Study on effective masses of meson in dense nuclear matter*

LI Xi-Guo(李希国)[1,2;1)] LI Yong-Qing(李永青)[1,3;2)]

1 (Institute of Modern Physics, Chinese Academy of Sciences, P.O. Box 31, Lanzhou 730000, China)
2 (Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Collisions, Lanzhou 730000, China)
3 (Graduate University, Chinese Academy of Sciences, Beijing 100049, China)

Abstract We introduce and summary our research progress on the effective masses of K meson in dense nuclear matter.

Key words dense nuclear matter, effective mass, K meson

PACS 21.62.Jk

The study of the effective mass, condensation and propagating of hadrons is not only useful for our understanding of strong interaction and chiral symmetry restoration, but also can give us new information about the equation of state of nuclear matter, which will be helpful for us to study the formation and structure of neutron stars.

Because of the weak kaon-nucleon interaction compared to nucleon-nucleon interaction, kaon almost can not be reabsorbed after being produced in dense nuclear matter, so kaon becomes one of the most perfect probes in probing the medium effects and provides a good supplement to lepton or electromagnetic probes. Recently, the study of the properties of asymmetric nuclear matter becomes one of the most important subjects in nuclear physics[1]. Since Kaplan and Nelson[2] initially proposed that there probably exist the kaon condensation in nuclear matter, people have carried on abroad theoretical investigations into the properties of kaon in nuclear matter. The properties of kaon in nuclear matter may differ significantly from those of free kaon. The effective mass of K^- in nuclear matter decreases as the density increases, which is correlative with the fact that the quark condensation decreases evidently as the nuclear density increases, and the kaon condensation is likely to happen when the density is more than three times the saturation density of nuclear matter. The shift of the in-medium effective mass may be the new mechanism of Kaon production under threshold.

Based on nonlinear $SU(3)_{\rm L} \otimes SU(3)_{\rm R}$ chiral Lagrangian, G.Q.Li et al[3, 4] investigated the dependence of the effective mass of kaon on the scalar density $\rho_{\rm S}$ and vector density $\rho_{\rm B}$ in nuclear matter using the dispersion relation. In the framework of linear and non-linear Walecka model, we[5] can get the relationship of $\rho_{\rm S}$ and $\rho_{\rm B}$, and systemically discuss the influences of the different models and parameters on the relation between scalar density $\rho_{\rm S}$ and vector density $\rho_{\rm B}$ in nuclear matter, then investigate the difference of meson effective masses in different cases[6, 7]. Using the density-dependent relativistic mean field model (DDRMF), we investigate the influence of isovector meson δ on the effective mass of kaon in asymmetric nuclear matter[8]. J.Schaffner et al.[9] have investigated the properties and conden-

Received 8 July 2008
* Supported by CAS Knowledge Innovation Project (KJCX3-SYW-N2, KJCX2-SW-N16) and Science Foundation of China (10435080, 10575123, 10710172)

1) E-mail: xgl@impcas.ac.cn
2) E-mail: liyongqing@impcas.ac.cn

sation of kaon in exotic nuclear matter by the extended relativistic mean field approximation and simple meson exchange model. Norman K.Glendenning and J.Schaffne r-Bielich[10, 11] have studied the first-order phase transition of kaon condensation in neutron stars using the minimal coupling model of kaon and meson field. Based on the DDRMF and relativistic mean field model, H.Guo et al[12, 13] gave the dispersion relation of kaon using the one-boson-exchange model and considering scalar-isovector δ meson, then studied the dependence of kaon mass on density and the critical density of K^- condensation in neutron stars. J.F.Gu et al[14, 15] investigated the critical density of kaon condensation and quark deconfinement in neutron stars using the chiral hadron model (FST) and the minimal coupling model of kaon and meson fields. In their investigation, J.Schaffner et al took into account the exchange of exotic meson between exotic hadrons without moderately considering scalar-isovector δ meson. H.Guo et al took into account scalar-isovector δ meson without considering the exotic interaction between hyperon. Hyperon and other exotic hadrons can be produced with the change of density in inner of neutron stars, and the nuclear matter is asymmetric. Thus, we need to systematically investigate the influences of exotic and isovector meson on the properties of kaon in asymmetric nuclear matter with high density which can be produced in heavy ion collisions.

