YU ISSN 0015—3206
FZKAAA 15 (3) 205 (1983)

INFLUENCE OF DIFFERENT COLLISIONAL PROCESSES ON THE STARK BROADENING

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Received 11 January 1983

UDC 535.338.334:539.186.24:533.9.082.5

Original scientific paper

Using a semiclassical formalism, elastic, inelastic and strong collision's contributions to the electron impact width of the Li I ($2s^2\,S$ - $2p^2\,P^0$; $\lambda = 670.78$ nm) resonance line have been computed for different angular momenta of the incoming perturbing electron and for $T = 2500$, 10000 and 20000 K. On the basis of the obtained results, the relative importance of elastic, inelastic and strong collision's contributions to the line width are discussed.

1. Introduction

During the Stark broadening investigations we have, in fact, two distinct problem to solve. The first is the collisional problem of the interaction between the radiator and one perturber and the second is a statistical problem of combining the effect of a large number of perturbers and of averaging over all possible motions of these[1]. In the impact limit, when the collision time is small compared to the time of interest for the line broadening as well as compared to the time between two collisions, the collisions are complete and the results of the collision investigations are directly applicable in the line broadening problem.

During the formation of the line profile, a large number of collisions take part and it is interesting to discuss the influence of different kinds of collisions on the Stark broadening of atomic and ionic lines. In order to analyse the importance

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of different processes on the electron impact broadening of atomic lines in plasmas, we have computed semiclassically various contributions to the impact Stark width of the Li I ($2s^2S$ - $2p^2\,P^0$; $\lambda = 670.78$ nm) resonance line for different angular momenta of the incoming perturbing electron. On the basis of obtained results we discuss the relative importance of elastic, inelastic and strong collision's contribution to the line width.

2. Theory

The starting point of our analysis is the semiclassical impact Stark broadening formalism based on the perturbational approach[2,3]. The halfwidth and shift of an electron impact broadened line can be expressed via elements of the scattering matrix S (see e. g. Ref. 2)

$$w + \mathrm{i}d = N \int_0^\infty vf(v)\,\mathrm{d}v \int_0^\infty 2\pi\varrho\,\mathrm{d}\varrho\,(1 - S_{ii}(\varrho, v)\,S_{ff}^{-1}(\varrho, v))_{Av}. \tag{1}$$

Here, N is the electron density, $f(v)$ is the velocity distribution function for electrons

$$f(v) = 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} v^2 \exp\left(-\frac{mv^2}{kT}\right), \tag{2}$$

ϱ denotes the impact parameter of the incoming electron and S_{ii} and S_{ff} are elements of the semiclassical S matrix for initial (i) and final (f) states of the radiator. The angular average $(\;)_{Av}$ over the directions of the colliding electron is expressed by a summation over the magnetic quantum numbers of the radiating atom

$$\sum_{\substack{M_i M_f \\ M_i' M_f' \\ \mu}} (-1)^{2L_i+M_i+M_i'} \begin{pmatrix} L_f & 1 & L_i \\ M_{f'} & \mu & -M_{i'} \end{pmatrix} \begin{pmatrix} L_f & 1 & L_i \\ M_f & \mu & -M_i \end{pmatrix} \times$$
$$\times \langle L_i\,S\,M_{i'}\,|S|\,L_i\,S\,M_i\rangle \langle L_f\,S\,M_f|\,S^{-1}|\,L_f\,S\,M_{f'}\rangle. \tag{3}$$

Using the conservation conditions (S matrix is unitary and symmetric) w can be expressed in terms of cross sections for elastic and inelastic processes[4]

$$2w = N \int_0^\infty vf(v)\,\mathrm{d}v\,\Big(\sum_{j\neq i} \sigma_{ij}(v) + \sum_{j'\neq f} \sigma_{fj'}(v) + \sigma_{el}\Big) \tag{4}$$

$$d = N \int_0^\infty vf(v)\,\mathrm{d}v \int_0^\infty 2\pi\varrho\,\mathrm{d}\varrho\,\sin 2\Phi_p. \tag{5}$$

