Microscopic model of optical potential for testing the ^{12,14}Be+p elastic scattering at 700 Mev

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Abstract. The data on the ^{12,14}Be + p elastic scattering cross sections at 700 Mev are compared with those obtained by solving the relativistic wave equation with the microscopic optical potentials calculated as folding of the NN amplitude of scattering with densities of these nuclei in the form of the symmetrized Fermi function with the fitted radius and diffuseness parameters, and also with the densities obtained in two microscopic models, based on the Generator Coordinate Method (GCM) and the other one – on the Variational Method of Calculations (VMC). For ^{12}Be, above models turn out to be in a small disagreement with the data at "large" angles of scattering $\theta \geq 9^\circ$, while for the ^{14}Be one sees some inconsistence at smaller angles, too.

1 Introduction

In the paper [1], the experimental data of the elastic scattering differential cross sections at small angles were obtained at near 700 MeV/u energy. These data have also been analyzed using the Glauber multiple-scattering theory where several phenomenological forms of density distributions for the ^{12,14}Be nuclei were fitted. In particularly, the symmetrized Fermi function (SF) was tested, too, as follows:

$$\rho_{SF}(r) = \rho_0 \sum_{\epsilon=\pm} \epsilon \frac{1}{1 + \exp \frac{r-\epsilon R}{a}} = \rho_0 \frac{\sinh(R/a)}{\cosh(R/a) + \cosh(r/a)} \qquad (1)$$

by fitting its radius R and diffuseness a parameters. This density has the true exponential asymptotic as compared to the other forms tested in [1] having the Gaussian behavior at their periphery.

In our study we, first, intend to calculate the so-called microscopic folding optical potentials (OP), depending on parameters of the NN amplitude of scattering, and also the effect of anti-symmetrization of nuclear nucleons. Then, second, to obtain the pA-amplitude of scattering and cross sections, we solve the relativistic Klein-Gordon wave equation rather than use the Glauber high-energy approach. And third, as for the input densities of nuclei ^{12,14}Be we apply the known SF-function with the same parameters as in [1], and also we test the densities, obtained in [2] by using the Variational Monte Carlo (VMC) model and densities of the Generator Coordinate Method (GCM) from [3]. All the computed cross sections have been compared with the corresponding experimental data. As for the sets of our input parameters for the NN amplitudes, we have used them as it is done in [1] in correspondence with the parametrization of the NN cross sections from [4], and the ratio of the imaginary to real NN amplitude of scattering at zero angle from [5].

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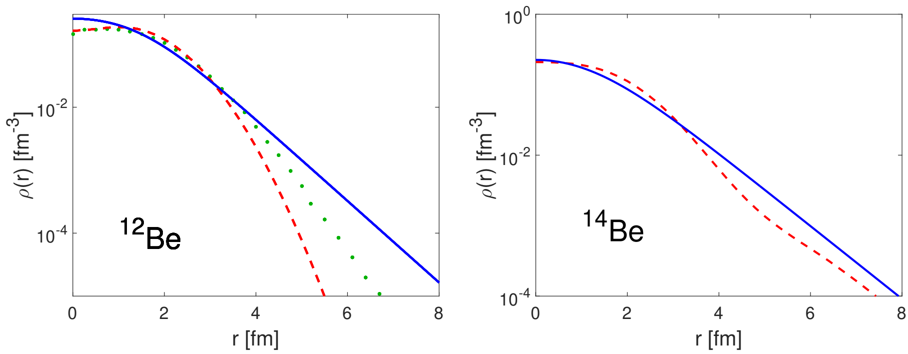

Figure 1. The ^{12}Be (left) and ^{14}Be (right) densities corresponding to the SF (blue solid), VMC (green dotted) and GCM (red dashed) models

