Energy dependence of ^{6}Li + ^{28}Si elastic scattering and the dispersion relation

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The strong coupling between the real and imaginary terms in the optical potential for ^{16}O + ^{60}Ni, ^{208}Pb previously reported for elastic scattering at bombarding energies close to the Coulomb barrier does not occur for the elastic scattering of ^{6}Li + ^{28}Si. This result confirms the suggestion of Mahaux, Ngô, and Satchler that the dispersion relation connecting the real and imaginary potential terms found for ^{16}O scattering will not occur for weakly bound projectiles.

A recent analysis [1] of the energy dependence of ^{6}Li + ^{12}C, ^{58}Ni elastic scattering finds evidence of a strong coupling between the strength of the real and imaginary potentials for ^{6}Li bombarding energies below 50 MeV. Earlier analyses [2] of ^{16}O + ^{60}Ni, ^{208}Pb had reported such a coupling between the two potentials for ^{16}O bombarding energies close to the Coulomb barrier. This strong coupling has been called [2] a threshold anomaly. In the case of ^{16}O + ^{60}Ni, where the Coulomb barrier corresponds to a laboratory bombarding energy of about 40 MeV, the strength of the imaginary potential rises by a factor of 4 in the laboratory energy range of 40 to 50 MeV and then is constant above this energy. In this same energy interval, the strength of the real double-folded potential rises from 1.3 to 1.6 and then back to 1.3, followed by a slow decrease to 1.0 at a bombarding energy of 140 MeV. The ^{16}O results were successfully described using dispersion relation arguments. Mahaux, Ngô, and Satchler [3] have shown that the dispersion relation is a general feature of heavy-ion scattering in the vicinity of the Coulomb barrier.

Mahaux, Ngô, and Satchler [3] give intuitive arguments that loosely bound projectiles like ^{6}Li will not display a threshold anomaly because the coupling between the elastic and breakup channels [4] gives rise to a large repulsive real and very weak imaginary potential that is almost independent of bombarding energy, target nucleus, and angular momentum. This Brief Report is a study of the energy dependence of the optical potential that describes ^{6}Li + ^{28}Si elastic scattering. This system was chosen because data exist over a wide enough energy range for the scattering to go from being Coulomb dominated at 13 MeV to almost pure nuclear scattering at 210 MeV. The system ^{6}Li + ^{12}C studied earlier by Kailas [1] suffers from rapidly changing elastic-scattering [5] angular distributions arising from a resonance in the crucial energy region around 20 MeV. The reproduction of the elastic scattering near this resonance by optical model calculations tends to be poor even when the potential parameters are allowed to vary freely. This rapid energy dependence in the scattering makes it difficult to find the systematic changes in the potential parameters arising from dispersion effects.

That the system ^{6}Li + ^{28}Si might not exhibit a dispersion effect can be anticipated from the analysis of Cook [6] who found that an energy-independent optical potential having Woods-Saxon real and imaginary potentials was able to describe data for ^{6}Li bombarding energies from 13 to 154 MeV. However, to achieve this energy-independent result, the overall normalizations of several data sets were changed by up to 25%. Since his study as well as others [7,8] were done to search for the energy and mass dependence of the optical potential parameters, it is possible that dispersive effects are lost by the choices made in searching for the potential parameters. The possibility of doing so has been pointed out by Fulton *et al.* [2].

In this study, a double-folded real potential with a Woods-Saxon imaginary potential was chosen for the optical potential. The double-folded real potential was chosen because it has been shown [9] to describe a large body of nucleus-nucleus scattering data if only the strength of the potential is allowed to vary. Also, the po-

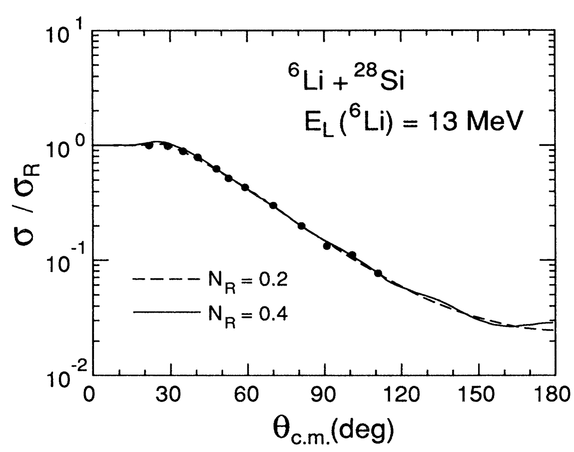

FIG. 1. Elastic scattering of 13-MeV ^{6}Li by ^{28}Si. The data are from Ref. [7]. The optical model calculation given by the solid curve has a real potential normalization of $N_R = 0.4$ and a volume imaginary integral per nucleon pair of $J_I = 60$ while the dashed curve is for $N_R = 0.2$ and $J_I = 114$.

