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Resonances in a positron-lithium (e^+-Li) system

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The method of complex scaling is used to calculate S- and P-wave resonance energies and widths below the Li($3s$,$3p$,$4s$,$4p$) excitation thresholds and positronium $n = 2$ formation threshold in the positron-lithium system. We use two different types of model potentials to determine the interaction between the core and the valence electron. Explicitly correlated Gaussian basis functions are used to represent the correlation effects between the valence electron, the positron, and the Li$^+$ core. A dipole series of resonances are found under the positronium $n = 2$ threshold. Furthermore, these resonances are found to agree well with an analytically derived scaling law. The present results are compared with those in the literature.

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I. INTRODUCTION

Theoretical investigation of atomic resonances relating to positrons and positronium (Ps) atoms has gained significant interest over the past several years. Calculations of the e^+-H system have predicted that a number of resonances exist under various excited Ps thresholds [1–6]. An interesting aspect of positron–alkali-metal systems lies in the possibility of Ps formation even at zero incident energy. In recent works [7,8] we reported benchmark calculations for dipole series of resonances associated with the Ps($n = 2$) threshold in e^+-Na and e^+-K systems. The sequence of these resonances below the Ps($n = 2$) threshold appears from an attractive long-range potential proportional to r^{-2}, which in turn arises from the degeneracy of the $2s$ and $2p$ Ps states. Importantly, the resonances associated with the Ps($n = 2$) threshold in the e^+-Li system have not been explored.

There are a few calculations reported with regard to resonances in the positron-lithium system [9–14]. Ward [9] conducted a study considering the close-coupling method, using only atomic states, with either Hartree-Fock wave functions or a model potential to describe the interaction between the active valence electron and the inert core. The two representations of the Li atom were found to agree well for the cross section. However, no Ps formation channel was included in that calculation. Later, McAlinden *et al.* [10] performed coupled-state calculations with and without the addition of the Ps formation channel. Roy and Ho [11] investigated S-wave resonances in positron-lithium scattering using a stabilization method with Hylleraas-type wave functions, a work that was later extended to P-wave resonances [12]. Moreover, Han *et al.* [13] used the stabilization method to find the resonances by using hyperspherical coordinates. Liu *et al.* [14] have carried out the momentum-space coupled-channels optical method approach to evaluate resonances in the e^+-Li system. These studies were found to be in reasonable agreement with each other in terms of resonance energies, whereas the resonance widths determined by these groups show less agreement.

In the present work we calculate the S- and P-wave resonances in the positron-lithium system. We apply the complex scaling method, which proves to be a very simple and powerful tool in analyzing the position and width of a resonance. We find that there is reasonable agreement with other theoretical calculations where applicable.

For Ps formation in positron-Li scattering, the loosely bound valence electron is involved in the transitions. The e^+-Li system can be modeled as a three-body system: a frozen core, a positron, and an electron. The interaction between the Li$^+$ core and the active electron is Coulombic only at very long range. At shorter distances the nuclear charge is only partially screened, which makes it necessary to employ some sort of model potential for the e^--Li$^+$ interaction. More generally, this interaction should also include electron exchange, but this is not explicitly included in our study. Prior calculations [15,16] suggest that the exclusion of the exchangelike potential would not effect the final results much. We apply two different types of analytical model potentials in our analysis to determine the interaction between the core and the valence active electron or positron. Explicitly correlated Gaussian wave functions are employed to include the correlation effects between the valence electron, the positron, and the core.

Atomic units are used throughout the work.

II. METHOD

The Hamiltonian H of the e^+-Li system is given by

$$H = -\frac{1}{2\mu}\nabla_1^2 - \frac{1}{2\mu}\nabla_2^2 + V^{(e^-)}(r_1) + V^{(e^+)}(r_2) + V^{(e^+e^-)}(r_{12},\rho), \tag{1}$$

where μ is the reduced mass, the subscripts 1 and 2 indicate the coordinates of the outer electron and positron, respectively, $r_{12} = |\mathbf{r}_2 - \mathbf{r}_1|$ is the relative distance between them, $V^{(e^-)}$ and $V^{(e^+)}$ are the interaction potentials between the core and the valence electron or the positron, respectively, and $V^{(e^+e^-)}(r_{12},\rho)$ is the electron-positron interaction. Here ρ is the distance between the core and the center of mass of the electron and positron (the reason for including such a dependence will be explained below). The potentials between the core and the particles have the form of screened Coulomb interactions. The Coulomb part $\pm 1/r$ of this interaction is treated analytically,

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while the remaining screening terms are fitted to a number of Gaussian functions in order to represent the potential using a functional form that allows the Hamiltonian matrix elements to be calculated analytically, also when complex scaling is used.

