DOUBLE SPIN-ISOSPIN-FLIP REACTION

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The reaction ^{6}Li(^{6}Li, ^{6}Li*)^{6}Li*, where ^{6}Li* denotes the $T=1$, $J^\pi=0^+$ state at 3.56-MeV excitation, was experimentally studied. The angular distributions of this reaction and the elastic scattering were measured at 32.0-MeV bombarding energy. The differential cross section was measured at 90° in the center-of-mass system, for bombarding energies between 28.0 and 33.0 MeV.

A nuclear reaction in which two $T=0$ particles produce two $T=1$ particles is of particular interest. The transition is of course allowed by the isospin selection rule. The fact that $\Delta T=1$ occurs for each particle suggests that a macroscopic potential-scattering description with a scalar-type interaction cannot be applied, and some kind of exchange interaction is responsible for the transition. It is also noted as described below that this type of reaction is closely related to the charge-exchange reaction which has recently become an interesting subject. In fact, the idea has been noted for some time and several attempts have been made to search for such reactions[1]; however, no conclusive experimental evidence has been found. This Letter presents definite experimental results in the reaction ^{6}Li(^{6}Li, ^{6}Li*)^{6}Li* where ^{6}Li* denotes the well known $T=1$, $J^\pi=0^+$ particle-stable state at 3.56 MeV.

The experiment was carried out by directly detecting the two outgoing ^{6}Li particles in coincidence at kinematically conjugate angles appropriate to the reaction Q value. An enriched ^{6}Li metal target with approximately 0.2 mg/cm^2 thickness evaporated on a 0.1-mg/cm^2 nickel backing was bombarded by the ^{6}Li^{+++} beam from the Rutgers-Bell tandem Van de Graaff accelerator. The beam intensity was kept at about 15 nA and the target thickness was monitored by a monitor counter. Two solid-state detector counter telescopes were used. The thickness of the front detectors was chosen to just stop the ^{6}Li particles so that lighter particles did not deposit high enough energies to cover the ^{6}Li energy region. The rear detectors were used to reject the particles going through the front detectors, for further reduction of background. Both counters were collimated by slits to define ±1.0°. The alignment of the system and the angular readings were carefully checked by observing the elastic and presently studied inelastic events. It was found that the alignment of the system was better than 0.2°, e.g., no elastic events were observed when the counters were set 2.5° away from the 90-deg angle between them.

The signals from the two front detectors were stored in twelve 64×64-channel two-dimensional arrays by an on-line SDS 910 computer. The 12 arrays were used in order to provide time channels for the time-of-flight difference between the two counters. The resolving time of the system was typically 0.3 nsec for relatively high-energy signals and no worse than a few nanoseconds for all cases in this experiment. These techniques resulted in no background in energy spectra in the region of interest except for a few forward-backward angle cases where ^{6}Li-α true coincidences could not be avoided by the system. Proper background subtraction was performed for these data [the bigger errors in the forward angle points shown in Fig. 1(a) reflect this situation]. The experiment was carried out in three independent runs with consistent results.

Since the coincidence technique was employed, the effective solid angle must be calculated, because of the recoils by gamma emission from the ^{6}Li*. The analysis was made using a kinematical four-body phase-space calculation to simulate the actual and an "ideal" experiment, where the "ideal" experiment is a single measurement with infinitesmal solid angle. The correction factor for effective solid angle is then the ratio of the simulated yields for the ideal and actual experiments. The integrations were carried out by a Monte Carlo method, which is similar to one described elsewhere.[2] At certain angles, where enough counts were accumulated, the data were compared with the simulated energy spectrum and good agreement was always found.

The results are shown in Fig. 1. Figure 1(a) shows the angular distribution of this reaction while 1(c) shows the angular distribution of the elastic scattering using the same setup. Figure 1(b) is the excitation function of the reaction measured at 90° in the center-of-mass system. The error bars indicated are of statistical origin. The uncertainty in the absolute cross sections is estimated to be about a factor of 2.5, reflecting mainly the uncertainty of the target thickness. The relative uncertainties among all points including the elastic and the reaction cross sections are, however, believed to be within the errors indicated.

According to the *LS* coupling scheme, the ground-state ^{6}Li and the excited-state ^{6}Li* are interpreted as an alpha-particle core coupled to a proton-neutron triplet-*S* and singlet-*S* state, respectively, with $L=0$. The transition is then from this triplet-*S* to singlet-*S* state in the proton-neutron system, just as in the reaction $d(d,d^*)d^*$ where d^* is the singlet deuteron.[3] The transition is, therefore, a spin-isospin-flip process. The reaction can be visualized by interpreting the transition to be a neutron-neutron or proton-proton exchange process (in terms of the one-pion-exchange potential theory of the nuclear force, this reaction uniquely corresponds to the π^0-exchange term with *P* wave). Alternatively, if the interaction is written in terms of the ordinary

