COMMENTS

Comments are short papers which criticize or correct papers of other authors previously published in the **Physical Review**. *Each Comment should state clearly to which paper it refers and must be accompanied by a brief abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

Comment on "Evidence for a nuclear halo from ^{11}Li elastic scattering measured at 637 MeV incident energy on a ^{12}C target"

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We discuss the analysis of ^{11}Li and ^{11}C scattering by Mermaz [Phys. Rev. C **47**, 2213 (1993)]. We argue that his results show the ^{11}C scattering to be more refractive than that of ^{11}Li, and indicate various effects that could be responsible.

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Recently, the scattering of ^{11}Li and ^{11}C from ^{12}C at $E/A \approx 60$ MeV were measured by Kolata *et al.* [1]. Unfortunately, the energy resolution was such that the elastic scattering could not be separated from inelastic scattering exciting low-lying states of the target and projectile, thus hindering efforts to learn about the optical model potentials for these systems. In an interesting approach, Mermaz [2] obtained a decomposition of the measured cross sections into elastic and inelastic ones. He took the elastic cross sections generated by an optical model potential of Woods-Saxon shape and added inelastic cross sections obtained in distorted-wave Born approximation (DWBA) using the same potential. Excitations of the 2_1^+ and 3_1^- states of the ^{12}C target were included. The potential parameters were then adjusted to optimize the fit of the summed cross sections to the measured ones.

It was concluded for the halo nucleus ^{11}Li that "This halo gives rise to a strong refractive phenomenon never seen so clearly before for heavy-ion elastic scattering." We wish to comment that this conclusion is erroneous. The error appears to arise because the elastic cross sections are displayed in ratio to the Rutherford ones. This neglects the fact that the Rutherford cross section for ^{11}C is four times that for ^{11}Li at the same energy because the charge on ^{11}C is twice as great as on ^{11}Li. Consequently, the ^{11}Li cross sections appear to be enhanced compared to those for ^{11}C. However, when the same "units" are used for both, one sees that the ^{11}Li cross sections are appreciably smaller than the ^{11}C ones.

It is convenient for display purposes to divide out the strong dependence on angle due to Rutherford scattering. Figure 1 compares the ^{11}Li and ^{11}C elastic cross sections obtained by Mermaz [2], both divided by the Rutherford cross sections for ^{11}Li. (Consequently, the ^{11}C ratio takes the value 4 at zero angle.) Clearly, the ^{11}C cross sections are larger.

Indeed, in common with other light heavy-ion systems such as ^{12}C+^{12}C [3], ^{13}C+^{12}C [4], and ^{16}O+^{16}O [5], the ^{11}C scattering already shows substantial refraction, as revealed by the dominance of farside scattering except at the most forward angles. It appears that instead of this being enhanced even further by the neutron halo present in the ^{11}Li nucleus, it has been somewhat damped relative to ^{11}C.

We can identify four influences which cause ^{11}Li scattering to differ from that of ^{11}C and which arise from

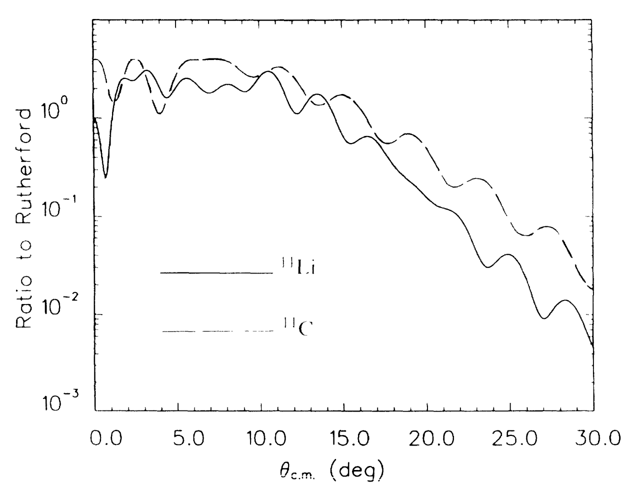

FIG. 1. Differential cross sections for ^{11}Li and ^{11}C elastically scattering from ^{12}C at $E/A \approx 60$ MeV, shown in ratio to the Rutherford scattering cross sections for ^{11}Li. The cross sections were generated using the optical model parameters of Mermaz [2].

two features. These are the halo tail of the density distribution of ^{11}Li and (not unrelated) the importance of breakup for such a loosely bound system in which the halo neutrons are removed in the field of the target. The halo density tail results in both the real and imaginary parts of the optical potential being more diffuse. (This becomes very evident if a folding model is used [6].) The stronger tail of the real potential does enhance its refractive effects, but this is partially offset by the strong damping due to the imaginary tail. The effects of breakup (^{11}Li$\rightarrow$^{9}Li$+n+n$) can be represented by adding to the optical potential a dynamic polarization potential (DPP) [7] which has both real and imaginary parts. The real part is repulsive, and tends to compensate for the additional attraction due to the halo tail. The imaginary part is absorptive and increases the reaction cross section. Both parts tend to have a longer range than the "bare" optical potential, and their relative magnitudes depend upon the details of the couplings between the elastic and the breakup channels. A more detailed account [8] of these effects will be published elsewhere. There are uncertainties such as the precise nature of the breakup DPP, but the net effect seems likely to be that the ^{11}Li cross sections are comparable to, or smaller than, those for ^{11}C. This is not in disagreement with the results of the analyses of Mermaz [2], as shown in Fig. 1.

Consequently, we must disagree that the ^{11}Li scattering shows the strongest refractive phenomenon seen in heavy-ion elastic scattering. The scattering of ^{16}O+^{16}O at 350 MeV [5] provides a more qualified candidate for that approbation, now supplemented by additional measurements at 145 MeV [9].

A subsidiary comment is that the quadrupole and octupole excitations of ^{11}C are likely to be comparable in strength to those of the ^{12}C target, whereas it may be argued that excitations of ^{11}Li are much less important since it has no bound states. If true, this implies that larger coupling strengths should be used in the ^{11}C calculations than for ^{11}Li. Then this would tend to reduce the estimate of the ^{11}C elastic cross sections at the larger angles, making them closer to, perhaps even smaller than, those for ^{11}Li. This provides another uncertainty in the analysis of these data. We certainly agree with Mermaz that "it would be of great interest to repeat this experiment with a very good energy resolution"!

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