trum are due mainly to random coincidences. One may deduce from these data that the 9.63, 10.8, and 14.1-MeV states must have "natural" parity since they decay to the Be^8_{gnd} state and that "unnatural" parity is indicated for the 11.8, 12.7, and 13.3-MeV states since the latter show no evidence for alpha decay to the Be^8_{gnd} state.

On the $Be^8_{2.9}$ curve in Fig. 2 the region corresponding to the 15.1-MeV C^{12} level shows no evidence for a peak. Based on the population intensity, as obtained from (p, γ) coincidence runs, the upper limit on a peak in Fig. 2 corresponds to the limit $\Gamma_\alpha/\Gamma < 0.05$ for the 15.1-MeV level.

Similar analyses of two runs at different angles on the $C^{13}+He^3$ reaction also lead to $\Gamma_\alpha/\Gamma < 0.05$ for the 15.1-MeV state.

The experiments which we have carried out have not been sensitive enough to find the isotopic-spin-violating alpha-particle decay of the 15.1-MeV of C^{12}, although our limit on this decay mode is sharper than any previously reported.

Discussion

Donovan: I would just like to point out that this experiment measures not only the isotopic spin purtiy of the 15.1 state in carbon, but also the isotopic spin purity of the region of Be^8 that it might decay to. Since the transition has not been seen, the width of that level for alpha decay is much less than the gamma width, or at most a few volts. This certainly indicates an extreme isotopic spin purity in the region of the 2+ level of Be^8, which was a point of earlier contention.

Holmgren: Your comment that the broad peak on the Be^8 ground-state kinematic curve might be due to the $B^{10}(He, \alpha)B^9$ reaction is indeed correct. The reaction proceeds through the 2.8-MeV state of B^9. This state appears to decay primarily by proton emission to the ground state of Be^8; whereas, the narrower state at 2.34-MeV decays primarily by alpha emission to the ground state of Li^5. Evidence for these decay modes can be seen in the figures of the paper by Etter *et al.* (p. 444).

Alburger: We did confirm that that broad bump didn't have anything to do with C^{12} levels, because it didn't move in the right way.

Holmgren: We have looked at it in detail and it does shift as a level of B^9.

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Direct Three-Body Decay $^{12}C \rightarrow 3\alpha$ in the Reaction $^{11}B(p, \alpha)2\alpha$ at the 163-keV Resonance

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It has been shown, that in the plane perpendicular to the proton beam the α-particle spectrum and the α–α coincidence spectra reveal a strong anomaly at the well-known 163-keV resonance of the reaction $^{11}B(p, \alpha)$.[1] Therefore a detailed study of the reaction was felt necessary, especially to look for the dependence of the observed anomaly on the incident proton energy.

The 200-keV Cockcroft–Walton accelerator of the Physikalisches Institut der Universitaet Marburg was used. At proton energies of less than 200 keV, the reaction $^{11}B(p, \alpha)$ can proceed via three reaction channels:

$$\begin{array}{lr} \qquad\qquad\quad \alpha_0+Be^8(\text{g.s.})\rightarrow\alpha_0+\alpha_{01}+\alpha_{02} & \text{(I)} \\ \qquad\qquad \nearrow & \\ ^{11}B+p\rightarrow {}^{12}C^*\rightarrow\alpha_1+Be^{8*}(2.9\text{ MeV})\rightarrow\alpha_1+\alpha_{11}+\alpha_{12} & \text{(II)} \\ \qquad\qquad \searrow & \\ \qquad\qquad\quad 3\alpha. & \text{(III)} \end{array}$$

The total cross section for the (p, α) reaction in the energy range below 200 keV has the following shape. Superimposed to the tails of two higher resonances at 675 keV ($\Gamma=295$ keV) and at 1388 keV ($\Gamma=1160$ keV) is the sharp resonance at 163 keV ($\Gamma=5.8$ keV). These three resonances indicate states in ^{12}C at excitation energies of 16.1 MeV ($J^\pi=2^+$, $T=1$), 16.57 MeV ($J^\pi=2^-$, $T=1$), and of 17.23 MeV ($J^\pi=1$, $T=1$). Because the 163-keV resonance is very sharp, the cross section below 150 keV and above 190 keV can be attributed almost completely to the tails of the other two resonances. Using a very thin target (in which 200-keV protons lose about 4 keV), one is able to reduce the contribution of the higher resonances at 163 keV to about 15%. On the other hand, taking the same target at 200 keV one may reduce the contribution of the 163-keV resonance to about 10%. Below the resonance a target of 50-keV thickness has been used, thus integrating the tails of the cross sections of the 675-keV and the 1388-keV resonances.

Five surface-barrier detectors have been used.[2] One of these counters could be moved to any point of a

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[1] D. Dehnhard, D. Kamke, and P. Kramer, *Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961*, edited by J. B. Birks (Heywood and Company, Ltd. London, 1961), p. 821; Phys. Letters **3**, 52 (1962); Ann. Physik **14**, 201 (1964).

[2] D. Dehnhard and P. Kramer, Nucl. Instr. Methods **26**, 337 (1964).