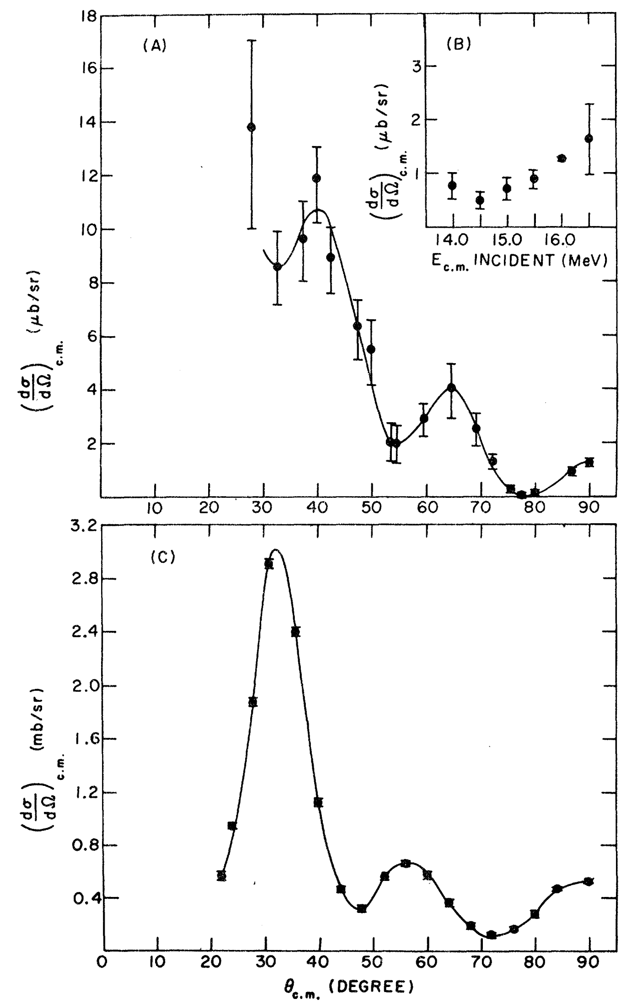

FIG. 1. (a) The angular distribution of the reaction ^{6}Li(^{6}Li, ^{6}Li*)^{6}Li* at the bombarding energy of 32.0 MeV. The angular resolution of the counter was ±1.0° in the laboratory system. The statistical errors are indicated by the error bars. The curve is drawn smoothly through the data points as a guide to the eye. (b) The differential cross sections measured at 90° versus incident energy. (c) The angular distribution of the elastic scattering at the bombarding energy 32.0 MeV. The measurement was made using the same setup as for (a). The error bars and the curve drawn are the same as described in (a).

two-body nucleon-nucleon potential, it is immediately noted that the reaction takes place only due to the $(\vec{\sigma}\cdot\vec{\sigma}')(\vec{T}\cdot\vec{T}')$ term in the scalar part of the potential. Therefore, a study of this type of reaction may provide information about the nature of the Majorana term in the nuclear interactions. In addition, it has been realized that in some charge-exchange reactions the tensor force plays an important role and may contribute in the present reaction. Coulomb excitation, which can mix isospins, is negligible here since the $M1$ transition is involved. It should be mentioned that since the system consists of identical bosons, the scattering wave function must be symmetrized. At 90° this constructive interference enhances the cross section. We therefore selected 90° to measure the excitation function as the point least sensitive to the fast-changing angular distribution. It is interesting to see the similarity between the angular distributions of this reaction and the elastic scattering. It almost seems that their diffraction patterns follow the Blair phase rule, which would suggest a surface interaction mechanism. The detailed discussion, however, has to await a more complete analysis. It should be desirable to extend the experimental investigation to ^{10}B and ^{14}N to obtain systematical information. By considering the isospin change of $T = 0$ to 1, one could speculate on the use of this kind of reactions to produce higher isospin states in residual nuclei. Further studies are obviously indicated.

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[1]G. M. Temmer, private communication; G. T. Garvey, private communication. We also learned that there are many investigations being made: D. Eccleshall, private communication.

[2]D. Boyd, P. F. Donovan, and J. F. Mollenauer, Phys. Rev. (to be published).

[3]We may also state that positive evidence was found in the present series of work in the reaction $d(d, d^*)d^*$. This reaction was studied by detecting two protons in coincidence and the enhanced peak due to the proper final-state interactions was observed. Since the analysis of this four-particle final-state reaction is not straightforward, we do not present it here.

EXPERIMENTAL STUDY OF THE VALIDITY OF THE GLAUBER THEORY FOR NUCLEAR PHYSICS*

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The elastic differential scattering cross section of protons on deuterons was measured for a series of incident proton momenta from 1.7 to 6.4 BeV/c. The observed scattering was compared with that predicted by the Glauber multiple-diffraction theory, out to momentum transfers of 1.0 BeV/c. Within experimental error (~10%), the experiments and theoretical predictions are in agreement.

As is well known,[1] the angular distribution of elastically scattered electrons from nuclei is a measure of the single-particle distribution of protons (charge density) in nuclei. Correlation effects can and most likely do affect the single-particle distribution of nucleons inside a real nucleus; however, these correlations are not explicitly seen in the measurement of elastic electron-nucleus scattering. In principle, it is possible to measure the pair correlation of protons inside the nucleus by means of inelastic electron scattering[2]; however, in practice at the appropriate momentum transfers radiative effects (bremsstrahlung) are many times larger than the nuclear correlation effects, and therefore this kind of approach has yielded very few results.

The use of high-energy protons to investigate the structure of the nucleus has demonstrated a