Sequential Decay in the Reaction $^{10}B+d \rightarrow \alpha+\alpha+\alpha$

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The $^{10}B+d \rightarrow 3\,\alpha$ reaction is studied at a 0.40 MeV bombarding energy in a kinematically complete experiment. It is concluded that the reaction mechanism is predominently sequential involving the ground and 2.9 MeV first excited state of ^8Be.

Nuclear reactions with three particles in the final state give valuable information on reaction mechanism, nuclear models and nuclear interactions, when studied through kinematically complete experiments. In particular, nuclear reactions leading to a final state with three α particles are of interest, in connection with the ^{12}C cluster configuration, $\alpha-\alpha$ final state interaction and possible interference effects arising from the symmetry of the final state. Such reactions have been studied in several experiments [1, 2] but only in the work of Bronson et al. [2] a complete experiment has been performed through the $^{11}B+p$ entrance channel. This experiment shows that the final state is reached through a sequential decay involving the ^8Be ground and first excited states. However, the investigated range of ^8Be excitation energy extended only to about 13 MeV.

The present work presents preliminary results of a multiparameter experiment on the $^{10}B+d \rightarrow 3\,\alpha$ reaction at 0.40 MeV bombarding energy. This reaction may proceed to the three α final state either through a direct three-body decay or through sequential two-body intermediate stages, i. e.

$$^{10}B+d \longrightarrow \alpha+\alpha+\alpha+10.911\text{ MeV}$$
$$\qquad\longrightarrow {}^8Be^{*}+\alpha$$
$$\qquad\qquad\longrightarrow \alpha+\alpha$$

For the particular deuteron energy employed in the present experiment, the sequential decay may proceed through the ^8Be ground state and the 2.9 and 11.4 MeV excited states as in reference [2]. It may further include contributions from the two close lying ^3Be states around 16 MeV.

A 92% enriched 100 μg/cm^2 ^{10}Be target was bombarded with a 0.4 μA beam of 0.40 MeV deuterons from the Democritus Van de Graaff accelerator. Two of the final state α particles were detected in coincidence in two solid state detectors, each with an angular acceptance of 5.8×10^{-3} steradians and resolution of 0.7% for the 5.3 MeV ^{210}Po α particles. The detectors and the deuteron beam axis were kept coplanar, one detector being fixed at 90° with respect to the beam. The peripheral electronic apparatus, together with the Modified Laben 512-Channel Analyser employed in the present experiment have been described in detail elsewhere [3, 4]. The measurements reported here (Fig. 1) were taken with the moving detector placed successively at angles 71°, 82° and 90° with respect to the beam. For the analysis and presentation of the experimental data a new method has been used. This involves unfolding the kinematic locus of contributions, predicted by energy and momentum conservation. In the usual presentation of experimental results from a three-body reaction [3] the number of coincident events is plotted versus the kinetic energies T_1 and T_2 of the two detected particles in the final state. For the direct three-body reaction energy and momentum conservation predict contributions along a uniformly populated curve on the T_1, T_2 plane. All information concerning the reaction mechanism will then be drawn from deviations from this uniform population. However, when quantitative measurements and angular correlations are attempted, two-dimensional spectra have to be considered. In this connection the usual practice has been to consider one-axis projections of the three-dimensional plot, which, nevertheless, contain a very sharp phase-space dependance. To avoid phase space normalization and the inevitable introduction of a considerable experimental error, the kinematic locus for each set of angles of detection is divided into fifty equal segments. The spectra in Fig. 1 are constructed by considering the population of each sector in the T_1, T_2 plane contained between two straight lines normal to the kinematic locus at two successive division points. It should be noted that the resolution obtained through this particular division of the kinematic locus is comparable to the overall resolution of the experimental apparatus. A detailed description of this method, together with the Fortran Code employed for the transformation, is given elsewhere [5].

In Fig. 1 the experimental spectra, transformed through the above method, are collected in a three-dimensional plot. With the fixed detector set a 90°, Θ_2 is the angle of the moving detector with respect to the deuteron beam, while on the S-axis the transformation channel is recorded. The nomograms E_1, E_2 and E_{12}, drawn with the 82° spectrum, relate, on the far side vertical axis, the intermediate state ^8Be excitation energy to the S-channel.

