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# Elastic scattering of $^{17}\text{F}$ nuclei from $^{58}\text{Ni}$ target: Comparison with three different models

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## ABSTRACT

In this study, elastic scattering for the system  $^{17}\text{F} + ^{58}\text{Ni}$  at the energies 58.5 MeV and 170 MeV were examined theoretically by using optical model, cluster model, double folding model and optical model. The results were compared with data in the literature and experimentally data. Total reaction cross sections were determined. The results obtained have been successful in explaining experimental data.

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## 1. Introduction

The studies of nuclear reactions with weakly bound nuclei have remarkable interested in recent years. Because of weakly bound nuclei can break up, it is important for reaction mechanism. Halo nuclei are important for study of nuclear reaction due to weakly bound structure of these nuclei.

There are many studies on  $^{17}\text{F}$  which is a weak bound nucleus.  $^{17}\text{F}$  nucleus is proton halo nuclei with valance proton by 0.6 MeV and its rms is 3.7 fm.  $^{17}\text{F}$  has low breakup and its first excited state is 0.4935 MeV. (Liang et al. 2002; Signorini et al. 2010)

Optical model, cluster model and CDCC model are some of the model developed to explain nuclear reactions. These models are very important to examine nuclear reactions with weakly bound nuclei. (Liang et al., 2009; Aygün, 2014; Küçük&Moro, 2012).  $^{17}\text{F}+^{58}\text{Ni}$  system has been studied both experimentally and theoretically at the different energies (Liang et al., 2002; Mazocco et al., 2010; Mazocco et al., 2011; Küçük&Moro, 2012; Grineviciute&Descouvemont, 2014).

The objective of this study is to examine  $^{17}\text{F}+^{58}\text{Ni}$  system. In this study, we have analyzed interaction of  $^{17}\text{F}$  projectile with  $^{58}\text{Ni}$  target at 58.5 MeV and 170 MeV energies by using three models as optical model, double folding model and cluster model. The results have compared with experimental data and each other.

## 2. Theoretical Analysis

The total effective potential in the optical model;

$$V_{total}(r) = V_{coulomb}(r) + V_{nuclear}(r) + V_{centrifugal}(r)$$

The total effective potential consists of centrifugal potential, coulomb potential and nuclear potential. Here the coulomb potential;

$$V_C(r) = \frac{Z_p Z_t e^2}{4\pi\epsilon_0 r} \quad r \geq R_C$$

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$$V_c(r) = \frac{Z_p Z_T e^2}{4\pi\epsilon_0 2R_c} \left(3 - \frac{r^2}{R_c^2}\right) \quad r < R_c$$

where  $R_c$  is coulomb radius,  $Z_T$  and  $Z_p$  are the atomic number of target and projectile, respectively. The centrifugal potential;

$$V_{centrifugal}(r) = \frac{(l+1)l\hbar^2}{2\mu r^2}$$

where  $\mu$  is the reduced mass. Nuclear potential is taken as the complex optical potential. The optical potential;

$$V_{op}(r) = V(r) + iW(r)$$

where  $V(r)$  is real part and  $W(r)$  imaginary part. Both  $V(r)$  and  $W(r)$  are defined as Woods-Saxon shape potential.

$$V(r) = -\frac{V_0}{\left[1 + \exp\left(\frac{r-R_V}{a_V}\right)\right]^2}$$

$$W(r) = -i\frac{W_0}{\left[1 + \exp\left(\frac{r-R_W}{a_W}\right)\right]}$$

the real part of optical potential in the double folding model is taken as double folding potential. The Double-folding potential;

$$U_{DF} = \int d\vec{r}_1 \int d\vec{r}_2 \rho_1(r_1) \rho_2(r_2) V(r_{12} = |\vec{R} + \vec{r}_2 - \vec{r}_1|)$$

Here,  $\rho_1(r_1)$  is nucleon density of the projectile nucleus,  $\rho_2(r_2)$  is the nucleon density of the target nucleus and  $V(r_{12})$  is the nucleon-nucleon interaction potential. For the nucleon interaction M3Y realistic interaction has been used. Density distribution has been obtained from RIPL-3 (RIPL-3). M3Y interaction potential;

$$v_{NN}(r) = 7999 \left[ \frac{\exp(-4r)}{4r} \right] - 2134 \left[ \frac{\exp(-2.5r)}{2.5r} \right] + J_{00}(E) \delta(r) \text{ MeV}$$

