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KAON-NUCLEON AND ANTI-KAON-NUCLEON INTERACTIONS IN A CONSTITUENT QUARK MODEL

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Abstract

A combined study of the KN and $\overline{K}N$ interactions is performed within a chiral constituent quark model with the parameters fitted by the masses of the octet and decuplet baryon ground states. The S, P, D, F wave KN phase shifts and the cross sections for K^-p scattering into K^-p, K^0n, $\pi^+\Sigma^-$, $\pi^-\Sigma^+$, $\pi^0\Sigma^0$ and $\pi^0\Lambda$ channels are dynamically calculated by solving a resonating group method (RGM) equation. A satisfactory agreement with the experimental data is obtained, and at the same time, the results show that both one-gluon exchange (OGE) and vector meson exchange are necessary to be included in the quark-quark interacting potentials if one tries to simultaneously describe the KN phase shifts and $\overline{K}N$ cross sections in a constituent quark model.

1 Introduction

In the past few years, the chiral SU(3) quark model and the extended chiral SU(3) quark model have been quite successful in reproducing the energies of the octet and decuplet baryon ground states, the binding energy of

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the deuteron, the nucleon-nucleon (NN) and kaon-nucleon (KN) scattering phase shifts, and the hyperon-nucleon (YN) cross sections [1–5]. In the original chiral SU(3) quark model, the short range quark-quark interaction is dominantly provided by one-gluon exchange (OGE) and quark exchange effects. In the extended chiral SU(3) quark model, the vector meson exchanges are included and consequently the OGE is largely reduced, thus the short range quark-quark interaction is dominantly provided by vector-meson exchange and quark exchange effects. In other words, the short range quark-quark interaction mechanisms in these two models are quite different. Using these two models, we have dynamically studied [1–9] the NN and KN scattering phase shifts and the $\Omega\Omega$, $N\overline{\Omega}$, ΔK, ΛK and ΣK interactions in the framework of the resonating group method (RGM). It was found that though the mechanisms of the short range quark-quark interaction are quite different, these two models give quite similar results for all those hadron-hadron systems. To get more definite information about the short range quark-quark interaction mechanisms, it seems interesting and necessary to investigate some special systems where the chiral SU(3) quark model and the extended chiral SU(3) quark model give quite different results.

One notices that the KN and $\overline{K}N$ cases are of special interest, since OGE exists in KN system while vanishes in $\overline{K}N$ system (which is because the OGE between two hadrons is always accompanied by simultaneous quark exchange between these two clusters due to the color of the gluon, but the quark content of $\overline{K}N$ prevents such a quark exchange diagram), and on the hadron level the vector-meson exchanges in KN and $\overline{K}N$ are related by a G-parity transition. Specially, the ω exchange is repulsive for KN while attractive for $\overline{K}N$, because of the negative G parity of the ω meson (on hadron level). Thus if OGE and vector meson exchange give similar contributions in KN, they must give quite different contributions in $\overline{K}N$, or vice versa.

In Refs. [3–5], we have dynamically studied the KN scattering in the chiral SU(3) quark model and the extended chiral SU(3) quark model, and got a satisfactory description of the S, P, D, F wave KN phase shifts. Further in Ref. [10], a preliminary study of the $\overline{K}N$ bound state problem is performed by use of the same models and parameters as in Refs. [3–5], and it is found that in the extended chiral SU(3) quark model the attractive $\overline{K}N$ interaction can make for a bound state which appears as a $\pi\Sigma$ resonance in the coupled-channel calculation, while the chiral SU(3) quark model cannot accommodate the existence of a $\overline{K}N$ bound state.

In this work [11], we use three different constituent quark models to perform a combined study of the S, P, D, F wave KN elastic scattering phase shifts and the cross sections for K^-p scattering into K^-p, K^0n, $\pi^+\Sigma^-$, $\pi^-\Sigma^+$,

$\pi^0\Sigma^0$ and $\pi^0\Lambda$ channels by solving the RGM equation. These three different models are briefly introduced in the next section. The results of KN phase shifts and K^-p cross sections are shown in Sec. III, where some discussion is presented as well. Finally, the summary is given in Sec. IV.

