\textbf{S, P, D, F wave }\textit{KN} \textbf{phase shifts in the chiral SU(3) quark model}

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The \textit{S, P, D, F} wave \textit{KN} phase shifts have been studied in the chiral SU(3) quark model by solving a resonating group method equation. The numerical results of different partial waves are in agreement with the experimental data except for the cases of \textit{P}_{13} and \textit{D}_{15}, which are less well described when the laboratory momentum of the kaon meson is greater than 400 MeV.

\textit{Keywords:} \textit{KN} phase shifts; quark model; chiral symmetry.

\section{Introduction}

The kaon-nucleon (\textit{KN}) scattering processes have aroused particular interest in the past \textsuperscript{12345} and many works have been devoted to this issue based on the constituent quark model. But up to now, most of them cannot accurately reproduce the \textit{KN} phase shifts up to the orbit angular momentum \textit{L} = 3 in a sufficient consistent way. In this work we perform a resonating group method (RGM) calculation of \textit{S, P, D, F} wave \textit{KN} phase shifts of isospin \textit{I} = 0 and \textit{I} = 1 in the chiral SU(3) quark model, which has been successful in reproducing the energies of the baryon ground states, the binding energy of deuteron, the nucleon-nucleon (\textit{NN}) scattering phase shifts, and the hyperon-nucleon (\textit{YN}) cross sections by the RGM calculations \textsuperscript{67}. The model is extended to include an antiquark $\bar{s}$ and the mixing of $\sigma_0$ and $\sigma_8$ is considered. A satisfactory description of the \textit{KN} phase shifts for different partial waves is obtained except for the cases of \textit{P}_{13} and \textit{D}_{15}, of which the calculated phase shifts are too repulsive and a little bit too attractive respectively when the laboratory momentum of the kaon meson is greater than 400 MeV in this present investigation.

\section{Formulation}

In the chiral SU(3) quark model, the potential between the \textit{i}th and \textit{j}th constituent quarks can be written as

\begin{equation}
V_{ij} = \sum_{i<j}(V_{ij}^{conf} + V_{ij}^{OGE} + V_{ij}^{eh}),
\end{equation}

where $V_{ij}^{conf}$, $V_{ij}^{OGE}$, and $V_{ij}^{eh}$ are the confining, OGE, and exchange potentials, respectively.
where the confinement potential $V_{ij}^{conf}$ describes the long-range nonperturbative QCD effect and the one-gluon-exchange potential $V_{ij}^{OGE}$ depicts the short-range perturbative QCD effect. The chiral-field-induced quark-quark potential is in the form of

$$V_{ij}^{ch} = \sum_{a=0}^{8} V_{\sigma_a}(r_{ij}) + \sum_{a=0}^{8} V_{\pi_a}(r_{ij}),$$

and mainly signifies the medium-range nonperturbative QCD effect. In this expressions, $\sigma_0, ..., \sigma_8$ are the scalar nonet fields, and $\pi_0, ..., \pi_8$ the pseudoscalar nonet fields. In order to study the $KN$ system, we extend our model to include an anti-quark $\bar{s}$. The interaction between $u(d)$ and $\bar{s}$ includes two parts: direct interaction and annihilation parts,

$$V_{i\bar{s}} = V_{i\bar{s}}^{dir} + V_{i\bar{s}}^{ann},$$

where

$$V_{i\bar{s}}^{dir} = V_{i\bar{s}}^{conf} + V_{i\bar{s}}^{OGE} + V_{i\bar{s}}^{ch},$$
$$V_{i\bar{s}}^{ann} = V_{ann}^K.$$

Now, the total Hamiltonian of $KN$ system is written as

$$H = \sum_{i=1}^{5} T_i - T_G + \sum_{i<j=1}^{4} V_{ij} + \sum_{i=1}^{4} V_{i\bar{s}},$$

where $T_G$ is the kinetic energy operator of the center of mass motion, and the explicit expressions of the potentials can be found in the literature 8,9,10.

In our calculation, the mixing of $\sigma_0$ and $\sigma_8$ is considered, and the mixing angle $\theta_S$ is taken to be two possible values. One is $35^\circ$ (ideal mixing) and the other is $-18^\circ$ (provided by Dai et al. 11). The model parameters are fixed by some special constraints 9,10 and their values are tabulated in Table 1.

Table 1. Model parameters. The meson masses are taken to be the experimental data except for $m_\sigma$ which is taken to be 675 MeV. The cutoff mass $\Lambda = 1100$ MeV.

| $\theta_S$ | $b_u$ (fm) | $m_u$ (MeV) | $m_s$ (MeV) | $g_u$ | $g_s$ | $a_{\sigma u}^c$ (MeV/ fm$^2$) | $a_{\sigma s}^c$ (MeV/ fm$^2$) | $a_{\sigma u}^{\alpha}$ (MeV) | $a_{\sigma s}^{\alpha}$ (MeV) |
|----------|------------|-------------|-------------|-------|------|----------------|----------------|----------------|----------------|
| $35^\circ$ | 0.5 | 313 | 470 | 0.886 | 0.917 | 52.4 | 72.3 | -50.4 | -54.2 |
| $-18^\circ$ | 0.5 | 313 | 470 | 0.886 | 0.917 | 55.2 | 68.4 | -55.1 | -48.7 |

3. Results and discussions

A RGM dynamical calculation is made to study the $KN$ scattering process, and the calculated phase shifts are shown in Figs. 1 and 2. Experimental values are taken from the analysis of Hyslop et al. 12 and Hashimoto 13.
For the $S$-wave we obtain the correct sign of the $S_{01}$ channel phase shifts comparing with the recent RGM calculation in which $\sigma$ and $\pi$ boson exchanges are considered, and our results are in agreement with the experimental data for both
isospin $I = 0$ and $I = 1$ channels, though for $S_{11}$ they are a little repulsive. For the higher angular momentum results, comparing with the study of Lemaire et al.\cite{4}, we now get correct signs of $P_{11}$, $P_{03}$, $D_{13}$, $D_{05}$, $F_{15}$ and $F_{07}$ waves, and a considerable improvement on the theoretical phase shifts in the magnitude for $P_{01}$, $D_{03}$ and $D_{15}$ channels. We also compare our results with those of the previous work of Black\cite{2}. Although our calculation achieves a considerable improvement for all partial waves, the results of $P_{13}$ wave are too repulsive in both Black’s work and our present one. Maybe the effects of the coupling to the inelastic channels and hidden color channels should be considered in future work.

From Figs. 1 and 2 one can see the results are very similar for the cases of $\theta^S = 35^\circ$ and $\theta^S = -18^\circ$. It is comprehensible because in both of these two cases the attraction of $\sigma$ is reduced, just in different approaches. When $\theta^S = 35^\circ$ the interaction between $u(d)$ and $s$ quarks vanishes, while $\theta^S = -18^\circ$ the attraction of $\sigma$ between $u$ and $d$ quarks is strongly reduced.

4. Conclusions

The $KN$ scattering process is studied in the chiral SU(3) quark model, which has been extended to include an antiquark, by solving a RGM equation. The numerical results of different partial waves are in agreement with the experimental data except for the cases of $P_{13}$ and $D_{15}$, which are less well described when the laboratory momentum of the kaon meson is greater than 400 MeV in the present investigation. It turns out that our model is successful to be extended to study the $KN$ system, and some useful information of the quark-quark and quark-antiquark interactions are obtained from this study.

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