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Diagnostics of high-temperature plasmas by the X-ray spectra of heavy elements

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Abstract. Modified comparison method is developed. In this method detailed theoretical calculations of spectra of heavy elements is conducted varying one parameter (Te) in order to find the most complete matching of the structure of the theoretical and the experimental Mo spectra in laser-produced plasmas.

Development of new methods of diagnostics of high-temperature plasma of heavy elements, including Mo and W, is of great interest. Heavy elements are present in almost all controlled thermonuclear fusion devices: plasmas of powerful Z-pinches — the wire arrays material, plasmas of tokamaks - the walls and the divertor material. Spectroscopic diagnostics of such plasmas is a very difficult task due to the complex structure and huge number of lines in the spectra. To solve this problem, the comparison method [1,2] which is based on the comparison of the spectra of the investigated source with the spectra of well-diagnosed laser-produced plasmas, is developed further in this paper. The laser-produced plasmas diagnostics is performed using the spectra of [H] - and [He] - like ions by well-known and proven techniques.

Further comparison of the spectra of heavy elements in laser-produced plasmas with the spectra of the investigated source allows to evaluate the electron temperature T_e of the source. As an example, experimental W spectra of laser-produced plasmas at T_e =720±60 eV is shown in Fig. 1.

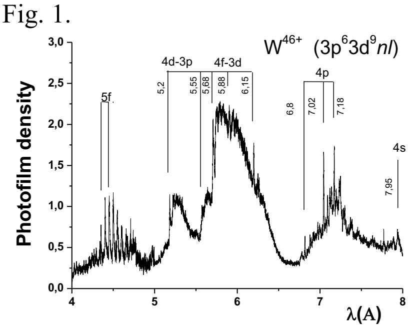

Fig. 1. Experimental W spectra of laser-produced plasmas at T_e=720±60 eV.

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This technique completely describes the structure of the X-ray spectra of W and Mo multiply charged ions, increases the accuracy of measurements and fully justifies the methods used. In particular, for the Mo laser-produced plasmas (n=3 - n=2 transitions in Mo^{31+} – Mo^{34+} ions) the electron temperatures determined experimentally by the comparison method (T_e = 685 eV) and calculated theoretically (T_e = 650 eV) coincided with a tolerance of less than (± 10) %. Fig.2 shows the comparison of experimental (Te = 685 eV) and theoretical (T_e = 650 eV) spectra of Mo.

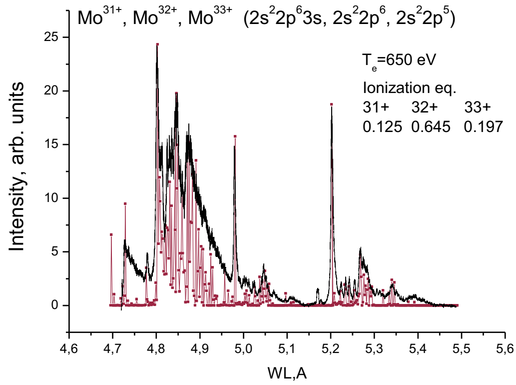

Fig. 2. Comparison of experimental (Te = 685 eV) and theoretical (T_e = 650 eV) spectra of Mo.

For the theoretical simulation of the experimental spectra the INDAHAUS code developed by the authors of the present paper (S.A. and I.T.) is used. The code is written in Python language which allows to run it in any platform (unix, windows, etc.). Ionization equilibrium and radiative-collisional characteristics being an input for the INDAHAUS code are calculated using GKU [3], ATOM [4] and FAC [5] codes. The INDAHAUS code is very flexible with respect to the number of ions included in the simulation and in the implementation of the various modes of behavior of plasma (coronal limit, the thermodynamic equilibrium, intermediate regimes).

After approbation of theoretical calculations on the experimental results for the high-temperature laser-produced plasmas, the theoretical spectra were calculated for higher temperatures: T_e> 1 keV, for which it is very difficult to carry out laboratory experiments. Thus, the modified method of comparison shows promising potential for the diagnostics of high-temperature plasma in fusion devices using the line x-ray spectra of multiply charged ions of heavy elements (W and Mo).

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