2 Theoretical Frame

The three different constituent quark models are well described in Ref. [11], and we refer the reader to this work for details. Here we just give the salient features of those models.

In those three models, the total Hamiltonian is written as

$$H = \sum_i T_i - T_G + \sum_{i<j} V_{ij} \,. \tag{1}$$

Here T_G is the kinetic energy operator for the center-of-mass motion, and V_{ij} is the effective quark-quark interaction,

$$V_{ij} = V_{ij}^{\mathrm{conf}} + V_{ij}^{\mathrm{S}} + V_{ij}^{\mathrm{PS}} + V_{ij}^{\mathrm{SR}} \,, \tag{2}$$

where V_{ij}^{conf} is the confinement potential, V_{ij}^{S} and V_{ij}^{PS} represent the effective quark-quark potentials stemming from scalar and pseudo-scalar meson exchanges, respectively, and V_{ij}^{SR} denotes the short-range quark-quark interaction. In model I, i.e. the chiral SU(3) quark model, V_{ij}^{SR} is represented by OGE,

$$V_{ij}^{\mathrm{SR}} = V_{ij}^{\mathrm{OGE}} \,, \tag{3}$$

and in model II, i.e. the extended chiral SU(3) quark model, V_{ij}^{SR} is represented by vector meson exchange,

$$V_{ij}^{\mathrm{SR}} = V_{ij}^{\mathrm{V}} \,, \tag{4}$$

and in model III, both OGE and vector meson exchange are included,

$$V_{ij}^{\mathrm{SR}} = V_{ij}^{\mathrm{OGE}} + V_{ij}^{\mathrm{V}} \,. \tag{5}$$

The expressions of these potentials can be found in the literature [3–5,10,11].

All the model parameters are fitted with the same method as in our previous work [1–9], and here we briefly give the procedure for the parameter determination. The three initial input parameters, i.e. the harmonic-oscillator width parameter b_u, the up (down) quark mass $m_{u(d)}$ and the strange quark mass m_s, are taken to be the usual values: $b_u = 0.5$ fm for model I and 0.45

Table 1: Model parameters. The meson masses and the cutoff masses: $m_{\sigma'} = 980$ MeV, $m_\kappa = 1430$ MeV, $m_\epsilon = 980$ MeV, $m_\pi = 138$ MeV, $m_K = 495$ MeV, $m_\eta = 549$ MeV, $m_{\eta'} = 957$ MeV, $m_\rho = 770$ MeV, $m_{K^*} = 892$ MeV, $m_\omega = 782$ MeV, $m_\phi = 1020$ MeV, $\Lambda = 1500$ MeV for κ and 1100 MeV for other mesons.

	Model I Without VME	Model II Without OGE	Model III With OGE and VME
b_u (fm)	0.5	0.45	0.45
m_u (MeV)	313	313	313
m_s (MeV)	470	470	470
g_u^2	0.77	0	0.37
g_s^2	0.55	0	0.47
$g_{\rm ch}$	2.62	2.62	2.62
$g_{\rm chv}$	0	2.35	0.83
$f_{\rm chv}$	0	0	3.33
m_σ (MeV)	675	675	675
a^c_{uu} (MeV/fm^2)	52.9	56.4	60.2
a^c_{us} (MeV/fm^2)	76.0	104.1	95.1
a^{c0}_{uu} (MeV)	-51.7	-86.4	-72.2
a^{c0}_{us} (MeV)	-68.5	-72.2	-86.9

fm for models II and III, $m_{u(d)} = 313$ MeV, and $m_s = 470$ MeV. The coupling constant for scalar and pseudoscalar chiral field coupling, $g_{\rm ch}$, is fixed by the relation

$$\frac{g^2_{\rm ch}}{4\pi} = \left(\frac{3}{5}\right)^2 \frac{g^2_{NN\pi}}{4\pi}\frac{m^2_u}{M^2_N}, \tag{6}$$

with the empirical value $g^2_{NN\pi}/4\pi = 13.67$. The masses of the mesons are taken to be the experimental values, except for the σ meson. The m_σ is treated as a parameter, and we adjust it to fit the S-wave KN phase shifts. The OGE coupling constants and the strengths of the confinement potential are fitted by baryon masses and their stability conditions. All the parameters are tabulated in Table I, where the first, second and third sets are for models I, II and III, respectively. All these three sets of parameters can give good descriptions of the masses of octet and decuplet baryon ground states [11].

