Publ. Astron. Obs. Belgrade No. 76 (2003), 11 - 17 *Invited lecture*

LINE BROADENING RESEARCH IN TUNISIA : HISTORY, PRESENT STATE AND INTERNATIONAL COLLABORATION

N. BEN NESSIB

Groupe de Recherche en Physique Atomique et Astrophysique
E–mail: nebil.bennessib@planet.tn

Abstract. We present a review and analysis of the results of spectral line shapes investigation in Tunisia since 1970 up to 2003.

1. INTRODUCTION

Now, in my country there are 300 000 students and 13 000 teachers at the 7 universities of Tunisia. The number of active researchers is 10 000 and the budget of the high school ministry makes 7% of the government total budget. The older institution is the Science Faculty of Tunis, it was built in 1968. Most teachers prepared their thesis in France and returned to Tunisia. Each one has a different subject in his research study: Raman effect, electronic microscopy, molecular physics, atomic physics, nuclear physics, semiconductors, . . .

The father of atomic physics in Tunisia is Professor Taoufik BEN MENA, he worked on instrumental spectroscopy in the Aimée Cotton laboratory of the University of Orsay Paris-Sud. After him Mrs Zeineb BEN AHMED-BEN OSMAN worked on the Zeeman effect and M. Mohamed MILADI worked on the electronic structure of the molecule NO in the same laboratory. After these three works, two other works were done at the University of Jussieu-Paris VI: the work on atomic broadening by M. Mohamed SASSI and on molecular broadening by Mrs Zohra BEN LAKHDAR-AKROUT.

Since the first paper on line broadening by Tunisians (Sassi *et al.*, 1970) up to now, more than 30 publications concerning line shapes investigations have been published. In these published works, various problems from this research field have been considered.

First theoretical investigations of Tunisians have been done by Professor Mohamed SASSI from 1970 up to 1975. They concern Stark broadening of non hydrogenic emitters and particulary the study of overlapping lines done specially with M. Claude DEUTSCH at the University of Paris VI. When SASSI returned to Tunisia, he formed a research group with M. Hédi BELAKRMI in the Ecole Normale Supérieur of Bardo. They studied particulary the ion dynamic effects and microfield distributions depending on time. In 1982, M. SASSI joined the Faculté des Sciences de Tunis with his student H. BELAKRMI. He took, a new student for the thesis, M. Nébil BEN NESSIB and proposed to him the study of strong collisions. After N. BEN NESSIB read the paper of BASSALO, CATANNI and WALDER in 1983 he tried to generalize their work on overlapping lines. So he generalized the convergent theory to overlapping lines, with application to the HeI 4471Å line. This research group dispersed 1988.

First experimental investigations of Tunisians have been done by Professor Zohra AKROUT-BEN LAKHDAR. They concern the shape of molecular spectrum : mercury 2537 Å line perturbed by noble gases. The work was done in the laboratory of LENNIER, in Paris from 1975 up to 1978. When she returned to Tunisia, she formed a research group with two students M. Abdelbari MEJRI and M. Youssef MAJDI who presented their thesis on the Faculté des Sciences de Tunis.

After his thesis in 1988, N. BEN NESSIB joined the BEN LAKHDAR research group and founded the "Laboratoire de Physique Atomique et Moléculaire" cooperating especially with the NGUYEN Hoe research group of the University of Paris VI. In four years, he worked on theoretical formalisms of Stark broadening and published 4 papers about quantum formalism of Stark broadening using the Coulomb-Born Oppenheimer approximation of calculating the scattering matrix. Miss Neila TERZI joined the "Laboratoire de Physique Atomique et Moléculaire". She worked on radial integrals and calculated Stark broadening of infrared helium lines (Terzi *et al.*, 1998).

In the same group, M. Mohamed Abdelbari MEJRI studied the hydrogenic spectral lines in hot and dense plasma, particulary the shift of hydrogenic-like ion lines due to electron collisions which are treated by including all effects due to monopole, dipole and quadripole interactions between radiator and perturbing electrons. He published with NGUYEN and BEN LAKHDAR a work in the Europeen Journal of Physics D(Eur. J. Phys. D., 1998).

The laboratory of Professor BEN LAKHDAR became "Laboratoire de Physique Atomique, Moléculaire et Applications" since 2000. The research in atomic physics is oriented toward the experimental study of a plasma induced in water by a stabilized arc at atmospheric pressure.

