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Polarization in nuclear excitation by electron impact

D.H. Jakubassa-Amundsen

Mathematics Institute, University of Munich, Theresienstrasse 39, 80333 Munich, Germany

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Abstract

Electron–electron polarization correlations from nuclear excitation by spin-polarized electrons are studied within the distorted-wave Born approximation. Restriction is made to spin-0 and to unpolarized spin-$\frac{1}{2}$ nuclei. When Coulomb scattering is dominant the resulting spin asymmetries may exceed those from elastic scattering. However, at the backmost scattering angles or for large transition current densities where magnetic scattering prevails, there is a strong suppression of the transverse polarization correlations. Predictions are made for the excitation of the lowest 3^- and 5^- states of ^{208}Pb and the lowest $\frac{5}{2}^-$ state of ^{89}Y by 60–220 MeV electrons.

Keywords: Polarized electron scattering; Nuclear excitation; Spin asymmetry

1. Introduction

With the design of new powerful electron accelerator and detector systems [1] and the availability of polarized electron beams of high intensity [2–5] the interest of investigating nuclear structure by inelastic electron scattering [6,7] has been revived (see, e.g. [8]). Probing the nucleus by electron impact has the advantage of a weak coupling between the collision partners such that a first-order perturbative treatment is usually sufficient. Early calculations of excitation probabilities and spin asymmetries relied on the plane-wave Born approximation (PWBA) [9–13], but later the use of distorted waves for the scattering electron (DWBA) has become standard for the analysis of experimental cross section data for medium and heavy nuclei ([6], see

E-mail address: dj@math.lmu.de.

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also [14–18]). Moreover, while photon-impact excitation of heavy nuclei is basically restricted to dipole transitions (for the $L = 1$ excitation of Pb by polarized photons, see [19]), electron impact allows for the population of nuclear states of arbitrary multipolarity [7]. The use of polarized electron beams or polarized targets and the measurement of spin asymmetries in addition to mere differential cross sections provide a sensitive probe of the nuclear form factors, including their relative phases, which are involved in the excitation of a given nuclear state [11–13]. On the other hand, the respective transition densities (the Fourier–Bessel transforms of the form factors), entering into the DWBA, depend strongly on the underlying nuclear models [20,7]. Hence, a precise experimental determination of the spin asymmetries provides a more stringent test of the nuclear models than the cross section measurements.

Up to now, mostly proton targets or light nuclei have been investigated. Measurements of the spin asymmetry for high-energy polarized electrons colliding with heavy targets [21,2,3] and corresponding calculations (see, e.g., [22–24]) have only been performed for elastic scattering. There are predictions for the polarization correlations in inelastic scattering of electrons from light polarized targets, as well as from ^{181}Ta, probing their sensitivity to different nuclear models [11,12,25]. Only longitudinally polarized electrons were considered, and the collision energies investigated were usually well above 200 MeV. Moreover, it was shown in the context of 180° scattering cross sections for ^{181}Ta that the PWBA used so far [11] even fails qualitatively when compared to DWBA results [26].

It is the aim of the present work to study the polarization correlations pertaining to arbitrary spin-polarized electrons in the initial as well as in the final state, which have not been investigated so far. In order to establish the significance of these polarization correlations and to investigate their dependence on the parameters of the collision system, use will be made of the known transition densities extracted from experiment. Conventionally these transition densities are obtained from the measured cross sections by means of a Fourier–Bessel analysis [27,17,18]. We will concentrate on the excitation of low-lying states of heavy nuclei because there the cross sections are large which is necessary for a precise measurement of the spin asymmetries. Restriction will be made to spinless nuclei, where only a single multipolarity contributes to the excitation, and to spin-$\frac{1}{2}$ nuclei where at most four transition densities come into play. By circumventing a superposition of too many multipolarities, this choice of targets allows for a separate study of the influence of these transition densities on the spin asymmetry. Emphasis will be laid on the backmost scattering angles, apt to the S-DALINAC detection system [28,29], and on collision energies near and below 200 MeV, where one knows from (elastic) potential scattering that the transverse spin asymmetries are large, particularly for heavy (spinless) nuclei [21,30–32].

In contrast, it was shown that for elastic scattering from nuclei carrying spin the presence of magnetic scattering strongly reduces the transverse spin asymmetry as compared to neighboring spin-0 nuclei [36], the more so, the smaller the nuclear charge. This might lead to the conjecture that for a nuclear transition in which only a fraction of the protons participate, the transverse asymmetry is considerably smaller than for elastic scattering. It will be shown below that this is not necessarily the case.

The paper is organized as follows. Section 2 provides an outline of the scattering theory, and numerical details are given in Section 3. Results for the cross sections and polarization correlations for electron-impact excitation of ^{89}Y ($5/2^-$) at an excitation energy $E_x = 1.745$ MeV, of ^{208}Pb (3^-) at 2.614 MeV and of ^{208}Pb (5^-) at 3.198 MeV are displayed in Section 4. The conclusion is drawn in Section 5. Atomic units ($\hbar = m = e = 1$) are used unless indicated otherwise. In particular, the electron mass m is retained throughout.