AN ESTIMATE OF THE ^{3}He SPIN-ORBIT POTENTIAL FROM SPIN-FLIP MEASUREMENTS ‡

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The spin-orbit potential depth of ^{3}He particles has been obtained by comparing back angle spin-flip measurements of the $^{12}C(^3He)^{12}C^*(4.44)$ inelastic scattering reaction with DWBA calculations, and is found to be 2.7 ± 0.7 MeV. This result is found to be relatively insensitive to the details of the spin-independent part of the optical model potential.

Recent work with direct nuclear reactions involving ^{3}He particles has stimulated interest in the optical potential for ^{3}He. It has been found that elastic scattering data can be satisfactorily fitted with optical model calculations without including a spin-orbit term [1-5] and that the inclusion of such a term has a small effect on the calculated differential cross sections [6]. Thus the character of the ^{3}He spin-orbit potential is not well established.

The ^{3}He spin-orbit potential could be obtained from elastic polarization measurements, but neither polarized ion sources nor good polarization analyzers are currently available, and recent double-scattering experiments with ^{3}He have been subject to very large uncertainties [7,8]. The present work is a study of the ^{3}He spin-flip probability [9] exploiting the fact that only $0^+ \rightarrow 2^+$ inelastic scattering events involving a spin-flip along the axis perpendicular to the reaction plane can give rise to ground state deexcitation γ rays along this axis. This type of experiment is in many ways similar to an inelastic polarization measurement and provides an alternative way of estimating the ^{3}He spin-orbit potential.

A beam of 22.5 MeV ^{3}He particles was used to bombard a 225 $\mu g/cm^2$ carbon foil. Gamma rays were detected with a 10×10 cm^2 NaI(Tl) crystal placed directly above the target. The ^{3}He particles were detected in coincidence with the γ rays. A dE/dX-E telescope was used to separate the ^{3}He particles from α particles prolifically produced by the $^{12}C(^3He,\alpha)$ reaction.

The absolute detection efficiency of the γ-ray detector was measured to an accuracy of about 2.5% by methods described elsewhere [10]; it is somewhat in disagreement with Monte Carlo calculations [11].

Fig. 1 shows DWBA predictions and our experimental results. Statistical and background subtraction errors are indicated by the error bars. There is also an estimated 6% systematic error in the absolute normalization of $d\sigma/d\Omega$ due primarily to uncertainty in target thickness. The error bars on the spin-flip probability include errors due to statistics, background subtraction and peak extraction, absolute γ detection efficiency, and uncertainties in the relative populations of the $m = 0$ and ± 2 magnetic substates of ^{12}C(4.44). The spin-flip data points were calculated assuming equal population of the latter.

The first set of optical model parameters given in fig. 1 was obtained by fitting the elastic data with an optical model computer program written at this laboratory [12]. The other sets were obtained from 20 MeV forward-angle elastic scattering data on ^{12}C by Mangelson [13]. The results of DWBA calculations using these parameters are shown in fig. 1. The calculations were performed with a computer program written by Sherif and Blair [14], using a deformed spin-dependent potential of the full Thomas form, i.e., $(\hbar/m_{\pi}c)^2 V_{SO}\, \boldsymbol{\sigma} \cdot [\nabla\rho(\boldsymbol{r}) \times \nabla/j]$, where $\rho(\boldsymbol{r})$ is the nuclear matter density function. It was found that the deformation of the spin-orbit potential has a negligible effect in our analysis. A deformation $\beta_2 = 0.6$ was used in all the calculations shown.

