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$^{10}B + d \rightarrow 3\alpha$ REACTION AT E_d = 1.83 MeV.

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ABSTRACT. -

The $^{10}B + d \rightarrow 3\alpha$ reaction was studied at E_d = 1.83 MeV using the tecnique of the bidimensional spectra of two α-particles. It was possible to observe the variation of the angular correlation vs. the excitation energy of the ^{8}Be complex formed in the sequential process. The angular correlation is in agreement, at this incident energy, with an heavy particle stripping mechanism with l = 2. Distorsion effects are present in the first stage of the sequential process.

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1. - INTRODUCTION. -

The $^{10}B + d \rightarrow 3\alpha$ reaction (Q = 17.913 MeV) is a typical reaction with three identical particles in the final state. This identity allows a good simplification of the theoretical expressions describing the angular α-α correlations in the final state, due to the definiteness of the parity of the 2α-states.

Of this reaction were studied the angular distribution of one of the α-particles at $E_d < 1.5$ MeV(1-4), the excitation functions at $\theta = 90^o$ and 100^o at $E_d > 2.5$ MeV(5), the angular correlations of two α-particles at $E_d < 1.5$ MeV(6).

The angular distributions at low energies for the α-particles leaving the ^8Be in its first excited state show two peaks, one at 0^o, the other at $\theta \approx 110^o$, the former of which decreases while the latter increases with the incident energy. A recent measurement(7) at the energy used in this work and the data at higher energies confirm such a trend.

The angular correlation data seem in agreement with a sequential mechanism of the type $^{10}B(d,\alpha)^8Be(2\alpha)$.

The first stage is dominated by compound nucleus formation evolving in pick-up mechanism at higher energies(6). No informations there are however above $E_d = 1.5$ MeV.

Furthermore no informations there are on the variations, if any, of the angular correlation vs. the excitation energy of the ^8Be complex in the region of the broad 2.9 MeV level.

To obtain these latter informations and to have informations on the reaction mechanism at other energies, we studied the bidimensional spectra of the $^{10}B + d \rightarrow 3\alpha$ reaction at $E_d = 1.83$ MeV.

2. - EXPERIMENTAL PROCEDURE AND RESULTS. -

2.1. - Collection of the experimental data. -

The ^{10}B target was obtained by vacuum evaporation of B_2O_3 enriched in ^{10}B at 95% on a thin formvar backing.

It was bombarded with deuterons accelerated by the 2.7 MV Van de Graaff machine of the CSFN and SM laboratories in Catania. The incident energy at the centre of the target was $E_d = 1.83$ MeV and the energy spread due to the target thickness was $\Delta E_d = \pm 170$ keV. To detect the α-particles of the $^{10}B + d \rightarrow 3\alpha$ reaction two surface barrier detectors supplied by ORTEC were used. One of them was fixed at $\theta_1 = 88.4^{o}$ and $\varphi_1 = 0^{o}$ and the other was allowed to rotate between $\theta_2 = 30^{o}$ and $\theta_2 = 150^{o}$ at $\varphi_2 = 180^{o}$. The detectors were distant from the centre of the scattering chamber by $d_1 = d_2 = 10.2$ cm. Their surfaces were $S_1 = S_2 = 7\ mm^2$.

The pulses of these two detectors were sent through two ORTEC amplification chains to a system of fast-slow coincidence ($\tau = 30$ ns) supplied by COSMIC and to a LABEN 4096 channels analyser operating in bidimensional operation mode, controlled by the output pulses of the coincidence system. The output pulses of the detector 1, acting also as beam monitor, were counted by a scaler.

A charge integrator supplied by Eldorado allowed to measure the incident charge collected by a Faraday cup. The runs were carried out at fixed collected charge.

As expected, the pulse distribution in the E_1E_2 plane was restricted to a strip around the kinematic curve as given in ref.(8).

2.2. - Experimental results in the laboratory system (LS). -

Fig. 1 reports schematically the loci of the pulses on a kinematic curve of the reaction.

