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VIRTUAL LABORATORY ASTROPHYSICS: THE STARK-B DATABASE

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Abstract. Stark broadening theories and calculations have been extensively developed for about 50 years. The theory can now be considered as mature for many applications, especially for accurate spectroscopic diagnostics and modelling. This requires the knowledge of numerous collisional line profiles, especially for very low abundant atoms and ions which are used as probes for modern spectroscopic diagnostics in astrophysics. Nowadays, the access to such data via an on line database becomes essential. STARK-B (http://stark-b.obspm.fr) is a collaborative project between the Astronomical Observatory of Belgrade and the Laboratoire d'Étude du Rayonnement et de la matière en Astrophysique (LERMA). It is a database of calculated widths and shifts of isolated lines of atoms and ions due to electron and ion collisions (impacts). It is devoted to modelling and spectroscopic diagnostics of stellar atmospheres and envelopes, laboratory plasmas, laser equipments and technological plasmas. Hence, the domain of temperatures and densities covered by the tables is wide and depends on the ionization degree of the considered ion. The STARK-B database is a part of VAMDC (Virtual Atomic and Molecular Data Centre, http://www.vamdc.eu), which is an European Union funded collaboration between groups involved in the generation and use of atomic and molecular data. VAMDC aims to build a secure, documented, flexible and interoperable e-science environment-based interface to existing atomic and molecular data.

1 Introduction

Pressure broadening of spectral lines arises when an atom or molecule which emits or absorbs light in a gas or a plasma, is perturbed by its interactions with the other particles of the medium. An atom or molecule may be neutral as well as charged.

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The so-called Stark broadening is due to electron and ion colliders. It has been extensively developed for about 50 years and is currently used for spectroscopic diagnostics and modelling.

In fact, thanks to the considerable developments of the spectral resolution, of the sensitivity (high S/N) of the recent past years, and to large ground-based telescopes and space-born missions allow to observe in all ranges of wavelengths (from XUV to radio). For interpreting the spectra, the lines must be identified, and the atomic parameters responsible for their intensities and their profiles must be known. The development of realistic models of interiors and atmospheres of stars and the interpretation of their evolution and the creation of elements through nuclear reactions, requires the knowledge of numerous profiles, especially for trace elements. Chemical abundances are crucial parameters to be determined. This needs an accurate interpretation of the detailed line spectra of the stellar objects and thus extensive sets of atomic data, including collisional broadening and especially Stark broadening. In addition, spectroscopic diagnostics for laboratory plasmas, magnetic fusion plasmas (Tokamaks, *e.g.* ITER), inertial confinement fusion plasmas (*e.g.* laser LMJ) and technological plasmas (*e.g.* LED lamps) are also needed for many lines of many ions.

Hence, calculations based on a simple but enough accurate and fast methods are necessary for obtaining numerous results. Furthermore, the development of powerful computers also stimulates the development of atomic data on a large scale. Besides, the access to these atomic data via on line databases becomes essential.

This is the purpose of STARK-B (Sahal-Bréchot *et al.* 2012). It is a database of calculated widths and shifts of isolated lines of atoms and ions due to electron and ion collisions. This database is devoted to modelling and spectroscopic diagnostics of stellar atmospheres and envelopes, to laboratory plasmas, laser equipments and technological plasmas. It is a collaborative project between the Paris Observatory and the Astronomical Observatory of Belgrade and has been opened online since the end of 2008, though not complete and currently under development.

