PHYSICAL REVIEW C VOLUME 22, NUMBER 2 AUGUST 1980

Elastic and inelastic scattering of ^{6}Li at about 74 MeV and the folding model

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(Received 1 April 1980)

The data for the elastic scattering of ^{6}Li at 73.7 MeV from ^{58}Ni, ^{90}Zr, ^{124}Sn, and ^{208}Pb have been fitted using the M3Y effective interaction and the folding model for the real potential. The results confirm that the renormalization of this interaction by about 0.6 needed to fit data at lower energies is required here also. Comparison with data for the inelastic scattering from ^{58}Ni at 71 MeV shows them to be consistent with folding model predictions using the same renormalization, but the dominance of the imaginary coupling makes more detailed conclusions difficult.

[NUCLEAR REACTIONS ^{58}Ni, ^{90}Zr, ^{124}Sn, ^{208}Pb(^{6}Li, ^{6}Li), $E=73.7$ MeV; ^{58}Ni(^{6}Li, ^{6}Li′), $E=71$ MeV. Deduced folding optical model parameters.]

Recently results were presented[1] for the elastic scattering of ^{6}Li at 73.7 MeV and also[2] for the inelastic scattering of ^{6}Li at 71 MeV. The authors presented exhaustive analyses of their data in terms of conventional Woods-Saxon optical potentials. The data have also been analyzed using a folding model[3] for the real potential and the results are presented here. These analyses are of interest for two reasons: (i) Previous studies[3,4] indicated that the M3Y effective nucleon-nucleon interaction,[5] which has been very successful[3,6] in reproducing the scattering of many other heavy ions, needs to be reduced in strength by a factor of about 0.6 in order to fit ^{6}Li scattering. These data were mainly for lower bombarding energies, so the present study confirms that this "anomaly" persists at 74 MeV. (ii) One would like to know whether the same reduction factor is required in order to reproduce the observed inelastic scattering. We are unable to answer this question precisely because the large contributions from the imaginary part of the coupling potential (here treated phenomenologically) make the results rather insensitive to the real folded part.

The model has been described in detail elsewhere.[3] Folding was used for the real potentials while phenomenological Woods-Saxon forms were used for the imaginary potentials. The folded real potential was multiplied by a factor N which, together with the imaginary parameters, was varied to optimize the fit to the elastic data. This gives a four-parameter model. The data are assigned[1] absolute errors of ±5%, but we did not adjust their normalization in any attempt to reduce χ^2 further, except those for ^{124}Sn which were reduced 4%. The fits to the data are not shown here because they are of the same quality as obtained and shown by Huffman *et al.*[1] using six-parameter Woods-Saxon potentials. Our parameter values are given in Table I; the average value of the renormalization factor N required is $\bar{N}=0.55\pm0.04$, thus confirming the need for a substantial reduction in strength. Consistent results are also obtained for the imaginary potential parameters $W=16.5\pm1.8$ MeV, $r_W=1.23\pm0.015$ fm, and $a_W=0.83\pm0.013$ fm.

For convenience, we also include in Table I the value $L_{1/2}$ of angular momentum for which the transmission coefficient $T_L=\frac{1}{2}$, and the distance $D_{1/2}$ of closest approach for the corresponding Rutherford orbit. The latter is a measure of the "strong absorption radius."

Fits were also made using the folded shape for

TABLE I. Optical model parameters.

Target	N^a	W (MeV)	$r_W{}^b$ (fm)	a_W (fm)	σ_R (mb)	$L_{1/2}$	$D_{1/2}$ (fm)	χ^2	ReN	ImN^c	σ_R (mb)	χ^2
^{58}Ni	0.54	16.3	1.216	0.815	2114	32.7	8.9	1.7	0.56	0.56	1951	4.7
^{90}Zr	0.55	15.8	1.230	0.822	2377	35.9	9.8	0.6	0.54	0.49	2136	3.1
^{124}Sn	0.61	19.4	1.228	0.849	2714	39.2	10.7	0.9	0.61	0.54	2426	2.2
^{208}Pb	0.50	14.4	1.256	0.837	2708	39.8	11.9	0.1	0.67	0.64	2580	0.2

[a] Renormalization factor for folded real potential when Woods-Saxon imaginary potential used.

[b] $R_W=r_W(6^{1/3}+A^{1/3})$.

[c] Complex renormalization factor when same folded shape used for imaginary potential.

the imaginary potential as well as the real one. This is equivalent to taking the renormalization factor N as a complex number, thus giving a two-parameter model. Good fits could be obtained to the data considered here but with χ^2 values always several times larger than when using a Woods-Saxon imaginary part. The predicted reaction cross sections σ_R are also about 10% smaller. These results are also included in Table I.

