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WIDE-ANGLE α-t COINCIDENCE MEASUREMENT IN THE BREAKUP OF ^{7}LI ON ^{27}AL

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We have performed wide-angle in-plane coincidence measurements of the alpha particles and tritons emitted in the 48-MeV ^{7}Li projectile breakup reaction on ^{27}Al. The data have been analyzed using the post-form distorted-wave Born-approximation (DWBA) theory of breakup reactions where Coulomb and nuclear breakup as well as their interference terms are included. The theory is able to provide a good description of the experimental data particularly at large relative angles between the fragments. The interference between the Coulomb and nuclear breakup modes is found to be significant.

1. Introduction

The breakup of a loosely bound projectile like deuteron and ^{6,7}Li in the Coulomb and nuclear fields of a target nucleus is a widely studied phenomenon, both experimentally and theoretically.[1–15] An in-depth study of this reaction is of considerable importance as it may lead to a better understanding of the breakup of the neutron rich ^{11}Li isotope and other isotopes which have a "halo" structure.[16] The cross section for the breakup of ^{11}Li into ^{9}Li (a stable isotope) and two neutrons has been found to be almost an order of magnitude larger than that of the stable lithium isotopes.[17] Furthermore, the energy and angular distribution of the fragments emitted in the breakup reaction induced by ^{11}Li show very different characteristics.[18]

The data for the breakup reactions involving ^{6}Li are available at beam energies ranging from sub-Coulomb[3,4] to those well above it.[5–9] However, the data on the breakup of ^{7}Li are mostly confined to beam energies of 70 MeV and above.[10–12] In this region (i.e., 10 MeV/nucleon) direct breakup mode is the major reaction mechanism. The set of data available below this energy are rather incomplete

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(inclusive measurements only). One set has been measured at a beam energy of 36 MeV[19] and another study exists which looks for the effects of post-Coulomb acceleration at 42 MeV.[13] However coincidence measurements of the alpha particles and tritons over a wide angular range, in a kinematically complete experiment, are still lacking, and the reaction mechanism of the breakup process at these energies is not well understood. Our motivation in this study is mainly to investigate the effect of nuclear part of the breakup mechanism which plays a prominent role in the wide-angle measurement of the breakup products. A kinematically complete experiment allows one to accurately select the channel. The reaction ^{7}Li + ^{27}Al has been studied with this objective by detecting tritons and alpha particles in coincidence.

2. Experimental Details

A ^{7}Li beam of 48 MeV was obtained from the 15UD Pelletron of the Nuclear Science Centre, New Delhi. The target was a self supporting ^{27}Al foil of thickness 190 μg/cm^2. The beam current on the target was $\approx$ 10 pnA. A 1.5-m diameter general purpose scattering chamber (GPSC)[20] was used to carry out the experiment. The particles were detected using two telescopes (each consisting of a 100-μm silicon ΔE and a 5-mm Si(Li) E detector) mounted on the two independent arms of the GPSC. One such telescope was fixed at 10° while the other was moved to different angles with respect to the beam direction in the horizontal plane. The solid angle subtended by each detector at the target was $\approx$ 0.3 msr. A surface barrier detector was kept at 10° to monitor the beam.

In order to get closer angles we have measured the cross sections with a new detector setup consisting of a gas ionisation chamber followed by a position sensitive strip detector (PSSD). This telescope was used as the alpha detector. The ionisation chamber with an active length of 10 cm and operated at 1 V/torr/cm was used as a ΔE detector for the alphas. The 1-mm thick silicon PSSD, with an active area of 50 × 50 mm was used as an E detector. The PSSD was divided into four sections each having an angular acceptance of 2°. The triton telescope consisted of a 100-μm thick silicon detector as ΔE followed by a 5-mm thick Si(Li) as the E detector. We have measured coincidence events of alpha and triton at various angles.

The total energy spectrum shows a quasi-elastic peak around 45 MeV. One such spectrum is shown in Fig. 1. The peak at the high energy side is used as a gate and the exclusive spectra taken at a few angles are shown in Fig. 2; the DWBA curves discussed later are also shown in the same figure. The exclusive spectra do not show any prominent peaks arising from the resonant breakup of ^{7}Li (especially via the 4.63-MeV state) and hence the breakup is expected to be dominantly direct.

At each angle the energy integrated triple differential cross sections (angular correlations) were extracted. In Fig. 3 we show the results for the case where the triton angle is fixed at 10° and that of the alpha particle is varied over a large range (the negative angle implies that the two detectors are on opposite sides of the beam). The reverse case where the alpha angle is fixed and the triton angle varied is shown in Fig. 4. The arrow indicates the region in which alpha (triton) cross sections could not be measured because of the fixed triton (alpha) telescope at 10° (in lab).

