第 22 卷 第 1 期
2005 年 3 月

原子核物理评论
Nuclear Physics Review

Vol. 22, No. 1
Mar., 2005

Artisle ID: 1007-4627(2005)01-0032-03

Symmetry Energy and Neutron Skin Thickness*

SHEN Gang[1,2], LI Jun[1,2], Hillhouse G. C.[3], MENG Jie[1,2,#]

(1 *Center of Theoretical Nuclear Physics, National Laboratory of Heavey Ion Accelerator of Lanzhou, Lanzhou* 730000, *China*;

2 *School of Physics, Peking University, Beijing* 100871, *China*;

3 *Department of Physics, University of Stellenbosch, Stellenbosch, South Africa*)

Abstract: After adding isospin dependent high order correction terms to existing relativistic mean field models (RMF), the density dependence of symmetry energy and the neutron skin thickness S for ^{208}Pb are studied. Using the new effective interaction PK1, together with NL3, S271 and Z271, a range of 29—38 MeV for the symmetry energy for nuclear matter at saturation point and the corresponding neutron skin thickness $S = 0.14$—0.28 fm for ^{208}Pb are obtained. For all effective interactions, a linear relation between the symmetry energy at saturation point and the neutron skin thickness for ^{208}Pb is observed.

Key words: relativistic mean field theory; symmetry energy; neutron skin; nuclear matter

CLC number: O571.5 **Document Code**: A

1 Introduction

Symmetry energy plays a crucial role in nuclear physics. The neutron skin thickness S in heavy nuclei is determined by the symmetry energy to a large extent. The situation regarding the determination of neutron radii is unsatisfactory with errors typically being an order of magnitude larger than those for proton radii. A widely used and successful approach for nuclear matter and finite nuclei is the relativistic mean field (RMF) theory[1], which gives S= 0.2—0.3 fm[2] for ^{208}Pb. Model-dependent analyses of experimental data with hadronic probes yield values of the neutron skin which vary between 0.0 and 0.2 fm, which seem to be more consistent with the predictions of nonrelativistic models. Hadronic measurements, however, suffer from potentially serious theoretical systematic errors associated with uncertainties in nuclear reaction mechanisms and, hence, one should be cautious about drawing the latter conclusion.

In this paper we supplement existing RMF Lagrangian densities with two new higher order correction terms associated with the coupling of the nucleon current to σ- and ρ-meson fields. Values for the various combinations of the new coupling constants are extracted by fitting to the properties of nuclear matter. The symmetry energy at high density is softened depending on the choice of new coupling constants and the corresponding values for the neutron skin of ^{208}Pb are compared to the predictions of other relativistic mean field models.

2 Formalism

The details of the RMF theory and its application in nuclear physics could be found in Ref. [3].

Received date: 31 Aug. 2004

* **Foundaton item**: Major State Basic Research Development Program(G2000077407); National Natural Seience Foundation of China (10025522, 10221003, 10047001)

Biography: Shen Gang(1979—), male (Han Nationality), Zhejiang, Wenzhou, Master degree, working on nuclear theory.

\# **Contact**: Meng Jie, E-mail: mengj@pku.edu.cn

The new high order isospin dependent correction terms are respectively,

$$L_1 = -\Gamma_1 \bar{\psi} g_\rho \gamma^\mu (g_\sigma \sigma / m) \boldsymbol{\tau} \cdot \boldsymbol{\rho}_\mu \psi,$$
$$L_2 = -\Gamma_2 \bar{\psi} g_\rho \gamma^\mu (g_\sigma \sigma / m)^2 \boldsymbol{\tau} \cdot \boldsymbol{\rho}_\mu \psi$$

and the term introduced in Ref. [4] :

$$L_{\mathrm{HP}} = 4\Lambda_v g_\rho^2 \boldsymbol{\rho}_\mu \cdot \boldsymbol{\rho}^\mu g_\omega^2 \omega_\mu \omega^\mu.$$

Detailed formalism can be found in Ref. [5].

3 Results and Discussion

We take the following regulation: the coupling constant g_ρ is adjusted in such a way that all the effective interactions have a fixed symmetry energy at average density of $k_f = 1.15\ \mathrm{fm}^{-1}$ ($\rho = 0.10\ \mathrm{fm}^{-3}$). The symmetry energy at $k_f = 1.15\ \mathrm{fm}^{-1}$ is 26.08 MeV for original effective interaction PK1[6] and 25.68 MeV for original NL3[7], S271, and Z271[4], respectively. After adding the new term for PK1, we find the density dependence of the symmetry energy softens at high density depending on the choice of new coupling constants.

The neutron radius (thus neutron skin) of ^{208}Pb relies on the density dependence of symmetry energy. Stiff density dependence (i. e., pressure) for neutron matter pushes neutrons out against surface tension, leading to a larger radius. Although there were some tentative explanations for the origin of this linear relation, it keeps unsettled. After adding the new terms, we illustrate the relation between them for three effective interactions, PK1, NL3, and S271 in Fig. 1[5]. The points are particularly taken with experimental binding energy and proton root-mean-square radii for ^{208}Pb. The neutron skin thickness S linearly depends on the symmetry energy. The range of symmetry energy a_{sym} at saturation point is 29—38 MeV with $S = 0.17$—0.28 fm[5].

