7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Experimental identification of new soft X-ray spectral lines of highly charged heavy ions through Z-dependence analysis

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Experimental data on soft X-ray spectral lines of highly charged heavy ions are important for plasma diagnostics relevant to nuclear fusion research and industrial light sources. Besides the applications, such spectra are of great interest in terms of basic atomic physics. Though soft X-ray spectra from various heavy ions have been measured so far in tokamaks, laser-produced plasmas and electron beam ion traps (EBITs), the available data are still incomplete for the elements with atomic numbers approximately larger than 50.

In this study we investigate the atomic number (Z) dependence of soft X-ray spectra from heavy ions having outermost N shell electrons, mainly based on the observations in high-temperature plasmas produced in the Large Helical Device (LHD) at the National Institute for Fusion Science (NIFS). In particular, we focus on isolated spectral lines from ions with one or two outermost 4s/4p subshell electrons (i.e., Cu-, Zn-, Ga- and Ge-like ions) which give rise to relatively simple spectral structure. In LHD, a small amount of heavy elements are injected by a tracer-encapsulated solid pellet (TESPEL) [1], and the temporal evolutions of soft X-ray spectra are recorded by multiple grazing incidence spectrometers.

In order to complement the missing elements in the past experiments, we have systematically observed spectra from almost all heavy elements with Z of 57–74 in LHD [2–5]. As an example, spectra from cerium and praseodymium ions are shown in Fig. 1 in which the resonance lines of Cu- and Zn-like ions are clearly seen. The measured wavelengths are compared with the results of the past EBIT experiments as well as our new experiment at Tokyo EBIT for europium. Consequently, we could successfully identify many new lines for the prominent transitions by interpolation or extrapolation of the Z dependence of the existing data.

Figure 2 plots the Z dependence of the wavelength of the $(4s)_{1/2} - (4p_+)_{3/2}$ resonance transition of Cu-like ions. The measurements in LHD and EBITs are indicated by diamonds and squares, respectively, together with the theoretical values calculated with a multi-configuration Dirac Fock code (GRASP92) by a dotted line. It is clearly shown that the measured wavelengths line up along a smooth curve, and the calculated wavelengths are slightly shifted to shorter side. Consequently, the lines for Z=57–59, 63, 65, 67, 69 and 71 are experimentally identified for the first time in this study. Similar Z dependence analyses have been carried out for major transitions of various ion stages. Accordingly, the present study would give fundamental data to study atomic physics specific to highly charged heavy ions.

References
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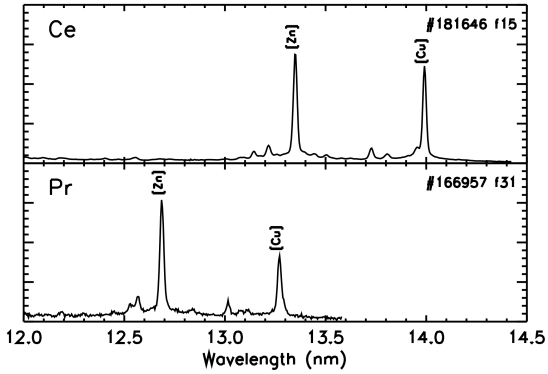

Figure 1. Soft X-ray spectra of cerium (top) and praseodymium (bottom) ions in LHD plasmas. The prominent lines from Cu-like and Zn-like ions are indicated by brackets.

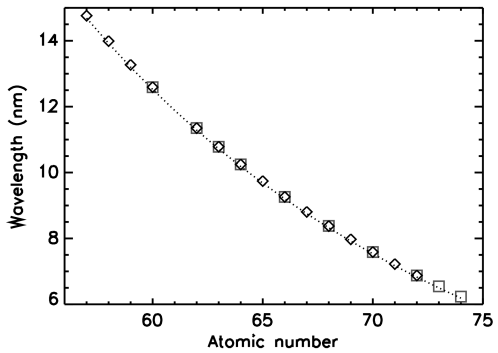

Figure 2. Z dependence of the wavelengths of the $(4s)_{1/2} - (4p_+)_{3/2}$ transition of Cu-like ions. The measurements in LHD (diamonds) and EBITs (squares) are shown together with the calculated values (dotted line).