some specific structure inside the blob. This blob is not a point any more. And that is what makes the rescattering different.

KANE: I would just like to reiterate Zupančič's question. It seems to me the conservation of energy and momentum gives you a spot on the diagram, Fig. 1b, rather than a band.

KACSER: No. By Dalitz plot I mean a plot which includes all possible angles. You are probably thinking in terms of a differential plot, obtained with two counters set at fixed angles.

Even in the full Dalitz plot it is not immediately obvious one should get a band. The reason is that it is the intermediate α_1', α_2' that must satisfy the "catch-up" condition. They then rescatter, giving the observed α_1 and α_2. By four-momentum conservation $S_3=(\alpha_1+\alpha_2)^2=(\alpha_1'+\alpha_2')^2=S_3'$. But $p+\alpha_1'\neq p+\alpha_2$ so that while $S_1'=(p+\alpha_2')_2=[\text{mass Li}^{5*}]^2$, S_1 is not determined, and can take on all possible values.

ZUPANČIČ: I don't have any objection whatsoever. I believe your calculation. I would just like to understand it physically. Why is it a condition that you should have the vertical band crossing the elipse in order that the horizontal band appears (Fig. 1b)? Why is it discontinous?

KACSER: Why didn't I get an effect in Fig. 1a? Because then, if the excitation of the Li^{5*} means anything at all on the far tail of the Breit–Wigner resonance, this particular Li^5 state would be exceedingly weak. To that extent it would also break up and give some effect. But I am looking for an effect you can observe, and this is best in the case of Fig. 1b.

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The $Be^9(He^3, \alpha\alpha\alpha)$ Reaction

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The Q values for many He^3 and tritium-induced reactions on light nuclei are sufficiently high that it is possible for the systems to decay to three- or four-body final states. $Be^9(He^3, \alpha\alpha\alpha)$ is an interesting example of such a reaction leading to a three-body final state.

Studies of the spectra and angular distribution for the $Be^9(He^3, \alpha)2He^4$ reaction at bombarding energies of 3 and 4 MeV by Erskine and Browne[1] and by Dorenbusch and Browne[2] have shown the existence of a large continuum in the α-particle spectrum, a feature characteristic of the single-particle spectra for multiparticle reactions. Dorenbusch and Browne[3] have proceeded to fit the shape of this continuum under the assumptions that the continuum results from the breakup of states of a compound nucleus, C^{12}, and that the density of final states is uniformly distributed in phase space.

Since all the states of Be^8 are unbound for α decay and since many of these states are rather short-lived, one might expect that, indeed, the phase-space distribution for the final state would not be significantly modulated by the interactions among the components of the final state for the $Be^9(He^3, \alpha\alpha\alpha)$ reaction, even at low bombarding energies. The study of the single-particle spectra, however, is not adequate to determine unambiguously the nature of the process leading to the multibody final state.

The origin of the continuum can be uniquely determined for the 3 α-particle final state by measuring the energies of two of the α particles, E_A and E_B, at angles θ_A and θ_B. Conservation of energy and momentum restrict all such events to a kinematic curve $E_B(E_A)$ in the two-dimensional energy spectrum E_AE_B at fixed θ_A and θ_B. Reactions which proceed by sequential processes through discrete states of the intermediate Be^8 system will appear as points on this curve, or segments of the curve in the case of broad resonances.

If the $Be^9(He^3, \alpha\alpha\alpha)$ reaction proceeds through the 0^+ ground state of Be^8 with the emission of the initial α particle at the angle θ_A, the angle θ_B at which one of the α particles from the subsequent breakup of the Be^8(g.s) is emitted is limited to a narrow cone (half-angle$=7.2°$ for $\theta_A=60°$) about the recoil direction of the Be^8(g.s.) system. Figure 1(a) represent the velocity vector diagram of $Be^9(He^3, \alpha)Be^8(\text{g.s.})\rightarrow 2\alpha$ reaction where $V_{\text{C.M.}}$ denotes the total center-of-mass velocity. V'_A and V'_{Be} are the velocities of the initial α and the Be^8 in the total center of mass system, and

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[1] J. R. Erskine and C. P. Browne, Phys. Rev. **123**, 958 (1961).
[2] W. E. Dorenbusch and C. P. Browne, Phys. Rev. **131**, 1212 (1963).
[3] W. E. Dorenbusch and C. P. Browne, Phys. Rev. **132**, 1759 (1963).