Here  $J_{00}(E)$  is ;

$$J_{00}(E) = -276 \left[ 1 - 0.005 \frac{E_{lab}}{A_p} \right] \text{ MeV fm}^3$$

The nuclear potential in the optical model;

$$V_N(r) = N_R V_{DF}(r) - i \frac{W_0}{\left[1 + \exp\left(\frac{r-R_W}{a_W}\right)\right]} \text{ MeV}$$

Here  $N_R$  is the normalization constant in Double folding model calculations. Double folding model depends on nuclear densities of nuclei in the interactions (Karakoç and Boztosun 2006; Boztosun 2008; Sert 2014).

Cluster model is the optical model with cluster structure.  $^{17}\text{F}$  projectile has taken as  $^{17}\text{F} \rightarrow ^{16}\text{O} + p$ .  $^{16}\text{O}$  is core and  $p$  is valance. Interaction potential is defined core + target potential, core + valance potential and valance + target potential. For  $^{17}\text{F} + ^{58}\text{Ni}$  system, interaction potential is the sum of  $^{16}\text{O} + p$ ,  $^{16}\text{O} + ^{58}\text{Ni}$  and  $p + ^{58}\text{Ni}$  systems.

### 3. Results and Discussion

We have investigated  $^{17}\text{F} + ^{58}\text{Ni}$  system at 58.5 MeV and 170 MeV. Firstly we have performed potential parameters for optical model, double folding model and cluster model. We have rearranged optical potential parameters which were used by Mazocco et al. (2010) and have calculated for optical model. We have used Woods-Saxon shape for both the real and imaginary part of optical potential.

Then we have performed potential parameters for double folding model. We have defined Woods-Saxon shape for imaginary part and have used folding potential for real part in calculations of double folding model. Double folding potential has calculated with DFPOT code for real potential. Density distributions of  $^{17}\text{F}$  and  $^{58}\text{Ni}$  have been taken RIPL-3 (RIPL-3). Normalization constant for theoretical calculations have been taken 0.3. Since the DF potential depth is large, normalization constant is taken as such.

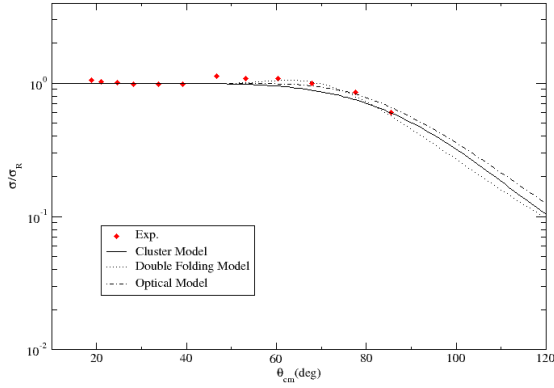
**Table 1.** Optical potential parameters for Optical Model and Double Folding Model at 58.5 MeV

$^{17}\text{F} + ^{58}\text{Ni}$	$V_0$ (MeV)	$r_v$ fm	$a_v$ fm	$W_V$ MeV	$r_w$ fm	$a_w$ fm
O. M	80.4	0.9	0.4	20.0	1.13	0.65
D.F Model	-	-	-	50.0	1.18	0.45
	$J_v$ MeV fm <sup>3</sup>	$J_w$ MeV fm <sup>3</sup>	$\chi^2$			
O. M	55.704	35.356	0.18			
D.F Model	-	96.535	0.25			

On the other hand, we have performed potential parameters for cluster model. This model has included potentials of  $^{16}\text{O} + ^{58}\text{Ni}$ ,  $p + ^{58}\text{Ni}$  and  $p + ^{16}\text{O}$  systems. For  $p + ^{58}\text{Ni}$  system, we have rearranged the global parameterizations of Bechetti-Greenless (1969). For  $^{16}\text{O} + ^{58}\text{Ni}$  system, we have reproduced parameters obtained by Keley (1995). As seen in Table 2, the value of diffuseness is quite small for real part and imaginary part. The obtained parameters for interactions have been shown in Table 1, 2, 3 and 4, respectively. All calculations have performed with code FRESKO (Thompson, 1988).