3 Results and Discussion

From Table I one sees that in model I, i.e. the original chiral SU(3) quark model, the vector meson exchange is not included and thus the short-range

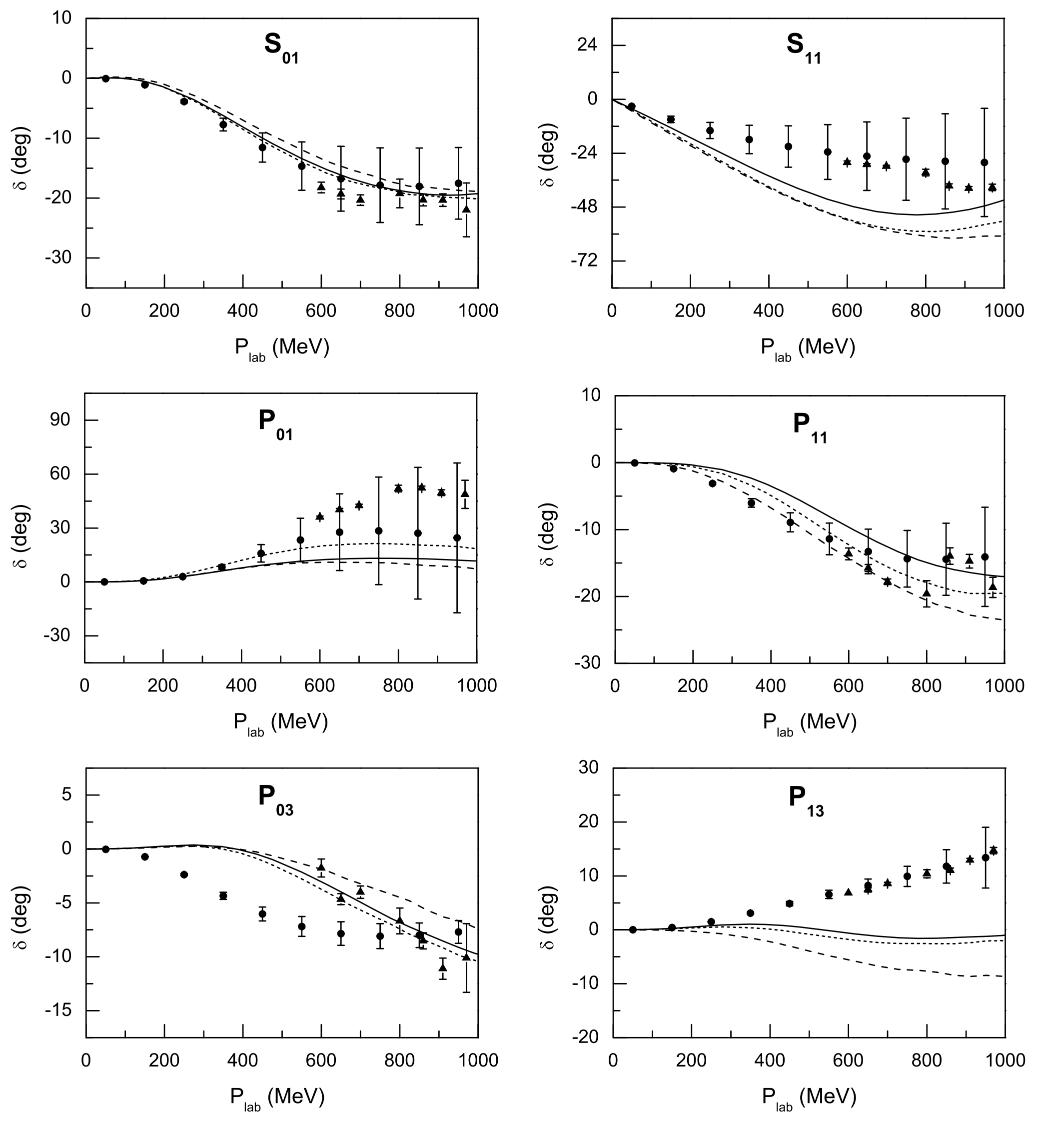

Figure 1: KN S- and P-wave phase shifts as a function of the laboratory momentum of kaon meson. The short-dashed and dashed lines represent the results obtained in the chiral SU(3) quark model and the extended chiral SU(3) quark model, respectively. The solid curves show the phase shifts from the model including both OGE and vector meson exchange. The experimental data are taken from Refs. [12] (circles) and [13] (triangles).

