EFFECT OF ELECTRIC FIELDS ON AUTOIONIZING RESONANCES

D. Kelleher, G. Lombardi, J. Delpech, J. Weiner

► To cite this version:

D. Kelleher, G. Lombardi, J. Delpech, J. Weiner. EFFECT OF ELECTRIC FIELDS ON AUTOIONIZING RESONANCES. Journal de Physique Colloques, 1982, 43 (C2), pp.C2-439-C2-441. 10.1051/jphyscol:1982235 . jpa-00221847

HAL Id: jpa-00221847

<https://hal.science/jpa-00221847>

Submitted on 1 Jan 1982

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

EFFECT OF ELECTRIC FIELDS ON AUTOIONIZING RESONANCES

D.E. Kelleher, G.G. Lombardi, J.F. Delpech* and J.W. Weiner**

*National Bureau of Standards, Washington, D.C. 20234, U.S.A.***Institut d'Electronique Fondamentale, Bât. 220, Université de Paris-Sud, 91405 Orsay Cedex, France****University of Maryland, College Park, Maryland, U.S.A.*

We have studied the effect of electric fields on autoionizing (AI) resonances. We have observed the broadening of a relatively sharp AI resonance by field mixing with another much broader resonance. The effect is analogous to the broadening of the metastable 2S in Hydrogen by field mixing with the 2P.⁽¹⁾ The AI problem differs, however, in that continua are involved, and AI decay rates (and therefore widths) are typically on the order of 10^4 times larger than radiative decay rates.

We have looked at doubly excited states of Sr, Ca, and Gd which lie near to but above the ionization limit. In contrast to the field-induced resonances discussed earlier this conference, we consider resonances which are present even at zero field, and observe how their autoionization rates (widths) change as a function of electric field.

The experiments were performed by laser scanning the resonances in a thermal beam between field plates, and detecting the resulting ions with an electron multiplier. Our experiment is complementary to earlier ones^(2,3) which were performed on Rydberg AI levels, where changes in width were observed at level anticrossings. The results we report here are monotonic in the field strength. Also, first order Stark splittings of a sharp Feshbach (AI) resonance in H^- were observed by Brint et al.⁽⁴⁾

Our measurements in Sr were performed on distinctly non Rydberg AI resonances. Some such "valence" levels are extremely broad, e.g. Sr $4d6p\ ^1P_1^o$, has a width of 415 cm^{-1} in zero field.⁽⁵⁾ In our experiment we scanned over a relatively sharp resonance (1.2 cm^{-1} in zero field) of opposite parity, $4d5d\ ^1D_2$, which falls energetically in the near wing ($E^P - E^D \simeq 600\text{ cm}^{-1}$) of the broad resonance. The increase in width of the relatively narrow 1D_2 resonance became large enough to measure at a field of about 50 KV/cm. Over a range of measurements in Sr from 50 to 130 KV/cm, a least squares fit through the data yields an electric field induced width $[r_F - r_0] = 6.5 \times 10^{-10} F_{V/cm}^{1.8 \pm 0.2}$, where r_0 is the zero field width in cm^{-1} . We would have liked to extend the measurements to higher field strengths, but even at 10^5 V/cm our apparatus tends to self destruct, and at $F > 1.3 \times 10^5$ the number of blown amplifiers per data point becomes

prohibitive.

We compare this result to a simple bound-bound perturbations mixing model, given by Davis and Jacobs,⁽⁶⁾ which can be written as

$$\Gamma_i = \frac{d^2 F^2}{(E_i - E_j)^2 + \Gamma_j^2/4} \Gamma_j \quad (1)$$

where Γ_i is the field induced width due to mixing with the much broader level j , $d = e \langle \Psi_i | z | \Psi_j \rangle$ is the dipole coupling constant, F represents the field strength and E_{0j} the energy of the center of the resonance. This is just the quadratic Stark expression with the smeared energy distribution of the j level taken approximately into account by using $E_j \rightarrow E_j + i\Gamma_j/2$. This zero-order estimate assumes the mixing of Lorentzian (infinite) profiles separated by $\Delta E_{ij} \gg \Gamma_j$. It does not address such questions as the effect of the field on the shape of the profiles, whether the energy E_{0j} should include the shift due to configuration interaction with the continuum, the case $\Delta E_{ij} \sim \Gamma_j$, or the effects of continuum mixing. These are all questions which pertain to our experiment, and which will be discussed in an ensuing publication (for an initial effort at a more fundamental approach to this problem, see ref. 7).

Notwithstanding the severe limitations of the bound-bound perturbation model, its predictions are in reasonable agreement with our experimental results. By comparing our results at 10^5 V/cm with eqn. (1), we obtain a dipole matrix element $d = 21 e a_0$, compared to a Coulomb approximation value⁽⁸⁾ of $d = 15 e a_0$. (Our Froese-Fischer Hartree-Fock code does not converge for the $4d5d \ ^1D_2$ state). Of course, improved calculations are required before we can conclude much from this relatively good agreement. However, these and related results appear to point consistently to a general feature of field mixing that warrants further theoretical consideration: bound-bound field mixing appears to dominate; continuum-continuum mixing effects have not been observed. This conclusion is consistent with null results we have obtained for other lines in Sr and Ca, (some of which were significantly sharper than the 1D_2 in Sr) and with the results of other experiments^(2,3,4).