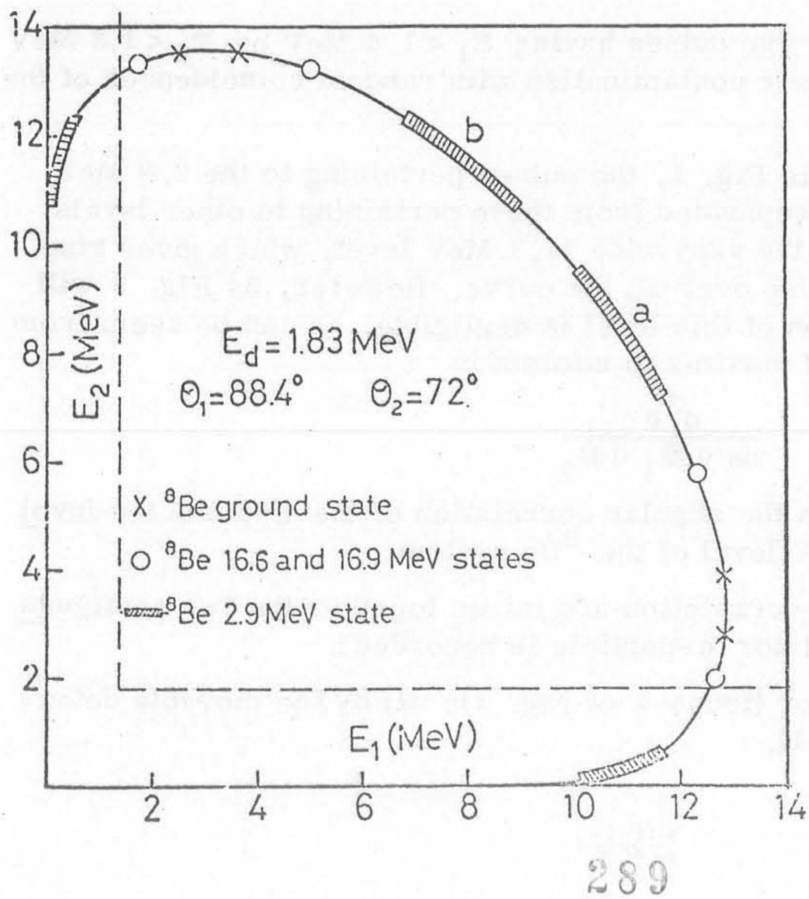

FIG. 1 - Kinematic curve of the $^{10}B + d \rightarrow 3\alpha$ reaction at θ_1=88.4° and θ_2 = 74°.

Fig. 2a reports the angular correlation in the LS made up by all the pulses recorded on each bidimensional spectrum in the strip around

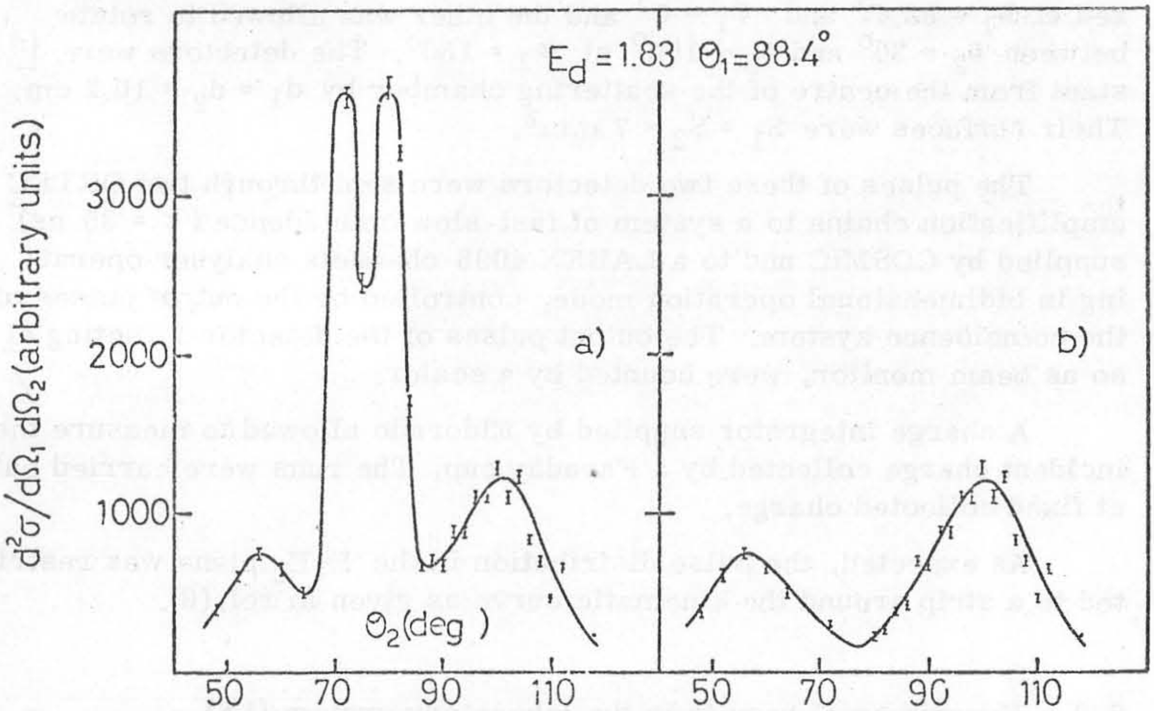

FIG. 2 - a) total angular α-α correlation in the reaction $^{10}B + d \to \to 3\alpha$; b) angular correlation of the α particles leaving the ^{10}Be in the first excited state.

