and ^{28}Si(^{3}He, p), R. R. Betts, H. T. Fortune, and D. J. Pullen, to be published; ^{29}Si(^{3}He, p), N. Al-Jadir, D. J. Pullen and O. Hansen, to be published.

[3]O. Hansen, in *Proceedings of the International Conference on Properties of Nuclear States, Montréal, Canada, 1969,* edited by M. Harvey et al. (Presses de l'Université de Montréal, Montréal, Canada, 1969), p. 421; ^{50}Cr(^{3}He, p), O. Hansen, T. Mulligan, and D. J. Pullen, to be published; ^{52}Cr(^{3}He, p), R. R. Betts, O. Hansen, and D. J. Pullen, to be published; ^{54}Cr(^{3}He, p), T. Caldwell, O. Hansen, T. Mulligan, and D. J. Pullen, to be published.

[4]See, for example, D. Fleming, J. Cerny, and N. K. Glendenning, Phys. Rev. 165, 1153 (1968).

Observation of a $T = \frac{1}{2}$ Resonance in ^{3}He by Inelastic α-Particle Scattering*

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A $T=\frac{1}{2}$ resonance in ^{3}He has been observed in the inelastic scattering of 63.7-MeV α particles by ^{3}He. The resonance is centered at 20.4 ± 0.3 MeV excitation and has a width of 3.4 ± 0.4 MeV.

Recently we reported on measurements of the radiative capture of deuterons by protons showing evidence for a $T=\frac{1}{2}$ resonance in the ^{3}He system.[1] Briefly, the 90° cross section as a function of bombarding energy shows a pronounced bump near 20-MeV excitation energy in ^{3}He, while the angular distribution displays marked anomalies in the same energy region. In this paper we present results from inelastic scattering of α particles by ^{3}He. These results confirm the existence of the resonance and provide more precise values for its energy and width.

Alpha particles accelerated by the Oak Ridge isochronous cyclotron were focused at the center of a thin-window gas cell filled to 0.1 atm with ^{3}He. The beam energy inside the cell was 63.7 ± 0.1 MeV. Scattered α particles and recoil ^{3}He particles were identified with a telescope of two silicon surface-barrier detectors, a 300-μm ΔE counter and a 1500-μm E counter. Spectra were obtained at ten angles from 4 to 19° lab. The angular acceptance of ±0.2° was defined by a 0.029-in. wide slit 6.8 in. from the center of the gas cell, and an aperture 0.060 in. wide by 0.188 in. high, 22 in. from the center. The energy scale was established by α particles elastically scattered from ^{3}He. To extend the calibration down to 38 MeV, one spectrum was taken at 32° lab.

Data from 4 to 9° were obtained with and without ^{3}He in the cell. The target-empty background varied smoothly as a function of α-particle energy and decreased rapidly with increasing angle. Figure 1 displays segments of the inelastic α-particle spectrum at various angles. For 4-9°, the gas-in gas-out difference is shown, while for 11° and 13° the gas-in spectrum is given. Each spectrum shows a bump at about 38 MeV. The continuum is presumably due to the two-body ($p+d$) and three-body ($p+n+n$) breakup of ^{3}He. These spectra were fitted with a Gaussian peak superposed on a continuum described by a qua-

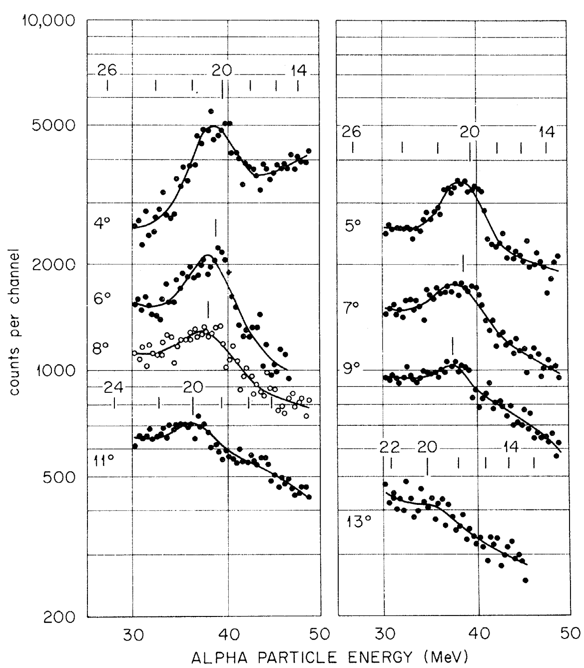

FIG. 1. Spectra of inelastic α particles observed at eight laboratory angles. For angles 4-9°, the gas-in gas-out difference is shown, while for 11° and 13° only the gas-in spectra are given. The curves were obtained with a peak-fitting program. The marker above each spectrum corresponds to 20-MeV excitation energy in ^{3}He. More complete excitation-energy scales are given for 4°, 5°, 11°, and 13°. The ordinate for each spectrum is adjusted to a ^{3}He gas pressure of 75 mm Hg and an integrated beam current of 435 μC of $^4He^{++}$.