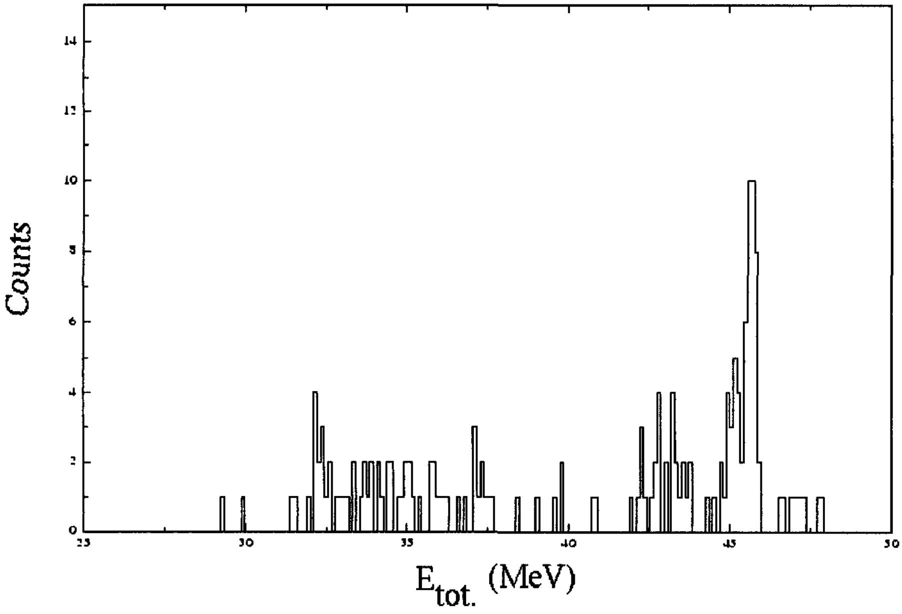

Fig. 1. Total energy spectrum for the reaction ^{27}Al (^{7}Li, αt) ^{27}Al at 48 MeV. $\theta_\alpha = 10°$ and $\theta_t = -14°$.

3. Direct Fragmentation Model Calculations

The data have been analyzed using the direct fragmentation model (DFM) of breakup reactions which has been formulated within the post-form DWBA.[14] In this model the incoming projectile is assumed to break up instantaneously in the Coulomb and nuclear fields of the target nucleus. The basic assumption of this theory is that the interaction between the two fragments in the final channel is weak, which is rather well fulfilled in our data where the two fragments in the final channel are detected at wide angles. The triple differential cross section for the reaction a + A → b + x + A is given by[14]

$$\frac{d^3\sigma}{d\Omega_b d\Omega_x dE_b} = \rho \left| T_{fi}^{DWBA} \right|^2 , \tag{1}$$

where the transition matrix is given by

$$T_{fi}^{DWBA} = \left\langle \chi_b^{(-)} \chi_x^{(-)} \middle| V_{bx} \middle| \chi_a^{(+)} \phi_a \right\rangle . \tag{2}$$

In Eq. (1) ρ is the three-body density of states.[21,22] In Eq. (2) V_{bx} is the interaction between fragments b and x in the ground state of the projectile a (described by ϕ_a). χ_a, χ_b and χ_x are the distorted waves describing the relative motion of particles a, b and x in their respective channels. These are evaluated by solving the Schrödinger equation with appropriate optical potentials. Equation (2) involves a six-dimensional integral which makes its calculation very cumbersome. The use of a zero-range approximation (ZRA) reduces this integral to a three-dimensional one. In the ZRA the details of the projectile structure enter in the amplitude through an overall normalization constant and only the s-wave relative motion between the fragments inside the projectile is allowed. Because of the relative p-state between α particle and triton in the ground state of ^{7}Li, this approximation is not suitable in this case. However, in an extended version of this model, calculations can be done for the projectiles with non-zero ground-state orbital angular momentum[23] while still retaining the basic structure of the ZRA transition amplitude. In this approximation Eq. (2) reduces to

$$T_{fi}^{DWBA} = N \int d^3r \; \chi_b^{(-)*}(k_b, r)\; \chi_x^{(-)*}(k_x, r)\; \chi_a^{(+)}(k_a, r)\,, \tag{3}$$

where N is a normalization constant.

