Resonance induced population transfer of Fe XVII ions in plasma environment

Chensheng Wu*‡, Xiang Gao* [1]

*Beijing Computational Science Research Center, Beijing 100193, China

‡Department of Engineering Physics, Tsinghua University, Beijing 100084, China

Synopsis We present a detailed study to resolve the discrepancy between the existing theoretically estimated oscillator strengths and the recently observed result from the X-ray free electron laser (XFEL) experiment for the intensity ratio between two of the strongest emission lines from Ne-like Fe XVII (Fe^{16+}) ion. Our study shows that, by considering the dynamic resonance induced population transfer between Fe XVII and Fe XVI (Fe^{15+}) ions, which coexist in the XFEL experiment, we are able to successfully resolve this difference in theory and experiment. Further experimental works are suggested for a more detailed understanding of the dynamic resonance processes for ions under the plasma environment.

The x-ray emission lines of the Ne-like Fe^{16+} ion have been observed in a variety of astrophysical objects, including the Sun, stellar coronae, elliptical galaxies, and supernova remnants. Two of the most intense lines of the Ne-like Fe^{16+} ion are the $2p^5 3d\ ^1P_1 \rightarrow 2p^6\ ^1S_0$ dipole emission line (3C) at 15.01Å and the $2p^5 3d\ ^3D_1 \rightarrow 2p^6\ ^1S_0$ inter-combination line at 15.26 Å (3D). However, the diagnostic utility of these two lines has been limited by the fact that although extensive studies have been carried out, discrepancies between the theoretical estimates and the measurements from astrophysical and laboratory sources persist. In a recent benchmark experiment [1], the Fe^{16+} ion were first generated in an electron beam ion trap (EBIT) and then photo-excited by the X-ray free electron laser (XFEL). This experiment was designed to allow a direct comparison of experimental and theoretical results, excluding the effects of electron collisions. The measured weighted 3C/3D ratio was 2.61±0.23, which is significantly lower than the most elaborated theoretical values at 3.4 or higher [1]. A more recent detailed atomic structure calculation suggests that other physical processes beyond those included in the atomic structure calculation of an isolated atomic system may be responsible for this discrepancy [2,3].

With an extended large scale full relativistic configuration interaction calculation including the quantum electrodynamics (QED) term such as the Breit interaction, the excitation energies from the current calculation are less than 0.02% from the NIST data and the f_{3C}/f_{3D} ratio is 3.567±0.003. We first came to the conclusion that the reliability of the theoretical results for an isolated Fe XVII ion from the present calculation and other earlier atomic structure calculations may not be the cause for the discrepancy between the experimentally observed intensity ratio and the theoretical estimates. Our detailed analysis on the influence from the outside plasma environment suggests that such effect is not the likely cause for the difference in f_{3C}/f_{3D} ratio either, although our calculation does suggest a substantial decrease in theoretical oscillator strength ratio that overlaps with the experimental intensity ratio if the plasma density is substantially higher than the ones in the XFEL experiment. Since it is known that the energies of the Fe XVII 3D line and the Fe XVI C line are both close to 812 eV and the pulse length of the XFEL experiment is sufficiently longer than the time scale of the autoionization process transferring the upper state of the Fe XVI ion to the ground state of Fe XVII ion, we decided to focus our investigation on the dynamic resonance induced population transfer from the Fe XVI to the Fe XVII ions. By solving the relevant rate equations, we are able to generate finally the theoretically simulated spectra as well as the intensity ratio in agreement with the experimental spectra from the XFEL experiment.

[1] E-mail: xgao@csrc.ac.cn

References

[1] S. Bernitt et. al. 2012 Nature **492**, 225
[2] N. S. Oreshkina, et. al. 2014 Phys. Rev. Lett. **113**, 143001
[3] S. D. Loch, et. al. 2015 Astrophys. J. Lett. **801**, L13