the kinematic curve. The pulses having $E_1 < 1.4$ MeV or $E_2 < 1.8$ MeV were neglected for their contamination with random coincidences of the scattered deuterons.

As is seem from Fig. 1, the pulses pertaining to the 2.9 MeV level of the ^8Be are separated from those pertaining to other levels with the exception of the very wide 11.7 MeV level, which gives rise to a quite uniform noise over all the curve. However, as Fig. 3 will show, the contribution of this level is negligible, as can be seem from the very high ratio of maxima to minima in

$$\frac{d^3\sigma}{ds\, d\Omega_1\, d\Omega_2} .$$

Fig. 2b reports the angular correlation of the α-particles invol ving only the 2.9 MeV level of the ^8Be system.

In this angular correlation are mixed together the two configura tions where the spectator α-particle is recorded:

i) by the fixed detector (locus a of Fig. 1); ii) by the movable detector (locus b of Fig. 1).

We analized then the pulses on the loci a) and b) of Fig. 1, projecting them on the kinematic curve using the method described in ref. (8).

Fig. 3 reports for some spectra the pulse density per unit length of kinematic curve $\frac{d^3\sigma}{ds\, d\Omega_1\, d\Omega_2}$ versus the curvilinear abscissa s on the same curve.

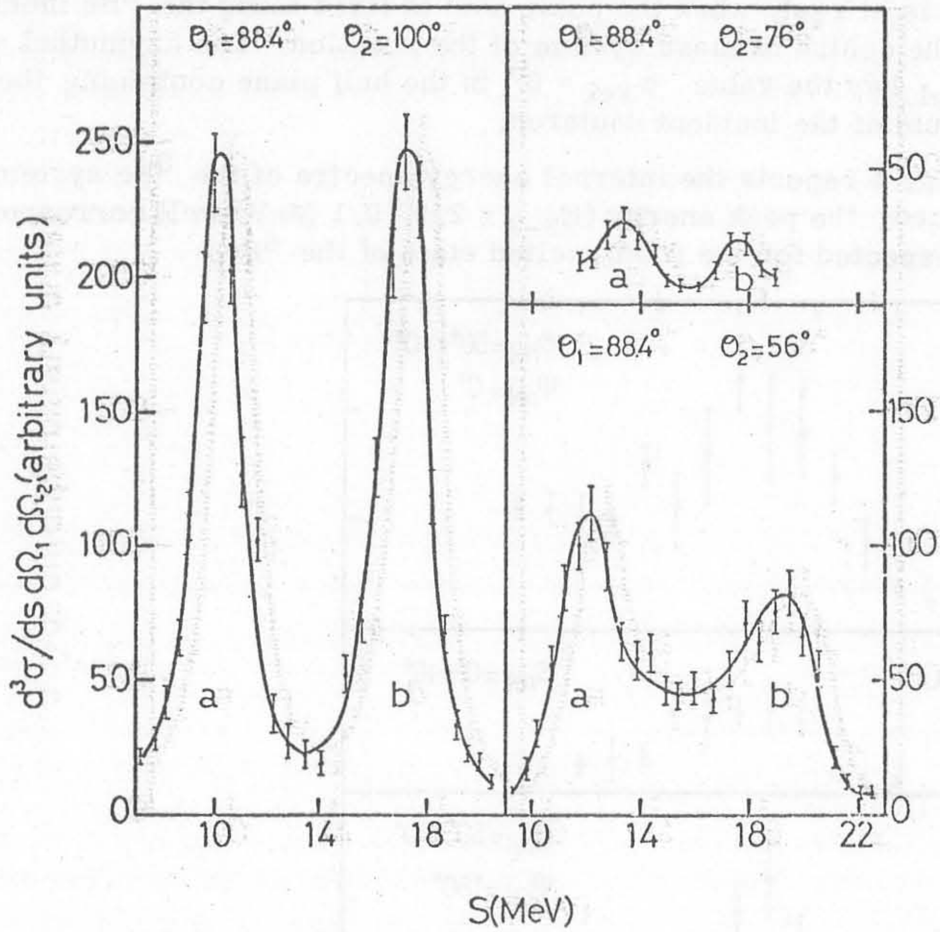

FIG. 3 - Distribution of counts along the kinematic curves in the LS for $E_d = 1.8$ MeV, $\theta_1 = 88.4^o$, $\varphi_2 - \varphi_1 = 180^o$ at various θ_2.