A. Model potentials

The first model potential (MP1) used by us is the same as the one used by Roy and Ho [11],

$$V^{(e^-)}(r) = -\frac{1}{r}[1 + 2(1 + \beta r)\exp(-2\beta r)]. \qquad (2)$$

This simple model potential for a nuclear charge screened by two $1s$ electrons has been discussed by Bachau *et al.* [17]. It captures the correct behavior in the limits $r \to 0$ ($V \propto -3r^{-1}$) and $r \to \infty$ ($V \propto -r^{-1}$). The model contains only a single adjustable parameter β, which can be interpreted as the effective charge experienced by the electrons. We used the value $\beta = 1.6559$ as was arrived at by Roy and Ho in [11] by fitting the calculated energy levels to experimental values [18]. For $V^{(e^+)}$ we use the same potential in Eq. (2) but with the opposite sign. In doing this we neglect the effect of exchange, which should be present in the case of the core-electron interaction, but not for the core-positron interaction. To accommodate this effect Roy and Ho used a slightly different value $\beta' = 1.7212$ when the interaction with the positron was considered. We note that this modification only has a marginal effect on atomic energies (see Table I in [11]), an effect that would be even smaller for the positron since the repulsive positron-core interaction ensures that the separation stays large. Studies on other alkali-metal systems have also confirmed that this effect is small [15,16]. For simplicity we have therefore used the same value of β for both electron and positron interactions.

Our second model potential (MP2) is the same as used by Han *et al.* [13] and was first introduced by Peach *et al.* [19]. It has the form

$$V^{(e^-)}(r) = -\frac{1}{r}[1 + 2e^{-\gamma r}(1 + \delta r + \delta' r^2)] - \frac{\alpha_c}{2r^4}W_2(\eta r), \qquad (3)$$

where

$$W_2(x) = [1 - e^{-x}(1 + x + 0.5x^2)]^2 \qquad (4)$$

is a cutoff function, ensuring that the second term in the potential remains finite as $r \to 0$. This potential also has the correct asymptotic forms, but contains four free parameters. These were empirically determined to be $\gamma = 4.049\,689\,462$, $\delta = 2.447\,656\,964$, $\delta' = 0.245\,046\,253$, and $\eta = 3.910\,776\,273$ in [16,19]. The second term in Eq. (3) is the leading long-range correction to the purely static approximation and arises from the polarization of the core by the charge particles, where $\alpha_c = 0.192\,456$ is the Li$^+$ polarizability [20]. For the positron-core interaction, the sign of the static potential in Eq. (3) is changed, while the polarization term remains the same (attractive for both the electron and positron).

The calculated ground- and excited-state energies of Li using both model potentials are displayed in Table I. We find that both models are in good agreement with the experimental energies [18]. For most states MP2 agrees slightly better, which could be expected since it includes the effect from polarizability and has more free parameters.

TABLE I. Comparison of the calculated bound-state energy levels of Li(nl). Energies are shown with respect to the Li$^+$ threshold in a.u. The experimental energies are weighted averages of all fine-structure levels [18].

	Present results		Experiment [18]
State	MP1	MP2	
$2s$	−0.19814	−0.19795	−0.19814
$3s$	−0.07431	−0.07422	−0.07418
$4s$	−0.03868	−0.03864	−0.03862
$5s$	−0.02367	−0.02365	−0.02364
$6s$	−0.01596	−0.01595	−0.01594
$2p$	−0.12993	−0.13022	−0.13023
$3p$	−0.05720	−0.05724	−0.05724
$4p$	−0.03197	−0.03197	−0.03197
$5p$	−0.02037	−0.02037	−0.02037
$6p$	−0.01411	−0.01411	−0.01411
$3d$	−0.05557	−0.05561	−0.05561
$4d$	−0.03126	−0.03127	−0.03127
$5d$	−0.02001	−0.02001	−0.02001
$6d$	−0.01389	−0.01390	−0.01390