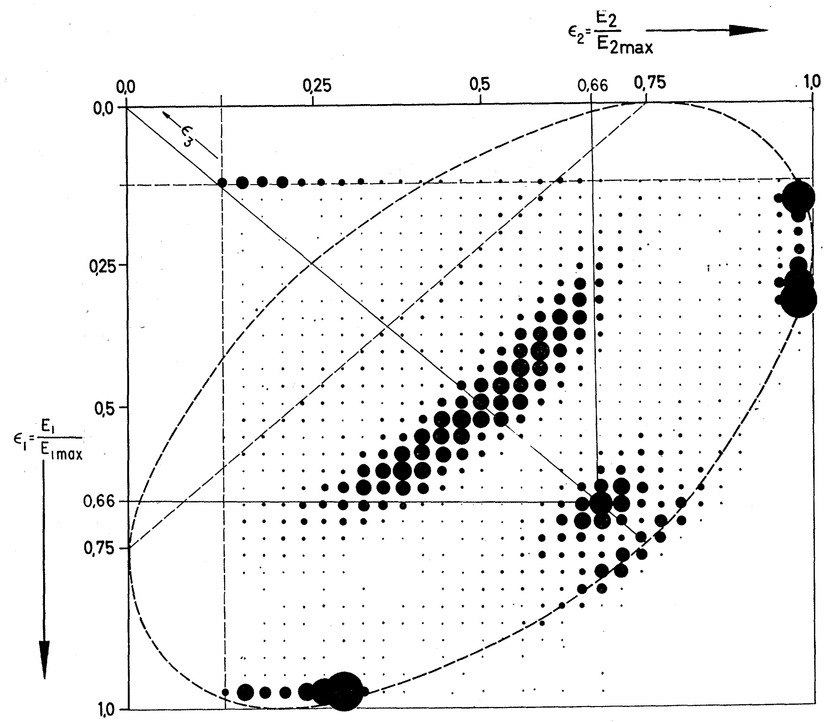

FIG. 1. Two-parameter coincidence spectrum in the plane perpendicular to the proton beam at $E_p = 163$ keV. Coincidence rates per channel are represented by points with diameters proportional to the rate. The low-energy cutoff is approximately 1.0 MeV.

hemisphere; the other four counters C_2^{I}, C_2^{II}, C_2^{III}, and C_2^{IV} have been mounted in one plane, which could be moved into any position with respect to the proton beam. Usually two measurements have been done in each of the planes at $\theta_{21} = 90°$, $120°$, $150°$, and $180°$ between counter C_1 and the various counters C_2 for the first run, and of $\theta_{21} = 75°$, $105°$, $135°$, and $165°$ for the second run. The four detectors have been connected in parallel within the chamber in order to superimpose the individual spectra. These pulses were fed into the Y input of the two-parameter analyzer, whereas the pulses coming from counter C_1 are fed into the X input. The energy spread in counter C_1 was 50 keV, in the counter assembly 150 keV; the resolving time was 80 nsec. Corresponding to the kinematics of the reaction, coincident events are expected to fall in four areas on the XY plane [or $\epsilon_1\epsilon_2$ plane, where $\epsilon_1 = E_1/(E_1)_{max}$ and $\epsilon_2 = E_2/(E_2)_{max}$] specified by the angle θ_{21} between the detectors and by the solid angle defined by the opening of the two detectors ($\Delta\theta_{21} = 15°$). Because of the small incident energy, c.m. transformations were not necessary.

Figure 1 shows the result of a measurement at 163 keV with the equipment described above. The five detectors have been moved into the plane perpendicular to the proton beam, the angles being $\theta_{21} = 90°$, $120°$, $150°$, and $180°$. The ellipse drawn within the $\epsilon_1\epsilon_2$ plane corresponds to the angle $\theta_{21} = 180°$, whereas the straight line connecting $\epsilon_1 = 0.75$ and $\epsilon_2 = 0.75$ on the axes corresponds to $\theta_{21} = 90°$. The two ellipses for $120°$ and $150°$ have not been drawn, but one can easily see the two groups of coincident events for $120°$ (going through the center of the $\epsilon_1\epsilon_2$ plane) and for $150°$. The next run for the intermediate angles filled up the valleys between the various groups. Because Fig. 1 shows an experimental result that covers only four areas of the whole plane, one expects maxima of the coincidence rate at the points at which the ellipses cross lines of constant energy ϵ_1, ϵ_2, and ϵ_3 if the decay proceeds via intermediate states of Be^8.