TABLE I. Optical potential parameters for ^{6}Li$+^{28}$Si elastic scattering. N_R is the renormalization factor for the real double-folded potential and $J_I/6(28)$ is the imaginary Woods-Saxon potential volume integral per nucleon pair. The radius convention $R_I = r_I(28^{1/3})$ is used.

^{6}Li energy (MeV)	N_R	W (MeV)	r_I (fm)	a_I (fm)	$J_I/6(28)$ (MeV fm^3)	Data from Ref.
13	0.20	26.5	1.65	0.98	114	[7]
13	0.60	7.43	2.25	0.64	64	[7]
27	0.56	12.72	1.96	0.76	77	[10]
34	0.59	14.10	1.89	0.88	82	[10]
46	0.52	12.19	1.99	0.74	77	[12]
99	0.48	18.75	1.90	0.76	105	[13]
135	0.50	33.27	1.59	1.02	135	[14]
154	0.51	29.69	1.66	1.02	133	[15]
210	0.59	33.74	1.71	0.77	144	[8]

tential ambiguities [8] found when a Woods-Saxon real term is used make it difficult to choose which potential set found at a given energy is to be identified with one found at another energy. Details of the double-folded potential for ^{6}Li$+^{28}$Si scattering are described by Vineyard, Cook, and Kemper [10]. The procedure used for obtaining a potential parameter set for a given energy data was to step the normalization factor, N_R, multiplying the strength of the real double-folded potential from 0.1 to 1.2 while allowing the three parameters W, r, and a that define the Woods-Saxon imaginary potential to vary until the best fit to the data was found. Searches then were carried out around the best value of N_R found from this grid search. The data sets were not renormalized. The optical model search program HERMES [11] was used for the calculations. Good fits to all data sets were found with the strength of the real potential having a value of 0.54 ± 0.04 over the ^{6}Li bombarding energy range of 27–210 MeV. At any given energy, the real normalization value could only vary by 5% before the fit was lost. Table I lists the strength of the real potential and the imaginary volume integral per nucleon pair for the Woods-Saxon potential values given. As can be seen there is a steady decrease in the imaginary volume integral as one goes from a ^{6}Li energy of 210 MeV down to 27 MeV.

The difficulty in this analysis to determine whether dispersive effects occur in ^{6}Li scattering comes in describing the 13-MeV data. Describing these low-energy data is important because the threshold anomaly should be close to a maximum at the ^{6}Li energy of 13 MeV. At this energy it is found that equivalent fits to the data can be obtained for real normalization values of N_R between 0.1 and 0.6. For this same range of N_R, the imaginary volume integral per nucleon pair goes from 143 MeV fm^3 for $N_R = 0.1$ to 64 MeV fm^3 for $N_R = 0.6$. Figure 1 shows the previous reported data [7] and calculations extending to 180° c.m. for calculations with $N_R = 0.2$ ($J_I = 114$ MeV fm^3) and 0.4 ($J_I = 60$ MeV fm^3). Even if one were to make measurements over the entire angular range, it would not be possible to distinguish between these two calculations. Consequently, it is not possible to give precise values to the potential at the low energies needed to define the characteristic bell shape that should occur in the real potential strength if the dispersion relation describes the data. However, the fact that it is not possible to find a fit to the 13-MeV data which has a real normalization that is much larger than the value of 0.59 found for the 210-MeV ^{6}Li data would seem to rule out the 60% increase in the real potential strength found for ^{16}O$+^{60}$Ni over a similar energy interval.

In summary, an analysis of ^{6}Li$+^{28}$Si elastic-scattering data for ^{6}Li bombarding energies from 13 to 210 MeV shows no evidence of a strong coupling between the real and imaginary potentials close to the Coulomb barrier. The present analysis is consistent with the speculation by Mahaux, Ngô, and Satchler [3] that loosely bound projectiles would not show a dispersion relation coupling the real and imaginary potentials at energies close to the Coulomb barrier.

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