The physical electron-positron interaction is of course the Coulomb attraction, however we also add an additional term V_{corr} so that

$$V^{(e^+e^-)}(r_{12},\rho) = -\frac{1}{r_{12}} + V_{\text{corr}}(r_{12},\rho). \qquad (5)$$

The motivation for this extra term is as follows. As mentioned above, the polarization correction in Eq. (3) arises from the response of the core to the interaction with a charged particle at distance r. This works well as long as there is only one additional charged particle in the vicinity of the core. However, when both the positron and electron interact with the core the polarization effect from the two oppositely charged particles should partly cancel. In the limit where the electron and the positron coalesce the core experiences no net charge and the polarization effect will completely vanish. When the interaction between the ionic core and Ps is considered there is therefore a risk of overestimating the effects of the polarizability, i.e., doubling it rather than canceling. In [16] this problem was dealt with by introducing a term in the electron-positron interaction that is analogous to a dielectronic correction, introduced for the sole purpose of correcting the polarizability potential in this situation.

In our calculation we used a correction with a different functional form, which can easily be calculated in the coordinate system used here,

$$V_{\text{corr}}(r_{12},\rho) = \frac{\alpha_c}{\rho^4}U(\rho)e^{-r_{12}^2/r_c^2}. \qquad (6)$$

Here $U(x) = (1 - e^{-x^2})^2$ is another cutoff function, which prevents this correction from diverging at the origin [for practical reasons we did not use the same form as W_2 in Eq. (4)]. We find that this correction has the desired properties, since if the polarizability potential is defined as ($r_{1/2}$ being the

TABLE II. Ground-state energy of the e^+-Li system calculated using different models. The results are compared to the result of Han *et al.* [13] using the same model potential as our MP2, but with an additional term analogous to a dielectronic correction added to the e^+-e^- interaction to cancel the core polarization when the two particles coalesce. We have also included other results using different forms of the model potential.

Model	Energy
MP1	– 0.252386
MP2	– 0.252446
Han *et al.* [13]	– 0.252455
Shertzer and Ward [16]	– 0.25237
Mitroy *et al.* [21,22]	– 0.252482

coordinate of either the electron or the positron)

$$V_{\rm pol}(r_{1/2}) = -\frac{\alpha_c}{2r_{1/2}^4}U(r_{1/2}), \tag{7}$$

then when the electron and positron coalesce $r_{12} = 0$ and $r_1 = r_2 = \rho$, giving

$$V_{\rm pol}(r_1) + V_{\rm pol}(r_2) + V_{\rm corr}(0,\rho) = 0, \tag{8}$$

i.e., no net polarization effect.

We have performed calculations with and without the correction $V_{\rm corr}$ and for the resonances we found very marginal differences. It should be emphasized that this correction of course does not represent any physical electron-positron interaction, but is a term of rather arbitrary form purely tailored to satisfy Eq. (8), as well as vanishing in the limits $r_{1/2} \rightarrow \infty$. There is therefore no *a priori* correct value of r_c and indeed calculations of the ground state of the e^+-Li system showed a slight dependence on this parameter. For the resonances, on the other hand, this dependence was on the level of the numerical uncertainty in our calculation (which can be understood from the larger interparticle separations). In Table II we compare our result for the e^+-Li ground state using different methods to other results in the literature. [Here we tuned r_c in Eq. (6) to 6 to get the best agreement with Han *et al.* [13]].

B. Numerical method

To solve the three-body problem we use the coupled rearrangement channels method developed by Kamimura and co-workers [23,24]. Here the three-body wave function Ψ_{JM} of total orbital angular momentum $\{J,M\}$ is represented using the form

$$\Psi_{JM} = \sum_{\alpha=1}^{3}\sum_{l_\alpha=0}^{l^{\rm max}}\sum_{L_\alpha=0}^{L_\alpha^{\rm max}}\sum_{i=1}^{i_{\alpha l}^{\rm max}}\sum_{I=1}^{I_{\alpha L}^{\rm max}} c_{\alpha l_\alpha L_\alpha i I}\phi_{\alpha l_\alpha L_\alpha i I}, \tag{9}$$

$$\begin{aligned}\phi_{\alpha l_\alpha L_\alpha i I} = {}& N_{\alpha l_\alpha L_\alpha i I} r_\alpha^{l_\alpha} R_\alpha^{L_\alpha} e^{-(r_\alpha/r_{\alpha l_\alpha i})^2} e^{-(R_\alpha/R_{\alpha L_\alpha I})^2}\\ & \times[Y_{l_\alpha}(\hat{\mathbf{r}}_\alpha)\otimes Y_{L_\alpha}(\hat{\mathbf{R}}_\alpha)]_{JM}.\end{aligned} \tag{10}$$