Based on J.Schaffner's research, we study baryon octet $n, p, \Lambda, \Sigma^+, \Sigma^0, \Sigma^-, \Xi^0, \Xi^-$, taking into account not only isoscalar meson σ, ω and isovector meson ρ, δ, but also exotic scalar meson $f_0(980)$ and $\phi(1020)$ which contribute to the interaction between hyperon. We obtain the Lagrangian and the equations of hadrons and meson fields by relativistic mean field approximation. Considering the case that kaon interact with baryon by exchanging one boson, we give the kaon dispersion relation using one boson exchange Lagrangian which is obtained by minimal coupling. We fix on the coupling constants of baryon meson interaction and the interaction between kaon and other meson, then investigate the shift of kaon mass in the exotic nuclear matter, and the results are compared to the $SU(3)_{\rm L} \otimes SU(3)_{\rm R}$ model.

If the exotic meson are included in exotic nuclear matter, the effective mass of K^+ increases slowly as the density increases under 2 times normal density, while decreases as the density increases above 2 times normal density. If the exotic meson are not included, the results are contrary. The effective mass of K^- decreases evidently with the density of exotic nuclear matter increases. The isovector meson δ affect the behavior of K^+ effective mass trivially, while greatly affect the behavior of K^- effective mass. And the influences on K^+ and K^- are also dependent on the choice of parameters. Compared to calculations based on one-boson-exchange model including the exotic meson, the K^- effective mass increases more greatly with density while using the model without the exotic meson[16]. Thus, it's probably that the condensation of K^- won't happen in exotic neutron stars.

References

1 LI B A, Schroeder W U, Isospin Physics in Heavy-Ion Cillisions at Intermediate Energies. New York: Nova Science, 2001

2 Kaplan D B, Nelson A E. Phys. Lett. B, 1986, **175**: 57

3 LI G Q, Ko C M, FANG X S. Phys. Lett. B, 1994, **329**: 149

4 LI G Q, Ko C M, LI B A. Phys. Rev. Lett., 1995, **74**: 235

5 GAO Yuan, LI Xi-Guo, JIA Duo-Jie. HEP & NP, 2003, **27**(11): 995 (in Chinese)

6 LI Xi-Guo, GAO Yuan, GUO Yan-Rui et al. HEP & NP, 2004, **28**(9): 973 (in Chinese)

7 LI Xi-Guo, GUO Yan-Rui, GAO Yuan et al. Rev. Nucl. Phys., 2004, **21**(3): 183 (in Chinese)

8 LI Xi-Guo, GAO Yuan, LIU Zi-Yu et al. HEP & HP, 2004, **28**(11): 1150 (in Chinese)

9 Schaffner J, Mishustin I N. Phys. Rev. C, 1996, **53**: 1416

10 Glendenning N K, Schaffner-Bielich J. Phys. Rev. Lett., 1998, **81**: 4564

11 Glendenning N K, Schaffner-Bielich J. Phys. Rev. C, 1999, **60**: 025803-1

12 GUO Hua, LIU Bao, ZHANG Jin-Wei. Phys. Rev. C, 2003, **67**: 024902-1

13 GUO Hua, CHEN Yan-Jun, LIU Bao et al. Phys. Rev. C, 2003, **68**: 035803-1

14 GU Jian-Fa, GUO Hua, ZHOU Ran et al. The Astrophysical J., 2005, **622**: 549

15 GU Jian-Fa, GUO Hua, LI Xi-Guo et al. Phys. Rev. C, 2006, **73**: 055803

16 LI Xi-Guo, LIU Yu-Xin, Gao Yuan, HNP & NP, 2007, **31**(10): 922 (in Chinese)