The inelastic cross section $\sigma_{ij}(v)$ can be expressed by an integration over the impact parameter of the transition probability $P_{ij}(\varrho, v)$

$$\sum_{j\neq i} \sigma_{ij}(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_d} 2\pi\varrho \, d\varrho \sum_{j\neq i} P_{ij}(\varrho, v) \tag{6}$$

with

$$P_{ij}(\varrho, v) = S_{ij}^2(\varrho, v).$$

The elastic cross section is given by

$$\sigma_{el} = 2\pi R_2^2 + \int_{R_2}^{R_d} 8\pi\varrho \, d\varrho \sin^2\delta \tag{7}$$

$$\delta = \Phi_p^2 + \Phi_q^2.$$

The cut-offs (R_1, R_2) as well as the symmetrization procedure are described in Ref. 3 (§ 1 of chapter 3). We only recall that the cut-off R_2 in the elastic-collision contribution is chosen so that

$$\sin^2\delta(R_2) = \frac{1}{2} \tag{8}$$

and thus

$$\int_0^\infty 8\pi\varrho \, d\varrho \sin^2\delta = 2\pi R_2^2. \tag{9}$$

In order to take into account the Debye shielding, we have introduced also the Debye cut-off R_d as an upper cut-off in the integration procedure.

The phase shifts Φ_p and Φ_q due, respectively, to the polarisation potential (r^{-4}) and to the quadrupolar potential (r^{-3}) are given in Ref. 2 (§ 1, chapter 3).

In order to exhibit the contributions to the line width of the collision between the emiter and electrons with a particular angular momentum l we have defined the corresponding semiclassical Stark broadening parameters w_l and d_l in the following manner. We replace the integration over the impact parameter ϱ of the perturbing classical particle by the integration over l using the relation

$$l \sim \varrho k \text{ with } k = mv.$$

The corresponding values for w_l and d_l can be obtained now from

$$w_l + i d_l = N \int_0^\infty v f(v) \, dv \int_{l/k}^{(l+1)/k} 2\pi\varrho \, d\varrho \, (1 - S_{ii}(\varrho, v) \, S_{ff}^{-1}(\varrho, v))_{Av}. \tag{10}$$

This procedure will allow us to investigate the importance of different collisional processess for collisions between the emitter and perturbing particles with different ngular moment a.

3. *Results and discussion*

The set of energy levels[5] and atomic data used in our calculations are listed in Table 1. By inspecting Eq. (5), we can see that the line shift is due only to elastic collisions. A detailed analysis of Stark broadening parameters as functions of

TABLE 1.

(a) Term i	E_i (cm^{-1})	$\bar{r}_i (a_0)$	$\bar{r}_i^2 (a_0^2)$
$2s^2S$	0	3.80	—
$2p^2P$	14904	4.75	27.5
$3s^2S$	27206	10	—
$4s^2S$	35012	21	—
$3d^2D$	31283	10	—
$4d^2D$	36623	21	—
$5d^2D$	39095	34	—

(b) Transition $i \to j$	Oscillator strength $(i \to j)$
$2s^2S \to 2p^2P$	0.753
$2p^2P \to 3s^2S$	0.115
$2p^2P \to 4s^2S$	0.0125
$2p^2P \to 3d^2D$	0.667
$2p^2P \to 4d^2D$	0.122
$2p^2P \to 5d^2D$	0.0452

Atomic data

the impact electron angular momentum quantum number and of the temperature is carried out in our preceding paper[6]. Therefore we restrict the discussion to the analysis of the different collisional processess which enter in the formation of the line width. We have studied the influence of elastic and inelastic contribution to the line width as function of the l and T. The influence of strong collisions is also analysed. The perturbative approach used in the semiclasical method requires a cut-off procedure for low impact parameter ϱ. The strong collisions correspond to the contribution of the ϱ values which are smaller than the cut-off radius R ($R = R_1$ for inelastic and $R = R_2$ for elastic collisions); the weak collisions correspond to $\varrho > R$.