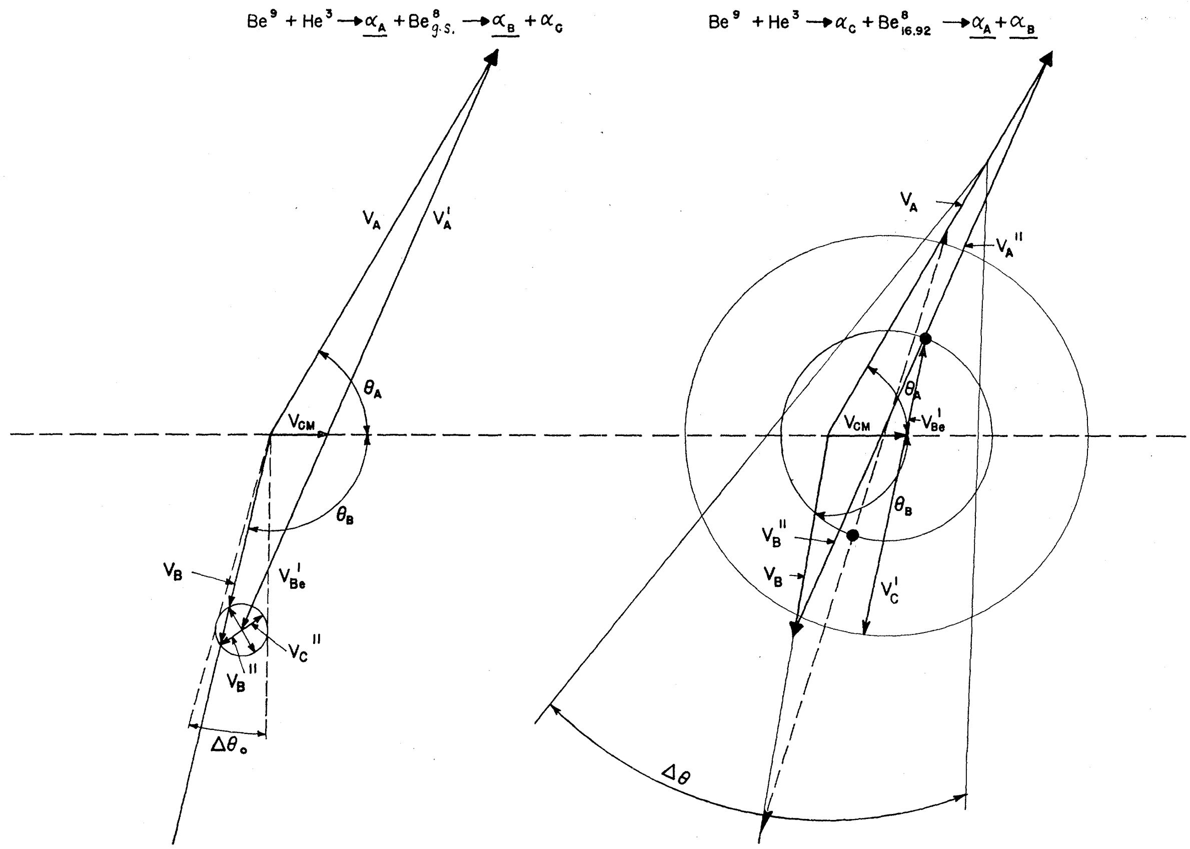
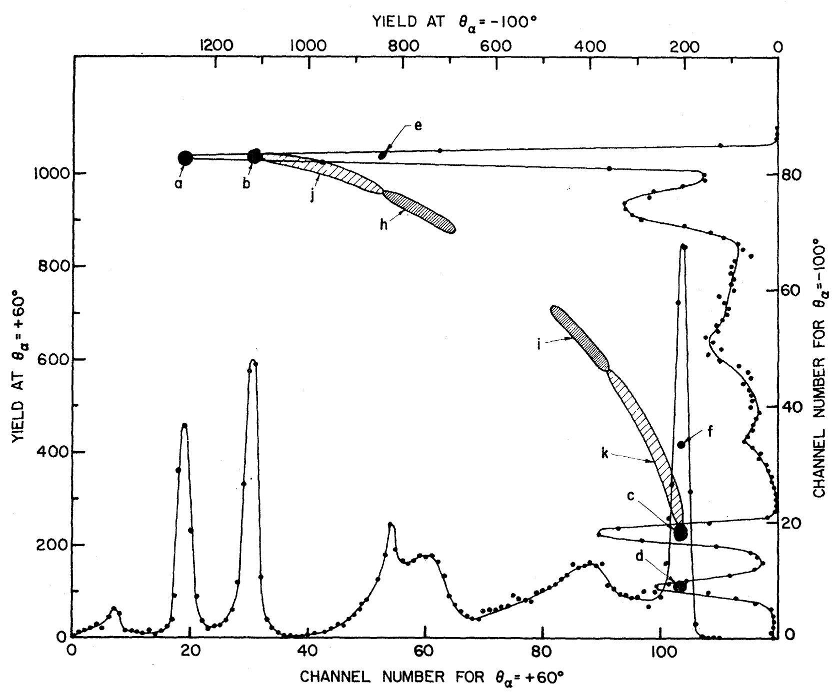