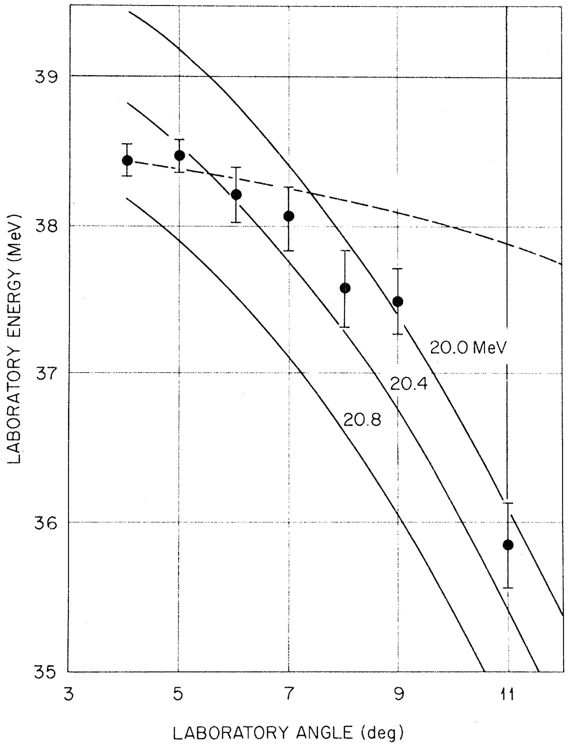

FIG. 2. Laboratory energy of the peak in the spectra of Fig. 1 as a function of laboratory angle. The full curves show the predicted positions of the peak for 20.0, 20.4, or 20.8 MeV excitation in ^{3}He. The dashed curve indicates how the position would vary if the peak were due to inelastic scattering from a possible ^{12}C impurity in the target gas.

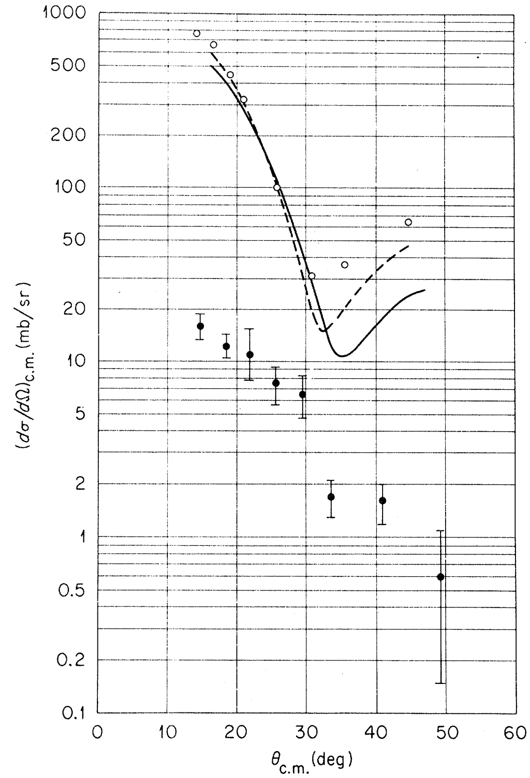

FIG. 3. Center-of-mass cross sections at 63.7 MeV lab for the 20.4-MeV resonance in ^{3}He (closed circles) and for elastic scattering of α particles by ^{3}He (open circles). The curves are elastic data from Ref. 3 for c.m. energies of 21.0 MeV (solid line) and 24.5 MeV (dashed line). The present results correspond to 27.3 MeV c.m.

dratic function of channel number. A six-parameter least-squares search was made for each spectrum to determine the centroid, width, and area of the peak, and the three parameters characterizing the continuum. The resulting best-fit curves are indicated in Fig. 1. There was no evidence for a peak in the spectrum obtained at 15°. A peak may have been present at 19°, but if so it was too close to an instrumental cutoff at low energies to be analyzed.

In Fig. 2 the position of the centroid obtained from the least-squares fitting is shown as a function of angle. The solid curves give the kinematic variation calculated under the assumption that the peak is due to a resonance in ^{3}He at 20.0, 20.4, or 20.8 MeV excitation. From the elastic-scattering data at large angles there is some evidence for a small quantity of a carbon, nitrogen, and/or oxygen contaminant in the target. The dashed curve shows the variation of the peak position if it is assumed that the peak observed at 4° is due to inelastic scattering from ^{12}C. The data of Fig. 2 demonstrate that the observed peak is not due to scattering from carbon or any heavier nucleus. The possibility that ^{4}He impurity gives rise to this peak can be ruled out by the isotopic purity of the target gas (99.8% ^{3}He) and the small cross section for exciting the 20.3-MeV state in ^{4}He by 64-MeV α particles on ^{4}He.[2] The short lifetime of the known excited states of the α particle[2] excludes the possibility that the peak is due to projectile excitation.

