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Investigation of nonlinear isoscalar–isovector coupling in a relativistic mean-field model by elastic magnetic electron scattering

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Abstract

In this paper, we study the sensitivity of single valence neutron properties and elastic magnetic form factors to three different relativistic mean-field (RMF) parameter sets: NL3, FSUGold, and IU-FSU. To perform our calculation, seven odd-A nuclei having single valence neutron on top of a magic neutron core: ^{7}Be, ^{17}O, ^{41}Ca, ^{57}Ni, ^{91}Zr, ^{139}Ba, and ^{209}Pb are considered as model nuclei. The wave-function of the outer most neutron orbit, matter density, valence neutron density, and magnetic form factors are numerically calculated. It is shown that there are significant differences between the magnetic form factors in the mediate- and high-momentum transfer regions when calculated with different parameter sets. Such separation is more evident with larger nuclear mass and isospin asymmetry. By fitting to the experimental data, the spectroscopic factors for ^{17}O and ^{41}Ca are obtained. From the fitting, we infer that including the isoscalar–isovector meson self-coupling can give a better performance of the RMF calculation.

Keywords: Elastic magnetic electron scattering; Relativistic mean-field model; Isoscalar–isovector meson self-coupling

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1. Introduction

Exploring the nuclear structure is a central topic of the nuclear physics. Along with the development of the field, a relativistic nuclear model, known as the relativistic mean field (RMF) model, was put forward in the last century [1,2]. Basing on the quantum hadrodynamics, the RMF model treats a nucleus as a system of Dirac nucleons coupled to exchange mesons through an effective Lagrangian. It has been shown to be one of the most successful nuclear structure models in depicting nuclear properties. The binding energies, the separation energies, the root-mean-square (rms) radii of charge density distributions, and the single-nucleon wave functions can be reproduced with good precision [3–8]. In addition, calculation results of the RMF model can be used as the input of some other investigations such as the relativistic elastic or quasi-elastic electron scattering [9–12,25], the anti-proton annihilation [26,27], the broken pseudo-spin symmetry [28–30], and the half lives of the cluster radioactivity of superheavy nuclei [31,32]. Nowadays, there are many applications with many refinements: Dirac–Hartree–Bogoliubov pairing mechanism [33,34], density-dependent meson–nucleon couplings [35], nonlinear isoscalar–isovector meson self-coupling [36], Λ-hypernucleon degrees of freedom [37,38], etc.

In a previous work [12], the authors theoretically examine the effect of the nonlinear isoscalar–isovector meson self-coupling (ω–ρ coupling) in the RMF model via the parity-violating electron scattering. Their work shows that different ω–ρ coupling strengths could give rise to the different sharps of the cross section which may be comparable with the experimental data in the future. Through their work one may take an insight into how the non-linear meson coupling effects in an atomic nucleus, and identify which parameter set is more suitable for a specific nucleus. Besides the parity-violating electron scattering, the elastic magnetic electron scattering is another sensitive and direct method to study the nuclear structure. Certain important magnetic properties and valence nucleon orbital shapes can be uncovered by comparing the experimental data with magnetic form factors and nuclear structure models. Inspired by these advances, it is interesting and necessary to address the effect of ω–ρ coupling from another point of view with elastic magnetic electron scattering, because this may open a new field of vision. To this end, we consider three RMF models, i.e., NL3, FSUGold, and IU-FSU, in which various values of the ω–ρ coupling parameter Λ_V are included. Moreover, seven odd-A nuclei: ^{7}Be, ^{17}O, ^{41}Ca, ^{57}Ni, ^{91}Zr, ^{139}Ba, and ^{209}Pb are chosen as model nuclei to accomplish our calculation and demonstrate the numerical analysis. The above nuclei all have an even number of protons and a single neutron outside a magic neutron core. According to the shell theory, their last neutron occupying the highest energy orbit determining the nuclear spin and parity. Therefore the magnetic form factors of these nuclei can be determined by the outermost-shell single-neutron orbital wave-function. Another reason for the chosen nuclei is that, they are not only representatives of the light, mediate, and heavy mass nuclei on the periodic table, but also characterized by very different isospin asymmetry ($T_z = (N - Z)/2$). For example, it is a quite small value of $1/2$ for ^{17}O and ^{41}Ca, a mediate value of $27/2$ for ^{139}Ba, while a huge value of $45/2$ for ^{209}Pb. Such that the calculation on these nuclei can also show the dependence of the effectiveness of the ω–ρ coupling on the nuclear mass as well as the isospin asymmetry.

Elastic magnetic electron scattering experiments on stable nucleus ^{17}O and long-lived nucleus ^{41}Ca were already performed in the last century [13–16]. In recent years, based on the development of radioactive-isotope beam technology, some new facilities for electron scattering on short-lived nuclei have been constructed or under construction at different groups. For instance, the MUSES and self-confining radioactive isotope ion target at RIKEN in Japan has been constructed and experiments are already performed in this facility [17–22]. Moreover, the

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