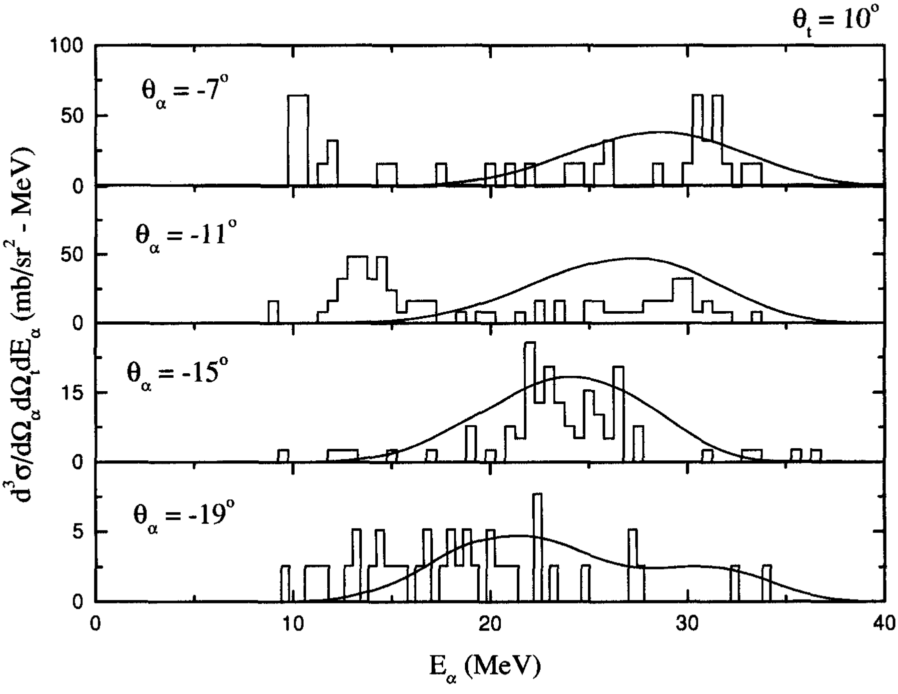

Fig. 2. The triple differential cross sections for the elastic breakup of ^{7}Li on ^{27}Al at 48 MeV at $\theta_\alpha = -7°$, $-11°$, $-15°$ and $-19°$. The solid line is the prediction from post-form DWBA described in the text.

4. Results and Discussion

Figure 2 compares the experimental triple differential cross sections with the values predicted by the DFM. The optical potentials needed to calculate the ^{7}Li relative motion in the entrance channel are taken from Ref. 24, while those for the triton and alpha particle are from Refs. 25, and 26, respectively. The value of the normalization factor N^2 was taken to be 32.0 in all the calculations. The triple differential cross sections shown in Fig. 2 fit well with the DWBA predictions.

In Figs. 3 and 4 the cross sections obtained by integrating the triple differential cross sections over the energies of alpha or triton are compared with the theoretical calculations. The dashed (dotted) line represents the results of the calculation performed with pure nuclear (pure Coulomb) interactions while the solid line is the full DWBA calculation which includes Coulomb, nuclear as well as their interference terms. It is clear that the experimental cross sections shown in Figs. 3 and 4 are reproduced by the full DWBA calculations. There is a good agreement between theory and experiment in the range of θ_α equal to $-7°$ to $-30°$ where the α and triton detectors are placed on opposite sides of the beam and the alpha-triton angular separation is large. However slight deviations from the theory are observed for θ_α between $+17°$ to $+37°$ (detectors on the same side of the beam); for this case the

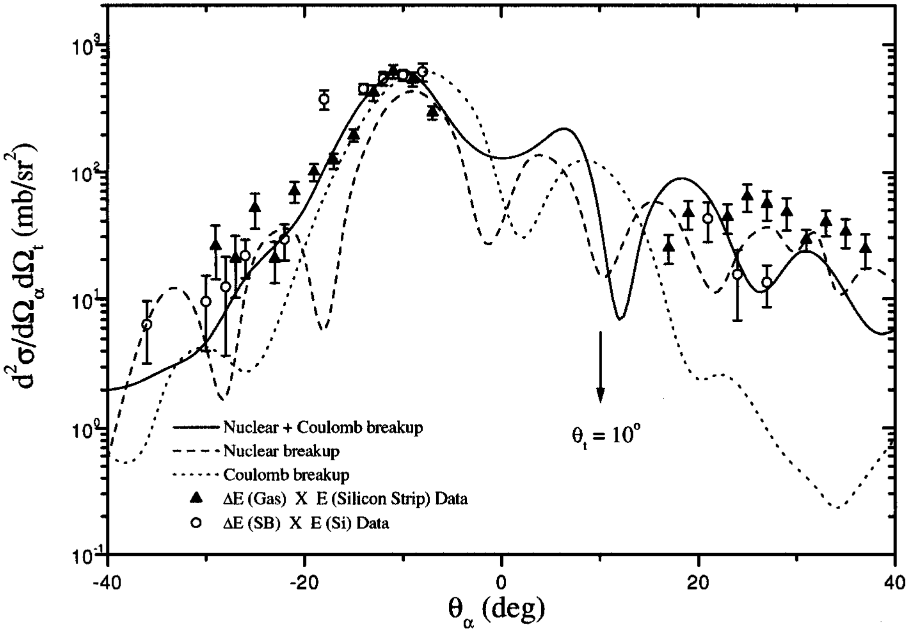

Fig. 3. Energy integrated alpha-triton cross section for the ^{7}Li breakup reaction on ^{27}Al at 48 MeV. The triton detector was fixed at 10°. The dashed (dotted) curve shows the nuclear (Coulomb) breakup cross sections calculated in the post-form DWBA formalism. The solid curve shows the total breakup cross section. The arrow indicates the position of the triton telescope (see text for details).