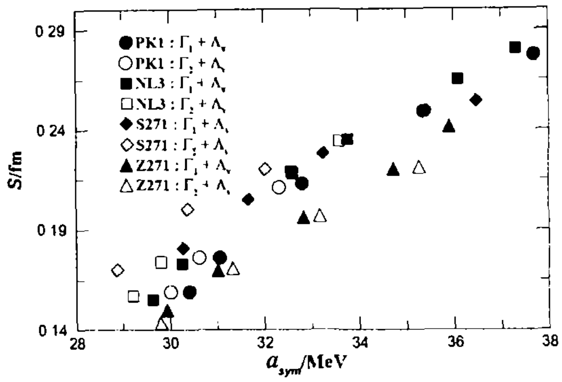

Fig. 1 The relation between neutron skin thickness S in ^{208}Pb and symmetry energy of nuclear matter at saturation density with new isospin dependent terms.

4 Summary

After introducing higher order correction terms to the existing RMF models, we have observed the new ranges of neutron skin thickness in ^{208}Pb, 0.17—0.28 fm for PK1 and NL3 models; 0.13—0.25 fm for S271 and Z271 models, whereas the binding energy and proton radii are both well constrained by experiments. The linear relation between neutron skin thickness S and the symmetry energy at saturation point is demonstrated. A precise measurement of the neutron radius (therefore neutron skin) for ^{208}Pb in Jefferson Lab[8] would place an important constraint on RMF models.

References:

[1] Meng J, Ring P. Phys Rev Lett, 1996, **77**: 3 963; Meng J, Ring P. Phys Rev Lett, 1998, **80**: 460.

[2] Typel S, Brown B A. Phys Rev, 2001, **C64**: 027302.

[3] Ring P. Prog Part Nucl Phys, 1996, **37**: 193.

[4] Horowitz C J, Piekarewicz J. Phys Rev Lett, 2001, **86**: 5 647.

[5] Shen G, Li J, Hillhouse G C, *et al*. Neutron Skin in ^{208}Pb and Neutron Star Radius (to be published).

[6] Long W H, Meng J, Giai N V, *et al*. Phys Rev, 2004, **C69**: 034319.

[7] Lalazissis G A, König J, Ring P. Phys Rev, 1997, **C55**: 540.

[8] Spokespersons Michaels R, Souder P A, Urciuoli G M. Jefferson Laboratory Experiment E-00-003.

(下转第 46 页)

1995, 167.
[3] Kraft G. Radiobiology of Heavy Charged Particles, 1996, GSI Reprint, 96—60.
[4] Hirao Y l. HIMAC001, Dec. 1992, 1—38.
[5] Kraft G. What Kind of Radiobiology Should Be Done at a Hadron Therapy Center, 1997, GSI Reprint, 9705.
[6] 李桂生, 王 经, 赵彦森等. 核技术, 1993, **16**: 547.

Physics Quality of Heavy Ions Beam with Tumor Therapy*

DANG Bing-rong, LI Wen-jian, MA Qiu-feng, LI Qiang, ZHOU Guang-min, WANG Ju-fang, HAO Ji-fang
(*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou* 730000, *China*)

Abstract: Heavy ion therapy has more advantages due to the physics quality of heavy ions. Therefore the investigation on heavy ion actions with biological materials will be a basic task. In this paper, the experimental results show a picture to resolve some problems currently concentrated.

Key words: tumor therapy with heavy ions; physics quality; tumor

(上接第33页)

核物质的对称能与中子皮厚度**

沈 刚[1,2], 李 俊[1,2], Hillhouse G. C.[3], 孟 杰[1,2]
(1 兰州重离子加速器国家实验室原子核理论中心, 甘肃 兰州 730000;
2 北京大学物理学院, 北京 100871;
3 *Department of Physics, University of Stellenbosch, Stellenbosch, South Africa*)

摘 要: 在现有的平均场模型中引入同位旋相关的高阶修正项, 研究了核物质对称能的密度依赖性和^{208}Pb的中子皮厚度。采用新提出的PK1相互作用以及NL3, S271和Z271相互作用, 得到核物质饱和点对称能的范围为29—38 MeV以及相应的^{208}Pb中子皮厚度为0.17—0.28 fm. 在所有相互作用中, 核物质饱和点的对称能与^{208}Pb的中子皮厚度近似呈线性关系.

关 键 词: 相对论平均场理论; 对称能; 中子皮; 核物质

* **Foundation item**: "Western Light" Program of Talent Cultivation of Chinese Academy of Sciences (XB040602); Youth Foundation of Natural Sciences of Gansu Province (3ZS041-A25-025); Key Project of National Natural of Sciences Foundation of China (10335050); National Basic Research Priority Program of the Ministry of Science and Technology of China (2003CCB00200)

** **基金项目**: 国家重点基础研究发展规划资助项目(G2000077407); 国家自然科学基金资助项目(1002522, 10221003, 10047001)