FIG. 1. (a) and (b) The velocity vector diagrams of Be⁹(He³, α) Be⁸(g.s.)→2α and Be⁹(He³, α) Be⁹(16.92)→2α at $\theta_A=+60°$ and $\theta_B=-100°$ for an incident 3.0-MeV He³.

FIG. 2. The projections of the two dimensional energy spectrum onto the E_A and E_B axes and the reconstructed kinematic curve at $\theta_A=+60°$ and $\theta_B=-100°$ for a bombarding energy of 3.0 MeV. The positions of the points and segments corresponding to the various levels of Be⁸, as well as resonances in the α–α system, are indicated.



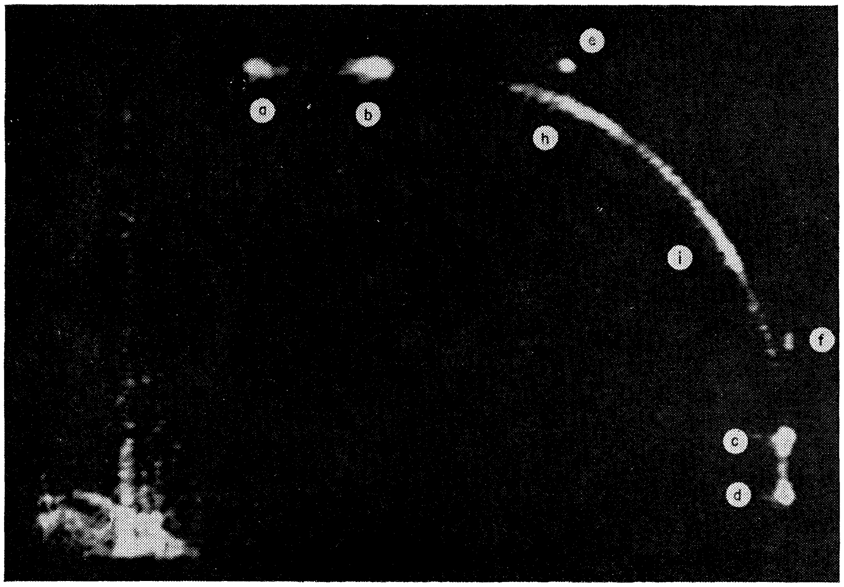


Fig. 3. The two-dimensional energy spectrum for the $Be^9(He^3, \alpha)2He^4$ reaction at $\theta_A=+60°$ and $\theta_B=-100°$ for a bombarding energy of 3.0 MeV.

V_B'' and V_C'' denote the velocities of the two breakup α particles in the rest system of Be^8(g.s.). This diagram illustrates the limits of the cone in which the two breakup α particles may be observed, as well as the double-valued behavior of E_B for every θ_B within this cone. The picture can also be reversed with the initial α particle emitted at θ_B and one of the breakup α particles at θ_A. Hence a total of four points will appear on the kinematic curve corresponding to reactions proceeding through the Be^8(g.s.) system. These are the points (a), (b), (c), and (d) shown in Fig. 2. In addition, when θ_B (or θ_A) is the laboratory recoil direction of the Be^8(g.s.) system it is possible to capture both of the breakup α particles in counter B (A). Points (e) and (f) in Fig. 2 correspond to such events. Since all three α particles are captured in such events, they are not restricted to the kinematic curve.

For highly excited states of Be^8, such as the 16.92-MeV state, the relative velocities of the breakup α particles are sufficiently large that coincidences between the initial α particle and one of the breakup α particles from the Be^8 can be observed at all angles. For all such states the solutions are single valued. Only two points can appear on the kinematic curve for a given state, one point corresponding to the initial α particle being observed at θ_A, the other point corresponding to the initial α particle being observed at θ_B. However, for such states it is possible to observe the two breakup α particles in coincidence over a limited angular region ($\approx$66° for the 16.92-MeV state). The velocity vector diagram of such a process is illustrated in Fig. 1(b) where V'_{Be} denotes the velocity of Be^8(16.92) in the total center-of-mass system and V_B'' and V_A'' represent the velocities of the two breakup α particles in the rest system of Be^8(16.92). Hence, for each such state and within the allowable angular region four points again appear on the kinematic curve.

