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PHYSICS LETTERS B

Physics Letters B 658 (2008) 198–202

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Virtual coupling potential for elastic scattering of ^{10,11}Be on proton and carbon targets

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Received 25 June 2007; received in revised form 31 October 2007; accepted 6 November 2007

Available online 12 November 2007

Editor: V. Metag

Abstract

The ^{10,11}Be(p, p) and (^{12}C, ^{12}C) reactions were analyzed to determine the influence of the weak binding energies of exotic nuclei on their interaction potential. The elastic cross sections were measured at GANIL in inverse kinematics using radioactive ^{10,11}Be beams produced at energies of 39.1*A* and 38.4*A* MeV. The elastic proton scattering data were analyzed within the framework of the microscopic Jeukenne–Lejeune–Mahaux (JLM) nucleon–nucleus potential. The angular distributions are found to be best reproduced by reducing the real part of the microscopic optical potential, as a consequence of the coupling to the continuum. These effects modify deeply the elastic potential. Including the Virtual Coupling Potential (VCP), we show the ability of the general optical potentials to reproduce the data for scattering of unstable nuclei, using realistic densities. Finally, the concepts needed to develop a more general and microscopic approach of the VCP are discussed.

PACS: 24.10.-i; 25.60.-t; 25.60.Bx; 25.40.Cm

Keywords: ^{10,11}Be(p, p); (^{12}C, ^{12}C); Virtual coupling potential; Weakly-bound nuclei

Light neutron-rich exotic nuclei are characterized by weak binding energies. They may develop peculiar structures like neutron-skin or halo structures. For instance, ^{6}He and ^{11}Be develop two-neutron and one-neutron halo, respectively. Another important effect is the couplings to the continuum states. The probability to be excited to continuum states is higher, compared to the stable isotopes, and this may induce new features in the interaction potential. The coupling to the other reaction processes may also be stronger. In principle, to calculate the interaction potential for elastic scattering, one should include all possible virtual couplings between the ground and higher excited states. These processes remove flux from the elastic channel. This effect is negligible for most stable nuclei, but be-

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0370-2693/$ – see front matter
doi:10.1016/j.physletb.2007.11.005

comes significant for weakly-bound nuclei [1]. The interaction term arising from couplings to inelastic channels is called the dynamical polarization potential (DPP) [1]. This term is complex, non-local and energy-dependent, it includes the coupling to excited states, the coupling to continuum states or to other reaction processes, like transfer reactions or break-up. We find it more appropriate to rename it as "virtual coupling potential" (VCP). The general formalism for such coupling processes in the interaction potential is described in Feshbach's theory [2]. But its exact calculation would require the precise knowledge of the spectroscopy of the nucleus and the transition strengths to bound and continuum excited states. Due to the difficulty to evaluate these interaction couplings, they are not taken into account a priori in the usual optical model approaches. However, in the case of a weakly-bound nucleus like ^{6}Li ($S_{alpha+d} =$ 1.46 MeV) easily described as a two-body nucleus, it was possible to describe microscopically the continuum states and to deduce the effect due to the coupling potential [3] in the elastic scattering of ^{6}Li on various targets. It was shown [1,3] that the coupling effects were responsible for the reduction of the real part of the potential needed to reproduce the elastic data in the framework of the folding model [4].

For exotic isotopes with lower particle thresholds, the coupling between the ground state and the continuum is expected to increase. Our aim is to investigate the effect of the weak binding of exotic nuclei on the elastic scattering data to test the validity of the effective nucleon–nucleon NN interactions used for the reaction analysis, and to know whether the weak binding of exotic nuclei should appreciably enhance the VCP. Finally we want to determine a general form of this potential. In [5], the ^{6}He(p, p) elastic scattering data at 38.3 A MeV were analyzed using the microscopic JLM potential [6]. It was shown [5] that the angular distributions of ^{6}He on proton are better reproduced with a reduction of the real part of the microscopic optical potential rather than with an enhancement of the imaginary part. The wide angular range of the angular distributions (up to 71.5° c.m.) allowed us to draw this conclusion. This effect was attributed to the continuum couplings. A phenomenological VCP was simulated. The same effect was found in the elastic scattering ^{6}He + ^{12}C [7]. The enhancement and the role of the continuum couplings in the case of the weakly-bound radioactive nucleus ^{6}He on proton target have been emphasized in [8] and the polarization potential was deduced microscopically from the inversion of the S-matrix in the framework of the Coupled Discretized Continuum Channels (CDCC) calculations.