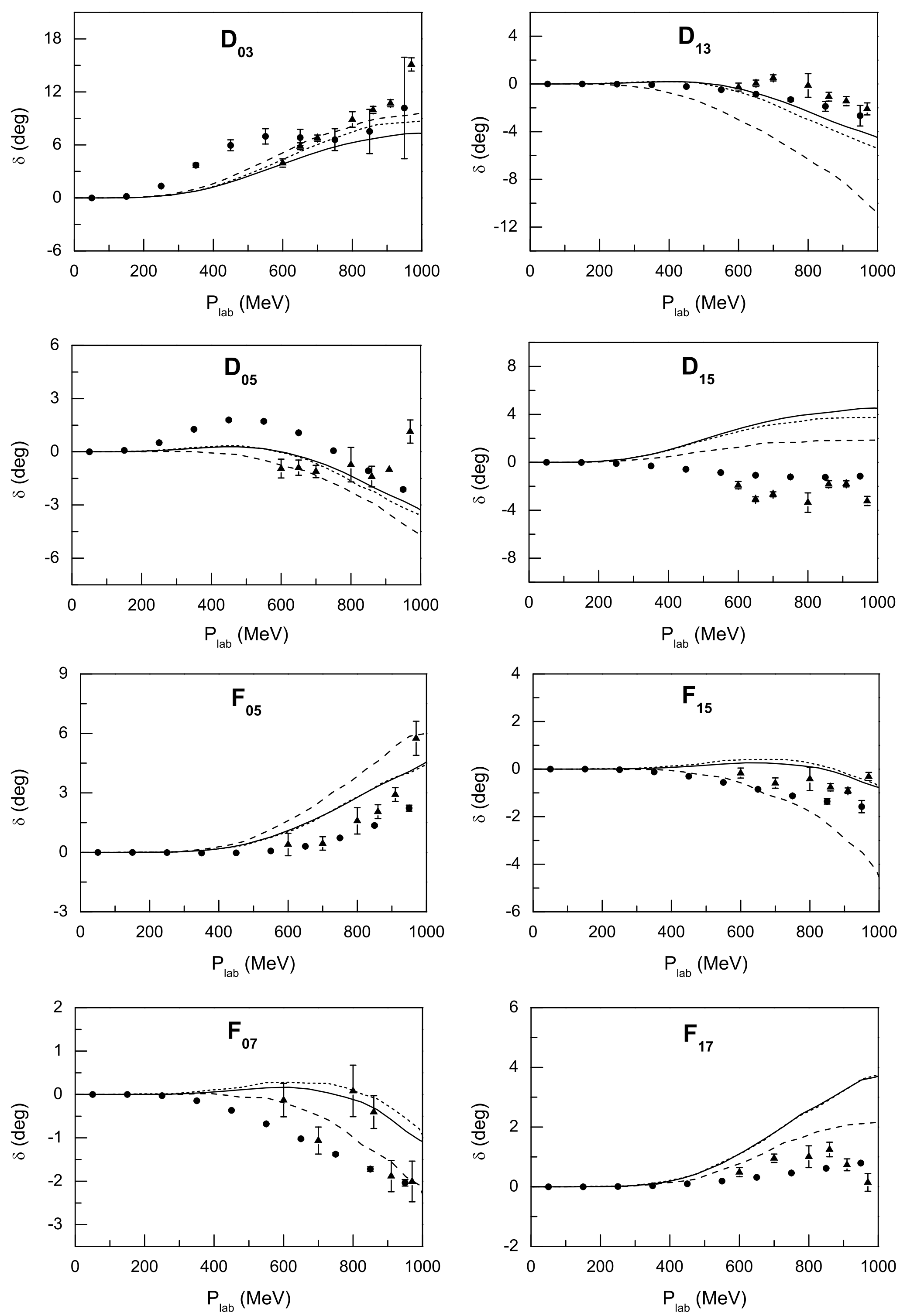

Figure 2: KN D- and F-wave phase shifts. Same notation as in Fig. 1.

