potentially important for a range of objects from supernova remnants to galactic outflows. However, theoretical and experimental studies of charge exchange have primarily focused on H-like and He-like ion emission. Here we present preliminary results for multielectron ions focusing on Fe^{16+} - Fe^{24+} colliding with H, He, H_2, and other neutrals. Final-state-resolved cross sections are obtained within the multi-channel Landau-Zener approach. The calculations adopt available ion energies from NIST supplemented with AUTOSTRUCTURE calculations. Assuming an optically thin plasma, charge-exchange X-ray emission spectra are predicted for photon energies and resolutions relevant to XRISM.

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Introduction

X-ray emissions from charge exchange (CX) have been observed by the Chandra, XMM-Newton, and Suzaku X-ray observatories in the following extrasolar regions:

- Boundaries between hot plasma and cool gas in the interstellar medium (Lallement 2009)

- The north polar spur above the Galactic center (Lallement 2009)

- Outflowing gas of star-forming galaxies (Liu et al. 2011, 2012)

The spectrum observed around the Cygnus loop by Katsuda et al. (2011) suggests that the emissions around 0.7 keV/u might be due to CX with Fe^{16+} and Fe^{17+} ions.

Charge exchange data for iron is currently lacking and is needed to completely model the X-ray spectra observed.

The charge exchange data calculated here will be relevant for various X-ray missions including Hitomi, XRISM, and Athena.

Methodology

We calculated total, n-resolved, and nlS-resolved cross sections for each charge exchange reaction. We used the work of Janev et al. (1983) to expand the Landau-Zener approximation formalized by Butler and Dalagarno (1980) to multiple channels. We used the calculated cross sections along with calculated transition energies and transition probabilities to create X-ray spectra. We used multiple code packages including *Autostructure*, *Stueckelberg*, and *Kronos* to automate the calculations. We performed calculations for Fe^{16+} to Fe^{24+} ions colliding with different neutral targets. The neutral targets include H, He, H_2, H_2O, CO, CO_2, and N_2.

Results

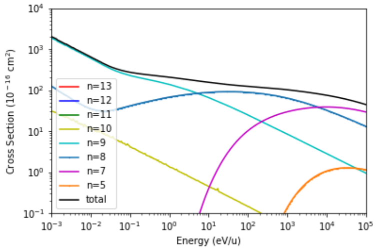

Figure 1. n-resolved cross sections for Fe^{17+} and He. N=8 is the dominant n because it has the biggest cross section at 1 keV/u.

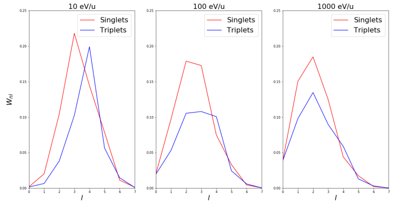

Figure 2. nl-resolved cross sections for Fe^{17+} and He at n=8 at various energies. Triplets and singlets are separated proportionally. Singlet states contribute more to the overall cross sections than triplet states in this figure.

Results

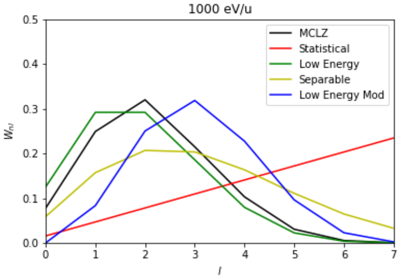

Figure 3. Comparison of l-distributions for Fe^{17+} and He at n = 8 and at 1keV/u. The MCLZ l-distribution is compared to analytical l-distributions. Statistical and low energy models came from Krasnopolsky et al. (2004). The separable and low energy mod models came from Smith et al. (2014).

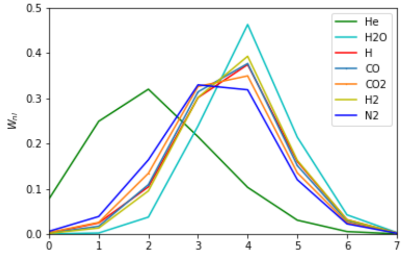

Figure 4. Comparison of l-distributions for Fe^{17+} and neutral targets at n = 8 and at 1keV/u. Most targets peak at l = 4, which correspond to g states.

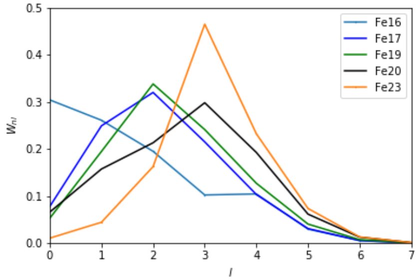

Figure 5. Comparison of l-distributions for Fe ions and He at n = 8 and at 1keV/u.

Spectra

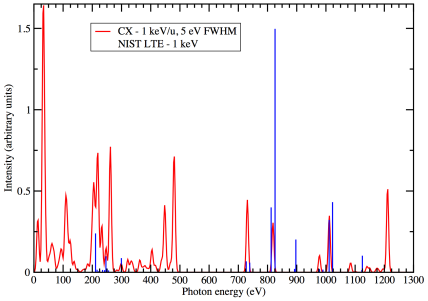

Figure 5. Spectrum of Fe^{17+} colliding with He. The red represents emission from CX, while the blue represents emission due to electron impact from NIST (Kramida et al. 2016).

Conclusion

The resulting MCLZ cross sections and spectra will be compared to the sparse available data. Development of Kronos is in progress to allow for merging NIST and computed (e.g., Autostructure) atomic structure data. X-ray spectra measurements are in progress at Clemson University to benchmark the current calculations.

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