2 Calculations of Stark broadening and shifts and STARK-B

2.1 Calculations of Stark broadening and shifts

Stark broadening theory is based on the founding papers by Baranger (1958a–c). The impact approximation is the first basic one: the duration of a collision must be much smaller than the mean interval between two collisions. So the collisions between the radiating atom (or ion) act independently and are additive. It is quite always valid for electron collisions and is generally valid for collisions with positive ions in the conditions of stellar atmospheres (Sahal-Bréchot 1969a,b). The second basic approximation is the complete collision approximation: the radiating atom has no time to emit (or absorb) a photon during the collision process. In the line center, the impact approximation and the complete collision approximation are both valid, and the line broadening theory becomes an application of the theory of collisions between the radiating atom and the surrounding perturbers. The present method is limited to the case of isolated lines: the levels of the studied transition broadened by collisions do not overlap with the neighbouring perturbing levels. So, hydrogen and hydrogenic ionic lines, some specific helium lines and some lines arising from Rydberg levels are excluded from our calculations and consequently from STARK-B. Therefore, the impact-complete collision-isolated lines approximation leads to a Lorentz line profile characterized by a width and a shift which depend on the physical conditions of the medium (temperature and density of the perturbers). Owing to the impact approximation, widths and shifts are proportional to the density. However, at high densities, the Debye screening effect can be important and is taken into account in our calculations. This decreases the width and the shift which thus become not proportional to the density.

Most of our calculations have been performed with the semiclassical-perturbation method (SCP) developed by Sahal-Bréchot (1969a,b) and further papers: Sahal- Bréchot (1974) for complex atoms, Fleurier *et al.* (1977) for inclusion of Feshbach resonances in elastic cross-sections of radiating ions, and by Mahmoudi *et al.* (2008) for very complex atoms. The numerical codes have been updated and operated by Dimitrijević and Sahal-Bréchot (1984) and further papers. The accuracy is about 20% for the widths but is worse for the shifts. The results of calculations made by Dimitrijević, Sahal-Bréchot, and co-workers are contained in more than 130 publications and enter STARK-B.

2.2 The Stark-B database: http://stark-b.obspm.fr

In this context, we are developing the STARK-B database. It is a collaborative project between the Astronomical Observatory of Belgrade and the Paris Observatory. The database is currently developed in Paris, and a mirror is planned in Belgrade. The domain of temperatures and densities covered by the tables is wide and depends on the ionization degree of the considered ion. The data are gradually implemented and the database is already on line though not yet complete. A graphical interface is provided. After clicking on the element in the Mendeleev periodic table and then on the ionization degree of interest, the user chooses the colliding perturber(s), the perturber density, the transition(s) by quantum numbers and the plasma temperature(s). Then a table displaying the widths and shifts is generated. Bibliographic references are given and linked to the publications via the SAO/NASA ADS Physics Abstract Service (http://www.adsabs.harvard.edu/) and/or within DOI. The papers can be freely downloaded if the access is not restricted. The widths and shifts data can be downloaded in ASCII. Request by domain of wavelengths instead by transitions, implementation of the remaining data, and fitting data are in progress. Fitting formulae as functions of temperatures and densities are also in progress. The current developments especially concern the compatibility of the output with the VO (Virtual Observatory) standards, which will be defined by VAMDC.

In fact, STARK-B is a part of VAMDC (Virtual Atomic and Molecular Data Centre, http://www.vamdc.eu). VAMDC, created in summer 2009 for the duration of three years, is an European Union funded collaboration between groups involved in the generation and use of atomic and molecular data. The free exchange of atomic and molecular data requires the definition both of standards which model the data structure and of tools that implement these standards and that help to carry out science using these data. VAMDC aims to build a secure, documented, flexible and interoperable e-science environment-based interface to existing atomic and molecular data. In addition, there is a collaborative project of standardisation of lists of lines within the IVOA (International Virtual Observatory Alliance, http://www.ivoa.net/) consortium as well as a wider collaborative project of standardisation concerning many more processes of atomic and molecular data. Paris Observatory is a major partner in development of both standards and tools. All that is commented and described in more details in Dubernet *et al.* (2010), Rixon *et al.* (2011) and Dimitrijević *et al.* (2010).

3 Conclusion

The development of space born spectroscopy, building of giant telescopes of the new generation and increase of accuracy of computer codes for modelling of stellar atmospheres and envelopes, as well as laser equipments, laboratory, magnetic fusion and technological plasmas, has opened up a new era for obtaining new and numerous Stark broadening data. The continuation of the development and service of a powerful and constantly updated online database, easily accessible and easy to use has become indispensable. STARK-B should fulfil this purpose.

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