Our qualitative interpretation of this observation may be expressed as follows: As Fano pointed out,⁽⁹⁾ an AI resonance may be considered as a superposition of discrete ("bound") states ϕ , and continuum states ψ_E :

$$\Psi_E = a_E \phi + \int b_E' \psi_{E'} dE'$$

The width of the resonance is proportional to the configuration interaction between the discrete and continuum parts: $\Gamma \sim |\langle \phi | H | \psi \rangle|^2$, where H is the Hamiltonian for the system. If we turn on an electric field, we will couple states of opposite parity. Three types of coupling arise

- (a) bound-bound: $\langle \phi^0 | z | \phi^e \rangle$ - important
- (b) bound-contin: $\langle \phi^0, e | z | \psi^{e,0} \rangle =$ zero

(c) contin-contin: $\langle \psi^0 | z | \psi^e \rangle$ - no observed effects

The bound-bound coupling gives rise in lowest order to eqn (1). The bound-continuum coupling is formally zero because the one electron operator "z" cannot couple two states that differ by two electrons (e.g. $\text{Sr}^{**} \rightarrow \text{Sr}^+ + e^-$). The apparently negligible role of continuum-continuum coupling is less straightforward to explain. We note that if one uses a perturbation expansion for the wave functions in a field F:

$$\phi^{(0)}(F) = \phi^0 + F \sum \langle \phi_n^e | d | \phi^0 \rangle \phi_n^e (E - E_n)^{-1} \quad (2a)$$

$$\psi_E^{(0)}(F) = \psi_E^0 + F \int \langle \psi_{E'}^e | d | \psi_E^0 \rangle \psi_{E'}^e (E - E')^{-1} dE' \quad (2b)$$

and analogous expression for $\phi^{(e)}$, $\psi^{(e)}$, (such a perturbation expansion for the continua is thoroughly unjustified due to the degeneracies involved), we obtain:

$$|\langle \phi^{(e)}(F) | H_0 + d \cdot F | \psi_E^{(e)}(F) \rangle|^2 = \Gamma^e + O(F^4) \quad (3a)$$

$$\begin{aligned} |\langle \phi^{(e)}(F) | H_0 + d \cdot F | \psi_E^{(0)}(F) \rangle|^2 &= F^2 |\sum (E - E_n)^{-1} \langle \phi_n^e | d_z | \phi^0 \rangle V_n^0|^2 \\ &+ F^2 |\int \langle \psi_{E'}^e | d_z | \psi_E^0 \rangle V_{E'}^e (E - E')^{-1} dE'|^2 \\ &+ O(F^4) \end{aligned} \quad (3b)$$

and analogous expressions for $\phi^{(0)}(F)$; where, Γ^e is the zero field width of the (narrower in our expt.) resonance: $\Gamma^e = 2\pi |V^e|^2$, $V^e = \langle \phi^e | H_0 | \psi^e \rangle$. The important point here is that the bound-bound mixing, $\langle \phi^e | d_z | \phi^0 \rangle$ is weighted by the large "width" V^0 , while the continuum-continuum is weighted by the small "width" V^e . In our Sr experiment, $\Gamma^0/\Gamma^e \approx 350$. Unfortunately, the validity of this argument suffers from the invalidity of the perturbative expansion for the continuum-continuum mixing.

We have also observed electric field effects on the Gadolinium AI resonance cited in ref. (10). We observed pronounced field effects at $F \gtrsim 1.5$ volts/cm! While this resonance is relatively isolated and clearly non-Rydbergian, it appears to be configuration mixed with a Rydberg series converging to the first excited state of Gd^+ . More details will be published elsewhere.

References

- (1) G. Lüders, Z. Naturforschg, 5a, 608 (1950).
- (2) R.R. Freeman and G.C. Bjorklund, Phys. Rev. Lett. 40, 118 (1978).
- (3) K.A. Safinya, J.F. Delpech, T.F. Gallagher, Phys. Rev. A22, 1062 (1980).
- (4) H.C. Bryant, et al., Phys. Rev. Lett. 40, 107 (1978). H.C. Bryant, et al., in "Atomic Physics 7", p. 29, Plenum Press, New York (1981) eds. Kleppner and Pipkin.
- (5) W.R. Garton, et al., J. Phys. B 1, 114 (1968).
- (6) J. Davis and V.L. Jacobs, Phys. Rev. A12, 2017 (1975).
- (7) D.E. Kelleher, in "Spectral Line Shapes 5", 281, Walter de Gruyter, New York (1981), ed. B. Wende.
- (8) We thank R.R. Freeman for providing us with the results of this calculation.
- (9) U. Fano, Phys. Rev. 124, 1866 (1961).
- (10) G.I. Bekov, V.S. Letokhov, O.I. Matveev and V.I. Mishin, JETP Lett. 28, 283 (1978).