2. HISTORY

2. 1. SASSI'S WORK: OVERLAPPING LINES

In the work in 1970, SASSI et al. proposed, for LiI 2P-4D and 2P-4F lines, the use of the intensity ratio of the forbidden and permitted components or from the wavelength separation of their intensity maxima. They showed that the 2P-4D permitted line is shifted towards the red while the 2P-4F forbidden line is shifted towards the violet. Thus, the line separation becomes very sensitive to the electron concentration variation. This is also true of the relative intensity of the two lines.

In the work of SASSI and COULAUD (J. Phys. B, 1972)they study the ionic profiles in the region of the forbidden component of CsI (6G-5D). It is shown that limiting the number of perturbing levels to those with the same principal quantum number introduces negligible errors in the peak separation between the allowed and forbidden lines but may affect the profile in the region of the forbidden component. In the case of CsI 6G-5D, this limitation contributes to overestimate the maximum intensity of the forbidden component and reduces the intensity between the allowed and the forbidden lines.

He contributed in the expressions of the generalized width and shift functions $A(z)$ and $B(z)$ defined with the second-order time integral of the electron-collision operator of partially degenerate lines (Phys. Rev., 1972).

The generalized impact theory of Stark broadening of overlapping lines in plasma, with the nonmarkovian and ion dynamic effects is treated in Annals of Physics 1994 and 1975.

He studies particulary the evolution of the ratio of the forbidden and allowed line maximum and the wavelength distance between the two components with the temperature and the electron density.

2. 2. BEN LAKHDAR'S WORK: MOLECULAR BROADENING

Mrs Zohra BEN LAKHDAR-AKROUT performed her research in the laboratory of Professor LENNUIER in the University of Pierre and Marie Curie Paris VI. She studied the absorption spectral profile of the line 2537 Å for the mercury perturbed by noble gases.

In her first work (J. Physique, 1976), she measured the absorption coefficient of mixtures of mercury-krypton and mercury-xenon vapors in the range 120-7500Ghz about the line center. At low frequency, she shows the existence of an anisotropy in the interaction potential between the Hg(3_1^P) and the perturber. This anisotropy has been observed both for the attractive side (Van der Waals terms) and the repulsive one. For high frequencies, the absorption profile shows successive peaks (blue satellites) which can be attributed to bound pairs. The near wing, although far from the impact approximation domain cannot be interpreted by pure quasistatic theory. Taking into account the significant movement of the perturber with respect to the active atom during the interaction period she suggests that wing can be attributed to the attractive potential branches.

In her second work (J. Physique, 1978) about the same line profile of Hg (2537 Å), she gives the same interpretation of experimental data when the perturber is argon and not krypton and xenon as in the first work. Comparison with the results obtained by other authors shows the need to question the meaning of the empirical expression proposed for the representation of interaction-potentials. In the second part of this second work, she studies the theoretical expressions which describe these potentials and in particular she consider the computation of the dipole-induced dipole coefficient of Hg(6^1S_0) and Hg(6^3P_1) interacting with rare gases. In the third part, she treats the case of heavy gases. It is shown that it is possible, in some cases, to interpret the coefficients deduced from experimental data as differences between dipole-induced dipole interaction coefficients.

In 1996, N. BEN NESSIB et al. present a work about theoretical calculation of Stark broadening of neutral oxygen lines (Physica Scripta, 1996). Concerning collisions of neutral atoms with electrons, the impact approximation is always valid in the physical conditions of stellar atmospheres and of laboratory experiments. Concerning collisions of neutral atoms with ions, the impact approximation is most often valid in the physical conditions of hot stellar atmospheres where the density is weak (10^{10} to 10^{14} cm^{-3}) and where the ion perturbers are light protons and He^+ ions. In laboratory experiments, the density is higher (10^{16} -10^{17} cm^{-3}) and the perturbers are heavier (Ar^+ for instance). Thus the validity condition of the impact approximation has to be checked for each line and conditions (Temperature and density). If the impact approximation is valid, then we have input the TOPbase (Opacity Project) sophisticated atomic structure data into the Sahal-Bréchot's computer code to calculate widths and shifts of spectral lines. But when the impact approximation breaks down, the quasistatic approximation has to be used. The quasistatic profiles for isolated lines provided by Griem are computed with quadratic interactions only. However, the quadrupolar interactions may be unnegligible. The quasistatic profile for quadrupolar interactions has been obtained by Sahal-Bréchot in 1991 and exist in her computer code. Still the quasistatic quadratic ion broadening parameter A, which is a measure of the relative importance of ion broadening has been calculated by Griem using a simplified Coulomb approximation for the atomic structure. So we have also computed the quasistatic ion parameter broadening A with the TOPbase atomic structure and compared to the A-value of Griem. The difference with Griem's values is about 20 per cent, except for the 5330 Å line, where the difference exceeds 50 per cent. On the whole, our results are in better agreement with experiments than the calculations by Griem, especially for the widths where the agreement can attain a few percent. We show that our results are improved with the use of TOPbase, and the calculation of the quasistatic ion parameter broadening , especially for the widths. These calculations are extended to infrared helium lines by TERZI (A& A suppl., 1998) and we are doing the same kind of calculations for ionic emitters (MAHMOUDI, 2003).

