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Theoretical study on nuclear structure by the multiple Coulomb scattering and magnetic scattering of relativistic electrons

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Abstract

Electron scattering is an effective method to study the nuclear structure. For the odd-A nuclei with proton holes in the outmost orbits, we investigate the contributions of proton holes to the nuclear quadrupole moments Q and magnetic moments μ by the multiple Coulomb scattering and magnetic scattering. The deformed nuclear charge densities are constructed by the relativistic mean-field (RMF) models. Comparing the theoretical Coulomb and magnetic form factors with the experimental data, the nuclear quadrupole moments Q and nuclear magnetic moments μ are investigated. From the electron scattering, the wave functions of the proton holes of odd-A nuclei can be tested, which can also reflect the validity of the nuclear structure model.
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1. Introduction

Electron scattering at high energies is one of the most powerful tools to investigate the nuclear structure, because the electron–nucleus interaction is well understood [1–6]. According to

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the contributions from the Coulomb and magnetic interactions, electron scattering can be divided into the Coulomb scattering (or longitudinal scattering) and magnetic scattering [7]. In the past decades, the nuclear charge densities of many stable have been determined accurately by the electron Coulomb scattering [8,9]. Recently with the development of Radioactive Ion Beam (RIB) facilities, some exotic nuclei far away from the β stability line with short half-lives can be produced [10,11]. It is valuable for us to explore the charge density distributions of exotic nuclei with the electromagnetic probes. For this purpose, the new generation electron scattering facilities are under construction at RIKEN [12–14] and GSI [15,16]. It is expected that in the near future elastic electron scattering off exotic nuclei can be achieved [17,18].

Besides the nuclear Coulomb scattering, the electron magnetic scattering is another fundamental method to explore the nuclear magnetic properties and valence nucleon orbits [19]. Differently from the Coulomb scattering where all the charged nucleons contribute equally, the magnetic electron scattering is largely due to contributions of the unpair nucleon in the outmost orbit. The electron magnetic scattering provides a model-independent method to determine the nuclear shell energy level and wave functions of the valence nucleon. Therefore the electron magnetic scattering experiments have been widely used to investigate the valence structure of the nuclei [20–26].

With the rapid development of the experiments, great efforts have also been devoted to the theoretical studies of electron scattering off nuclei in the last decade [27–39]. The plane-wave Born approximation (PWBA) is a simple method to solve the electron scattering where the effects of nuclear Coulomb field on the scattering electrons are neglected. The phase-shift analysis method is an effect way to study the electron scattering which includes the Coulomb distortion effects by the exact phase-shift analysis of Dirac equations. This calculation method is also referred to as the distorted-wave Born approximation (DWBA) [40,41]. The phase-shift analysis method is an accurate method to calculate the cross sections of scattering electrons and has been applied in many theoretical studies [32–38].

During the studies of electron scattering, the nuclear form factors can be decomposed into several multipoles according to the selection rules, such as C_0, C_2 and M_1. For the Coulomb scattering off spherical nuclei, only the C_0 contributions need to be taken into consideration. For the deformed nuclei, the high multipoles C_λ ($\lambda \geq 2$) can reflect the contributions of nuclear deformation. In the last decade, some researches focused on the Coulomb scattering off spherical nuclei where the C_0 contributions are precisely calculated under the DWBA method [29,32, 33,37]. As we know, most of the nuclei are found to be deformed in their ground states both theoretically and experimentally [42–44], and the high multipoles C_λ ($\lambda \geq 2$) need to be included during the studies. In Ref. [45], the dependence of the cross section on the parameter ξ of DWBA calculations of C_2 multipole were investigated for ^{27}Al. For the C_0 and C_2 contributions, there are also detailed comparative analysis on the PWBA and DWBA calculations in Refs. [46–49].

On the basis of studies done before, in this paper the Coulomb and magnetic multipoles are systematically investigated for the odd-A nuclei with proton holes in the outermost orbits. The nuclei ^{14}N, ^{27}Al and ^{39}K are chosen as the candidate nuclei. Their nuclear quadrupole and magnetic moments are assumed as the contributions of the proton holes in the outermost orbits. The density distributions of deformed nuclei are constructed by the relativistic mean-field (RMF) model. After providing the deformed density distribution, the nuclear longitudinal form factors $F_L(q)$ are derived under the PWBA method. Then we take into account the Coulomb distortion corrections. By comparing the theoretical $F_L(q)$ with the experimental data, the nuclear quadrupole moments Q can be extracted from the electron scattering experiments.

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