The obtained results are presented in Figs. 1-6. The relative halfwidths due to strong, elastic and inelastic collisions, respectively, as functions of l and T are shown in Figs. 1, 2 and 3. It must be pointed out that strong and weak contributions are contained in the inelastic and elastic halfwidth while the strong halfwidth contains strong inelastic and strong elastic contribution. We can notice the

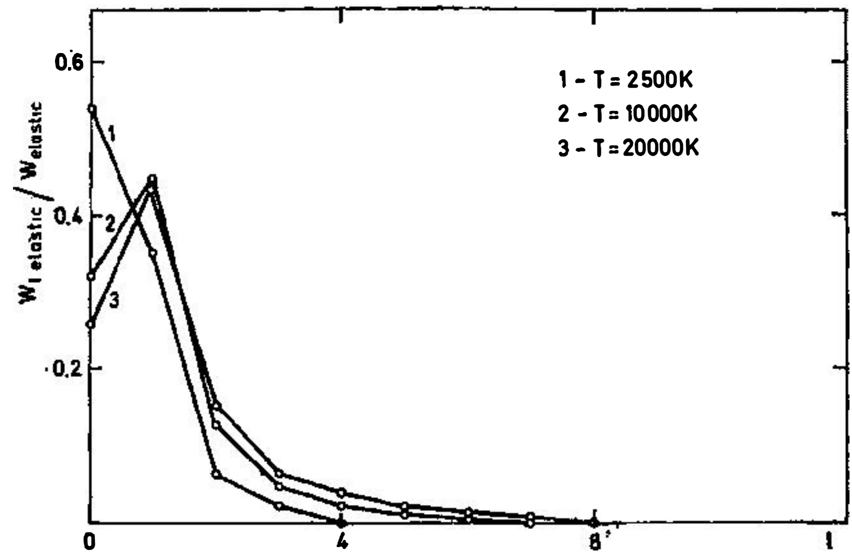

Fig 1. Relative halfwidths due to elastic collisions as functions of l and T; $N = 10^{16}\,\mathrm{cm}^{-3}$.

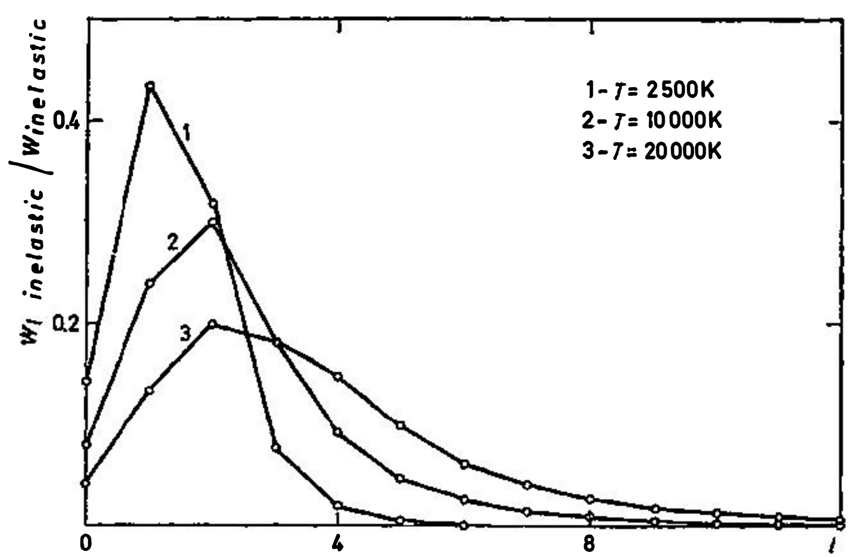

Fig. 2. Relative halfwidths due to inelastic collisions as functions of l and T; $N = 10^{16}\,\mathrm{cm}^{-3}$.

importance of very low l values for all investigated contributions as well as the increase of the importance of electrons with higher l values with the temperature, especially for the inelastic contribution.