Only the inelastic data for the two strongest excitations, those of the 3^- level at 4.45 MeV and the lowest 2^+ at 1.45 MeV, were considered. Transition densities of Tassie type were used for the folding calculations, normalized to give the observed $B(EL)$ values [$B(E2)=695\ e^2\text{fm}^4$ and $B(E3)=18\,600\ e^2\text{fm}^6$] plus the assumption that the neutron part was (N/Z) times the proton part. This prescription has been found[3,7] to give good agreement with data for the excitation of ^{60}Ni by ^{16}O as well as[8] for the excitation of ^{58}Ni and other targets by alpha particles. The Woods-Saxon imaginary potential was deformed in the usual way[2] with deformation parameters obtained from the $B(EL)$ values scaled according to $\beta R=$ constant. This gives $\beta_2^{(W)}=0.123$ and $\beta_3^{(W)}=0.137$. Coulomb excitation was included. None of these parameters were adjusted because our purpose is not to fit the data but rather to compare them with the predictions of a model found successful in other cases.[3,7,8] The inelastic scattering was calculated in the distorted-wave Born approximation (DWBA), using the optical potentials with $N=0.54$ which fit the elastic data at 74 MeV (Table I).

Unfortunately, for the present study, the predicted inelastic cross sections are dominated by the contributions from the phenomenological imaginary coupling, making it difficult to judge to what extent the real folded coupling needs renormalizing. Figure 1 illustrates this. Here the normalization $N=0.54$ was used for the real coupling; by itself (dotted curves) this gives much smaller cross sections than are observed. The full complex coupling (full curves) is a little too small for the 2^+ excitation; increasing N to about 0.7 would improve the fit. On the other hand, $N=0.54$ already gives too large a cross section for the 3^-; indeed, the imaginary coupling by itself ($N=0$) gives a good match to these data. Note, however, that any uncertainties in the measured $B(EL)$ values reappear here because our prescription gives cross sections directly proportional to $B(EL)$. Further, the assumption that the neutron and proton transition densities have the same shape and magnitudes in the ratio (N/Z) is open to question, although it has given good results elsewhere.[3,7,8] Consequently, we can conclude little more than that the observed cross sections are consistent with using

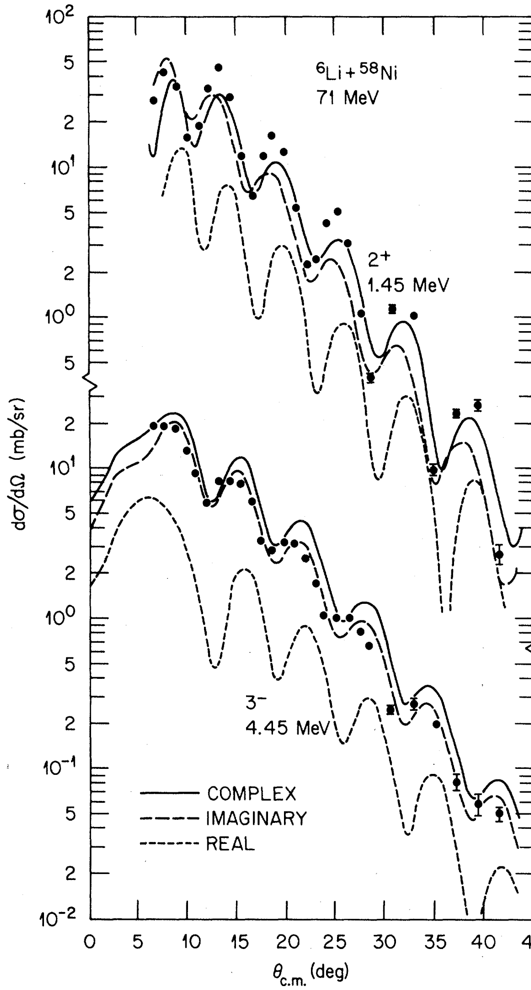

FIG. 1. Comparison of data (Ref. 2) for inelastic scattering with predictions of the folding model as described in the text. "Real" refers to use of the real folded coupling potential ($N=0.54$) alone, "Imaginary" to the use of the deformed Woods-Saxon imaginary coupling potential alone, and "Complex" to the use of both.

renormalization factors for the folded transition potentials which are the same or similar to those required for the elastic scattering potentials.

We note from Fig. 1 that the imaginary coupling term is also needed in this model to give angular distributions similar to those observed. This provides further evidence against the imaginary interaction having the same shape as the real folded one because in that case the angular distributions are almost the same as those shown in Fig. 1 for the real coupling alone. They have minima which are too deep. The peak magnitudes are similar to those for the complex coupling in Fig. 1, but the peaks are shifted to slightly larger angles.

I am indebted to the authors of Refs. 1 and 2 for making their data available before publication.

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