

PARAMETRISATION OF $2pns(^1P^0)$ RESONANCE STRUCTURES IN C^{2+}

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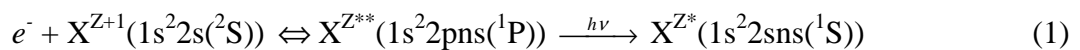
1. Introduction

Doubly excited states (resonances) offer a very suitable laser frequency regime within which to undertake investigative calculations has already attracted interest. The resonance regions have been studied in the context of multiphoton transitions. There have been several theoretical methods introduced to describe multiphoton processes in atoms. Of these calculations only those employing the R-matrix Floquet[1] method couple the field to the ion non-perturbatively and only those of Latinne *et al.*[2] explicitly investigated the laser induced modification of doubly excited states, that is to say, the interplay of laser-induced degenerate states (LIDS). Specifically, the frequency and the intensity of the light field can be adjusted such that the energy and the width of the dressed ground state coincide with the energy and the width of the dressed autoionizing state.

This work describes progress in understanding the role of Laser Induced Degenerate State (LIDS) phenomenon on resonances obtained by using lasers. The resonance structures corresponding to $2pns(^1P^0)$ autoionising states in C^{2+} are parametrised using QDT .

2. Method of Calculation

The calculation reported here is part of a general investigation which started with studies of $\Delta n = n' - n = 0$, n, n' ranging from 5 to 12 for C^{2+} and from 9 to 12 for Al^{9+} [3] and $\Delta n = 2$ in Be-like carbon[4]. We only recall here the principal ideas of the theory and the numerical methods. Only the relevant equations will be repeated here. The basic process of interest is:



Instead of using a probe laser to reach a high-lying state in the continuum, this state can be reached by choosing the energy of the incident electrons to be at resonance with the resonant state of the composite electron-atom system. An intense laser is then used to strongly couple the autoionizing state to another state. The advantage of such approach is that it allows flexibility: tuning the energy of the electrons over a wider energy range is easy, while lasers operate in restricted frequency intervals. Additionally, resonant states of all symmetries can be excited, not only the dipole selected states. In the above equation X^{Z+1} signifies the Li-like

C ion, of nuclear charge Z , in its ground state, and X^{Z+**} is the doubly excited state of the corresponding Be-like ion of nuclear charge Z .

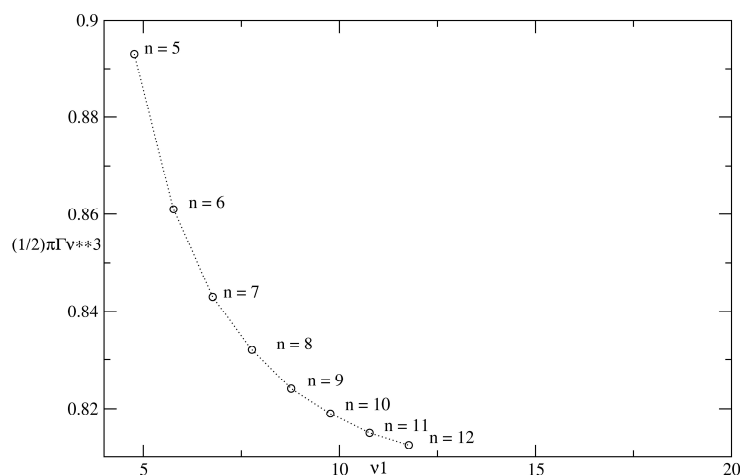
An initial calculation based on the quantum defect theory (QDT) and the standard R-matrix has been done to calculate the $1s^2 2s^2$ and $1s^2 2p^2$ ground states for Be-like C ions, including full description of the electron-electron correlation and exchange effects. The energies belonging to the corresponding Rydberg excited states $1s^2 2snl$ and $1s^2 2pnl$ ($n = 5 - 12$) have been taken from the Opacity Book or evaluated from the QDT, if missing. The $1s^2 2pn'l$ state energy has been evaluated relative to 2P ionization threshold while, the energy of the excited 'bound' state $1s^2 2snl$ is evaluated relative to 2S ionization threshold. The atomic system is then dressed by a monochromatic mono-mode linearly polarized laser field. We consider a laser field of angular frequency $\omega = \Delta E$ (the transition energy corresponding to the initial unperturbed – field free- Rydberg states) and an intensity given (as an appropriate guess) by the electric field strength of the $2s - 2p$ core transition in Li-like ion. The laser dresses the autoionizing state, and the projectile electron, and we assume the following: at resonance this dressing is dominated by the resonant coupling between these states so that we can ignore the influence of the remaining states. Models of this type have been able to reproduce well a variety of *ab initio* calculations of multiphoton ionization processes involving autoionizing states.