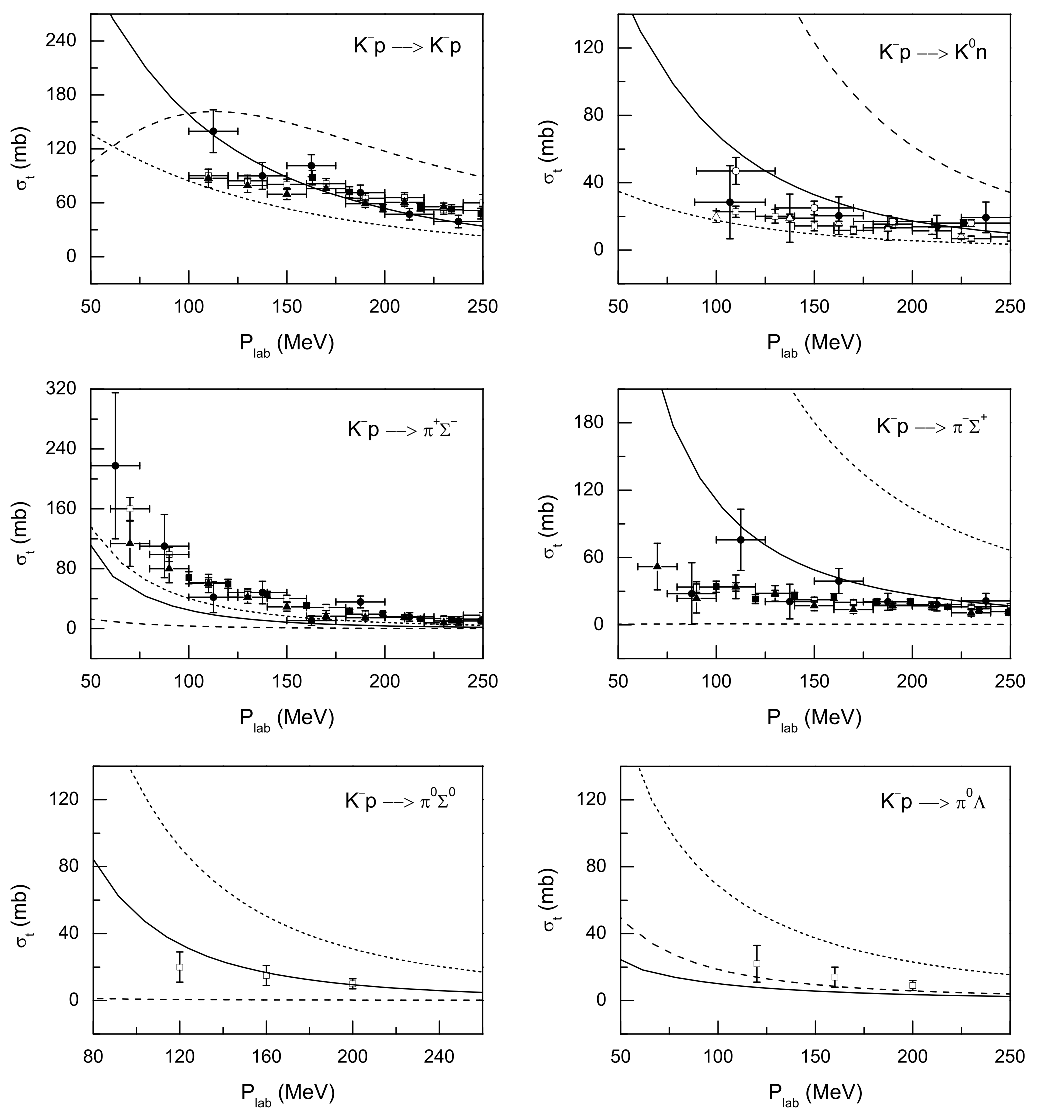

Figure 3: Total cross sections for K^-p scattering into various channels as a function of the laboratory momentum of K^- meson. The short-dashed and dashed lines correspond to the results from the chiral SU(3) quark model and the extended chiral SU(3) quark model, respectively. The solid curves represent the results from the model including both OGE and vector meson exchange. The experimental data are taken from Refs. [14] (empty circles), [15] (empty squares), [16] (empty triangles), [17] (filled circles), [18] (filled squares), and [19] (filled triangles).

quark-quark interaction is dominantly described by OGE; in model II, i.e. the extended chiral SU(3) quark model, the OGE is not included and thus the short-range quark-quark interaction is dominantly described by vector meson exchange; and in model III, both OGE and vector meson exchange are included. In other words, the short-range quark-quark interaction mechanisms are quite different in those three different models. We use those three models to perform a combined study of KN and $\overline{K}N$ scattering processes in the framework of resonating group method (RGM). The results are shown in Figs. 1-3.

Figures 1 and 2 show the S-, P-, D-, and F-wave KN phase shifts calculated in our models. The short-dashed, dashed and solid lines represent the results from models I, II, and III, respectively. One notices that except for the P_{13} and D_{15} channels, our theoretical phase shifts for all partial waves are in good agreement with the experiment. One also sees that the phase shifts from those three different models are quite similar, even the short-range quark-quark interaction mechanisms are quite different in those three models. This means that for the KN system, the short range interaction can be identified as either OGE or vector meson exchange or both of them.