Here α denotes the three rearrangement channels, l_α and L_α are the angular momenta along $\mathbf{r}_\alpha$ and $\mathbf{R}_\alpha$, respectively, and i and I are numbers of Gaussian functions along the two radial coordinates. The widths of the Gaussian functions $r_{\alpha l_\alpha i}$ and $R_{\alpha L_\alpha I}$ are chosen as geometric progressions to describe the short-range correlation effects and long-range tail behavior. The angular momenta l_α and L_α are taken to be consistent with the total J (i.e., $|l_\alpha - L_\alpha| \leqslant J \leqslant l_\alpha + L_\alpha$, up to some maximum values $l_\alpha^{\rm max}$ and $L_\alpha^{\rm max}$, which may be different for different rearrangement channels).

Since the wave functions are represented by Gaussian functions all matrix elements of the Hamiltonian can be calculated analytically if the potentials are expressed as sums of products of polynomials and Gaussian functions. We have therefore represented both model potentials above by fits to a number of Gaussian functions. Since $V_{\rm pol}$ cannot be represented by Gaussian functions, this term was broken out of the fit and its matrix element calculated analytically.

In the present work the complex scaling method [25–28] is employed to determine the energies and widths. The theoretical aspects of this method have been discussed in our previous publications and will not be repeated [6–8,29].

III. RESULTS AND DISCUSSION

A. e^+-Li resonances

The resonance parameters determined in the present work are listed in Table III. We find only marginal differences between the results calculated using the two different models. We therefore conclude that as long as the atomic energies are reproduced correctly, the details of the model potential have minor importance. This is confirmed by the relatively good agreement between Roy and Ho [11,12], who use MP1, and Han *et al.* [13], who use the same potential as our MP2. Both these works, however, use very different numerical techniques to solve the three-body problem and neither uses the complex scaling method. Additionally, there are small differences in how the positron interaction is handled, though this should not have a significant impact on the results. In Table IV we compare our results with other available results [9–14]. The tabulated threshold energies E_t included are extracted from MP2 (see Table I). The convergence of our calculations has been examined by progressively increasing the number of Gaussian basis functions. The results were obtained using more than 7500 Gaussian basis functions with different possible combinations for angular momentum, with maximum values $(l_\alpha,L_\alpha) = (4,4)$ used for S and P waves.

S-wave resonances in positron-lithium scattering below the Li($3s,3p,4s,4p$) excitation thresholds and Ps($n = 2$) formation threshold are calculated. The resonance obtained by Ward [9] and Liu *et al.* [14] at −0.129 786 is not found in the present calculations or in the studies by Roy and Ho [11] and Han *et al.* [13]. In addition, McAlinden *et al.* [10] have reported coupled-state calculations of positron scattering by lithium and found a structure that could be interpreted as a resonance in the elastic cross section near −0.130 264 using only lithium eigenstates. This feature is not visible when Ps eigenstates are inserted. Therefore, as remarked by Han *et al.* and confirmed by our calculation, one could speculate that the resonance determined by Ward [9] may occur because of the omission of the Ps channel in those calculations and possibly does not exist in more realistic calculations including Ps channels. This is however contradicted in Ref. [14], where this resonance was observed even when Ps channels were included via an optical potential.

TABLE III. Comparison of our results for S- and P-wave resonance energies E_R and widths Γ in the e^+-Li system. The threshold energies shown here are calculated using the respective model potential (see Table I) and are close to the experimental values. The notation $x[y]$ means $x \times 10^{-y}$.