For bombarding energies extending from 2 to 7 MeV the four points for the 16.92-MeV state very nearly coincide with the four points for the Be^8(g.s.) when θ_A and θ_B correspond to the Be^8(g.s.) recoil directions.

Figure 3 represents the two-dimensional energy spectrum for $\theta_A=+60°$ and $\theta_B=-100°$, the Be^8(g.s.) recoil direction. The kinematic curve with points corresponding to various states of Be^8 and segments for the resonances in the α–α scattering system are clearly seen. This picture was obtained by applying the signals from two solid-state detectors to the x and y axes of an xy oscilloscope and intensifying the trace whenever a coincidence occurred between the two counters.

Quantitative information was obtained by projecting the energy spectrum onto the x and y axes. A diagonal window condition requiring that $E_1<E_A+E_B<E_2$, in addition to the coincidence requirement, can be imposed in order to remove most of the accidental coincidences from the projections. The projections for the two-dimensional energy spectrum shown in Fig. 3 are illustrated on the horizontal and vertical axes in Fig. 2. A reconstruction of the kinematic curve indicated by points and segments corresponding to various states of Be^8 and α–α scattering resonances is also shown in this figure. The lengths of the segments correspond approximately to the widths of the resonances. Similar two-dimensional energy spectra and projections have been obtained at a large number of angles, θ_A and θ_B.

Observations at angles off the Be^8(g.s.) recoil axis indicate that only a small fraction of the intensity of

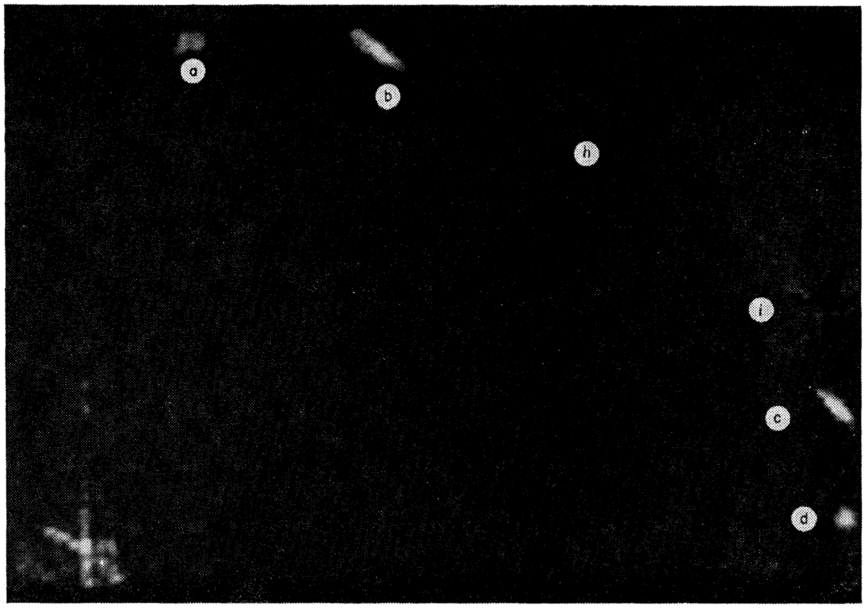


FIG. 4. The two-dimensional energy spectrum for the $Be^9(He^3, \alpha)2He^4$ reaction at $\theta_A=+60°$ and $\theta_B=-100°$ for a bombarding energy of 3.0 MeV.

the peaks corresponding to the positions (a), (b), (c), and (d) is due to the reaction proceeding through the Be^8(g.s.) and that most of the contribution to these peaks is from the 16.92-MeV state. Further, since the contribution from the Be^8(g.s.) is limited to a very small cone, the total yield for this state is very small. Figure 4 represents the two-dimensional energy spectrum for $\theta_A=+60$ and $\theta_B=-120°$, outside the Be^8(g.s.) cone. Hence, points (a), (b), (c), and (d) correspond to the Be^8(16.92) level only and region (h) and (i) correspond to $L=2$ resonance. It should be pointed out that the kinematic behavior of the points corresponding to the 16.92-MeV state is such that a narrow peak is produced in the single particle spectrum by the contributions from this state. This peak coincides with the ground-state α-particle group in the single-particle spectrum for a wide range of bombarding energies in the region of 3 MeV. Hence, observations of single-particle spectra for the $Be^9(He^3, \alpha)Be^8$ reaction can often be misleading.