The two peaks in the spectra of Fig. 3 correspond respectively to the loci a) and b) of Fig. 1 and are effectively well separated, so making sure against interference effects.

2.3. - Experimental results in the system of the relative coordinates (RCS). -

As is known, the angular correlation between two exit particles can depend from the angle of emission of the spectator particle.

So we analized at the various angles only the pulses under the peaks a) (Fig. 3). They infact pertain all to the same angle of emission of the spectator particle.

The data in the LS were trasformed to the RCS introduced in ref. (8). In this system the relative energy E_{2-3} is the internal energy of the recoiling ^{8}Be system and θ_{rel} is the angle of the α-particle produced in the subsequent decay, in the reference frame where the ^{8}Be is at rest, when the polar axis is fixed along the ^{8}Be momentum in the centre of mass system of the reaction. The azymuthal angle φ_{rel} has the value $\varphi_{rel} = 0^o$ in the half plane containing the momentum of the incident deuteron.

Fig. 4 reports the internal energy spectra of the ^{8}Be system. As is seemed, the peak energy ($E_{2-3} = 2.9 \pm 0.1$ MeV) well corresponds to that espected for the first excited state of the ^{8}Be.

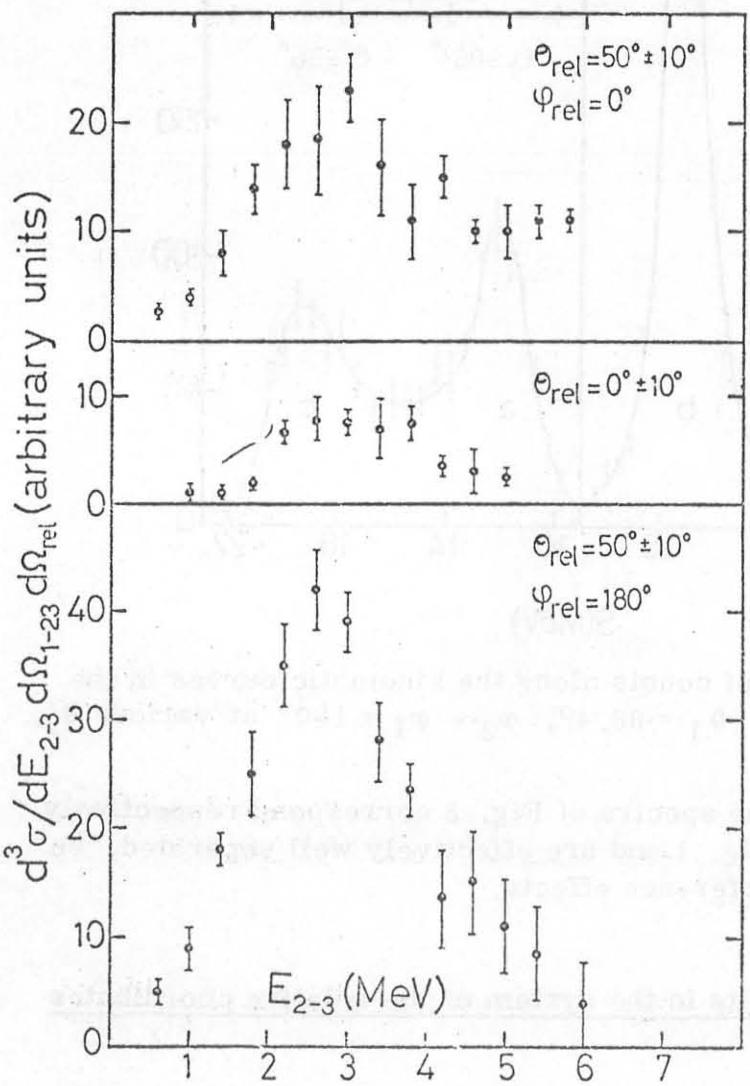

FIG. 4 - Internal energy spectra of the ^{8}Be system seen at various angles θ_{rel} of the emitted α-particles with respect to the direction of the motion of the ^{8}Be.

