

Analysis of Elastic Scattering Angular Distributions of $^{11}\text{Be} + ^{64}\text{Zn}$ System: Compression with Different Models

Şule Karatepe^{1,*}, İsmail Boztosun² and Mahmut Doğru³

¹Hizan Vocational School, Bitlis Eren University, Bitlis, Turkey; skaratepe@beu.edu.tr

²Department of Physics, Faculty of Sciences, Akdeniz University, Antalya, Turkey; boztosun@akdeniz.edu.tr

³Department of Physics, Faculty of Sciences, Firat University, Elaziğ, Turkey; dogrum@gmail.com

Abstract

Objectives/methods: In this study, $^{11}\text{Be} + ^{64}\text{Zn}$ system was analysed in the energy around coulomb barrier. Within the optical model, the frameworks were phenomenologically investigated using cluster structure and coupled-channels model. **Findings:** The model with the best results was determined. Reaction cross-section and error account were made. The obtained results were compared with both experimental data and each other. **Applications:** This comparison showed that the cluster structure within optical model was better than coupled-channels model and optical model for experimental data.

Keywords: Optical Model, Elastic Scattering, Coupled Channels, Cluster Structure

1. Introduction

In the recent years, important studies have been conducted for elastic scattering analysis. Elastic scattering of the exotic nuclei from the stable targets is important for understanding the structure of the exotic nuclei. Elastic scattering provides information about the size of the nucleus, surface diffusion attempt and the surface features. It also shows the effect of projectile-target potential form.¹ Numerous researches about exotic nuclei such as ^{11}Li and ^{11}Be have been reported.¹⁻³

^{11}Be is known as a neutron halo nucleus whose neutron separation energy is 504 keV. Its primary excitation energy is 320 keV.²⁻⁴ It is important to examine the transfer or breakup processes of elastic scattering of ^{11}Be projectile with the target around coulomb barrier. Thus, both experimental and theoretical studies have been reported in literature with different target nuclei such as ^{12}C , ^{64}Zn , ^{209}Bi and ^{208}Pb . Models such as phenomenological and microscopic optical models, CC (coupled channels)

model, CDCC (continuum discretized coupled channels) have been used in these studies.⁵⁻⁸

In this study, the interaction of ^{11}Be projectile with ^{64}Zn target was analyzed at the energies around the coulomb barrier. Calculations using the cluster structure with phenomenological optical model, CC model and optical model were performed and compared with experimental results in literature.

2. Optical Model Analysis

2.1. Phenomenological Optical Model

One of the best models explaining elastic scattering is the optical model. The interaction potential between the projectile and the target is important. The total interaction potential composed of nuclear, coulomb and centripetal potential is

$$V_{total}(r) = V_{Coulomb}(r) + V_{Nuclear}(r) + V_{Centripetal}(r) \quad (1)$$

*Author for correspondence

where the coulomb potential is formed by the interaction of the projectile and the target depending on the distance between them.

$$V_{\text{Coulomb}}(r) = \frac{1}{4\pi\epsilon_0} \frac{Z_p Z_T e^2}{r} \quad r \geq R_c$$

$$= \frac{1}{4\pi\epsilon_0} \frac{Z_p Z_T e^2}{2R_c} < R_c \quad (2)$$

where R_c is the interaction radius, Z_p and Z_T are the charge of the projectile and the target. For $^{11}\text{Be} + ^{64}\text{Zn}$ reaction, coulomb barrier is approximately 20 MeV. The centripetal potential is

$$V_{\text{centripetal}} = \frac{\hbar^2 l(l+1)}{2\mu r^2} \quad (3)$$

where μ is the reduced mass of the interaction ($^{11}\text{Be}-^{64}\text{Zn}$).

The last term of the total potential, the complex nuclear potential is defined $V_{\text{Nuclear}}(r)$ as sum of the Woods-Saxon square shaped real and Woods-Saxon shaped imaginary potentials as

$$V_N(r) = - \frac{V_0}{\left[1 + \exp\left(\frac{r-R_v}{a_v}\right)\right]^2} - i \frac{W_0}{\left[1 + \exp\left(\frac{r-R_v}{a_v}\right)\right]^2} \quad (4)$$

where V_0 , W_0 are the real and imaginary potential depths, respectively, and the nuclear radius is

$R_i = r_i(A_p^{1/3} + A_T^{1/3})(i = v \text{ or } w)$, where A_p and A_T are the masses of the projectile (incoming nuclei) and the target (fixed core-nuclei), respectively, and r_v and r_w are radius parameters of the real and imaginary parts of the nuclear potential, respectively.

In the optical model, the volume integral term was calculated for both real and imaginary parts.

$$J_{v,w} = \frac{4\pi}{A_p A_T} \int_0^\infty U_{v,w}(r) r^2 dr \quad (5)$$

where A_p , and A_T are the mass of the target and the projectile nuclei.

2.2. CC Model

In the CC model, deformed optical potential is defined in the interaction between two nuclei.⁹ The deformed structure of the nucleus is considered. Optical model calculation has been done.¹⁰ In this study, the square of a Woods-Saxon shape was used for the real part and the

standard Woods-Saxon shape was used for the imaginary part.

Deformation was used for both the projectile and the target. In this study, deformation was applied for the projectile. Deformation parameter(β) derived at B(E1) value was used in the calculations.

2.3. Cluster Model

In this model, calculation was done at optical model limits. It is important that the nuclear potential is well-defined. Here, it is considered as a cluster structure in the form of $^{11}\text{Be} \rightarrow ^{10}\text{Be} + n$.