The effects of the very broad, $L=4$, α–α resonance near 11.4 MeV are relatively weak in Figs. 2–4. However, contributions involving this resonance have been clearly seen at angles outside of the limiting cone for the $L=2$ resonance. They are rather weak compared to the yield from the 16.92-MeV state.

The lack of yield in various regions of the two-dimensional spectrum, of Fig. 2 and 3, readily apparent in the projected spectra of Fig. 2 as well as in the spectra at other angles, clearly indicates that at bombarding energies in the region of 3 MeV (corresponding to an excitation in C^{12} of 28.5 MeV) the phase-space distribution of the final state produced by the $Be^9(He^3, \alpha\alpha\alpha)$ reaction is strongly modulated by the two-body interactions among the various components of the final state.

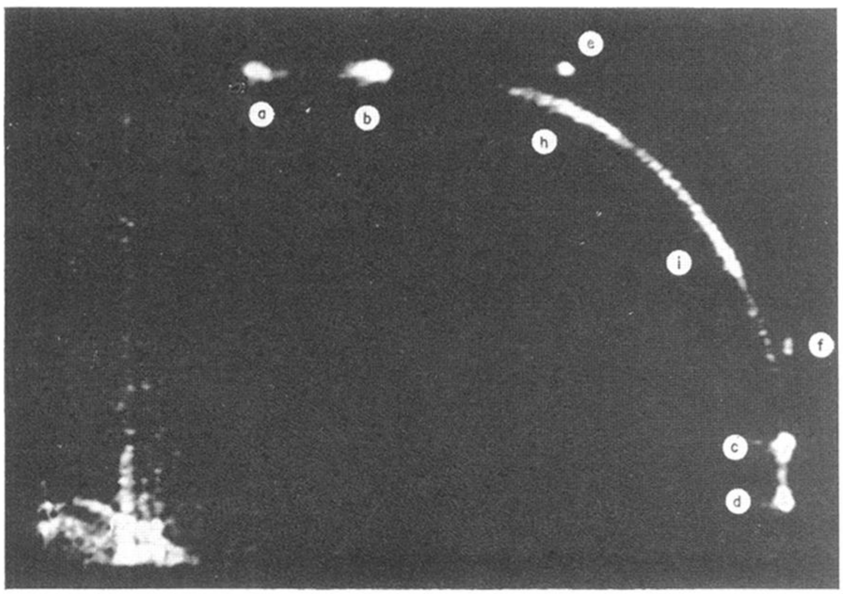


FIG. 3. The two-dimensional energy spectrum for the $Be^9(He^3, \alpha)2He^4$ reaction at $\theta_A = +60°$ and $\theta_B = -100°$ for a bombarding energy of 3.0 MeV.

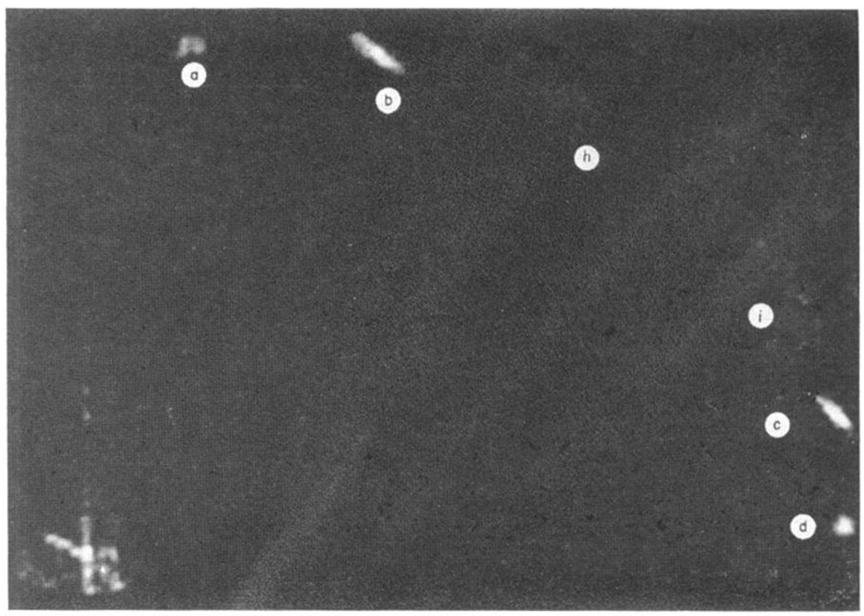


FIG. 4. The two-dimensional energy spectrum for the $Be^9(He^3, \alpha)2He^4$ reaction at $\theta_A = +60°$ and $\theta_B = -100°$ for a bombarding energy of 3.0 MeV.