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Positron-hydrogen scattering below Ps-formation threshold using CCA

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Abstract : Five-state (H(1*s*, 2*s*, 2*p*) + Ps(1*s*, 2*s*)) and six-state (H(1*s*, 2*s*, 2*p*) + Ps(1*s*, 2*s*, 2*p*)) close coupling methord have been carried out below the positronium (Ps) formation threshold to study positron-hydrogen scattering. The *s*-wave and *p*-wave phase-shifts are obtained. The *s*-wave phase-shifts are found to satisfy the bound principle properly.

Keywords : Positron, hydrogen atom, scattering, phase-shifts

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In our earlier studies [1-3], we have investigated positron-hydrogen (atom) scattering in the framework of close-coupling approximation (CCA) using the following basis sets,

i) H(1*s*, 2*s*, 2*p*) + Ps(1*s*)

ii) H(1*s*, 2*s*, 2$\bar{p}$) + Ps(1*s*)

iii) H(1*s*, 2*s*, 2$\bar{p}$, 3$\bar{d}$) + Ps(1*s*).

The low-order phase-shifts at low energies are sensitive test for the validity and reliability of the method employed. We have compared the low-order phase shifts [1,2] with those of most accurate variational prediction of Bhatia *et al* . Our earlier results obtained by using the above mentioned basis sets, are found to be very encouraging. It is well known that in positron-hydrogen scattering, convergence of the scattering parameter is very slow with the addition of eigen-states in the direct channel [4]. In the present study we planned to study the convergence of *s*- and *p*-wave phase-shifts below the positronium (Ps) formation threshold with the addition of eigen-states in the capture channel. In the present study, the following expansion scheme have been employed to investigate positron-hydrogen scattering :

a) H($1s$, $2s$, $2p$) + Ps($1s$, $2s$)

b) H($1s$, $2s$, $2p$) + Ps($1s$, $2s$, $2p$).

This study provides also the relative importance of each eigen-state in the capture channel in predicting the low-order phase-shifts below the Ps-formation threshold.

Recently, Hewitt *et al* [5] have performed a six-state (basis (b)) CCA calculation at intermediate and high energies, and they have predicted only the results in the capture channel. We may recall that Wakid and LaBhan [6] have also carried out a six-state algebriac CCA to predict only the s-wave elastic phase-shifts below the Ps-formation threshold. Neither of the above two investigations has looked for the rate of convergence of the elastic scattering parameter with the inclusion of excited states in the capture channel.

Instead of solving the coupled integral-differential equations, we have emolyed the coupled integral equation approach in momentum space following Basu *et al* [1,2]. The present programme reproduces all the results of all the lower-order expansion schemes taking ground state of hydrogen-atom as initial state.

Table 1. Elastic s-wave phase-shifts (rad.) using the basis sets (a) H($1s$, $2s$, $2p$) + Ps ($1s$, $2s$), (b) H($1s$, $2s$ $2p$) + Ps ($1s$, $2s$, $2p$), (c*) H($1s$, $2s$, $2p$) + Ps ($1s$) and (d*) H($1s$, $2s$, 2 $\bar{p}$) + Ps ($1s$, $2s$, 2 $\bar{p}$).

Basis : K (a.u.)	(a)	(b)	(c*)	(d*)
0.1	0.0509	0.0503	0.0338	0.0491
0.2	0.0425	0.0457	0.0206	0.0321
0 3	–0.0007	–0.00449	–0.0262	0 0055
0.4	–0.0534	–0 0492	–0.0670	–0.0500
0.5	–0.1086	–0 1035	–0.1234	–0.1150
0.6	–0.1663	–0 1605	–0.2245	–0.1773
0.7	–0.2199	–0.2146	–0.2330	–0.2260

* Basu *et al* [1] ; + Wakid and LaBhan [6]

In Table 1, s-wave elastic phase-shifts below the Ps-formation threshold using both the expansion schemes (a) and (b) are displayed. The corresponding phase-shifts obtained by Basu *et al* [1] using the 4-state (H($1s$, $2s$, $2p$) + Ps ($1s$)) CCA and those of Wakid and LaBhan [6] are compared (Table 1). The s-wave phase-shifts obtained by using CCA satisfies the bound principles and is found to improve with the addition of eigen-state in the expansion scheme. The results of Wakid and LaBhan are in good agreement with the corresponding results of us (basis (b)). It has been found that the inclusion of Ps-polarization is not as important as the hydrogen polarization in predicting elastic s-wave phase-shift. This has also been noticed by Wakid and LaBhan [6].

Table 2 presents two sets of p-wave phase-shifts alongwith those of Basu *et al* [1] below the Ps-formation threshold. The present two sets of p-wave phase-shifts are slightly higher than those obtained by Basu *et al* . The effect of inclusion of Ps-polarization in the

expansion scheme in the elastic channel, is short range in nature. Therefore, it is not very surprising that elastic p-wave phase-shifts do not change appreciably.

Table 2. Elastic p-wave phase-shifts (rad.) using the basis sets (a) H($1s$, $2s$, $2p$) + Ps ($1s$, $2s$), (b) H($1s$, $2s$, $2p$) + Ps ($1s$, $2s$, $2p$) and (c*) H($1s$, $2s$, $2p$) + Ps ($1s$).

Basis : K (a.u.)	(a)	(b)	(c*)
0.1	0.0055	0.0061	0.0053
0.2	0.0188	0.0219	0.0181
0.3	0.0351	0.0404	0.0344
0.4	0.0497	0.0552	0.0498
0.5	0.0647	0.0688	0.0614
0.6	0.717	0.0761	0.0684
0.7	0.0818	0.0863	0.0762

* Basu *et al* [1]

Comparison with the variational predictions [7,8] (not shown here) with those of CCA (present and Basu *et al* [1]) suggests that the effect of higher excited state in the direct channel and the continuum are more important to get a reliable elastic prediction at low incident energies.

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