STUDY OF (K^-, K^+) REACTIONS WITHIN THE QUANTUM MOLECULAR DYNAMICS APPROACH

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We show the recent developments of theoretical study on (K^-, K^+) and stopped Ω^- reactions based on microscopic simulation models. The mechanism of the K^+ production from (K^-, K^+) reactions on nuclear targets is discussed. Quantum Molecular Dynamics (QMD) model is used to study the Ξ^- momentum distribution and hyperon emission/stopping ratio from (K^-, K^+) reactions. The effects of hyperon-nucleon interaction on some observable are discussed. The possibility of producing the S =–3 system in stopped Ω^- reactions is investigated.

1 Introduction

The study of nuclear systems with strangeness $S = -2$ is one of the most important and hottest subjects in nuclear physics, since these systems give us unique information on YY interaction and they might be a doorway to study multi-strangeness systems such as the strange matter. Among the reactions in which these double strangeness nuclear system can be formed, there have been considerable efforts devoted to study the (K^-, K^+) reactions theoretically and experimentally. It is necessary to understand the reaction mechanisms to reveal various properties of S =–2 systems. The aim of this study is to shed light on the reaction mechanism of (K^-, K^+) by using a microscopic transport approach called Quantum Molecular Dynamics (QMD) [1,2,3]. In this paper We study the global reaction mechanism.

2 The QMD model and its inputs

Essential ingredients of the QMD model are phase space dynamics, stochastic two-body collisions, particle productions and their decays with Pauli-blocking. In QMD, single particle wave functions are assumed to be Gaussian wave packets and the propagation of their centroids is described by the Hamilton's equation of motion. We introduce the relativistic corrections in the equation of motion according to Niita *et al.*[3], since incident and produced particles are energetic in the reactions under consideration. Potentials used in this work contain Skyrme type nuclear potential with symmetry energy and Coulomb potential. Nuclear mean field potentials of hyperons U_Y ($Y = \Lambda, \Sigma, \Xi$) are assumed to be proportional to that of nucleons, $U_Y = \alpha_Y U_N$,

$$U_Y = \alpha_Y \frac{U_N(\rho)}{|U_N(\rho_0)|}, \quad U_N = \alpha \left(\frac{\rho}{\rho_0}\right) + \beta \left(\frac{\rho}{\rho_0}\right)^\gamma . \tag{1}$$

The factor α_Λ is chosen to reproduce the depth of –30 MeV in nuclear matter. For Σ, we chose 10 MeV. The depth of the Ξ potential is taken as a free parameter. The width of the Gaussian size ν is fixed to be 0.12 fm^{-2} during the time evolution. All the cross sections of S =–2 baryon-baryon collisions below particle threshold are implemented using the Nijmegen model D with a hard core parameter $r_c = 0.5$ fm.

3 Results

3.1 K^+ Momentum distribution from (K^-, K^+) reaction

We investigate the K^+ momentum distribution on various targets to understand the strangeness production/exchange mechanism in nuclear medium using the intranuclear cascade model(INC). Detailed explanation can be seen in Ref. [4]. The INC model is nothing but the model in which the potential(mean field) effects are neglected in QMD. In comparison with the KEK-E176 experiment[5], it is found that the momentum distribution of K^+ can be explained mainly by following mechanisms (see Fig. 1):

(1) Direct-type reactions: $K^- p \to K^+ \Xi^-$, $K^- p \to K^+ \Xi^{*-}(1530)$.

(2) Decay of scalar/vector mesons[6]:

$$K^- p \to M\Lambda, \quad M \to K^- K^+ \quad (M = \phi, a_0, f_0)$$

(3) Two-step processes:

$$K^- N \to Y^{(*)} M, \quad MN \to K^{(*)} Y^{(*)},$$

$M = \{\pi, \rho, \eta\}, \omega$, $Y = \{\Lambda, \Sigma\}$, $Y^* = \{\Lambda(1405), \Lambda(1520), \Sigma(1385)\}$ and $K^* = K^*(892)$.