In the work of TERZI *et al.* (1998), they have calculated Stark widths and shifts for six infrared lines of helium arising from highly excited levels. In this work, they have checked several criteria as the validity condition of the perturbation theory, impact or quasistatic approximation, isolated or overlapping line, . . .

Dr. N. BEN NESSIB studied the semiclassical collisional functions in a non ideal plasma (A& A, 1997). He obtained new analytic expressions of the non adiabatic semiclassical collisional functions which generalize the $A(z)$ and $a(z)$ standard ones to a strongly non ideal plasma by using the Coulomb cutoff potential. He present the correlated collision functions for transition probability A_0^c, $A_\pm^c$ and A_2^c and for total cross-sections a_0^c, $a_\pm^c$ and a_2^c.

Dr. M.A. MEJRI studied broadening of hydrogenic-like ion lines due to electron collision in dense and hot plasmas (Eur. Phys. J. D., 1998). These collisions are treated by including all effects due to monopole, dipole and quadrupole interactions between radiator and electron perturbers. The latter follows exact hyperbolic trajectories with a possible penetrating part inside atomic orbits. Applications are to the Paschen lines alpha and beta.

3. PRESENT STATE

Line broadening research is developed now, particulary in two research groups:

3. 1. TUNIS GROUP

In the new laboratory "Laboratoire de Physique Atomique, Moléculaire et Applications", there is a division of plasma physics where the aim of the work is the study of water plasma and pollution in water by spectroscopic investigations (the work is particulary done by Mrs N. TERZI and some new students in the laboratory). A cooperation is particulary established, in this field with Professor Guy TAIEB from Orsay University. The alkaline dusts in water are the major elements studied. The study of the arc plasma is another interesting work of Y. MAJDI and N. TERZI.

3. 2. BIZERTE GROUP

In the frame of the semiclassical approach, investigations of the applicability of different theories have been carried out.

The theory for multiply charged ions has been improved.

The work on a new quantum mechanical approach to the Stark broadening has been carried out with a thesis of M. Haykel ELABIDI. Research on Stark broadening of multiply charged ions was developed and new quantum calculations for the electron-impact broadening in intermediate coupling is in progress.

With another student, Miss Hédia BEN CHAOUACHA, the development of semiclassical collisional functions in a strongly correlated plasma is going on. We generalize the functions $A(z)$ and $a(z)$ to the case of non Coulomb potential as the cut-off potential, with one correction term and the ion sphere potential, with two correction terms.

We study also the singly ionized emitters as CII, NII and OII with the semiclassical formalism. This is the subject of the thesis of M. Walid MAHMOUDI. In this research field, we calculate widths and shifts of ionized atoms with the impact and quasistatic approximation as done for neutral emitter by BEN NESSIB et al. (Physica Scripta, 1996).

New approaches, especially convenient for quick calculations of a large number of lines have been developed, a new formalism where we show the temperature dependence is developed and application to neutral helium and magnesium spectral lines is in progress. This is the subject of the thesis of Miss Besma ZMERLI.

Working on microfield distributions, is one of the axes of the research group. This is at the limit of the line broadening but it just gives a complementary information on the interactions in a plasma. A new thesis on microfield distributions in low, medium and high correlated plasma is the subject of M. Belhassen TRABELSI. The work is at the beginning but we found new expressions especially for low and medium correlated plasma.

