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Unconventional Medium Effect in K^+- and π^+-Nucleus Scattering*

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Abstract

The ratios of total cross section of K^+-nucleus to K^+-deuterium at 400 MeV/c $\leq p_k \leq$ 800 MeV/c for ^{6}Li, ^{12}C, ^{28}Si, ^{40}Ca and the differential cross section of π^+-^{12}C scattering at p_π = 800 MeV/c are calculated by taking into account of the unconventional Medium effect. An enhancement of both the K^+ and π^+ nucleus scattering cross sections is obtained.

The interactions of K^+-N (with $P_k \geq$ 300 MeV/c) and π^+-N (with $P_\pi \geq$ 500 MeV/c, at energies above the Δ_{33} resonance) are rather weak, the multiple-scattering theory should be rapidly convergent, and then the calculation of microscopic optical potentials based on first-order KMT theory should give good results in comparison with experiments. However, the calculated results, even the conventional medium effects are taken into account carefully, are systemaically lower than the experimental data, whether for the ratios R_T of total cross section of K^+-nucleus to K^+-deuterium defined as

$$R_T = [\sigma_t(K^+ - A)]/[\sigma_t(K^+ - d)/2] \tag{1}$$

or for the differential cross section of K^+- or π^+-nucleus scattering at P_k (or P_π) = 800 MeV/c. As a possible explanation of the discrepancy, a density-dependent correction for

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K^+-N scattering amplitude was proposed by Brown et al. [1]. On the other hand, the high-energy (above Δ_{33} resonance) pion-nucleus elastic scattering may also be sensitivity to unconventional nuclear medium effects [2].

It is well known [1] that the K^+-N scattering amplitude is roughly proportional to $[q^2 + M_v^2]^{-1}$ in vector meson exchange model, and to $[q^2 + (2M_q)^2]^{-1}$ in simple quark model, and the assumption of momentum transfer q being much smaller than the vector-meson mass M_v or the constituent quark mass M_q in the above energy region is usually valid. Therefore,

$$f_{K^+N}(\rho)/f_{K^+N}(0) = (M_q(0)/M_q(\rho))^2 = (M_v(0)/M_v(\rho))^2. \tag{2}$$

where (ρ) corresponds to the quantities in the nuclear medium of density ρ, and (0) to the quantities in free space ($\rho = 0$). Based on eq. (2), Brown et al. supposed [1]

$$f_{K^+N}(\rho(r))/f_{K^+N}(0) \approx 1.0 - \lambda\rho(r)/2\rho_0)^{-2} \tag{3}$$

where λ is an adjustable parameter of which the value lies within some range.

For comparison, besides the approach of Brown et al. (we call it method I), in this work we also calculated the optical potential multiplier $[M_q(0)/M_q(\rho(r))]^2$ based on a quark NJL model [3] (we call it method II). Along the simple approach of Henley and Müther [3], the in-medium constituent quark mass M_q can be solved from

$$M_q = m + \frac{2Gn_f n_c}{\pi^2} M_q \int_{k_F}^{\Lambda} \frac{p^2 F(p^2)}{\sqrt{p^2 + M_q^2}} dp \tag{4}$$

where $n_f = 2$ is the number of quark flavours, $n_c = 3$ is the number of quark colors, and Λ is a momentum space cut-off parameter. The form factor

$$F(p^2) = 1 - \exp[-(\frac{r_0 p}{\hbar c})^2] \tag{5}$$

reflected the quark confinement is some degree, the parameter r_0 is a measure of the confinement radius. Fermi momentum $k_F(r)$ is related to nuclear density $\rho(r)$ as

$$k_F(r) = [\frac{3}{2}\pi^2\rho(r)]^{1/3} \ (\text{fm}^{-1}) \tag{6}$$

According to ref. [3], let m = 5 MeV, Λ = 800 MeV and $G = 2/\Lambda^2$, for $F(p^2) = 1$ and $k_F = 0$, then a constituent quark mass in vaccum $M_q \approx$ 325 MeV and a pion mass $m_\pi \approx$ 150

MeV can be obtained. In our calculations, m, Λ and G are always taken as above values, $k_F(r)$ is calculated from eq. (6) (of course should change unit from fm^{-1} to MeV).

We calculated the ratios of total cross section R_T in eq. (1) (at 400 MeV/c $\leq P_k \leq$ 800 MeV/c) which are given in Figs. 1. We also calculated the differential cross section of π^+-scattering on ^{12}C at P_π = 800 MeV/c, the results are given in Fig. 2. Except for ^6Li, the calculated results of R_T without considering the unconventional medium effect (UME) are about 10% lower than experimental data [4]. Both method I and II can get same very good calculated results in agreement with experimental data. The optimal parameters λ (r_0) for method I and II are 0.2 (0.42) for ^{12}C, 0.25 (0.45) for ^{28}Si and ^{40}Ca, ^6Li is an exception for which all calculated results are larger than experimental data, at present the reason is not yet very clear. For the differential cross sections, the calculated results without UME are about 30% lower than experimental data [5]. Both method I and II with the same optimum λ and r_0 as above give same good calculated results in accordence with experimental data.

