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Stark broadening of spectral lines of multicharged ions of astrophysical interest

XXI. Sc X, Sc XI, Ti XI and Ti XII spectral lines*

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Abstract. By using the semiclassical-perturbation formalism, we have calculated electron-, proton-, and He III-impact line widths and shifts for 4 Sc X, 10 Sc XI, 4 Ti XI and 27 Ti XII multiplets, significant for analysis, investigation and modeling of different plasmas in solar and stellar physics, physics and technology. The results are presented as a function of temperature and perturber density.

Key words: lines: profile — atomic data — plasmas

1. Introduction

A number of problems in solar and stellar physics, plasma physics and technology (see e.g. Griem 1974) depends on a comprehensive set of reliable data on the influence of impacts with charged particles on spectral line shapes, i.e. on the Stark broadening parameters. For example, Stark broadening parameters for multiply charged ions are needed for the modelling and theoretical considerations of subphotospheric layers (Seaton 1997), as well as for the examination of radiative transfer. Such data for multiply charged ion lines are of additional interest as well due to the development of soft X-ray lasers, where Stark broadening data are needed to calculate gain values, to model radiation trapping and to consider photoresonant pumping schemes (see e.g. Griem & Moreno 1990; Fill & Schöning 1994). Of course such data are also useful for the rafinement and checking of theory, as well as for the consideration of systematic trends along isoelectronic sequences. Scandium and titanium in various ionization stages are present in stellar plasma. For example Rogerson & Ewell (1985) have found 7 Ti IV lines in the τ Sco spectrum. One should mention as well that Stark broadening parameters for 10 scandium III and 10 Titanium IV multiplets, have been calculated recently within the semiclassical perturbation approach by Dimitrijević & Sahal-Bréchot (1992).

This paper is the twenty first of a series devoted to the research of Stark broadening parameters of spectral lines of multicharged ions (see Dimitrijević & Sahal-Bréchot 1995 and references therein, as well as Dimitrijević & Sahal-Bréchot 1996a,b, 1997, 1998a-e). As the continuation of our project (see e.g. Dimitrijević 1996) to make available to astrophysicists and physicists an as large as possible set of reliable semiclassical Stark broadening data needed for the investigation, diagnostics and modeling of various plasmas in stellar and solar physics, abundance determinations, opacity calculations, modeling and consideration of subphotospheric layers, diagnostics and investigation of laboratory plasma,as well as for laser physics, fusion research, and various devices as e.g. light sources, we have calculated within the semiclassical-perturbation formalism (Sahal-Bréchot 1969a,b), electron-, proton-, and He III-impact line widths and shifts for 4 Sc X, 10 Sc XI, 4 Ti XI and 27 Ti XII multiplets.

2. Results and discussion

In order to examinate Stark broadening of Sc X, Sc XI, Ti XI and Ti XII spectral lines and to determine the corresponding broadening parameters (the full line width at half maximum - W and the line shift - d), the semiclassical perturbation formalism has been used, which, as well as the corresponding computer code (Sahal-Bréchot 1969a,b), have been updated and optimized several times

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* Tables 1-4 are only available in electronic form at the CDS via anonymous ftp (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

(Sahal-Bréchot 1974; Fleurier et al. 1977; Dimitrijević & Sahal-Bréchot 1984; Dimitrijević et al. 1991; Dimitrijević & Sahal-Bréchot 1996b). Also, we have published several times descriptions of the calculation procedure, with a discussion of updatings and validity criteria, as e.g. in Dimitrijević & Sahal-Bréchot (1996c) and Dimitrijević (1996). Atomic energy levels needed for calculations have been taken from Bashkin & Stoner (1978) for Sc X and Sc XI, and from Wiese & Musgrove (1989) for Ti XI and Ti XII. The oscillator strengths have been calculated within the Coulomb approximation (Bates & Damgaard 1949; and the tables of Oertel & Shomo 1968). For higher levels, the method of Van Regemorter et al. (1979) has been used.

Our results for electron−, proton−, and He III−impact line widths and shifts for 4 Sc X, 10 Sc XI, 4 Ti XI and 27 Ti XII multiplets are shown in Tables 1−4 (accessibles only in electronic form), for Sc X (Table 1) for temperatures from 200 000 K up to 5 000 000 K and perturber densities 10^{19} cm^{-3}−10^{22} cm^{-3}, for Sc XI (Table 2) for temperatures from 500 000 K up to 5 000 000 K and perturber densities 10^{18} cm^{-3}−10^{22} cm^{-3}, for Ti XI (Table 3) for temperatures from 500 000 K up to 5 000 000 K, and perturber densities 10^{18} cm^{-3}−10^{22} cm^{-3}, and for Ti XII (Table 4) for temperatures from 500 000 K up to 6 000 000 K, and perturber densities 10^{18} cm^{-3}−10^{23} cm^{-3}.

Stark broadening data for densities lower than for tabulated data, are proportional to the perturber density. Moreover, we present in Tables 1−4 as well, a parameter c (Dimitrijević & Sahal-Bréchot 1984), which gives an estimate for the maximum perturber density for which the line may be treated as isolated, when it is divided by the corresponding full width at half maximum. For each value given in Tables 1−4, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal-Bréchot 1969a,b). Values for $NV > 0.5$ are not given and values for $0.1 < NV \leq 0.5$ are denoted by an asterisk. When the impact approximation is not valid, the ion broadening contribution may be estimated by using the quasistatic approach (Sahal-Bréchot 1991 or Griem 1974). In the region between where neither of these two approximations is valid, a unified type theory should be used. For example in Barnard et al. (1974), a simple analytical formula for such a case is given. The accuracy of the results obtained decreases when broadening by ion interactions becomes important.

The present results are the first Stark broadening data concerning scandium X and XI as well as titanium XI and XII spectral lines. We hope that the presented data will be of interest for some problems in stellar and laboratory plasma research, modeling and diagnostic, as well as for consideration of plasmas in various devices in physics and technology, as e.g. subphotospheric layers, radiative transfer, investigation and modeling of fusion and laser-produced plasmas, and of soft X-ray lasers. Such results also have an interest for the checking and development of the Stark broadening theory for multicharged ion line shapes as e.g. for investigations of systematic trends along isoelectronic sequences.

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