2 Folding OP for pA elastic scattering

The microscopic folding OP, taken as done in [6], includes the real and imaginary parts:

$$U(r) = V(r) + i\,W(r) = -\frac{(\hbar c)\beta_c}{(2\pi)^2}\,\sigma\,[\alpha + i]\cdot \int j_0(qr)\,\rho(q)\,f(q)\,q^2 dq, \tag{2}$$

where $\beta_c = k/E$ is the light velocity, $f(q)$ – the form factor of the NN amplitude $F_{NN}(q)$, and $\rho(q)$ is the form factor of a nuclear density distribution:

$$\rho(q) = \int e^{i\mathbf{qr}}\,\rho(r)\,d^3r. \tag{3}$$

Here we use the charge-independent NN high-energy amplitude of scattering:

$$F_{NN}(q) = \frac{k}{4\pi}\,\sigma\,[i+\alpha]\cdot f(q), \qquad f(q) = e^{-\beta q^2/2}, \tag{4}$$

depending on 3 averaged parameters: σ – the total NN cross section, α - the ratio of the real part to the imaginary one of the NN amplitude at forward angles, and β – the slope parameter. In the case of SF-density for the ^{12,14}Be nuclei one can use the analytic form factor:

$$\rho_{SF}(q) = -\rho_0\,\frac{4\pi^2 aR}{q}\,\frac{\cos qR}{\sinh(\pi aq)}\left[1 - \left(\frac{\pi a}{R}\right)\coth(\pi aq)\tan qR\right], \tag{5}$$

where for the radius and diffuseness parameters and corresponding rms radii we take their magnitudes as they were fitted in [1], namely, for ^{12}Be: R=1.37 fm, a=0.67 fm, R_{rms}=2.7 fm and for ^{14}Be: R=0.99 fm, a=0.84 fm, R_{rms}=3.21 fm.

As for the VMC [2] and GSM [3] densities they are shown in Fig. 1 together with the SF-densities. Their rms-radii for the proton, neutron and nucleon (matter) distributions are done as follows for ^{12}Be : VMC R_{rms}(p)=2.2946 fm, R_{rms}(n)=2.601 fm, and GSM R_{rms}(p)=2.20 fm, R_{rms}(n)=2.33 fm, R_{rms}(m)=2.29 fm; and for ^{14}Be: GSM R_{rms}(p)=2.28 fm, R_{rms}(n)=2.95 fm, R_{rms}(m)=2.78 fm. The corresponding calculated optical potentials are shown in Fig. .2 for their real parts having the depths proportional to $\sigma \cdot \alpha$ while their imaginary parts have the same forms but the depths being negative and proportional to σ only. In our estimations, we have taken the OP parameters in Eqs. (2),(4) as they are done in [1] but neglecting differences between *pp* and *pn* interactions, namely, σ=43.6 mb, α=-0.3 and β=0.17 fm^2. One can see that OPs calculated for the given forms of the ^{12}Be densities behave differently at $r > 4$ fm while the ^{14}Be+p potentials for SF and GSM densities have almost the same slope but different magnitudes at $r > 5$ fm.

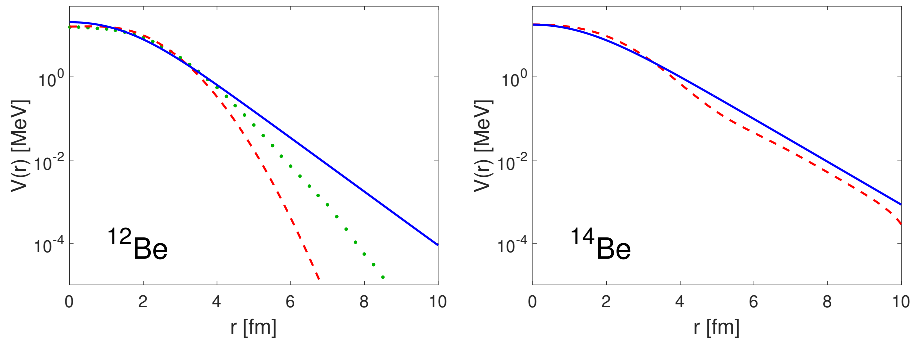

Figure 2. The real parts of optical potentials for ^{12}Be+p (left) and ^{14}Be+p (right) scattering calculated using the SF (blue solid), VMC (green dotted) and GCM (red dashed) densities

