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Electron scattering of ^{14}N based on two-hole excitations

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ABSTRACT

The nuclear structure of ^{14}N is studied in the framework of the hole-hole Tamm-Dancoff Approximation (*hh*TDA) and hole-hole Random Phase Approximation (*hh* RPA). The Hamiltonian is diagonalized within a model space with particle orbits {$1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$ and $1f_{7/2}$}and the hole orbits {$1s_{1/2}$, $1p_{3/2}$ and $1p_{1/2}$} using Warburton and Brown interaction WBP. The TDA and RPA amplitudes are used to calculate the longitudinal and transverse electron scattering form factors. The results for $J_f^\pi T_f(E_x\ \mathrm{MeV}) = 1^+0(0.0)$, $0^+1(2.313)$, $1^+(3.945)$, $2^-0(5.106)$ and $3^-0(5.834)$ states are interpreted in terms of the harmonic-oscillator (HO) wave functions of size parameter b and compared with the available experimental data. Configurations outside the model space are included approximately, in terms of polarization effective charges and g-factors.

1. Introduction

A nuclear many-body problem is generally difficult to solve exactly. Various approximate approaches exist to deal with such systems. The collective excited states of closed shell nuclei can be described as a linear combination of particle-hole (*ph*) states for a truncated model space [1–7]. The nuclear charge-changing *ph* excitations correspond to the transition of nucleon from the ground-state of the nucleus (N, Z) to the final states in the neighboring nuclei ($N \mp 1$, $Z \pm 1$) [8]. The generalized density random phase approximation GDRPA Hamiltonian is expressed in terms of the one-body particle-particle (*pp*) and hole-hole (*hh*) density matrices, and the nuclear force contributes not only in the *ph* channel, as in normal RPA [9].

According to the collective models, the excited states of A-2 nuclei can be described as a linear combinations of hole-hole pairs. Such an approximation is called hole-hole Tamm-Dancoff Approximation *hh* TDA [1,3]. A system of states more general than that considered in the TDA appears when treating the ground states and the excited states more symmetrically. In that case, the ground state as well as the excited states are treated on the same footing, both the ground states and the excited states can be described as a linear combination of hole-hole states. Such an approximation is referred as the hole-hole Random Phase Approximation *hh* RPA [10–12], see Fig. 1

The Electron-nucleus scattering is a successful and powerful tool in studying nuclear structure and gives the most precise information about nuclear size and charge distribution, and it provides important information about the electromagnetic currents inside the nuclei. The well-understood electron scattering reaction provides a clear test for the reliability of the TDA and RPA wave functions.

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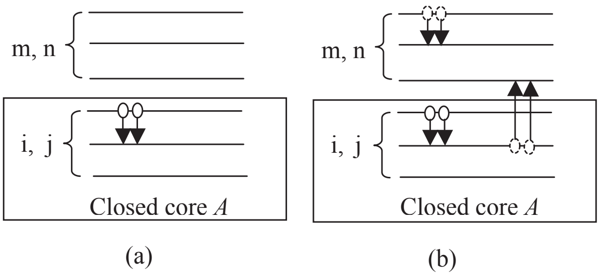

Fig. 1. Collective excited model space, (a) *hh* TDA and (b) *hh* RPA.

The scattering cross section for relativistic electrons from spinless nucleus of charge Ze was first derived by Mott [5,13]. The nuclear size can be taken into account by multiplying the Mott's cross section by a factor depending on the charge, current and magnetization distributions in the target nucleus, this factor is called Form Factor (*F*). The form factor can be found experimentally as a function of the momentum transfer (q) by knowing the energies of the incident and scattered electron and the scattering angle.

The first Born-approximation is valid only if $Z\alpha \ll 1$, where α is the fine structure constant. There are two types of nuclear form factors. The first is the longitudinal form factor (Coulomb form factor) in which the electron interacts with the charge distribution of the nucleus where the interaction is considered as an exchange of a virtual photon carrying a zero angular momentum along the direction of the momentum transfer (q). This process gives all information about the nuclear charge distribution. The second type is the transverse form factor where the electron interacts with the magnetization and current distributions, a virtual photon with angular momentum ± 1 along q direction being exchanged between the incident electron and the nuclear target. It provides the information about the nuclear current and magnetization distributions [14,15].

In this work, the structure of ^{14}N is studied in the framework of the *hh*TDA *and hh* RPA. The calculation within a model space with particle orbits $\{1d_{5/2}, 1d_{3/2}, 2s_{1/2}$ and $1f_{7/2}\}$and the hole orbits $\{1s_{1/2}, 1p_{3/2}$ and $1p_{1/2}\}$ using Warburton and Brown interaction WBP [16] is performed. The1*s*, 1*p*, 2*s*1*d*, 2p1f-shells (WBP) interaction is determined by least square fitting with experimental single particle energies SPE and two-body matrix element TBME. The TDA and RPA amplitudes are used to calculate the longitudinal and transverse electron scattering form factors. The results for $J_f^{\pi} T_f (E_x \text{ MeV}) = 1^+0(0.0), 0^+1(2.313)$, $1^+(3.945)$, $2^-0(5.106)$ and $3^-0(5.834)$ states are interpreted in terms of the harmonic-oscillator (HO) wave functions of size parameter *b*. Configurations outside the model space are included approximately, in terms of polarization effective charges and g-factors. A comparison with the available electron scattering form factors is presented.

2. Theory

2.1. Random phase approximation RPA

Collective excited states of $A-2$ systems of multipolarity J and isospin T are generated by operating on the ground state of A nucleons system with annihilation operators [10]:

$$|A-2,\lambda\rangle = \left(\sum_{i \le j} X_{ij}^{\lambda} a_i a_j - \sum_{m \le n} Y_{mn}^{\lambda} a_m a_n \right) |A,0\rangle \tag{1}$$

Here $|A{,}0\rangle$ is the ground state in the closed shell system of A nucleons, a is annihilation operator, Indices (ij) represent the quantum numbers of orbits below the Fermi sea and we shall call refer to these states as hole states. Indices (mn) represent orbits above the Fermi sea and we call such states particle states.X_{ij}^{λ} and Y_{ij}^{λ} are amplitudes.

The familiar hole-hole *hh*RPA equations can be written as:

$$\begin{aligned} (-\omega_\lambda + \varepsilon_i + \varepsilon_j)\, X_{ij}^{\lambda} &= \sum_{i' < j'} V_{iji'j'}^{JT}\, X_{i'j'}^{\lambda} - \sum_{n' < m'} V_{ijn'm'}^{JT}\, Y_{n'm'}^{\lambda} \\ (\omega_\lambda - \varepsilon_n - \varepsilon_m)\, X_{nm}^{\lambda} &= -\sum_{i' < j'} V_{nmi'j'}^{JT}\, X_{i'j'}^{\lambda} + \sum_{n' < m'} V_{nmn'm'}^{JT}\, Y_{n'm'}^{\lambda} \end{aligned} \tag{2}$$

$\omega_\lambda = E_0^A - E_\lambda^{A-2}$ is the excitation energy, ε_i is single particle energy and $V_{iji'j'}$ are antisymmetrized two-body matrix elements. Solving Equations (2) is equivalent to diagonalize a matrix [17]