As seen in fig. 1, the elastic cross section is fairly well fitted by parameter set 1 while sets 2 and 3 produce only qualitative fits. The inelastic cross section data are poorly fitted by all three sets of parameters. Further, the inelastic cross

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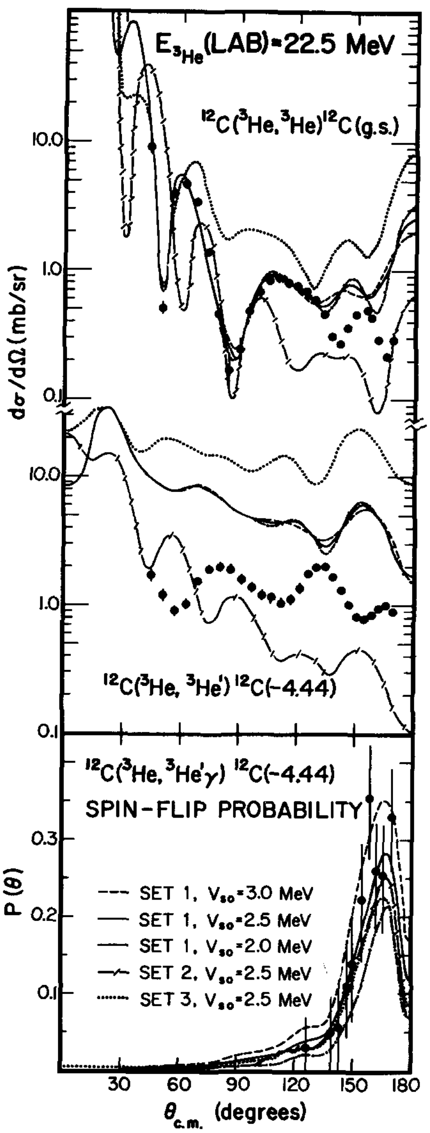

Fig. 1. $^{12}C(^3He, ^3He')$ elastic and inelastic differential cross sections from experiment and DWBA calculations are shown in the upper portion of the figure; spin-flip probability data and calculations are shown below. Note that optical parameters giving very different inelastic cross sections predict similar spin-flip probabilities. The parameter sets are: SET 1: V = 172 MeV, WS = 9.7 MeV, r_0 = 1.23 fm, r_i = 1.48 fm, a_0 = 0.725 fm, a_i = 0.960 fm; SET 2: V = 146 MeV, WS = 36.5 MeV, $r_0 = r_i$ = 1.25 fm, a_0 = 0.65 fm, a_i = 0.47 fm; SET 3: V = 220 MeV, W = 12.4 MeV, r_0 = 1.16 fm, r_i = 1.55 fm, a_0 = 0.60 fm, a_i = 1.05 fm.

sections for the three sets differ in magnitude among themselves, especially at back angles. No effort was made to force a fit to the inelastic dσ/dΩ at the expense of the elastic.

The poor fits may be an indication of channel-coupling effects or of compound nuclear or other competing reaction mechanisms. However, in view of the sizable deformation parameter for ^{12}C, it is likely that the fits to the inelastic cross sections can be improved by performing coupled-channel calculations. An attempt is currently made by Asoussa et al. [15] to analyze lower-energy ^3He + ^{12}C angular correlation and spin-flip data in this way.

The lower part of fig. 1 shows the calculated spin-flip probabilities for the three sets of parameters. Rather surprisingly, the spin-flip predictions of these potentials agree fairly well. In particular, the difference in the predictions for the height of the beck-angle peak is equivalent to that produced by a variation in the spin-orbit potential of about 25%. This illustrates an effect which has been found in DWBA calculations with both protons and ^3He particles in this energy region: the back angle peak in the spin-flip probability is an invariable feature of the calculation, and its height is relatively insensitive to variations of all of the optical model parameters except V_{SO}.

Fits to the spin-flip probability data can be obtained consistent within uncertainties in optical potentials and experimental data for V_{SO} = 2.0 to 3.5 MeV. The best fit to the data occurs with V_{SO} = 2.7 MeV. This potential is consistent with the 3.5 MeV upper limit on the ^3He spin-orbit potential set by Hutson et al. [8], and with calculations performed by Kunz [16]. It is also consistent with a $1/A$ dependence for the spin-orbit potential since the proton potential is about 7 MeV. It is very desirable to repeat these measurements on a nucleus other than ^{12}C in order to verify the above conclusions concerning the ^3He spin-orbit potential.

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