Visible M1 transitions in $4f$ open shell heavy ions observed with an electron beam ion trap

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Synopsis We present visible spectra of silverlike ($4d^{10}4f$), cadmiumlike ($4d^{10}4f^2$), and indiumlike ($4d^{10}4f^3$) ions of holmium (atomic number $Z = 67$), erbium (68), and thulium (69) observed with a compact electron beam ion trap. The observed wavelengths are compared with theoretical values calculated using relativistic many-body perturbation theory and relativistic CI + all-order approach.

Visible transitions in highly charged heavy ions are demanded by several areas. For example, transitions in highly charged tungsten ions are in strong demand from the diagnostics of the fusion reactor plasmas [1]. Although all the wavelength ranges, including short wavelength ranges such as EUV and x-rays, are important for the diagnostics, transitions in the visible range are especially demanded due to the advantage that a variety of common optical components, such as mirrors, lenses, and fiber optics, can be applied. In recent years, an optical clock utilizing visible transitions in highly charged ions has been proposed as a potential candidate for an accurate and stable clock that has an excellent sensitivity to the fine structure constant variation [2].

In these applications, $4f$ open shell ions are often planned to be used. Thus several efforts have been maid both experimentally and theoretically to observe and identify visible transitions in such ions. However, complex energy level structures make it difficult to identify the observed emission lines. Theoretically it is a kind of challenging work to calculate the fine structure energy splitting precisely. In the present study, we present visible spectra of $4d^{10}4f^n$ (n =1–3) configuration ions for the atomic number Z =67–69 to understand the complex energy level structures systematically.

In the experiment, a compact electron beam ion trap, called CoBIT [3], was used for producing and trapping ions. Elements of interest were injected into CoBIT as a vapor by using an effusion cell operated at 700 - 950 °C depending on the element. The emission excited by an electron beam was observed with a commercial Czerny-Turner type of visible spectrometer (Jobin Yvon HR-320).

Figure 1 shows typical spectra obtained for holmium ($Z = 67$). Based on the electron energy dependence and the time of flight analysis, the charge state has been assigned to each observed line. We have also made theoretical calculations of the wavelength and the transition probability using relativistic many-body perturbation theory [4] and relativistic CI + all-order approach [5]. Generally good agreement is obtained between the experimental and the theoretical wavelengths.

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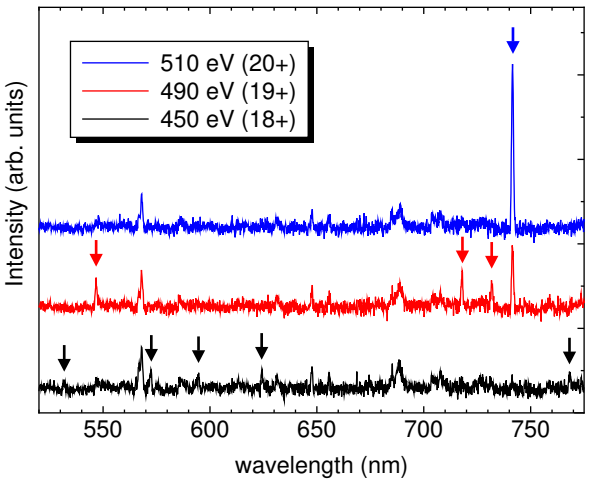

Figure 1. Spectra of holmium ions observed with a compact electron beam ion trap at electron energies of 450, 490, and 510 eV. The lines indicated by arrows are assigned to the charge state shown in the legend.

References

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