Elastic data are well reproduced when the coupling effect is taken into account, as done, for instance, within the CDCC calculations, including some cluster structure or introducing a phenomenological VCP. Through the analysis of such data we can understand how the cross sections are affected by the coupling effects and it is possible to deduce the optical potentials required to describe the direct reactions; afterwards, we can check the validity of the microscopic densities tested in the reaction analysis. A similar analysis was carried out for the neutron-deficient ^{10,11}C [9]. In the case of the elastic scattering ^{8}He + p [10], we found that it was necessary to take into account the coupling to the (p, d) reaction within the coupled-reaction framework. It was shown that the important modification of the potential needed to reproduce the elastic scattering was due to the loss of flux in the one-neutron transfer reaction. In this case, the VCP was mainly produced by the (p, d) coupling effect.

A set of elastic data of light nuclei on protons, including ^{10,11}Be, was presented and analyzed in Ref. [11]. The data were well reproduced using global or microscopic proton–nucleus potentials provided that the real part was reduced or the imaginary part enhanced. However, the data did not extend to large enough angles to choose between the two possibilities.

This article presents new elastic scattering data of ^{10,11}Be on proton and carbon targets, collected at the GANIL (Grand Accélérateur National d'Ions Lourds, Caen, France). The angular distributions were measured at energies close to 40 A MeV up to 70° in the center of mass (c.m.) frame for proton scattering, and up to 20° c.m. for scattering on carbon.

The data were collected on a wide angular domain to investigate the VCP effect. The article explains the analysis carried out to discuss the coupling effects induced by ^{10,11}Be.

We first present our measurement. The analysis of the proton–nucleus elastic data is discussed, the VCP is introduced, and its effect is shown on the p-nucleus data. The data for ^{10,11}Be on carbon target are then compared to the folding model calculations and the influence of the VCP is explained. In conclusion, we discuss the general framework needed to develop a microscopic analysis of the VCP.

The experiment was carried out at the GANIL coupled cyclotron facility. The ^{10,11}Be secondary beams were produced by fragmentation of a 75 MeV/nucleon primary ^{18}O beam on a carbon production target located between the two superconducting solenoids of the SISSI device [12]. The secondary beams were purified with an achromatic degrader set in the beam analysis spectrometer. The ^{10,11}Be beams were obtained at energies of 39.1A and 38.4 A MeV, with intensities of the order 10^5 pps and 3.10^4 pps, respectively. They were scattered from a 10 mg/cm^2 thick polypropylene target (density of 0.896 g/cm^3). Elastic angular-dependent cross sections of ^{10,11}Be projectiles on protons and carbon nuclei were measured with the SPEG spectrometer [13]. The scattered particles were identified at the focal plane by the energy loss measured in an ionisation chamber and the residual energy measured in a thick plastic scintillator. The momentum and the angle after the target were obtained by track reconstruction of the trajectories determined by two drift chambers straddling the focal plane of the spectrometer. Position and angle of the projectiles on the target were determined event by two beam detectors. The experimental set-up is similar to the one described in [5,7] for the case of ^{6}He on protons and ^{12}C. With the polypropylene reaction target containing both hydrogen and carbon nuclei, we obtained a simultaneous measurement of the cross sections on protons and ^{12}C. The laboratory angle range covered was from 1.3° to 8.5°. The good energy resolution of the SPEG spectrometer ($\frac{\Delta E}{E} = 10^{-3}$) allowed us to extract the elastic scattering data on ^{12}C without any contamination from scattering to the ^{12}C excited states. Cross sections on ^{12}C are dominated at small an-