Although for $\epsilon_1 = 0.99$ (corresponding to the decay via the ground state of Be^8) one finds strong peaks on the θ_{21} ellipse, no maxima were found for $\epsilon_1 = 0.66$ and $\epsilon_2 = 0.66$ (decay via the 1 excited state of Be^8) on the $120°$ ellipse. Only for $\theta_{21} = 150°$ has a high counting rate been found at the crossing point of the two lines $\epsilon_1 = \epsilon_2 = 0.66$. The density of events on the Dalitz plot can be obtained from the $\epsilon_1\epsilon_2$ plot (Fig. 1) by multiplying the measured coincidence rate by $\sin\theta_{21}$ to correct for the solid angle. This factor means that the density, especially for the area between $175°$ and $180°$, is much less than one would expect from inspection of Fig. 1. The broad distribution along the $\theta_{21} = 120°$ shows that the density on the Dalitz plot is almost constant over a large area in the middle of the plot. In contrast, a stepwise decay would lead to a deep minimum in the center of the plot, as has been found below and above the resonance. Figure 2 shows slices through the density of events along ellipses $\theta_{21} = 120°$ passing exactly through the center of the Dalitz plot. These slices have been obtained by projecting the measured coincidence rate on a line $\epsilon_3 = \text{constant}$. The minimum at the center is not as a pronounced for the run at 180 keV as for that at 200 keV because the contribution of the sharp resonance cannot be neglected.

For $\theta_{21} = 180°$, the points are distributed over an area

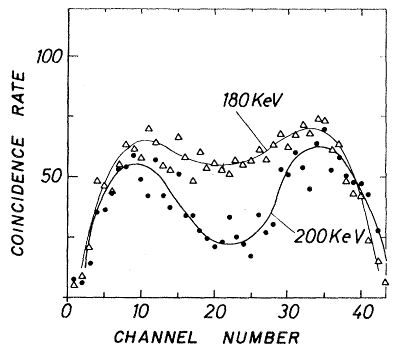

FIG. 2. "Slices" through the density of points on the Dalitz plot along an ellipse $\theta_{21}=120°$. Channel number 22 corresponds to the center of the plot.

at the edge of the plot. This includes the region in which $\epsilon_1 \approx \epsilon_2 \approx 0.75$ and $\epsilon_3 \approx 0$. The experimental spectra (Fig. 3) are compared with the shape expected for the stepwise decay via Be^{8*} (2.9 MeV) (broken lines).

The poor statistics of the run at 200 keV do not allow a clear conclusion that the stepwise decay takes place, but the spectrum obtained at 163 keV is far from being in agreement with the predicted shape. Experiments performed in other planes have revealed a strong dependence of the coincidence counting rate on the angle with respect to the beam. However, the center of the plot has been filled up only at the resonance.

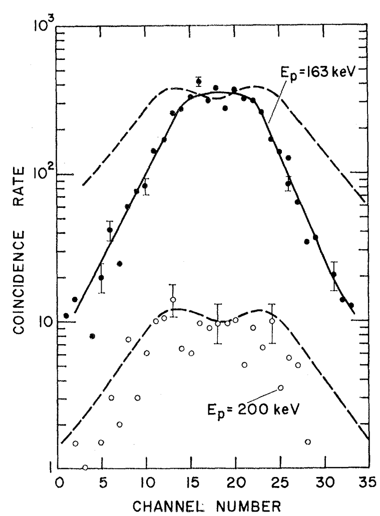

FIG. 3. Same as Fig. 2 except that $\theta_{21}=180°$; $\alpha_0-\alpha_{01}$ coincidences are omitted. Channel number 18 corresponds to $\epsilon_1=\epsilon_2=0.75$.

Two points of the Dalitz plot, the center and the intersection of the two resonance bands at $\epsilon_1=0.66$ and $\epsilon_2=0.66$, were studied in more detail. It was found that the excitation function of the density at the center shows much more resonance character than the density at the crossing points (Fig. 4). The excitation function for the center is even more resonant than the cross section for the decay to the ground state of Be^8, for which only the two resonances at 163 and 1388 keV have to be taken into account. Therefore one can conclude that the high density in the center of the plot is associated with the 16.1-MeV state of C^{12} ($J^\pi=2^+$, $T=1$).

P. Kramer[3] has pointed out that for the case of a decaying three-alpha-particle system with total angular momentum $L=2$ and positive parity there exists a completely symmetrized three-particle wave function

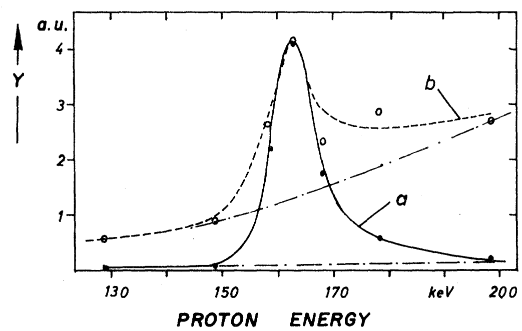

FIG. 4. Excitation function (Y) of the density on the Dalitz plot for two points: a, $\epsilon_1=\epsilon_2=0.50$; b, $\epsilon_1=\epsilon_2=0.66$.

for which the probability of finding each pair of α particles in a $J^\pi=2^+$ state is very high. This means that a resonant interaction such as that in Be^{8*} (2.9 MeV) can take place between each pair of alpha particles. On this basis one is able to explain the measured angle-energy correlation at 163 keV as a result of a direct three-body decay.

ACKNOWLEDGMENTS

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[3] P. Kramer, thesis, Marburg/Lahn (1964).