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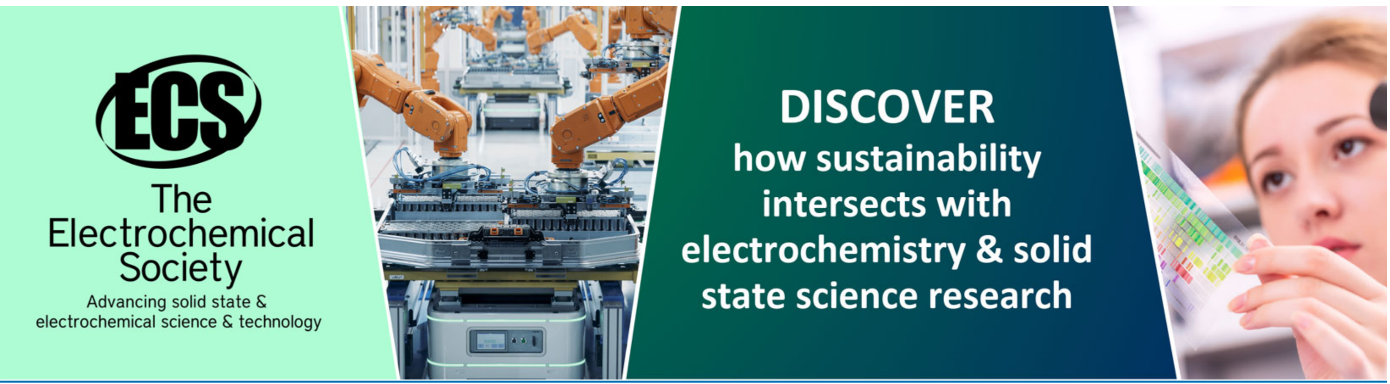

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Modeling of Synthetic Spectra in Tokamak Edge Plasmas

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Abstract. Atomic processes and plasma surface interactions play a key role in the physics of the edge, divertor and X-point plasmas. Passive spectroscopy is one of the best methods to characterize tokamak edge plasmas. In this work, we report on synthetic spectra calculations for the characterization of electron density in recombining divertor plasma conditions. It is shown that an analysis of the Stark broadening of Balmer lines with moderate principal quantum number provides the electron density with good accuracy.

1. Introduction

For diagnostic purposes and supporting the preparation of ITER and the subsequent demonstration power plant DEMO, modeling efforts have been performed in recent years in order to provide a spectroscopic database for the interpretation of line spectra in magnetic fusion devices [1,2]. Atomic processes and plasma surface interactions play an important role in the physics of the edge, divertor and X-point plasmas. A specific issue that requires careful examination is the broadening of the hydrogen isotope lines observed in the edge and in the divertor of tokamaks. In this work, synthetic spectra obtained from the coupling between a transport code and a Stark line shape code have been calculated and analyzed. A focus is put on Balmer lines with moderate ($n = 6, 7$) quantum number. Stark broadening has been evaluated by using a database obtained from a computer simulation method [1].

2. Stark Broadening Modeling

The number of investigations devoted to improving the accuracy of Stark line shape based spectroscopic diagnostics has been increasing; see e.g. [3] for a recent review. Stark broadening has been modeled here using a computer simulation method. The method involves a numerical integration of the time-dependent Schrödinger equation for the hydrogen wave function under the influence of a fluctuating electric field (the plasma microfield). Essentially, the numerical simulation consists of:

- The simulation of a set of trajectories corresponding to randomly generated initial conditions, which provides a set of realizations for the electric field;
- A numerical integration of the Schrödinger equation for each realization, which provides an expression for the atomic evolution operator $U(t)$;
- An evaluation of the dipole autocorrelation function by ensemble averaging and a Fourier transform that provides the spectrum:

$$I(\Delta\omega) = \frac{1}{\pi} Re \int_0^\infty dt \langle \vec{d}\, U^+(t)\, \vec{d}\, U(t) \rangle\, e^{i\Delta\omega t} \quad (1)$$

$\Delta\omega = \omega - \omega_0$ denotes the frequency detuning with respect to the line centred on ω_0 and $\vec{d}$ is the dipole operator. In this work, we consider that the ions move along straight line trajectories with constant velocities that are sampled among the particles according to an equilibrium Maxwell distribution function. The electron broadening is described using the Griem-Kolb-Shen collision operator model [4]. In a diagnostic routine, the numerical simulation method is not appropriate for systematic use because it can be CPU time consuming, depending on the plasma conditions and the spectral line under consideration. The database reported in [1] was set up in order to avoid this issue. Spectra have been calculated for a set of density, temperature, and magnetic field values, and an interpolation formula suitable for numerical application has been developed.

3. Application to Calculations of Spectra

A reliable interpretation of hydrogenic spectral line shapes for diagnostics in tokamak edge and divertor plasmas should involve the use of accurate Stark models. An additional problem that occurs in the interpretation of passive spectroscopy signals is the non-uniformity of the emission zone along the line-of-sight. The formation of a spectral line is the result of emission from atoms in regions with different values of N_e (electron density), T_e (electron temperature) etc., which makes the spectral interpretation intricate. We consider here an application to a virtual plasma background calculated by the SolEdge2D-EIRENE code in conditions relevant to the divertor of tokamak [5] as an illustration (see Figure 1).