	MP1		MP2	
Resonance	E_R	Γ	E_R	Γ
S	−0.08062273	2.34[4]	−0.08062182	2.18[4]
P	−0.07894845	1.11[4]	−0.07894557	1.07[4]
Li(3s)	$E_t = -0.07431$		$E_t = -0.07422$	
S	−0.06756303	3.50[4]	−0.06755521	3.58[4]
	−0.06389787	6.12[5]	−0.06389506	6.08[5]
	−0.06287662	1.43[5]	−0.06287586	1.41[5]
	−0.06260091	3.68[6]	−0.06260071	3.62[6]
	−0.06252702	9.74[7]	−0.06252697	9.60[7]
	−0.06250724	2.62[7]	−0.06250722	2.56[7]
P	−0.06676975	1.20[4]	−0.06676122	1.26[4]
	−0.06426986	1.61[4]	−0.06428345	1.59[4]
	−0.06349082	7.36[5]	−0.06349093	7.46[5]
	−0.06275830	1.15[5]	−0.06275801	1.14[5]
	−0.06256553	2.56[6]	−0.06256544	2.54[6]
	−0.06251654	6.40[7]	−0.06251651	6.42[7]
	−0.06250417	1.62[7]	−0.06250417	1.62[7]
Ps($n = 2$)	$E_t = -0.062500$			
S	−0.05740669	4.68[5]	−0.05744307	4.76[5]
P	−0.05749186	4.44[4]	−0.05752947	4.52[4]
Li(3p)	$E_t = -0.05720$		$E_t = -0.05724$	
S	−0.04068196	1.31[4]	−0.04067531	1.30[4]
P	−0.04033773	1.43[4]	−0.04033170	1.42[2]
Li(4s)	$E_t = -0.03868$		$E_t = -0.03864$	
S	−0.03519315	1.75[4]	−0.03518081	1.72[4]
	−0.03267219	5.82[5]	−0.03267388	5.82[5]
	−0.03211193	2.78[5]	−0.03212689	2.98[5]
P	−0.03591115	5.26[5]	−0.03591636	5.90[5]
	−0.03464239	1.36[4]	−0.03463509	1.39[4]
	−0.03266855	5.66[5]	−0.03267719	5.50[5]
	−0.03218063	3.62[5]	−0.03219104	3.64[5]
Li(4p)	$E_t = -0.03197$		$E_t = -0.03197$	

TABLE IV. Comparison of the S- and P-wave resonance energy E_R and width Γ for the e^+-Li system with other calculations. The notation $x[y]$ means $x \times 10^{-y}$.

	Present results (MP2)		Ward [9]		Roy and Ho [11,12]		Han *et al.* [13]		Liu *et al.* [14]	
Resonance	E_R	Γ	E_R	Γ	E_R	Γ	E_R	Γ	E_R	Γ
S			−0.129786	1.29[3]					−0.129262	2.35[3]
Li(2p) threshold ($E_t = -0.13022$)										
S	−0.080622	2.18[4]	−0.087525	1.47[3]	−0.080685	2.15[4]	−0.080658	2.02[4]	−0.089436	4.85[3]
P	−0.078946	1.07[4]	−0.083850	4.78[3]	−0.07882	5.5[5]			−0.085320	1.13[2]
Li(3s) threshold ($E_t = -0.07422$)										
S			−0.074478	3.7[5]	−0.072545	8.0[5]	−0.073743	4.4[5]	−0.070914	7.31[3]
	−0.067555	3.58[4]								
	−0.063895	6.08[5]					−0.063831	6.9[5]	−0.064740	4.85[3]
P					−0.07165	7.5[5]				
	−0.066761	1.26[5]			−0.06884	5.5[5]			−0.068562	1.62[3]
Ps($n = 2$) threshold ($E_t = -0.06250$)										
S									−0.049086	1.80[3]
	−0.040675	1.30[4]			−0.040295	3.5[5]	−0.040636	4.1[5]	−0.040155	1.80[3]
Li(4s) threshold ($E_t = -0.03868$)										

We can see that the lowest-lying S-wave resonance we obtained for Li($3s$) is at energy position $-0.080\,622$ and width 2.18×10^{-4}, which agrees well with Roy and Ho [11] and Han *et al.* [13]. Ward [9] and Liu *et al.* [14] found this resonance as well, but with rather different values of the resonance parameters.

Earlier works have reported the next S-wave resonance lying just above the Li($3s$) threshold and therefore interpreted as a shape resonance in [13]. We have not found this type of resonance in our calculations. A similar shape resonance reported in the e^+-Na system also could not be found by us [7]. We speculated that this may be due to a very-low-energy continuum state being misidentified as a resonance. We do however find a resonance at $-0.067\,555$, but this is not a shape resonance; instead it is the first member of the dipole series described below. Similarly, a resonance identified by Liu *et al.* [14] at $-0.049\,086$ could not be confirmed by us and has not been found in other calculations.

