Rank I and Rank II Yamaguchi Type Separable Kernels of Nucleon-Nucleon Interaction in the Covariant Bethe-Salpeter Approach for $J = 0$ and 1 Channels

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Abstract

We propose a covariant separable potential for the nucleon-nucleon (NN) interaction in $J = 0$ ($^1S_0$, $^3P_0$) and $J = 1$ ($^3S_1$, $^1P_1$, $^3P_1$) channels. We calculate the nucleon-nucleon (NN) T matrix in the framework of the covariant Bethe-Salpeter approach for a two spin-one-half particle system with rank I and extended rank I and rank II Yamaguchi type separable kernel of interaction. The explicit connection between parameters of the separable kernel and low energy scattering parameters, deuteron binding energy and phase shifts is established. This approach can be applied to higher partial waves for NN scattering and other reactions.

1 Formalism

We start with the partial-wave decomposed Bethe-Salpeter equation for the nucleon-nucleon T matrix (in the rest frame of two-nucleon system):

$$\begin{aligned} T_{l'l}(p'_0,p',p_0,p;s) &= V_{l'l}(p'_0,p',p_0,p;s) \\ &+ \frac{i}{4\pi^3}\sum_{l''}\int dk_0 \int k^2\,dk\,\frac{V_{l'l''}(p'_0,p',k_0,k;s)T_{l''l}(k_0,k,p_0,p;s)}{(\sqrt{s}/2-e_k+i0)^2-k_0^2}. \end{aligned} \tag{1}$$

Here $T_{l''l}$ is the partial-wave decomposed T matrix and $V_{l'l}$ is the kernel of the NN interaction with $e_k = \sqrt{k^2+m^2}$. There is only one term in the sum for the singlet case ($L = J$) and there are two terms for the coupled triplet case ($L = J \mp 1$). We introduce square of the total momentum $s = P^2 = (p_1+p_2)^2$ and the relative momentum $p = (p_1-p_2)/2$ [$p' = (p'_1-p'_2)/2$] (for details, see reference [**?**]).

Assuming the separable form (rank N) for the partial-wave decomposed kernels of NN interactions,

$$V_{l'l}(p'_0,p',p_0,p;s) = \sum_{i,j=1}^{N}\lambda_{ij}g_i^{[l']}(p'_0,p')g_j^{[l]}(p_0,p), \tag{2}$$

2 Result

The results of Rank II calculations are given in Table(1) and Figs(1-4).

Table 1. The binding energy and low-energy parameters for singlet and triplet channels.

$^1S_0$	a_{0s}(Fm)	$^3S_1$	a_{0t}(Fm)	$E_d(MeV)$
Calculated	-23.745	Calculated	5.419	2.224606
Experiment	-23.748±0.010	Experiment	5.424±0.004	2.224644±0.000046

	$^1S_0^+$ n=10	$^3S_1^+$(Without D-wave) n=13	$^3P_0^+$ n=15	$^1P_1^+$ n=12	$^3P_1^+$ n=15
β_1 (GeV)	0.3849	0.3095	0.21425	0.37036	0.3741
β_2 (GeV)	0.6877	0.8376	0.51963	0.363609	0.40618
λ_{11} (GeV^2)	0.866	-0.394	-0.0116239	0.9343	0.7125
λ_{12} (GeV^2)	21.89	17.654	0.36589	1.8371	1.57199
λ_{22} (GeV^2)	-7.5	21.982	43.887	6.9663	11.523

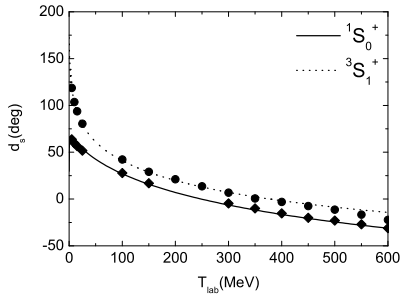

Figure 1. Phase shifts in the ${}^1S_0^+$ and ${}^3S_1^+$ channels.

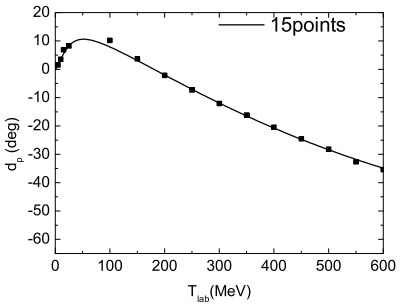

Figure 2. ${}^3P_0^+$ channel phase shifts.

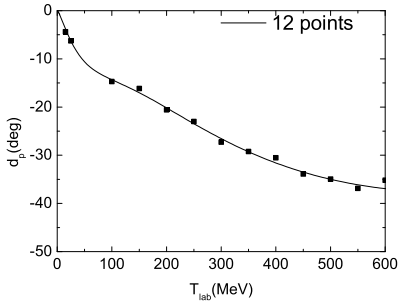

Figure 3. Phase shifts in the ${}^1P_1^+$ channel.

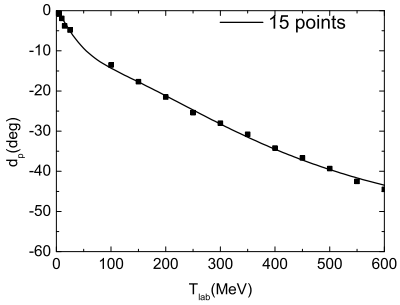

Figure 4. Phase shifts in the ${}^3P_1^+$ channel.

3 Conclusion

We have constructed covariant separable potentials for the nucleon-nucleon interaction in singlet and triplet channels. We have found that the use of the rank I and the extended rank I kernels is not able to reproduce the ${}^1S_0$ and ${}^3S_1$ and ${}^3P_0$ phase shifts. The rank II Yamaguchi type kernels are able to reproduce the deuteron static properties and the phase shifts up to $T_{lab} = 600MeV$. We are planning to apply the rank II kernels for various phenomena in the two body nucleon systems.

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