The two-state model qualitatively reproduces the behavior of the Floquet states, showing that the coupling via the continuum is more important than the direct dipole coupling between states. E_g is the zero-field position of the ground state on the real energy axis, while the energy of the autoionizing state is shifted by $-\omega$. Thus the zero-field position of the autoionizing state changes with ω , being scaled at the complex energy $-\omega + E_a - i\Gamma^a/2$, where Γ^a is the field-free width of the autoionizing state. The corresponding detuning is defined as $d = E_a - E_g - \omega$. The model can give an indication for finding system in which LIDS occurs. Table 1 presents the field-free energies of the $1s^2 2sns$ ($^1S^e$) and $1s^2 2pns$ ($^1P^0$) states as obtained from RMF calculation. These are to be compared with the corresponding values given by Opacity calculations (OP). Table 2 gives comparison between the autoionization probability, Γ^a (meV), calculated with this simple model and those reported by more sophisticated method [5]

Table 1.				Table 2		
n	E _b (au)		E _a (au)	n	Γ ^a	Γ ^a
	This work	OP			(meV)(RMF)	(meV)(Ref. [5])
5	-.21394	-.21518	.09496	5	150	138
6	-.13801	-.13849	.15984	6	81	74
7	-.10091	-.10106	.19794	7	49	44
8	-.07656	-.07664	.22221	8	32	28
9	-.06001	-	.23861	9	21.8	19
		.060059		10	15.6	-
10	-.04828	-.0483	.25021	11	11.6	-
11	-.03967	-.03967	.25872	12	8.8	-
12	-.03317	-.03315	.26514			

The cross section of the resonant process ('capture-escape' resonance) is zero for a particular value $E(I, \omega)$ of the electron energy. Therefore for each frequency and intensity of the laser, there is a particular electron energy at which exists a window in the resonant cross section where the two resonant processes interfere fully destructively. In the limit of low intensities, the width of the quasibound state will be much smaller than the width of the autoionizing state, $\Gamma_g \ll \Gamma_a$. For this case it follows that the electron energy, $E = E_g + \omega$, and therefore the zero in the cross section appears at the position of the quasibound resonant state shifted by the photon energy. When $\Gamma_g \gg \Gamma_a$, i.e., at high intensities, $E = E_a$, so the zero is at approximately the position of the autoionizing resonance.

A number of procedures have been developed to analyze resonances in atomic and molecular physics. One can identify to main approaches: the use of multichannel quantum defect theory (MQDT) based on analytic properties of Coulomb functions and the energy variation of the calculated \mathbf{K} matrix or its eigenphase (δ) near an isolated resonance. The latter is more general than MQDT, in the sense that it is not restricted to reactions between to oppositely charged particles. In our calculation, the relative energy parameter according to Fano theory[6] has been calculated as: $\varepsilon = 2\omega_{tune} / (\Gamma^a / 2)$, ω_{tune} defining the numerical values for field-free energy difference between Rydberg states. Our calculation yields a scaling relation as function of the effective quantum numbers and ionic charge of type: $\varepsilon = 4n^{*3} \omega_{tune} / Z$. Figure 1 shows the 'scaled' widths of resonances as obtained from calculation. Figure 1 shows a dependence of the autoionizing width with the 'bound' excited Rydberg state effective quantum number (ν_1).

**Fig. 1.****Table 3.**

n	$2n^{**}\Gamma(au)$
5	0.17
6	0.15
7	0.15
8	0.15
9	0.15
10	0.15
11	0.14
12	0.16

Considering our very simple 2-state model for C^{2+} , in all our calculation for frequencies near the LIDS frequency the real part of the energy is nearly constant for low intensities up to the LIDS intensity but the imaginary part changes rapidly converging together at LIDS position. Beyond LIDS the real and imaginary parts both diverge from each other. Table 3 gives the calculated widths of the quasienergies at the first LIDS positions. The effect of constant ratio in Table 3 is to produce a resonance profile that becomes narrowed and taller, then wider and lower as laser field intensity increases. Preliminary results show that in this type of profile the LIDS play the most important role.

Conclusion

A simple model has been developed so as to reinforce the role of Laser Induced Degenerate State phenomenon on resonances obtained by laser. The calculation predicts a resonance parametrization in terms of Fano relative energy parameter and effective quantum number of the excited Rydberg state. The work is in progress.

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