So we have reason to believe that the introduction of the above unconventional medium effect may lead to an enhancement of both K^+- and π^+-nucleus scattering cross sections and provide a possible explanation for the missing theoretical cross sections in conventional nuclear physics calculations.

References

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Figure Captions

Fig. 1 The K^+ total cross section ratios R_T defined in eq. (1). The dot-dashed lines correspond without UME, the solid lines with UME of method II, the doted lines with UME of method I with optimal values of λ (0.1 for ^6Li, 0.2 for ^{12}C, 0.25 for ^{28}Si and ^{40}Ca), and the dashed lines with $\lambda = 0.2$ for ^6Li, ^{28}Si and ^{40}Ca.

Fig. 2 Elastic scattering differential cross section for π^+-^{12}C at 800 MeV/c. The dashed curve is the result without the nucleon swelling effect. The solid and dotted curves are the results with the nucleon swelling effect obtained by method I and II repectively. The experimental data are taken from ref. [5].

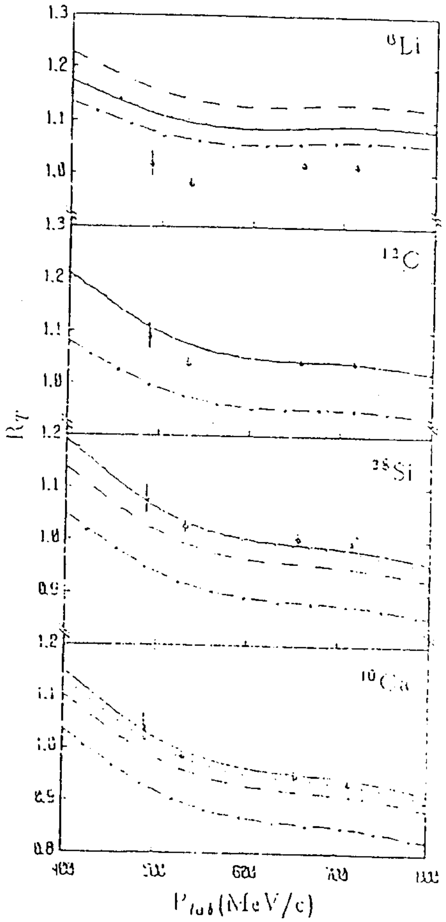

Fig. 1: The K^{+} total cross section ratios R_T defined in eq. (1)

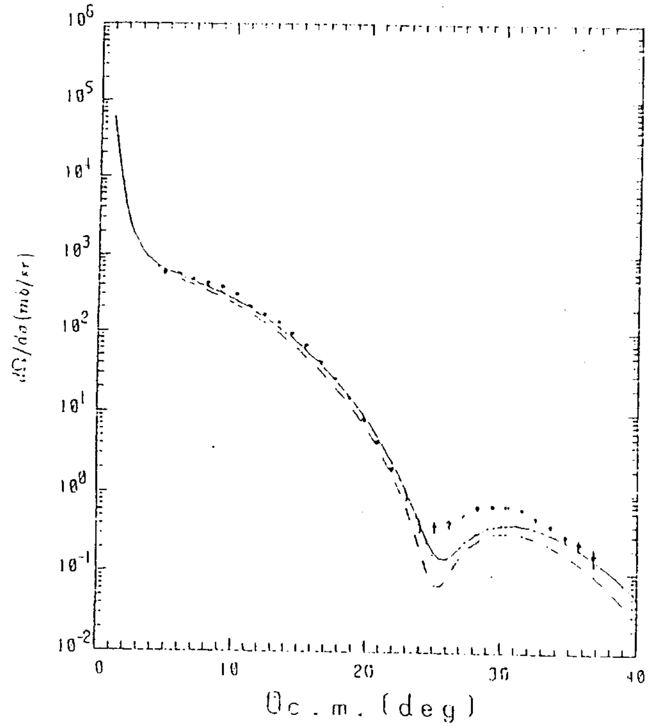

Fig. 2.

Fig.3. Elastic scattering differential cross section for $\pi^{+}-{}^{12}C$ at 800 MeV/c. The dashed curve is the result without the nucleon swelling effect. The solid and dotted curves are the results with the nucleon swelling effect obtained by method I and II respectively. The experimental datas are taken from ref.(5).