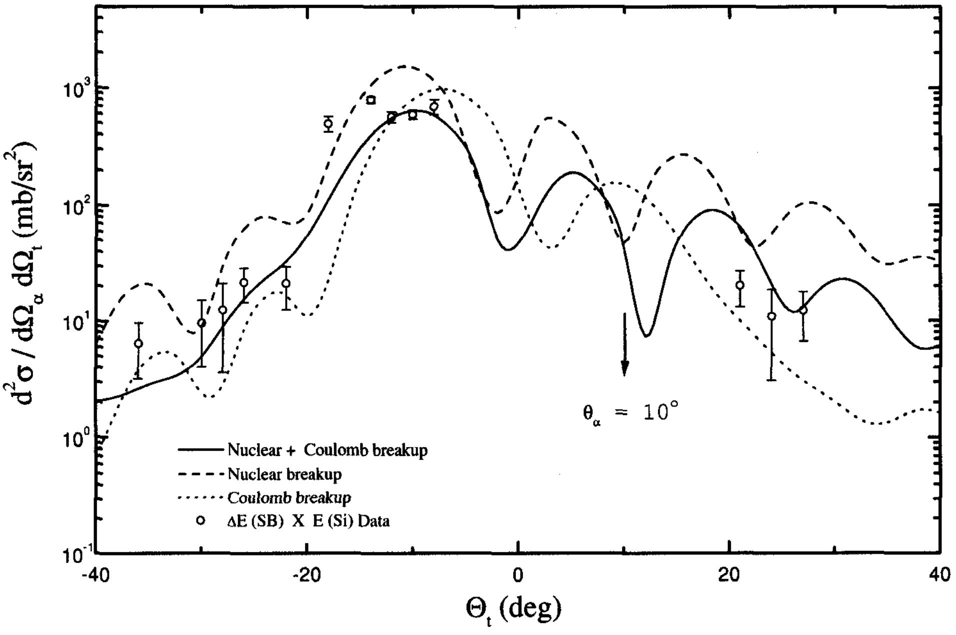

Fig. 4. Energy integrated alpha-triton cross sections for the ^{7}Li breakup reaction on ^{27}Al at 48 MeV. The alpha detector was fixed at 10°. For other details see caption of Fig. 3.

angular separation between the breakup fragments is not large. The experimental breakup cross sections fall slowly and show weak oscillations as compared to the theory.

In effect, the DFM is able to describe quantitatively the features of the breakup of 48-MeV ^{7}Li on ^{27}Al in the region where the separation between the two breakup fragments is large. This is expected as the assumptions of the DFM are better satisfied in the region. It may be noted that the interference between the Coulomb and nuclear breakup modes is significantly responsible for reproducing the data properly in this region. This behaviour of the breakup cross sections was also evident in earlier applications of the DFM for describing the breakup of lighter projectiles.[27] At relatively smaller angles of separation between the outgoing fragments, the final-state interaction (which is ignored in the DFM) may become important. Another reason is that the theory at the moment avoids a full finite-range treatment of the DWBA amplitude. The evaluation of the transition amplitude is a major problem even in the ZRA (or its extended version) as it involves a product of three scattering waves which converge very slowly. Our data may provide an incentive for improving the DFM to include full finite-range effects.

In some ^{6,7}Li induced breakup reactions, the angular correlations have also been analysed within a prior-form DWBA,[9,12] where breakup is supposed to occur via excitation of projectile internal state. In some cases coupled-channel calculations have also been performed.[7] In these models the interaction between the two outgoing fragments is taken into account. Therefore, the data in the region where the relative angle between the two fragments is very small are more amenable to these theories. Since we do not have enough data in this region, we have avoided using these models in the analysis of our data where our emphasis is more on the wide-angle behaviour of the angular correlations.

In summary, we have studied the breakup of ^{7}Li nucleus on ^{27}Al target at the beam energy of 48 MeV. The measured angular correlations were analysed using a direct fragmentation model of breakup reactions which is formulated in the framework of the post-form DWBA. The theory is able to reproduce our data well in the region where the relative angle between the two outgoing fragments is rather large. In this region, the interference between Coulomb and nuclear breakup is quite strong and is required to explain the data even for a light target like ^{27}Al. This is a significant result of our study. This should have an important bearing on the analysis of the angular distributions of the fragments emitted in the breakup reactions induced by halo nuclei on light targets where the Coulomb-nuclear interference is usually ignored (see e.g. Ref. 28).

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