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Observation of magnetic dipole (M1) forbidden lines in fusion plasmas and its contribution to atomic physics and burning plasma diagnostics

S. Morita[1], T. Oishi[1], D. Kato[1], M. Goto[1], I. Murakami[1] and L. Zhang[2]
[1] National Institute for Fusion Science
[2] Institute of Plasma Physics Chinese Academy of Science
e-mail (speaker): morita@nifs.ac.jp

The M1 line was discovered in visible region from the planetary nebula in 1927[1], NII (6584Å), and the Sun in 1939[2,3], FeXIV (5303Å). In fusion research FeXX forbidden line was observed at 2665Å from Princeton Large Torus (PLT) tokamak plasmas in 1978 for the first time.[4] Subsequently, many M1 lines have been observed in several fusion devices. The M1 line study has been also progressed in Large Helical Device (LHD) by installing new spectroscopic devices such as polarizers and high-throughput visible/VUV spectrometers. The results from fusion devices contribute to not only the atomic physics and burning plasma diagnostics but also the space plasma diagnostics.

The M1 lines from fusion plasmas have been studied for highly charged ions of high-Z elements because the intensity of M1 lines becomes strong with increase in the Z number due to a breaking of L-S coupling based on a large enhancement of the relativistic effect such as spin-orbit interaction. The M1 line has several specific features in comparison with the electric dipole (E1) line which has been generally observed in plasmas. In particular, the M1 transition among sublevels in the ground level of highly ionized ions is emitted in VUV and visible ranges with long wavelengths. Resultantly, the wavelength can be determined with high accuracy.[5] A typical example is shown in Fig.1. It enables an accurate quantitative comparison among atomic theories including semi-empirical formula. The polarization component of M1 line has an entirely inverse characteristic compared to the E1 line. Polarization spectroscopy was then applied to the M1 line observation.[6] The long wavelength, i.e. small transition energy, of M1 lines allows a sufficient collisional excitation by high-energy ions.[7] It opens a possibility of alpha particle detection in a deuterium-tritium burning plasma of next-generation fusion device.[8] In LHD, recently, the M1 line was also found for highly charged tungsten ions in visible range, e.g. W^{26+} (3337Å) and W^{27+} (3357Å)[9,10] and VUV range, e.g. W^{37+} (646.7Å) and W^{38+} (532.33Å, 559.30Å).[11]

In the plenary talk, history of the M1 line observation, atomic physics of the M1 line, M1 line observations and analyses done in LHD and contributions of the M1 line study to atomic physics and plasma diagnostics are described with the future prospect.

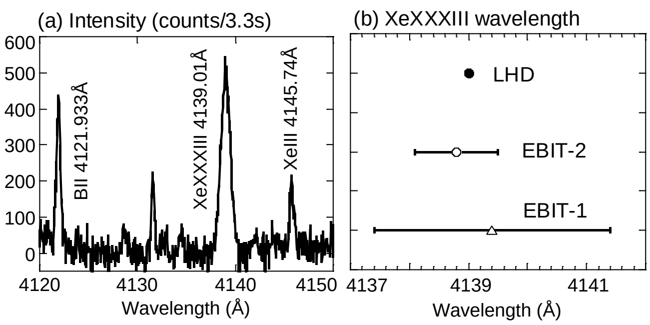

Figure 1. (a) Ti-like XeXXXIII M1 line spectrum and (b) wavelength determinations of XeXXXIII. The small error bar in LHD data originates in extremely high brilliance of Xe line emissions in the LHD plasma in addition to the high throughput of visible spectrometer system. It should be noticed that the plasma volume and electron density are entirely different between LHD and EBIT [LHD: Ref.5, EBIT-1: C. Morgan *et al*, PRL **74**, 1716 (1995) and EBIT-2: H. Watanabe *et al*, Phys. Rev. A **63**, 042513 (2001)].

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