We conclude that the observed peak is due to a resonance in ^{3}He at an excitation energy of 20.4 $\pm$ 0.3 MeV with a width of 3.4 $\pm$ 0.4 MeV. The estimated error in the resonance energy includes the uncertainty in the absolute energy scale.

For each angle the cross section for exciting the resonance was calculated from the peak area, geometry, integrated beam, and gas pressure. The full points in Fig. 3 show the angular distribution in the c.m. system. Also shown are the elastic cross sections (open circles); these results are consistent with the measurements by

Schwandt *et al.*[3]

The inelastic scattering of α particles and the radiative capture of deuterons by protons can excite $T=\frac{1}{2}$ states only. In the radiative-capture experiment,[1] the apparent position (19.5 ± 0.5 MeV) and width (~2 MeV) of the resonance are similar to the values observed in the present experiment. We infer that the same resonance is being observed. The discrepancy between the two sets of resonance parameters is presumably due to incomplete information from the capture experiment, where we had sufficient beam energy to measure up to 20.4 MeV excitation only. To estimate the position and width of the resonance we had incorporated results from an experiment on the two-body photodisintegration of ^{3}He.[4] If the absolute energy scale of the latter excitation function were shifted by 1 MeV, a revised estimate of the resonance parameters from the photonuclear work would agree with the present results. Indeed, the excitation function in the capture experiment[1] is consistent with a maximum at 20.4 MeV.

Many experiments have been performed to search for excited states of ^{3}He. Recent surveys were made by Slaus[5] and Bray *et al.*[6] Only three experiments examined the energy region above 20 MeV excitation, namely, the inelastic scattering of ^{3}He by ^{3}He,[7] the reaction ^{6}Li(p,α),[6] and the reaction ^{3}H(p,n).[8] The 20.4-MeV $T=\frac{1}{2}$ resonance was not observed in any of these experiments.

Recent data[9] on the three-body photodisintegration of ^{3}He show some structure near 20.4 MeV excitation, and the forward-backward asymmetry changes sign at about 21 MeV. These phenomena might be correlated with the resonance observed in the present work. However, in the three-body photodisintegration the resonance would presumably be much harder to see since the $T=\frac{1}{2}$ component is predicted to be small. In the calculations of Barbour and Phillips,[10] the $T=\frac{1}{2}$ contribution to the three-body breakup at 20.4 MeV was found to be about 15% of the total three-body cross section. If we assume that the ratio of the resonant to the nonresonant part for the $T=\frac{1}{2}$ contribution to the three-body process is the same as was observed in the two-body reaction,[1] we would expect the $T=\frac{1}{2}$ resonance to show up as a bump at 20.4 MeV of about 5-10% of the total three-body yield. This is consistent with the measured excitation function for three-body photodisintegration.[9]

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[1]A. van der Woude, M. L. Halbert, C. R. Bingham, and B. D. Belt, Phys. Rev. Lett. 26, 909 (1971).

[2]E. E. Gross, E. V. Hungerford, J. J. Malanify, H. G. Pugh, and J. W. Watson, Phys. Rev. 178, 1584 (1969).

[3]P. Schwandt, B. W. Ridley, S. Hayakawa, L. Put, and J. J. Kraushaar, Phys. Lett. 30B, 30 (1969).

[4]B. L. Berman, L. J. Loester, Jr., and J. H. Smith, Phys. Rev. 133, B117 (1964).

[5]I. Slaus, in *Three Body Problem in Nuclear and Particle Physics*, edited by J. S. C. McKee and P. M. Rolph (North-Holland, Amsterdam, 1970).

[6]K. H. Bray, S. N. Bunker, M. Jain, K. S. Jayaraman, G. A. Moss, W. T. H. van Oers, D. O. Wells, and P. M. Rolph (North-Holland, Amsterdam, 1970).

[7]R. J. Slobodrian, J. S. C. McKee, D. J. Clark, W. F. Tivol, and T. A. Tombrello, Nucl. Phys. A101, 109 (1967).

[8]L. E. Williams, C. J. Batty, B. E. Bonner, C. Tschalär, H. C. Benöhr, and A. S. Clough, Phys. Rev. Lett. 23, 1181 (1969).

[9]B. L. Berman, S. C. Fultz, and P. F. Yergin, Phys. Rev. Lett. 24, 1494 (1970).

[10]I. M. Barbour and A. C. Phillips, Phys. Rev. C 1, 165 (1970).