3 Comparison with experimental data

When calculating the differential cross sections for scattering in the corresponding optical potentials (2) with the SF-, VMS- and GSM-densities of ^{12,14}Be nuclei we apply the DWUCK4 code [7] transformed for relativistic energies when the code solves the wave equation:

$$\left(\Delta + k^2\right)\psi(\vec{r}) = 2\bar{\mu}U(r)\psi(\vec{r}), \quad U(r) = U^H(r) + U_C(r). \tag{6}$$

Here k, the relativistic momentum of a nucleon in center-of-mass (c.m.) system,

$$k = \frac{Mk^{lab}}{\sqrt{(M+m)^2 + 2MT^{lab}}}, \quad k^{lab} = \sqrt{T^{lab}\left(T^{lab} + 2m\right)}, \tag{7}$$

and $\bar{\mu} = \frac{EM}{E+M}$ is the relativistic reduced mass, $E = \sqrt{k^2 + m^2}$, the total energy in c.m. system, m and M are the nucleon and nucleus masses.

The results of the cross section calculations for the ^{12,14}Be + p scattering at 700 MeV are shown in Fig. 3. First, one sees that for ^{12}Be the tested VMC-density provides a reasonable agreement with all the data, and the GSM-density is consistent with the data only at $\vartheta < 9°$, while in the case of SF-density one gets a good fit of the data at all angles of scattering. In the case of ^{14}Be one obtains the remarkable accordance with the data for the SF-density while in the case of GCM-density one sees a considerable excess of the data at $\vartheta > 4°$.

4 Summary

- We have used the folding optical potentials which include the nuclear density and NN amplitude, and thus their forms and parameters are tested when the calculated cross sections are compared with the existing experimental data.
- In calculations, the relativistic wave equation has been applied to get the wave functions of scattering and corresponding differential cross sections of the proton-nucleus scattering.
- Comparison of the calculated cross sections with existing data has shown a good agreements for the phenomenological SF nuclear density having a long tail for the ^{14}Be nucleus while the GSM and VMC densities give acceptable agreements for scattering on ^{12}Be for both densities, but some limited agreement for scattering on ^{14}Be.

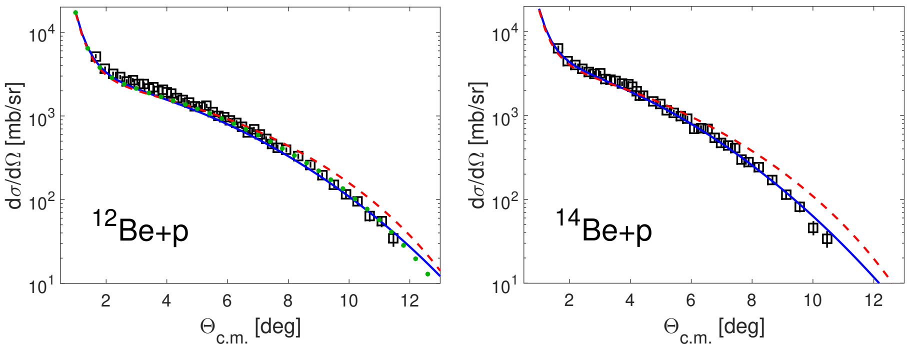

Figure 3. Comparison with experimental data of the calculated cross sections when using the SF (blue solid), VMC (green dotted) and GCM (red dashed) nuclear density distributions. The left side is for ^{12}Be+p at 703.5 MeV, and the right one is for ^{14}Be+p at 702.9 MeV

- Comparison of our calculations with those based on Glauber approximation has shown close agreement at rather high energies.
- Bearing in the mind that the given nuclear densities have been tested here in comparison with the corresponding experimental data at rather high energies it would be desirable to test them also when considering the data of scattering at lower energies.

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