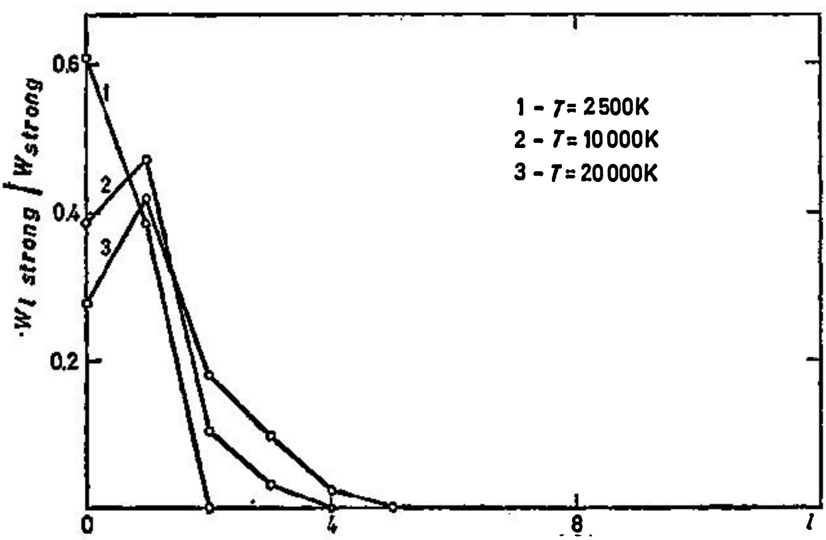

Fig. 3. Relative halfwidths due to strong collisions as functions of l and T; $N = 10^{16}\,\mathrm{cm}^{-3}$.

The relative importance of elastic, inelastic and strong contributions for different l and T values are compared in Figs. 4-6. For the lowest l values i. e. for slow impact electrons or very small impact parameters, the strong elastic contribution, which is the weakest point of the semiclassical method, is dominant.

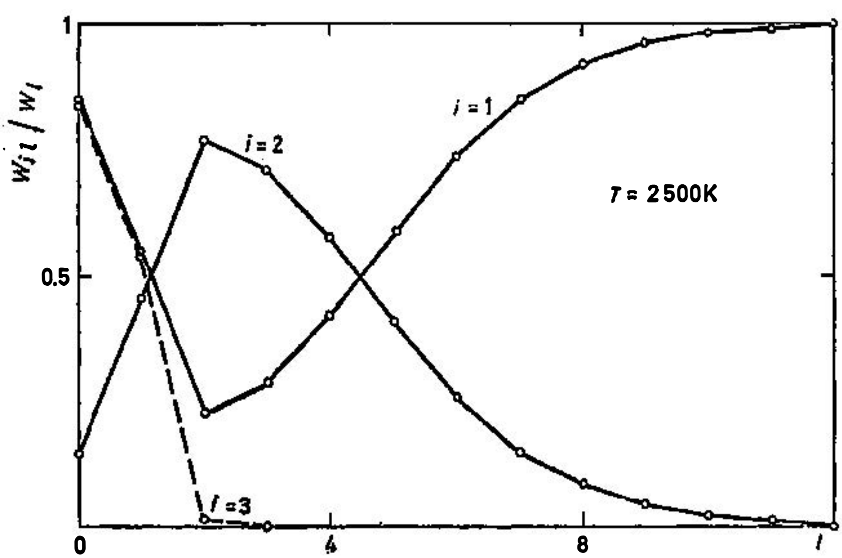

Fig. 4. Relative contriburion of elastic ($i = 1$), inelastic ($i = 2$) and strong ($i = 3$; broken curve) collisions to the halfwidth as a function of l, $N = 10^{16}\,\mathrm{cm}^{-3}$ and $T = 2500$ K.