Figure 3 shows the cross sections for K^-p scattering into K^-p, K^0n, $\pi^+\Sigma^-$, $\pi^-\Sigma^+$, $\pi^0\Sigma^0$ and $\pi^0\Lambda$ channels. The solid lines show the results from model III. The short dashed and dashed lines represent the results from models I and II, respectively. One sees neither model I nor model II can give a satisfactory description of the K^-p cross sections. While in model III, the theoretical results are in qualitatively agreement with the experiment. This means that although for the KN system, all these three models can give satisfactory description of the data, for the $\overline{K}N$ system, only the model with both OGE and vector meson exchange can describe the data. In other words, in order to give a unitary description of the KN phase shifts and $\overline{K}N$ cross sections by use of one set of parameters, both OGE and vector meson exchanges are necessarily to be included in the quark-quark interactions.

4 Summary

We have performed a combined study of S-, P-, D-, F-wave KN phase shifts and the cross sections for K^-p scattering into K^-p, K^0n, $\pi^+\Sigma^-$, $\pi^-\Sigma^+$, $\pi^0\Sigma^0$ and $\pi^0\Lambda$ channels by use of three different constituent quark models and the resonating group method [11]. Some interesting results are obtained:

- we get a satisfactory description of the KN phase shifts for all partial waves except P_{13} and D_{15},

- the OGE and vector meson exchange give similar contributions to KN system, which is similar to the cases of NN, $\Omega\Omega$, $N\overline{\Omega}$, ΔK, ΛK and ΣK systems,
- for the $\overline{K}N$ system, the OGE and vector meson exchange give quite different contributions,
- both OGE and vector meson exchange are necessary to be included in the quark-quark potentials if one tries to simultaneously describe the KN phase shifts and $\overline{K}N$ cross sections in a constituent quark model.

In the next step work, the effects of s-channel quark-anti-quark annihilation interaction and the coupling to a three-quark component will be investigated.

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