A theoretical reconstruction of the experimental spectra in Fig. 1 has been attempted. For this purpose the method described by Swan [6] in the solution of the

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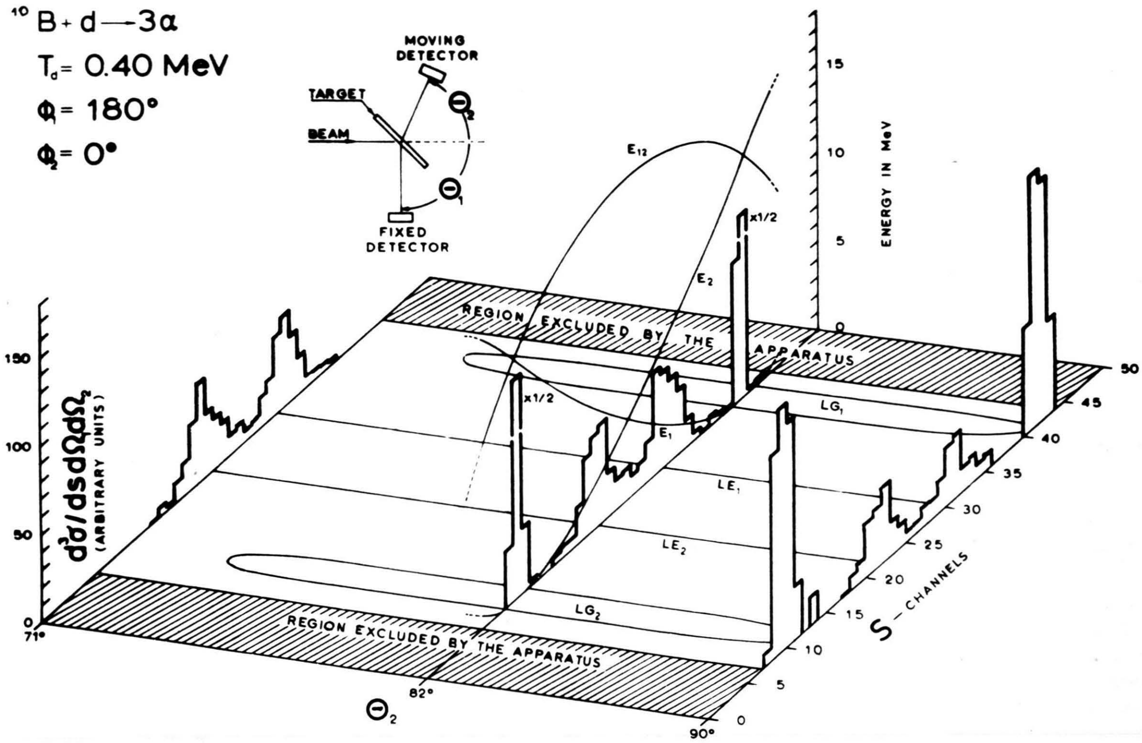

Fig. 1. A three-dimensional plot of coincident events versus Θ_2 and S. The definition of the S-channel is given in the text. The nomograms E_1, E_2 and E_{12}, drawn with the spectrum for $\Theta_2=82°$, relate, on the far side energy axis, the ^{8}Be excitation energy to the S-channel. E_1 and E_2 are the nomograms for the first emitted α particle detected at the first (fixed) and second (moving) detector, respectively. E_{12} describes the case in which both detected α particles are products of the decay of ^{8}Be*. The curves LG_1, LG_2 and LE_1, LE_2 on the S, Θ_2 plane are the loci of the expected contributions from the ground and 2.9 MeV first excited state of ^{8}Be. The suffices 1 and 2 have the same meaning as in the nomograms E_1 and E_2. The experimental set-up is also given schematically in the upper left-hand corner of the figure, together with the deuteron bombarding energy and azimuthal angles of detection Φ_1 and Φ_2.

^{11}B + p triple correlation problem has been closely followed. In this context, SWAN's $(d^3\sigma/dT_1)\, d\Omega_1\, d\Omega_2$ cross-section was transformed through

$$\frac{d^3\sigma}{dS\, d\Omega_1\, d\Omega_2} = \left[1+\left(\frac{dT_2}{dT_1}\right)^2\right]^{-1/2} \frac{d^3\sigma}{dT_1\, d\Omega_1\, d\Omega_2}. \qquad (1)$$

For the density of final states factor involved in the reaction amplitude for the decay of the ^{12}C system, the BREIT–WIGNER form has been employed.

Preliminary calculations of the cross-section of Eq. (1) show that the experimental spectra can be accounted for by considering contributions from the ^{8}Be ground and 2.9 MeV first excited state only.

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