Potential is defined separately for $n + ^{10}\text{Be}$ (valance-core), $n + ^{64}\text{Zn}$ (valance-target) and $^{10}\text{Be} + ^{64}\text{Zn}$ (core-target), and nuclear potential is determined. Thus, the best interaction potential between the target and the projectile nucleus is defined. These potentials are also at the optical potential limits. These potentials were determined in Woods-Saxon type. The potential obtained in the literature was arranged for $n + ^{64}\text{Zn}$, and also the literature data were used for the $n + ^{10}\text{Be}$ binding potential.

3. Results and Discussion

In this study, the interaction of ^{11}Be projectile with ^{64}Zn target was examined and compared using different models. Scattering angular distribution of $^{11}\text{Be} + ^{64}\text{Zn}$ reaction at 25.4 MeV was analyzed. Calculations were performed using optical model, cluster model and CC model. The potentials used in calculations were determined as the best values to obtain compatible results with the experimental data and were compared with experimental data.

At first the shape of the nuclear potential within the optical model limits was determined by FRESKO program codes. From the literature, it was found that real and imaginary parts of optical potential showed a fit in Woods-Saxon volume form. Thus, in phenomenological optical model calculations, optical potential in Woods-Saxon volume form was used as the interaction potential for real and imaginary potentials. Volume parameter of both real and imaginary potentials was taken as a free parameter. The obtained results were used to explain the experimental data in literature.^{1,6,11-13}

In calculating the optical model framework, coulomb potential was taken as $r_c = 1.2$ fm. Table 1 shows potential depth, radius and diffusion parameters used for nuclear potential. In imaginary potential, radius and diffusion

Table 1. Optical potential parameters for the optical model

V_0 (MeV)	r_0 (fm)	a_0 (fm)	W_V (MeV)	r_w (fm)	a_w (fm)	J_V (MeVfm ³)	J_W (MeVfm ³)	σ_{top} (b)	χ^2
150.8	1.5	0.4	50.9	1.7	0.7	216.1378	72.0459	2093.9	0.29

parameters were kept constant at the beginning, and the effect of depth on angular distribution was examined.

Then, analysis was performed in the same way for other parameters and the best fit was obtained. Figure 1 shows angular distribution of the effect section calculated by optical model parameters. Elastic scattering was explained well by the optical model. The total cross-section was obtained as $\sigma = 2093.9$ mb. ¹¹Be + ⁶⁴Zn interaction does not have a structure with oscillation. However, it cannot explain the coulomb peak well.

In the calculation of CC model, the parameters used in the optical model were used. Although the optical model explained elastic scattering, it cannot explain the flux going to the non-elastic channel. The CC model was applied to explain the flux in imaginary potential. Deformation parameter was added for the E1 level for ¹¹Be nucleus. Deformation coefficient was used as $\beta = 0.6075$ (Satchler, G. R., 1983; Thompson, I. J., 1988). It showed the coulomb peak in the experimental data better. The effect section was obtained as $\sigma = 2471.28$ mb. Figure 1 shows the angular distribution of the cross-section.

Cluster model calculation was performed within the limits of optical model. In the cluster model, considering the ¹¹Be nucleus as core and valence, it was taken as $11\text{Be} \rightarrow 10\text{Be} + n$. In this case, examination was performed as if there are three objects, and a neutron of ¹¹Be exotic nucleus was taken as the valence. Interaction potential was determined as the potential between the core + valence binding potential, core + target, and valence + target.

Optical potential was used for the nuclear potential used in the calculation, and Woods-Saxon volume form was selected for thereal and imaginary parts.

Because the neutron was uncharged, due to the absence of coulomb potential in the interactions between

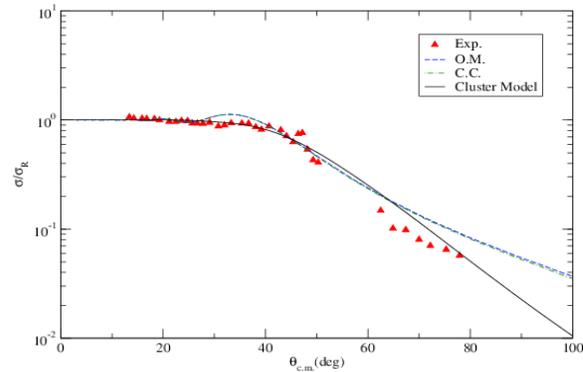


Figure 1. Elastic scattering angular distribution for the ¹¹Be + ⁶⁴Zn system at 25.4 MeV. The continuous line is the result of the optical model.

valence-core and valence-target, it was not included in the calculation in FRESKO program card. Table 2 shows the parameters used in the calculation and reaction cross-section obtained.

4. Conclusion

The exotic nuclei have been subject to numerous studies within the last 30 years due to their different structures. In addition to experimental studies, theoretical studies shedding light on the experimental studies have been conducted and continue to be reported.

Theoretical studies are important to determine parameters such as proper target and energies while conducting experimental studies to observe the effect of coulomb and nuclear potentials in exotic nuclei. In the present study, ¹¹Be + ⁶⁴Zn system was analysed at 25.4 MeV around the coulomb barrier energy. From our results, it was observed that cluster model is better than optical model and CC model in explaining the

Table 2. Optical potential parameters for the cluster model

¹¹ Be + ⁶⁴ Zn	V_0 (MeV)	r_0 (fm)	a_0 (fm)	W_V (MeV)	r_V (fm)	a_V (fm)	σ_{top} (mb)	χ^2
Core + valence	39.93	1.375	0.5	14.12	1.35	0.2		
Core + target	142.36	0.9	0.7	5.79	1.5	0.7	2686.37	0.9
Valence + target	43.16	0.6	0.5	16.33	1.35	0.2		

experimental data. In the CC model, it was determined that the effect of the first excited state of ^{11}Be nucleus was low. Therefore, it was determined that the results from the CC model were less different from that obtained for the optical model.

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