**Table 2.** Optical potential parameters for Optical Model within cluster structure at 58.5 MeV

$^{17}\text{F}+^{58}\text{Ni}$	$V_0$	$r_v$	$a_v$	$W_V$	$r_w$	$a_w$
cluster structure	MeV	fm	fm	MeV	fm	fm
$\text{p}+^{58}\text{Ni}$	66.68	0.9	0.35	25.0	0.9	0.35
$^{16}\text{O}+^{58}\text{Ni}$	50.67	0.9	0.40	20.0	0.9	0.3


**Figure 1.** Elastic scattering angular distribution for the  $^{17}\text{F}+^{58}\text{Ni}$  system at 58.5 MeV.

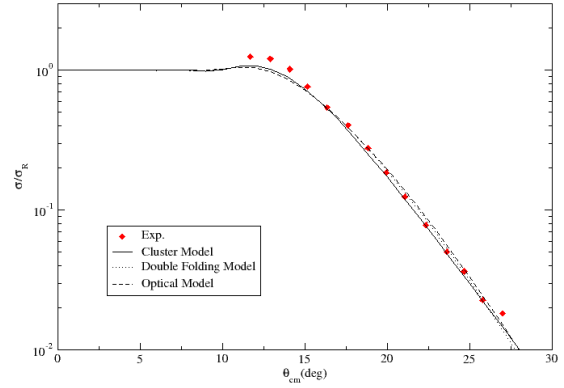
As seen in Table 1 and 3, the value of radius is 0.9 fm for the real part of optical model at 58.5 MeV and 170 MeV. Also the value of depth and radius are 20 MeV and 1.23 fm, respectively for imaginary part of double folding model and optical model at 170 MeV. On the other hands, the value of radius and diffuseness for cluster model at 58.5 MeV and 170 MeV are similar. All parameters of cluster model have given in Table 2 and 4.

**Table 3.** Optical potential parameters for Optical Model and Double Folding Model at 170 MeV

$^{17}\text{F}+^{58}\text{Ni}$	$V_0$	$r_v$	$a_v$	$W_V$	$r_w$	$a_w$
	MeV	fm	fm	MeV	fm	fm
O. M	60.4	0.9	0.3	20.0	1.23	0.65
D.F Model	-	-	-	20.0	1.23	0.95

	$J_v$	$J_w$	$\chi^2$
	MeV fm <sup>3</sup>	MeV fm <sup>3</sup>	
O. M	55.704	35.356	0.18
D.F Model	-	96.535	0.25


**Figure 2.** Elastic scattering angular distribution for the  $^{17}\text{F}+^{58}\text{Ni}$  system at 170 MeV.

**Table 4.** Optical potential parameters for Optical Model within cluster structure at 170 MeV

$^{17}\text{F}+^{58}\text{Ni}$	$V_0$	$r_v$	$a_v$	$W_V$	$r_w$	$a_w$
cluster structure	MeV	fm	fm	MeV	fm	fm
$\text{P}+^{58}\text{Ni}$	26.68	0.9	0.75	20.0	1.0	0.7
$^{16}\text{O}+^{58}\text{Ni}$	150.67	0.9	0.60	100.0	1.0	0.7

The obtained results for optical model, double folding model and cluster model are shown in Figure 1 and 2. . We have compared theoretical results with experimental data. The solid squares are the experimental data from Ref. (Liang 2009). Solid, dashed and dot-dashed lines show, respectively, cluster model, double folding model and optical model. As seen in Figure 1 and 2, we have noticed that all theoretical results are similar. We have also observed that all results explained well experimental data.

#### 4. Conclusions

In this study, we have analyzed  $^{17}\text{F}+^{58}\text{Ni}$  system with different potential parameters at 58.5 MeV and 170 MeV. We have used optical model, double folding model and optical model within structure. We have compared results with experimental data. Obtained results are similar for cluster model, double folding model and optical model. We have observed that cluster effect is also quite small.

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