The width of the peak ($\Gamma \sim 2$ MeV) is somewhat larger than other accepted values(9). It is to be noted also that the forms of the spectra at the various relative angles are not the same. So seemed us useful to study the angular correlation in the RCS at various values of the internal energy.

Fig. 5 reports the angular correlations of the α-particles in the RCS, for three internal energy intervals.

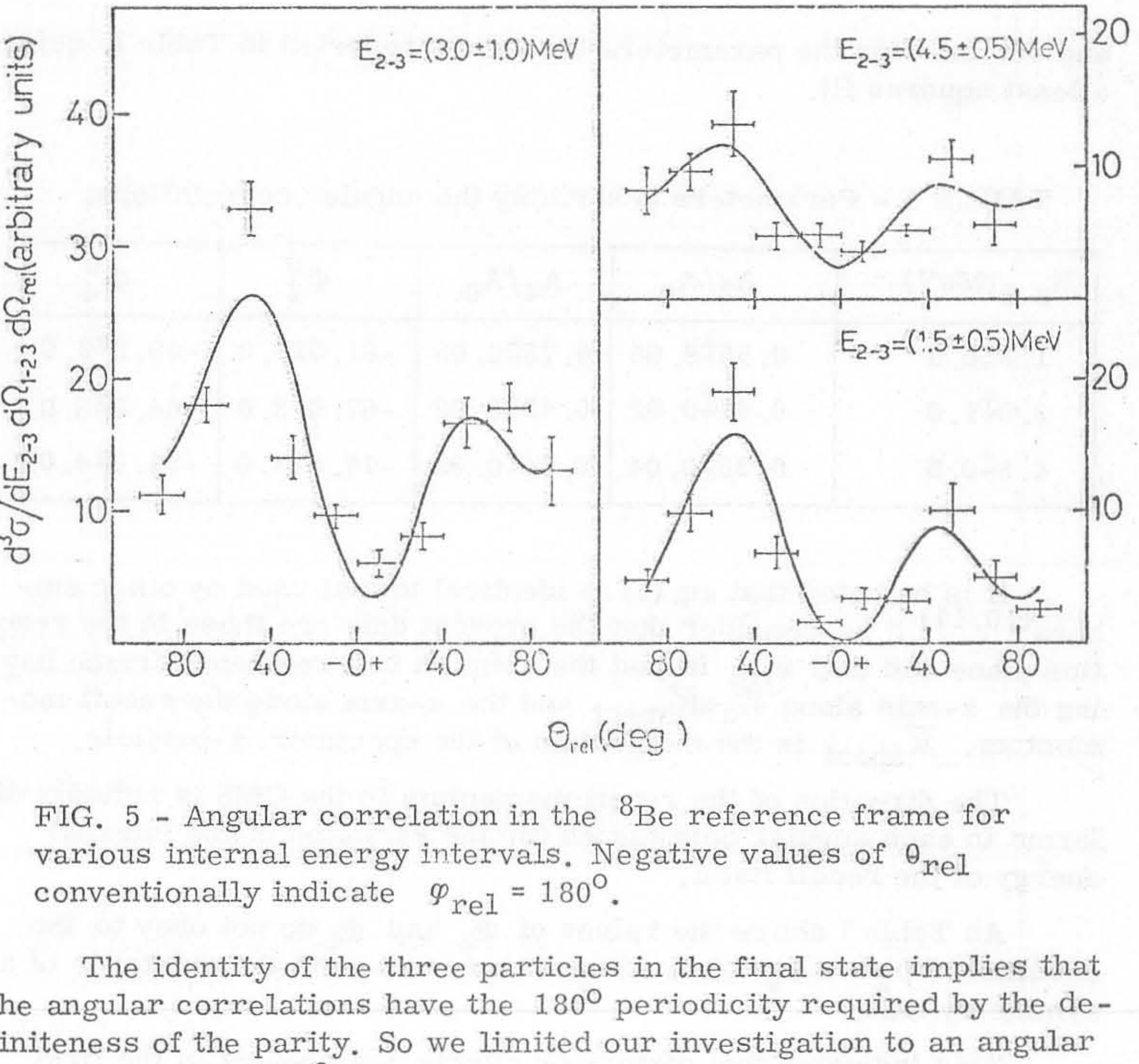

FIG. 5 - Angular correlation in the ^{8}Be reference frame for various internal energy intervals. Negative values of θ_{rel} conventionally indicate $\varphi_{rel} = 180^o$.