4. INTERNATIONAL COLLABORATION

4. 1. FRENCH COLLABORATION

The principal cooperation is with Dr. Sylvie SAHAL-BRECHOT from the LERMA (Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique), Paris-Meudon Observatory. This cooperation started with the works of Ben Nessib and after that with Terzi. Mrs SAHAL-BRECHOT is considered in Tunisia as a very important personality with her scientific and human qualities.

The Tunis research group collaborates also with Toulouse research group the " Centre de physique des plasmas et de leurs applications de Toulouse" and with the "Laboratoire de Photophysique moléculaire", Université Paris-Sud, Orsay.

The Bizerte research group collaborates also with the LUTH (Laboratoire de l'Univers et de ses théories) of the Paris-Meudon Observatory. This cooperation is particulary maintained with Mrs Marguerite CORNILLE and M. Jacques DUBAU. The cooperation consist in the study of atomic and collisional data of multicharged ions. This new research axis permits us to elaborate new quantum formalism for Stark broadening in intermediate coupling and ab initio semiclassical spectral line broadening.

4. 2. SERBIAN COLLABORATION

The Tunis research group collaborates with Professor Nikola KONJEVIĆ from the Institute of Physics in Belgrade. He visited Tunisia several times, gave lectures there and offered ideas for equipments and new experimental setup.

The Bizerte research group collaborates with Dr. Milan DIMITRIJEVIĆ from the Belgrade Observatory. The work on the four time ionized silicon opens a new method for calculating. This new method of calculating can be used for elements whose spectrum is poorly known and it is not possible to obtain a sufficiently complete set of experimental atomic energy levels needed for adequate semiclassical perturbation calculations. The energy levels are then calculated using the general purpose atomic structure code SUPERSTRUCTURE developed at the University College in London.

Cooperation of the Bizerte group is also maintained with KONJEVIĆ for the study, experimentally and theoretically of isoelectronic sequences. We started with the carbon isoelectronic sequence and found some discrepancy between semiclassical prediction and experimental results for some transitions.

A new cooperation will start with Professor Stevan DJENIŽE and Dr Vladimir MILOSAVLJEVIĆ from the Faculty of Physics, University of Belgrade. This research concerns transition probabilities in multicharged ions as N IV, N V, Ar IV and Ar V and other ions. We have powerful theoretical methods for calculating this parameters and in Belgrade they can obtain this parameter by using the relative line intensity ratio. The collaboration is then immediate.

5. CONCLUSIONS

More than 30 years of line broadening studies by Tunisian researchers, four generations have passed, more than 30 works on this field have been executed. This is not too much, but just enough to say that line broadening in Tunisia has a favorable terrain to be developed.

The scientific research does not distinguish between races, religions and nationalities, it stands above all. We try to do the best and we are open to any cooperation.

References

Bel Akremi, H.: 1987, Effet Stark dépendant du temps et raies partiellement dégénérées, thèse de spécialité, Université de Tunis, April 1987.

Ben Lakhdar, Z., Perrin, D., Lennuier, R.: 1976, Etude expérimentale des railes de la raie 2537 Å du mercure perturbée par le krypton et le xénon, *J. Physique* **37**, 831.

Ben Lakhdar, Z., Perrin, D., Lennuier, R.: 1978, Sur les potentiels d'interaction Hg(6^1S_0) ou Hg(6^3P_1)-gaz rares, *J. Physique* **39**, 137.

Ben Lakhdar, Z.: 1978, Etude du profil spectral d'absorption de la raie 2537 Å du mercure perturbé par les gaz rares, Université Pierre et Marie Curie Parie VI, September 1978.

Ben Lakhdar, Z., Ben Nessib, N.: 1991, Collision width function in a correlated plasma, *Spectral Line Shapes* **5**, 88.

Ben Nessib, N.: 1988, " Elargissement des raies partiellement dégénérées. Application à l'hélium neutre ", thèse de spécialité, Université de Tunis, January 1988.

Ben Nessib, N., Ben Lakhdar, Z., Nguyen H., Arranz, J.P.: 1994, Modélisation de l'élargissement Stark dans les lasers X, *Ann. Phys.* **C1**, 45.

Ben Nessib, N., Sahal-Bréchot, S., Ben Lakhdar, Z.: 1996, Stark Broadening of Neutral Oxygen Neutral Lines in the Impact and Quasistatic Approximation, *Physica Scripta* **54**, 608.