The resonances located below the Ps($n = 2$) threshold belong to the dipole series, discussed below in Sec. III B. In previous studies Roy and Ho [11] and Han *et al.* [13] found only one resonance under the Ps($n = 2$) threshold, while Liu *et al.* [14] reported two resonances. We predict a newly identified resonance located below the Li($3p$) threshold at energy $-0.057\,443$ and with the width 4.76×10^{-5}. For the Li($4s$) threshold we found one resonance located below the energy $-0.040\,675$, which agrees well with [11,13,14], and a width 1.30×10^{-4}, which is somewhat larger than the values obtained in [11,13]. We found three other resonances below the Li($4p$) threshold, shown in Table III.

Our first P-state resonance at energy $-0.078\,946$ is in reasonable agreement with the result of Roy and Ho [12], but the width 1.07×10^{-4} is larger. Resonance parameters below Li($3s$) again differ from the reported results of Ward [9] and Liu *et al.* [14]. Similarly, we found a dipole series under the Ps($n = 2$) threshold, which will be discussed in Sec. III B. Roy and Ho found two resonances below the Ps($n = 2$) threshold, whereas Liu *et al.* [14] reported only one resonance. We have found the next resonance below the Li($3p$) threshold at energy $-0.057\,592$ with width 4.52×10^{-5}. We could find no other results in the literature for higher-n states in P-wave calculations. For higher-n states between the Li($4s$) and Li($3p$,$4p$) thresholds we found five resonances.

B. Dipole series

In recent studies [7,8] we found a dipole series of resonances associated with Ps($n = 2$)-Na$^+$ and Ps($n = 2$)-K$^+$ channels in positron-sodium and positron-potassium systems, respectively. Similarly, in the case of positron-lithium scattering, we found the existence of dipole series. Han *et al.* [13] concluded that the Ps($n = 2$) threshold has an attractive dipole potential due to the degeneracy between the Ps($n = 2$) states. This long-range dipole potential is responsible for, in principle, an infinite series of resonances lying under the Ps($n = 2$) threshold, but they were only able to find one resonance in this series (at $-0.063\,831$). These resonances are very narrow and close to the threshold and thus require extremely high accuracy for the calculation. The energy and width ratios of the successive resonances are given approximately by the formula [5]

$$\frac{\mathcal{E}_j}{\mathcal{E}_{j+1}} = \exp\left(\frac{2\pi}{\alpha}\right), \quad \frac{\Gamma_j}{\Gamma_{j+1}} = \exp\left(\frac{2\pi}{\alpha}\right), \qquad (11)$$

where α takes different values for different thresholds. Below the Ps($n = 2$) threshold we investigate the energy and the width ratios, which are in line with the expected scaling. Our numerical results for the scaling of the dipole series are displayed in Table V. We notice that the widths ratios are slightly less accurate but still agree reasonably well with the analytical values, except for the first few resonances. This deviation is however expected because the scaling law should be more accurate for the pairs of higher-lying resonances. One of the P-wave resonance located at position $-0.064\,283$ a.u. does not seem to fit into the dipole sequence in Table V. In our calculations for the e^+-Na system [7] we observed a similar resonance. It is difficult to obtain an extremely high numerical accuracy for the imaginary part of the energy for states adjacent to the threshold.

TABLE V. Energy and width ratios of successive resonances located by the present calculation for Ps($n = 2$).

Ratio	Numerical result	Analytical value
$\mathcal{E}_j/\mathcal{E}_{j+1}$		
	S wave	
1/2	3.62	3.73
2/3	3.69	
3/4	3.76	
4/5	3.73	
5/6	3.73	
	P wave	
1/2	4.30	3.95
2/3	3.84	
3/4	3.94	
4/5	3.96	
5/6	3.96	
Γ_j/Γ_{j+1}		
	S wave	
1/2	5.89	3.73
2/3	4.31	
3/4	3.90	
4/5	3.77	
5/6	3.75	
	P wave	
1/2	1.69	3.95
2/3	6.56	
3/4	4.48	
4/5	3.96	
5/6	3.97	

IV. CONCLUSION

We have reported a theoretical calculation for total orbital angular momentum $J = 0$–1 resonances in the e^+-Li system. Resonance positions and widths have been compared with other available theoretical results. Reasonable agreement has been found with available results. Different possible resonances are reported. Furthermore, the energy and width ratios of the successive resonances of these sequences were found to agree well with analytical results. Further theoretical studies are suggested to confirm these possible resonances.

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