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Study of EUV spectrum from Kr^{25+} ion in Kr gas puffing experiment at the large helical device using a collisional radiative plasma model

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High-temperature fusion plasma spectroscopy is an active area of research for exploring various plasma diagnostics in the context of magnetic confinement fusion devices. Large tokamak and stellarator devices like ITER, DEMO, LHD, Wendelstein 7-X, JET, and others are designed to incorporate inert gases as external impurities, which are introduced into the system to serve as coolant gases [1-5].

In this study, we delve into the line emissions originating from Na-like Kr^{25+} ion within the Extreme Ultraviolet (EUV) range of 14-23 nm. These emissions were observed during a Kr gas impurity seeding experiment conducted at the Large Helical Device (LHD). In the LHD plasma spectrum, we have identified emission lines associated with the Kr^{25+} ion in the EUV wavelength range, specifically at wavelengths of 22.00, 17.89, 16.51, 15.99 and 14.08 nm respective to $2p^6 3p(^2P_{1/2})$-$2p^6 3s(^2S_{1/2})$, $2p^6 3p(^2P_{3/2})$-$2p^6 3s(^2S_{1/2})$, $2p^6 3d(^2D_{3/2})$-$2p^6 3p(^2P_{3/2})$, $2p^6 3d(^2D_{5/2})$-$2p^6 3p(^2P_{3/2})$, and $2p^6 3d(^2D_{3/2})$-$2p^6 3p(^2P_{1/2})$ transitions, respectively.

To provide a comprehensive understanding of these observations, we have developed a collisional radiative model. This model generates a synthetic spectrum for K^{25+} ion, allowing us to validate the atomic ion and electron collision calculations against experimental measurement. In developing a plasma model, we have incorporated vital electron impact excitation processes, including their reverse processes, and computed essential atomic structure data and electron collision parameters using various relativistic methods.

Our approach involved conducting Relativistic Multiconfiguration Dirac-Hartree-Fock (RMCDHF) and Relativistic Configuration Interaction (RMCDHF-RCI) calculations utilizing the General-Purpose Atomic Structure Package (GRASP 2018) [6]. Additionally, we employed the relativistic Many-Body Perturbation (RMBPT) and RCI methods within the Flexible Atomic Code (FAC) [7]. These calculations yielded transition energies, oscillator strengths, transition rates, and wavelengths for the various fine structure transitions. A thorough comparison of these parameters across different methodologies and with previous results demonstrates consistent and favorable agreement.

Furthermore, we calculated Electron Impact Excitation (EIE) cross-sections for fine structure transitions, considering both ground-to-excited state and among the excited states transitions using the Relativistic Distorted Wave (RDW) method [8]. These cross-section results span a range of incident electron energies, from the excitation threshold up to 21 keV. We determined excitation rates for transitions from the ground states as a function of electron temperature, extending up to 600 eV. To incorporate these processes appropriately, we integrated the excitation and de-excitation rates derived from the cross-section data into the collisional radiative model. In this model, the rate balance equations were simultaneously solved to determine the distribution of state populations for the considered fine structure levels.

To validate our findings, we compared the emission lines from Kr^{25+} ion at wavelengths of 22.00, 17.89, 16.51, 15.99 and 14.08 nm measured in the LHD experiment with the collisional radiative model spectrum. Our comparative analysis demonstrates a strong overall agreement between the experimental and theoretical spectra. This comparison underscores the reliability of our atomic ion structure, electron collision, and collisional radiative model calculations for Kr^{25+} ion. These findings can be utilized in the development of advanced plasma models, enabling comprehensive investigations of fusion plasma behavior in Kr seeding experiments across different tokamak devices in the future.

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