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Nuclear Physics A 974 (2018) 124–137

NUCLEAR PHYSICS A

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Influence of the Pauli exclusion principle and the polarization of nuclei on the nuclear part of the interaction potential in the $^{40}Ca + ^{40}Ca$ system

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Received 18 June 2016; received in revised form 26 January 2018; accepted 21 February 2018
Available online 12 March 2018

Abstract

In the framework of the energy density method with the use of the wave function of the two-center shell model, the influence of the simultaneous account for the Pauli exclusion principle and the monopole and quadrupole polarizations of nuclei on the nuclear part of the potential of their interaction by the example of the $^{40}Ca + ^{40}Ca$ system is considered. The calculations performed in the framework of the adiabatic approximation show that the consideration of the Pauli exclusion principle and the polarization of nuclei, especially the quadrupole one, essentially affects the nucleus–nucleus interaction potential.

Keywords: Nucleus; Interaction potential; Nucleon density distribution; Pauli principle; Antisymmetrization; Polarization

1. Introduction

The study of the interaction of atomic nuclei is one of the main tasks of nuclear physics. On this way, a lot of various approaches were developed. Our purpose consists in the calculation of the real part of the nucleus–nucleus interaction potential. To be more exact, we will calculate its nuclear part, which is of basic interest now from the viewpoint of the study of the interaction of atomic nuclei, since the Coulomb part of the potential is considered sufficiently well studied. The consideration is carried on with the exact account for the Pauli exclusion principle and

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https://doi.org/10.1016/j.nuclphysa.2018.02.006
0375-9474/

the polarization of nuclei. The latter involves generally changes in the size and the shape of nuclei due to their interaction. In the present work, we consider two types of polarization. In the case of monopole polarization, the nuclei can vary their size, by preserving the spherical shape. Under the quadrupole polarization, the nuclei can change not only sizes, but also the shape, by elongating or shrinking themselves along the interaction axis. Thus, they become the ellipsoids of rotation. Since we will consider the nuclear part of the nucleus–nucleus interaction potential, the influence of the Coulomb repulsion between protons namely on the polarization of nuclei lies somewhat outside the limits of our study. Here, it is worth noting that, in view of the quite different intensities of the nuclear and Coulomb interactions, the polarization of interacting nuclei due to the Coulomb interaction is insignificant as compared with the polarization caused by nuclear forces.

As is known, the polarization of nuclei can reveal itself most obviously at a sufficiently slow approaching of nuclei. Therefore, we will perform calculations in the framework of the adiabatic approximation, by assuming the relative motion of nuclei sufficiently slow in order that the nucleon density distribution in nuclei has time to be respectively rearranged for every specific distance between the centers of masses of nuclei. In practice, this can occur, for example, in the processes of cold fusion of nuclei, including those in the synthesis of superheavy elements.

We note that the monopole polarization of clusters in the lightest nuclei, i.e., nuclei at the onset of the p-shell, was considered in the framework of such microscopic approach as the method of resonating groups [1–8], and both the quadrupole and monopole polarizations were efficiently treated in its algebraic version [9–17]. These approaches are sufficiently sequential, but their realization is so complicated, that the solution of the problem posed in the present work is practically unreal now. Therefore, we choose a simpler approach to the solution of the posed problem, which allows us, nevertheless, to clearly indicate the importance to consider the Pauli exclusion principle and the polarization of interacting nuclei in the construction of potentials of their interaction.

Among many approaches [18–38] developed for the calculation of the nucleus–nucleus potential, we consider the energy density method [33,34] as the most convenient one for the above-posed problem. There, the potential is defined as the binding energy of the total system, from which the binding energies isolated nuclei is excluded. In this case, we will use the density-dependent energy functional for the Skyrme forces to determine the energy of a system [38]. These forces were fruitfully applied to the description of properties of the ground states of atomic nuclei in a wide interval of mass numbers and to quantum-mechanical calculations in the framework of the Hartree–Fock method [39–42], as well as to calculations executed in the quasiclassical approximation [43–47]. The simplicity of the chosen approach consists in that we should to determine, in fact, only the nucleon density ρ and the kinetic energy density, which will be denoted below by τ.

In the present work, we use the two-center shell model to calculate ρ and τ. The information about the development of this model can be found in [48]. Recently, its various modifications were applied to the solution of diverse problems, in particular, concerning the creation and decay of superheavy elements [49–51]. Like, for example, work [31], we represent the total wave function of a system of two nuclei as the Slater determinant on functions of a three-dimensional harmonic oscillator for two oscillator wells, whose centers are located at a distance R from each other. The axis z of the coordinate system, along which the nuclei approach each other, is directed along the straight line joining the centers of their masses. In this case, our wave function depends on, besides R, two oscillator lengths (b on the axes x and y; and c on the axis z), being the parameters. This allows the interacting nuclei to take the spherical or axisymmetric (ellip-