A program for electron-impact broadening parameter calculations of ionized rare-earth element lines

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Abstract. In order to provide atomic data needed for astrophysical investigations, a set of electron-impact broadening parameters for ionized rare-earth element lines should be calculated. We are going to calculate the electron-impact broadening parameters for more than 50 transitions of ionized rare-earth elements. Taking into account that the spectra of these elements are very complex, for calculation we can use the modified semiempirical approach – MSE or simplified MSE. Also, we can estimate these parameters on the basis of regularities and systematic trends.

Key words: rare-earths – line profile – atomic data

1. Motivation

The spectral lines of rare-earth elements are present in Solar as well as in stellar spectra (see e.g. Grevesse & Blanquet 1969, Molnar 1972, Adelman 1987, Mathys & Cowley 1992, Sadakane 1993, Bidelman et al. 1995, Cowley et al. 1996, etc.). Principally, these lines originate in layers of stellar atmospheres with higher electron density (photosphere or subphotosphere). Consequently, electron-impact broadening mechanism can be important, especially for hot (A and B) stars as well as for white dwarfs. So, it is important to have a set of electron-impact broadening data for the lines of ionized rare-earth elements. For some transitions of La II and La III we have calculated Stark widths (Popović & Dimitrijević 1997) by using the modified semiempirical approach (Dimitrijević & Konjević 1980, Popović & Dimitrijević 1996a,b). Here we present our plans and specify the number of lines for which we may calculate electron-impact broadening parameters with a satisfying accuracy and discuss the difficulties which may appear in the calculation.

2. Methods of calculation

Due to the lack of known energy levels as well as of reliable transition probabilities for rare-earth elements, the approximate methods are adequate for Stark broadening calculations. Consequently the modified semiempirical approach will be applied. This method was developed by Dimitrijević & Konjević(1980). For

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the case of ions with complex spectra the improvement was done by Popović & Dimitrijević (1996a,b). Also, as regards lines for which it is not possible to apply this method, we will use the simplified modified semiempirical formula (SMSE) given by Dimitrijević & Konjević (1987). For the lines which are very important for astrophysical purposes and for which, due to the lack of atomic data, it is not possible to use even the SMSE method, we will estimate Stark broadening parameters on the basis of regularities and systematic trends (RST, Dimitrijević & Popović 1989).

Table 1. List of the ions for which we are going to calculate the electron-impact broadening parameters. The number of transitions given in the table could be calculated using the modified-semiempirical (MSE) and simplified modified-semiempirical (SMSE) methods, the x indicates that the data can be provided for several other transitions by using regularities and systematic trends (RST) for astrophysically very important lines. Key to the columns: I, IV – Ion, II, V – Number of transition for which we can calculate the Stark broadening parameters, III, VI – Method which we are going to use.

I	II	III	IV	V	VI
La II	3+x	SMSE+RST	La III	6+x	MSE+RST
La IV	x	RST	Ce II	x	RST
Ce III	5+x	SMSE+RST	Ce IV	4+x	MSE+RST
Pr II,III	x	RST	Nd II	5+x	SMSE+RST
Nd III	x	RST	Sm II	x	RST
Eu III	2+x	SMSE+RST	Gd II	2+x	SMSE+RST
Tb III	3+x	SMSE+RST	Ho II	2+x	SMSE+RST
Ho III	x	RST	Er II	1+x	SMSE+RST
Er III	x	RST	Tm II,III	x	RST
Yb II	5+x	MSE(SMSE)+RST	Yb III	3+x	MSE+RST
Yb IV	x	RST	Lu II	2+x	SMSE+RST
Lu III	5+x	MSE+RST	Lu IV	3+x	MSE+RST

Moreover, due to the very complex spectra of ionized rare-earth elements we have to improve the existing software developed by us (Popović 1994). It means that calculations within intercoupling approximation have to be performed. For example in the spectra of Ce III, the $4f6p$ levels are well described by jj coupling approximation, while $4f6d$ levels, which are perturbed by $4f6p$ ones, are well described by $j\ell$ coupling approximation. Such interaction between these two levels should be taken into account. Also, a numerical experiment about the influence of this effect on calculated parameters should be done.

3. The list of ions

In Table 1 we present the ions and number of lines for which we are going to calculate the electron-impact broadening parameters. As one can see from Table 1, there is a very limited number of transitions for which this is possible (only 51 transitions). The list has been made taking into account atomic data given by Martin et al. (1978), so, this list may be extended after a detailed search through literature and after including the new experimental results.

References

Adelman, S.J.: 1987, in *Elemental Abundance Analyses*, Proc. of the IAU working group on Ap stars Workshop, eds.: S.J. Adelman and T. Lanz, Institut d'Astronomie de l'Université de Lausanne

Bidelman, W.P., Cowley, C.R., Iler, A.L.: 1995, *Publ. Obs. Univ. Mich. Vol.* **XII**, 3

Cowley, C.R., Bord, D. J., Noequist, P.L.: 1996, *Bull. Am. Astron. Soc.*, **28**, 965

Dimitrijević, M.S., Konjević, N.: 1980, *J. Quant. Spectrosc. Radiat. Transfer* **24**, 451

Dimitrijević, M.S., Konjević, N.: 1987, *Astron. Astrophys.* **173**, 345

Dimitrijević, M.S., Popović, M.M.: 1989, *Astron. Astrophys.* **217**, 201

Grevesse, N., Blanquet, G.: 1969, *Sol. Phys.* **8**, 5

Martin, W.C., Zalubas, R. and Hagan, L.: 1978, *Atomic Energy Levels – The Rare-Earth Elements*, NSRDS-NBS, Washington D.C., **60**

Mathys, G., Cowley, C.R.: 1992, *Astron. Astrophys.* **253**, 199

Molnar, H.: 1972, *Astron. Astrophys.* **20**, 69

Popović, L. Č.: 1994, *Stark broadening of heavy ion spectral lines in spectra of hot stars*, Publ. Obs. Astron. Belgrade **46**, 1

Popović, L. Č. and Dimitrijević, M.S.: 1996a, *Phys. Scr.* **53**, 325

Popović, L. Č., Dimitrijević, M.S.: 1996b, *The modified semiempirical approach for lines from complex spectra*, in The Physics of Ionized Gases, eds.: B. Vujičić, S. Djurović and J. Purić, University of Novi Sad, Novi Sad, Yugoslavia, 477

Popović, L. Č., Dimitrijević, M.S.: 1997, *Publ. Obs. Astron. Belgrade* **47**, 123

Sadakane, K.: 1993, in *Peculiar Versus Normal Phenomena in A-type and Related Stars*, eds.: M. M. Dworetsky, F. Castelli and R. Faraggiana, *ASP Conf. Series* **44**, 72