The identity of the three particles in the final state implies that the angular correlations have the 180^o periodicity required by the definiteness of the parity. So we limited our investigation to an angular interval of about 180^o.

3. - DISCUSSION AND CONCLUSIONS. -

As Fig. 5 shows, the angular correlations are not symmetric with respect to the direction of the recoiling ^{8}Be momentum in the centre of mass system ($\theta_{rel} = 0$).

Assuming that the reaction proceeds in a sequential mechanism of the type $^{10}B + d \rightarrow {}^8Be + \alpha \rightarrow 3\alpha$, this absence of symmetry indicates that direct effects are involved in the first stage of the process (ref. (6), (10)). Furthermore the l transfer of the direct process must be different from zero[10].

We compared the experimental angular correlation with the theoretical expression

$$W(\theta_{rel}) = A_o + A_2 \cos 2(\theta_{rel} - \Phi_2) + A_4 \cos 4(\theta_{rel} - \Phi_4) \quad (1)$$

and obtained for the parameters the values reported in Table I, using a least squares fit.

TABLE I - Parameters describing the angular correlations.

E_{2-3}(MeV)	A_2/A_0	A_4/A_0	Φ_2^o	Φ_4^o
1.5±0.5	0.55±0.05	0.73±0.05	-61.0±4.0	-49.0±3.0
3.0±1.0	0.47±0.02	0.42±0.02	-67.0±3.0	-44.0±3.0
4.5±0.5	0.38±0.04	0.34±0.05	-77.0±5.0	-51.0±4.0

It is be noted that eq. (1) is identical to that used by other authors[10, 11] if we consider that the present data are those in the reaction plane and that θ_{rel} is just the azimuth in a reference frame having the z-axis along $\vec{K}_d \times \vec{K}_{spect}$ and the x-axis along the recoil momentum. $\vec{K}_{spect}$ is the momentum of the spectator α-particle.

The direction of the recoil momentum in the CMS is actually different in each angular correlation for the variation of the internal energy of the recoil itself.

As Table I shows the values of Φ_2 and Φ_4 do not obey to the condition $2\Phi_2 = 4\Phi_4 + (0 \text{ or } \pi)$ necessary to assert the existence of a symmetry axis.

This indicates that distorsion effects are present in the first stage of the reaction.

It is interesting to note the regular trend of the parameters of the angular correlation, showing an anisotropy continously decreasing with the excitation energy of the complex. The Φ_2 angle is also decreasing while Φ_4 is quite constant.

The possible direct mechanism sees the ^{10}B nucleus in this ground state described in a two clusters model essentially as : i) a ^{6}Li core plus an α-particle ; ii) a ^{8}Be core plus a deuteron. This latter case gives rise to the pick-up process and the final ^{8}Be state can be well described by a two α-particles configuration. The former case gives rise to the heavy particle stripping process and the ^{8}Be state must be described by a ^{6}Li-d configuration.

In the case of plane waves, one could expect definite symmetry axes making with the recoil momentum the angles $\Phi \simeq 10.7^{o}$ for pick-up and $\Phi = -45.5$ for heavy particle stripping, as found by the wave vector technique(6-12).

By comparison with Table I, it seemed that no one of these angles corresponds to Φ_2, while Φ_4 well corresponds to the angle associated to the heavy particle stripping. The interpretation in terms of this mechanism is also supported by the constancy of Φ_4 vs. the excitation energy.

Furthermore, the angular distribution of the spectator α-particle at $E_d = 1.83$ MeV(7), seems to confirm a mechanism of heavy particle stripping.

If this is the case, since it is Φ_4 which shows agreement with the angle of the expected symmetry axis, one can conclude that $l_{transf} = 2$(11).

In this hypothesis one has also to say that the ^{8}Be recoil seems to be formed initially in a ^{6}Li-d configuration soon decaying in the α-α configuration.

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RIASSUNTO. -

La reazione $^{10}B + d \rightarrow 3\alpha$ è stata studiata a $E_d = 1.83$ MeV usando la tecnica degli spettri bidimensionali di due particelle α. E' possibile osservare la variazione della correlazione angolare con l'energia di eccitazione del complesso ^{8}Be formato nel processo sequenziale.

La correlazione angolare è in accordo, a questa energia incidente, con un meccanismo di heavy particle stripping con $l = 2$.

Effetti di distorsione sono presenti nel primo stadio del processo sequenziale.