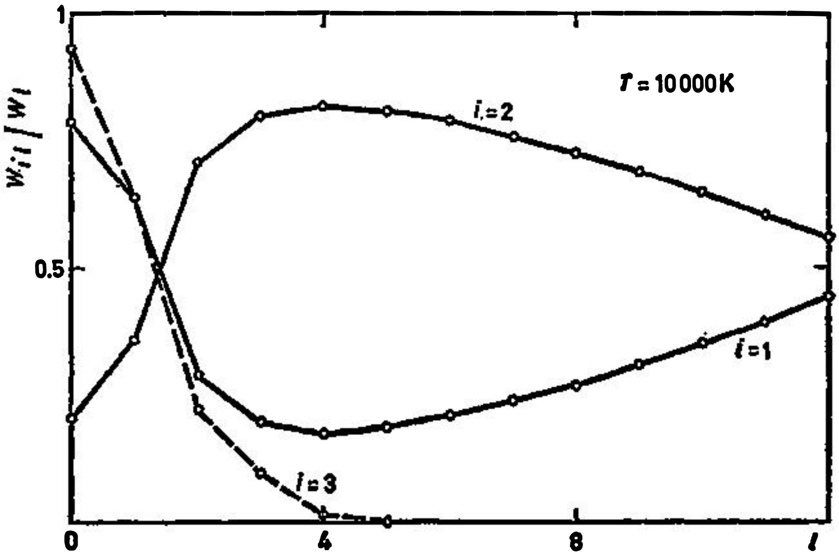

Fig. 5. Same notation as in Fig. 4 but for $T = 10000$ K.

With the increase of l, the inelastic contribution increases and the elastic decreases but for higher l values the elastic contribution becomes dominant. This is well illustrated on Fig. 4, where T is equal to 2500 K, while for $T = 20000$ K (Fig. 6) l values are not sufficiently high to notice this effect.

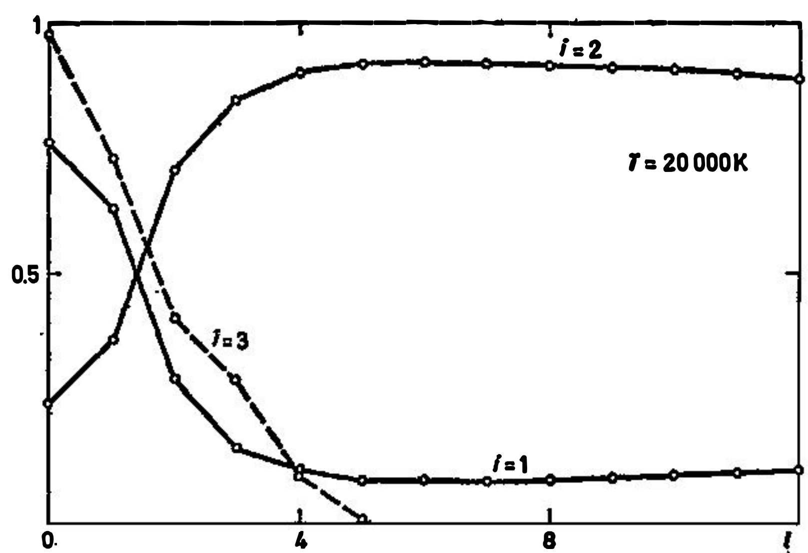

Fig. 6. Same notation as in Fig. 4 but fot $T = 20000$ K.

Increase of the importance of elastic contribution for higher l values is connected to the fact that it is more probable that an electron with higher l has larger ϱ and smaller v closer to the maximum of Maxwellian distribution, than smaller ϱ and larger v. Such electrons product mainly elastic collisions as l increases. In conclusion, we think that this perturbative semiclassical approach is not reliable at low temperatures (2500 K) since the strong collisions are dominant. But it gives good values of the width for higher temperatures as was discussed before[6].

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UTICAJ RAZLIČITIH SUDARNIH PROCESA NA ŠTARKOVO ŠIRENJE

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UDK 535.338.334:539.186.24:533.9.082.5

Originalni naučni rad

Doprinos Štarkovoj širini rezonantne linije Li I ($2s^2\ S - 2p^2\ P^0$; $\lambda = 670.78$ nm), izračunat je za različite ugaone momente upadnog elektrona i za $T = 2500$, 10000 i 20000 K, u okviru semiklasičnog prilaza. Na osnovu dobijenih rezultata, razmatran je relativni značaj doprinosa širini linije usled elastičnih, neelastičnih i jakih sudara.

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