Ben Nessib, N., Sahal-Bréchot, S., Ben Lakhdar, Z.: 1997, Semiclassical Stark Broadening Calculations of Neutral Oxygen Lines, *Spectral Line Shapes* **9**, 117.

Ben Nessib, N., Ben Lakhdar, Z., Sahal-Bréchot, S.: 1997, Semiclassical collisional functions in a non ideal plasma, *Astronnomy and Astrophysics* **324**, 799.

Ben Nessib, N.: 1997, Contributions à l'élargissement spectral dans un plasma d'atomes complexes ", thèse d'Etat, Université de Tunis II, May 1997.

Chapelle, J., Coulaud, G., Deutsch, C., Diatta, C., Sassi, M.: 1971,*J. Phys. Fr. Supp.* **C5b**, 151.

Coulaud, G., Deutsch, C., Sassi, M.: 1971, Contributed papers to the Tenth Conference on Phenomena in Ionized Gases, Oxford, 378.

Deutsch, C., Sassi, M., Coulaud, G.: 1972, Off-Diagonal matrix elements in the Stark-broadening theory of neutral lines in plasmas, *Phys. Rev.* **A6**, 2484.

Deutsch, C., Sassi, M., Coulaud, G.: 1974, Stark broadening of the overlapping 4471.48 Å HeI line in a plasma, *Ann. Phys.* **83**, 1.

Dimitrijević, M.S., Ben Nessib, N.: 1991, Simple convergent formula for estimating Stark widths of neutral atom lines, *Spectral Line Shapes* **5**, 605.

Dimitrijević, M.S., Ben Lakhdar, Z., Ben Nessib, N.: 1993, Simple convergent formula for estimating stark widths and shifts for neutral and ionic lines, Proceeding of the I.C.S.L.S., ed. Nova.

Mejri, M.A., Nguyen, H., Ben Lakhdar, Z.: 1998,Shifts of one-electron ion lines from interactions with electrons in hot and dense plasma, *Eur. Phys. J. D* **4**, 125

Mejri, M.A.: 1987, Etude théorique de l'élargissement des raies hydrogénoïdes émises par un plasma. Application à la raie $P_\alpha$de l'hélium II., thèse de spécialité, Université de Tunis, June 1987.

Nguyen, H., Arranz, J.P., Ben Lakhdar, Z., Ben Nessib, N.: 1993, Atomic structure of Li-like ions in hot and dense plasmas, Proceeding of the I.C.S.L.S., ed. Nova.

Nguyen, H., Arranz, J.P., Ben Lakhdar, Z., Ben Nessib, N.: 1995, Broadening of Li-like ions in hot and dense plasmas, *Spectral Line Shapes* **8**, 213.

Perrin, D.J., Benlakhdar, Z., Jeanett, J.C., Lennuier, R.: 1982, Experimental shape of the 253.7nm mercury line perturbed by the light noble gases (Fr.), *J. Phys. E* **43**, 45.

Sassi, M.: 1972, , *J. Quant. Spectrosc. Radiat. Transfer* **12**, 75.

Sassi, M., Coulaud, G.: 1972, Calculated ionic profiles in the region of the forbidden component CsI (6G-5D), *J. Phys. B.* **5**, L35.

Sassi, M., Herman, L., Coulaud, G.: 1970, Relative intensities and relative shifts of the 2P-4F and 2P-4D LiI lines as a function of electron concentration, *Phys. Lett.* **32A**, 549.

Sassi, M.: 1974, Contributions à l'étude de l'Elargissement des raies partiellement dégénérées. Application à la raie 4471 Åde l'hélium neutre ", thèse d'Etat, Université Paris VI.

Sassi, M., Deutsch, C., Coulaud, G.: 1975, Stark broadening of the overlapping 4471.48 Å HeI line in a plasma II. Nonmarkovian and ion dynamic effects, *Ann. Phys.* **89**, 274.

Sayer, B., Wang, R., Jeannet, J.C., Sassi, M.: 1971, Absorption measurements of quadrupole transition probabilities 6S-nD in caesium vapour, *J. Phys. B* **4**, L20.

Terzi, N., Sahal-Bréchot, S, Ben Lakhdar, Z.: 1998, Stark profiles of infrared helium lines, *Astronomy and Astrophysics Supplement* **133**, 229.

Terzi, N.: 1999, Etude théorique et expérimentale de l'élargissement Stark de profils de raies de l'hélium neutre. Application astrophysique, 15 June 1999.