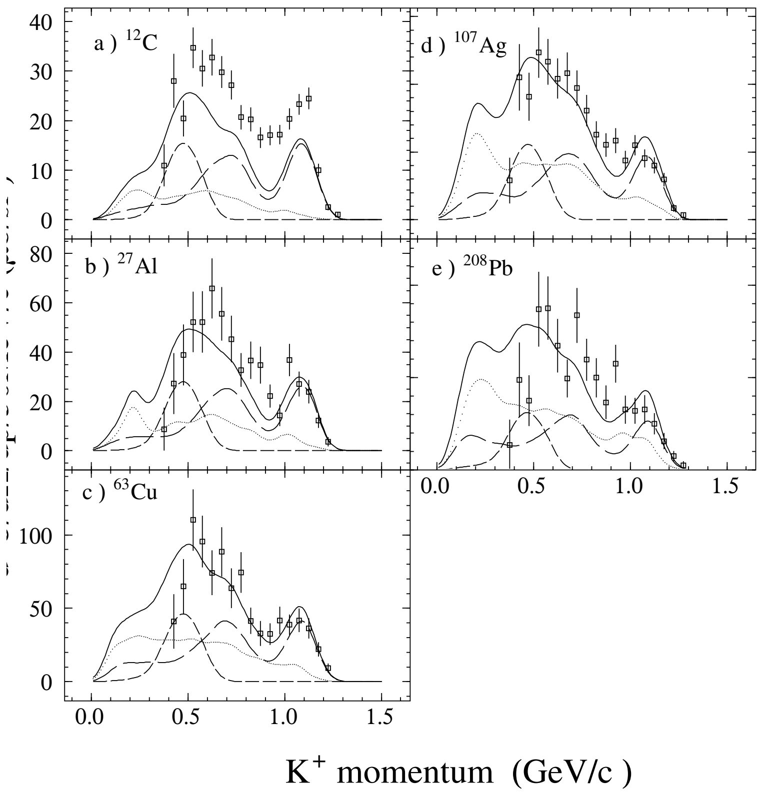

Figure 1: Calculated momentum spectra of K^+ for C, Al, Cu, Ag, Pb targets at $p_{K^-} =$ 1.65 GeV/c using the INC model. The Fermi density is used for the density of targets. The squares represent the data by Iijima *et al.* [5]. The contributions of Ξ and $\Xi(1535)$ productions are represented by long dashed lines. The dashed and dotted lines corresponds to the contributions of $\phi/a_0/f_0$ productions and of two-step processes,respectively. Solid lines denote the results of the total spectrum.

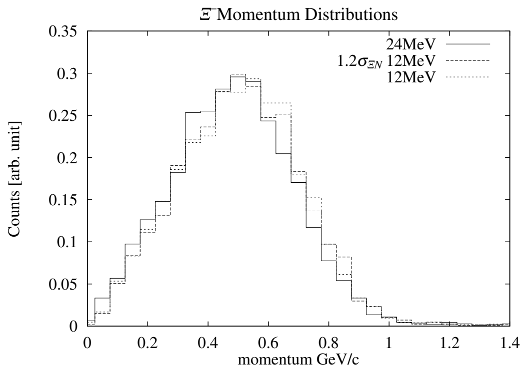

Figure 2: Calculated Ξ^- momentum spectra for ^{12}C target at $p_{K^-} = 1.65$ GeV/c using the QMD model. Detected K^+ angle is $8.59° \pm 6.875°$. Solid and dotted lines denote the results with the ΞN potential depth 12MeV and 24MeV case, respectively. QMD result with 12MeV and $0.8\sigma_{\Xi N}$ is represented by long dashed line.

Among two-step processes (3), it is important to include meson and hyperon resonances to reproduce the K^+ spectrum.

There are mainly two reasons of the enhancement of the two-step contributions compared with previous estimations[5,6]. The first one is the variety of intermediate mesons and final hyperons, which results in the huge number of paths to produce K^+ particles. In addition, meson resonances have larger masses than pions, and stored energies in their masses are released in the second step reactions. Thus the K^+ production cross section with these meson resonances becomes larger than that of pions. The second reason is related to the meson momentum region. The mesons produced in this reaction is just in the baryon resonance region where the cross sections have the largest values.