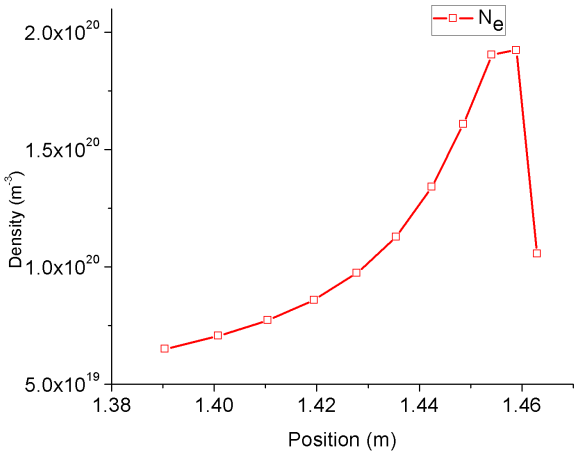

Figure 1 – Calculated spatial profile of the electron density along a line-of-sight crossing the divertor of WEST. The right side corresponds to the wall. At such high values, the spectral lines emitted by neutral deuterium are affected by Stark broadening and can serve as a diagnostic.

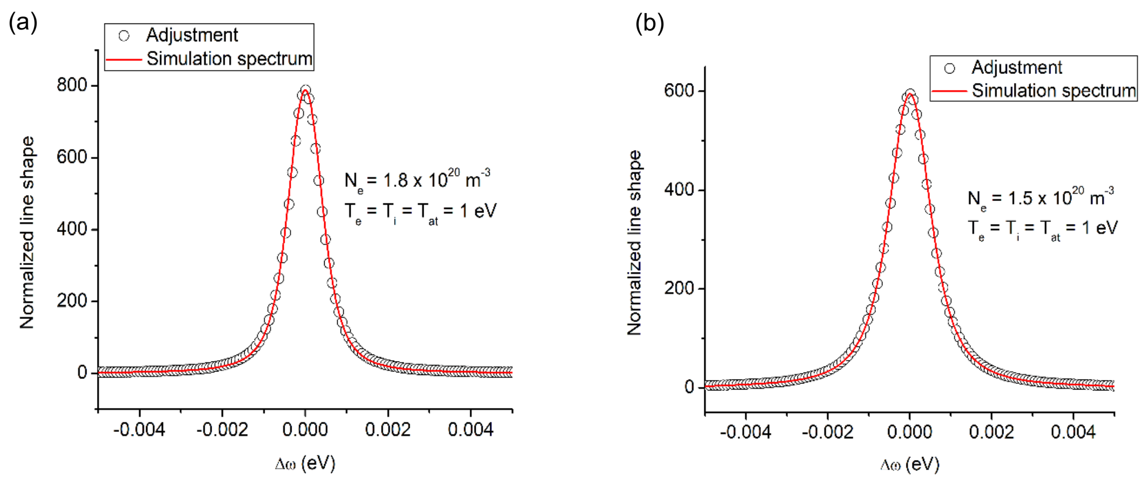

Figure 2 – Adjustment of synthetic spectra of (a) Dδ (Balmer delta) and (b) Dε (Balmer epsilon) using a Stark broadening model. The inferred value for the electron density is close to the value at the densest location on the line-of-sight.

Figure 2 shows an example of spectra calculated assuming a line-of-sight crossing the divertor region. The Stark broadening model presented in Sec. 2 has been applied to the Dδ and Dε lines at each point along the line-of-sight and a spatial integration along that line-of-sight has been performed. We have next performed an adjustment of these simulated Dδ and Dε spectra assuming a homogeneous plasma, using the Stark broadening database and assuming the electron, ion and atomic temperature are 1 eV ($T_e = T_i = T_{at} = 1$ eV) and N_e as an independent parameter. For the adjustment, we did calculations and found good agreement on the line width by taking $N_e = 1.8 \times 10^{20}$ m^{-3} for Balmer delta and 1.5×10^{20} m^{-3} for Balmer epsilon. As can be seen in Figure 2, the best-fit profiles (open circles) are in a good agreement with the simulated spectra (solid line). A relatively good estimate is obtained for the electron density with a deviation 20 % to the local value on the emission zone.

4. Conclusion

The operation of magnetic fusion devices requires passive spectroscopy diagnostics in the edge plasma region. We have calculated hydrogen Balmer lines in the conditions of a high-density recombining divertor plasma. In this work, we have performed synthetic diagnostic calculations on a plasma background obtained from a transport code and we have shown that an estimate of the electron density can be obtained from Stark broadening analysis. The best-fit profiles are in a good agreement with the simulated spectra. A relatively good estimate is obtained for the electron density with a deviation 20 % to the local value on the emission zone. Work is ongoing in order to reduce this deviation and analysis of experimental spectra are presently underway.

Acknowledgments

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