§14. Observation of Forbidden X-ray Transitions following Charge Exchange in Collisions of O^{7+} with He

Tanuma, H. (Tokyo Metropolitan Univ.),
Kato, D., Sakaue, H.A., Murakami, I.

Emissions following charge exchange processes of multiply charged ions are related to the plasma diagnostic. Particularly, emission observation in collisions of bare charged carbon ions with a neutral hydrogen atom in the fusion plasma is useful to measure the spatial distribution of carbon ions. On the another hand, in the 1990's, the soft X-ray emission whose intensity fluctuated in a cycle of a few days was observed during the all-sky survey by the ROSAT (Röntgen-satellite, an X-ray observatory launched in 1990)[1)]. It was found that this phenomenon is due to solar wind charge exchange (SWCX)[2, 3, 4)]. The SWCX means the electron capture of multiply charged ions constituting the solar wind in collisions with neutral matter within the heliosphere and has been regarded as a dominant mechanism of the soft X-ray emission in the solar system[5)]. In order to analyze the X-ray spectra observed with the observatory satellites quantitatively in detail, accurate emission cross sections in collisions of multiply charged ions with neutral atoms/molecules are required by astrophysicists.

We have a 14.25 GHz electron cyclotron resonance ion source (ECRIS) and beam lines for measurements of charge exchange cross sections and soft X-ray emission cross sections. Our beam lines can be provided beams of multiply charged ions, namely bare, hydrogen-like, and helium-like O, N, and C ions, with solar wind speed of 300 - 800 km/s which corresponds to the kinetic energy range of 0.5 - 3.3 keV/u. Using the multiply charged ion beam facility, we have been performing the following experiments:

1. Total charge exchange cross section measurements:
Charge states of an ion beam passing through a collision cell filled with a neutral gas have been analyzed by a retarding potential method to obtain total charge changing cross sections.

2. Emission cross section measurements:
Soft X-ray emissions following charge exchange collisions have been observed at magic angle by a silicon drift detector (SDD) to obtain absolute emission cross sections of resonance lines, these are 1s-np ($n \geq 2$) transitions for hydrogen-like ions and $1s^2$-1snp ($n \geq 2$) transitions for helium-like ions, respectively[6, 7)].

3. Observation of forbidden transitions:
Helium-like ions produced in charge exchange collisions of hydrogen-like ions are in both singlet and triplet states. The most of singlet states, except the 1s2s $^1S_0$, emit the photons with the electric dipole transitions and are observed by SDD because of very short lifetimes. However, all triplet states will transfer to the 1s2s $^3S_1$ state with a long lifetime of about 1 ms. For observation of forbidden transition lines, we have developed a Kingdon ion trap[8)].

We have reproduced the SWCX by injecting highly charged O^{7+} ion beam into a collision cell filled with helium gas. After the collisions, only O^{6+} ions were introduced and trapped in a Kingdon ion trap, and soft X-ray emission from the trapped ions were observed with the SDD. Figure 1 shows an observed forbidden transition. This peak energy of this line is 560 eV, which correspond to the transition of $1s^2\ ^1S_0$ - 1s2s $^3S_1$ of helium-like O^{6+} ions. We also had observed the resonance lines $1s^2\ ^1S_0$ - 1snp $^1P_1$ of O^{6+} with the same set-up. In this figure, the intensities are normalized at the peaks, and it can be seen that the energy difference of about 10 eV between two peaks. This result is the first observation of the pure forbidden emission from helium-like oxygen ions produced in the charge exchange collisions with the solar wind velocity.

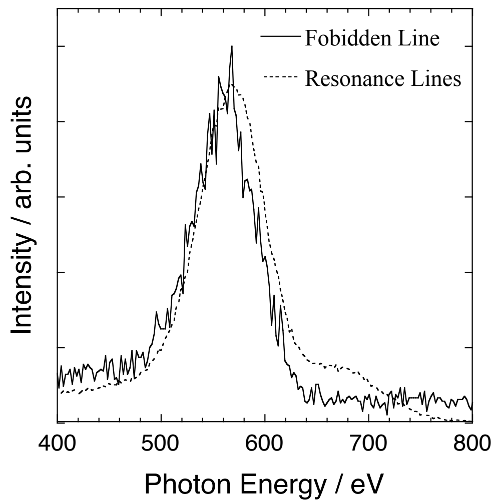

Fig. 1: Forbidden and resonance lines from O^{6+} ions following the charge exchange collisions of O^{7+} with He.

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