3.2 QMD predictions of hyperon stopping rate

Next, we discuss the high momentum region of K^+, i.e. the Ξ^- particle production. We calculate the Ξ^- momentum distribution on ^{12}C target. To see the sensitivity to the ΞN interaction, we take the ΞN potential depth and the ΞN cross section ($\sigma_{\Xi N}$) to be free parameters. We find that the QMD calculation reproduces the experimental spectrum shape of KEK-E224 [7], and both the ΞN potential depth and $\sigma_{\Xi N}$ are not sensitive to the shape of the Ξ^- momentum spectrum within the range of 12 MeV–24 MeV (see Fig. 2). However, it is shown that the total yield of double-hyperfragments is about five times larger in the case of ΞN potential depth of 24 MeV. On the other hand,

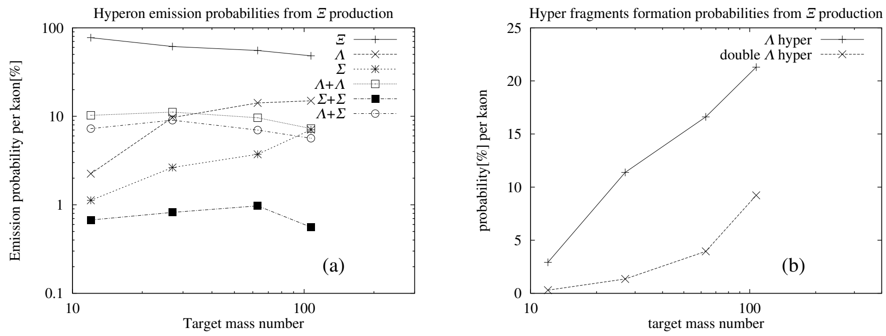

Figure 3: QMD results of hyperon emission probabilities(a) and hyperon stopping probabilities(b) per kaon from Ξ production.

the total yield of the single-Λ hyperfragments is found to be about 3% which does not depend on the ΞN potential depth strongly. The escaping probability of Ξ^- is calculated to be 75–81% within the elementary cross section range $0.8\sigma^{(0)}_{\Xi N} \leq \sigma_{\Xi N} \leq 1.2\sigma^{(0)}_{\Xi N}$, where $\sigma^{(0)}_{\Xi N}$ represents the Nijmegen model D prediction as described before. Note that Ξ^- escaping probability is experimentally estimated to be about 80%.

We show in Fig. 3, target mass number dependence of hyperon emission/stopping probabilities from (K^-, K^+) reaction assuming Ξ production ((1) of sec.3.1). It is found that stopping rate increase with target mass number and in ^{107}Ag case, about 50% of the produced Ξ particles is stopped. However, 2-hyperon stopping rate is not very sensitive with target mass number. It is seen from Fig. 3(b) that total hyperfragment(single and double) formation probabilities strongly depend on target mass number.

3.3 Stopped Ω^- reaction

There are some efforts to investigate multi-strangeness composite particles productions(stranglet or MEMO) in high energy heavy ion collisions, although no clear candidates of them have been found until now. On the other hand, a new 50-GeV PS project at INS/KEK can provide us with high intensity K^- beam. Therefore, there is a possibility to perform stopped Ω^- experiments and/or (K^-, K^+K^0) reactions. A preliminary QMD predictions for S =–3 system with stopped Ω^- reactions show the following results: After the absorption of a Ω^- particle, we assume that Ω^- converts via the following strong process in nuclei: (a) $\Omega^- N \rightarrow \Xi\Lambda$ or (b) $\Omega^- N \rightarrow \Xi\Sigma$. In the case of ^{12}C, within the 1,000 event, QMD simulation gives no S =–3 systems both in (a) and (b) cases. However, in the ^{63}Cu case, S =–3 system (triple Λ hypernucleus) can be seen in QMD with probabilities 0.07% and 0.15 % in the case of (a) and (b), respectively. Σ production process enhances the stopping rate.

4 Summary

In summary, the INC model can explain the K^+ momentum spectra from the (K^-, K^+) reactions at $p_{K^-} = 1.65$GeV/c on various targets consistently. Both the two-step strangeness exchange and production processes with various intermediate mesons and ϕ, a_0 and f_0 productions and their decay into K^+K^- which was first quoted in Ref. [6], are necessary to reproduce the experimental data in the low momentum region.

QMD calculations show that ΞN interaction is sensitive to the hyperfragment production probabilities and strong mass dependence on the hyperfragment production probabilities can be seen.

In addition to the global dynamics study of (K^-, K^+) reactions, the formation mechanism of $^4_\Lambda$H from the K^- absorption at rest was well studied [8], as well. Stimulated by successes of these works in describing K^- induced reactions, it is very promising to study the formation pattern of the double-hyperfragment production from the (K^-, K^+) reaction.

Acknowledgments

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