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$^{18}O(\alpha, ^8He)^{14}O$ reaction*

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The $^{18}O(\alpha, ^8He)^{14}O_{g.s.}$ reaction has been observed at $E_\alpha = 58$ MeV. The measured cross section is 40 ± 15 nb/sr at $\theta_{lab} = 8°$. The mass excess of ^8He was determined to be $31\,600 \pm 25$ keV. Possible reaction mechanisms are discussed.

[NUCLEAR REACTIONS $^{18}O(^4He, ^8He)$, $E = 58$ MeV. Measured $\sigma(E_f, 8°)$. Deduced $Q_{g.s.}$ and mass excess for ^8He. Magnetic spectrometer.]

The $(\alpha, ^8He)$ reaction is the simplest of the few four-neutron transfer reactions which are experimentally feasible.[1,2] Its usefulness for measuring masses and energies of excited states of proton-rich nuclei, however, requires an accurate mass value for ^8He and further information on cross-section systematics.

We have studied the $^{18}O(\alpha, ^8He)^{14}O$ reaction at $E_\alpha = 58$ MeV. In addition, data for the related two-neutron transfer reactions $^{18}O(\alpha, ^6He)^{16}O$ and $^{16}O(\alpha, ^6He)^{14}O$ were also obtained and have been discussed elsewhere.[3] The experiment was performed with an α-particle beam from The University of Michigan 2 m variable energy cyclotron.[4] Targets consisted of oxidized nickel foils (140 $\mu g/cm^2$ ^{18}O and 450 $\mu g/cm^2$ Ni). The reaction products were detected and identified in the focal plane of a high dispersion (8 keV/mm) analyzing magnet using a special position-sensitive ΔE-E counter telescope. The solid angle of the magnet was 1.9 msr and the angular acceptance 6°. The focal-plane detection system[5] consisted of two gas-proportional ΔE counters providing the signals ΔE_1 (or alternately x_1), and ΔE_2 backed by a 20 mm high by 50 mm long solid-state position-sensitive detector (PSD) of 350 μm thickness which generates the signals E and xE. The system thus provides two energy loss signals (ΔE_1 and ΔE_2), the magnetic rigidity $B\rho$ (from x) and the total energy ($\Delta E_1 + \Delta E_2 + E$). The signal E is another energy loss signal if the particles are not stopped. Discrimination for stopped particles (such as $^3He^+$, $^4He^+$, $^6He^+$, $^6He^{++}$, etc.) presented no problem since mass identification is then very good. At $E_\alpha = 58$ MeV, however, the stopped ^8He particles ($Q \approx -38$ MeV) have a relatively low magnetic rigidity and must be identified amongst background arising from energy straggling and pileup of energetic $^4He^{++}$ and $^3He^{++}$ particles which are not stopped. A ratio of typically 10^7 $^4He^{++}$ and $^3He^{++}$ particles per $^8He^{++}$ particle was observed. Most but not all of this background could be suppressed by requiring multiple coincidences and employing pileup rejection.

The data were accumulated event by event onto magnetic tape and analyzed off-line. Data from several other reactions such as (α, α'), $(\alpha, ^3He)$, and $(\alpha, ^6He)$ were also obtained. These were used to calibrate the energy and position signals from the focal plane counters. The beam analyzing magnets were calibrated by means of the momentum crossover technique.[6]

An $(\alpha, ^8He)$ spectrum from ^{18}O at $\theta_{lab} = 8°$ is shown in Fig. 1. It was obtained by setting gates on the ΔE_1, ΔE_2, and E signals at values determined for ^8He particles based on $^4He^{++}$, $^4He^+$, $^3He^{++}$, and $^6He^{++}$ data. The spectrum is a composite of several runs at slightly different magnet settings appropriately combined. The spectrum shown in the lower part of Fig. 1 includes background subtraction based on the number of events in neighboring regions of ΔE_1, ΔE_2, and E. The background is not uniform due to the nonlinear response of the PSD. The usable length covered by the PSD was chosen to span a region of approximately 350 keV centered at the predicted position of the ground-state transition based on the previously accepted ^8He mass.[1] The $(\alpha, ^8He)$ reactions on the dominant Ni isotopes in the target cannot interfere, as the Q values are more negative. A group of ^8He events is observed close to the calculated position of the ^{14}O g.s. as displayed in the figure. The centroid for this group, including corrections for target thickness etc., corresponds to a mass excess[5] for ^8He of $31\,600 \pm 25$ keV. This value is in good agreement with the earlier value[1] of $31\,650 \pm 120$ keV and the recent remeasurements[7,8] of $31\,570 \pm 30$ keV and $31\,611 \pm 18$ keV, respectively. The cross section (lab) for $^{18}O(\alpha, ^8He)$ is 40 ± 15 nb/sr at 8° (lab) and may be compared with other data (target, energy, angle): ~20 nb/sr (^{12}C, 156 MeV, 2°, Ref. 2); ~7 nb/sr (^{24}Mg, 156 MeV, 2°, Ref. 2);

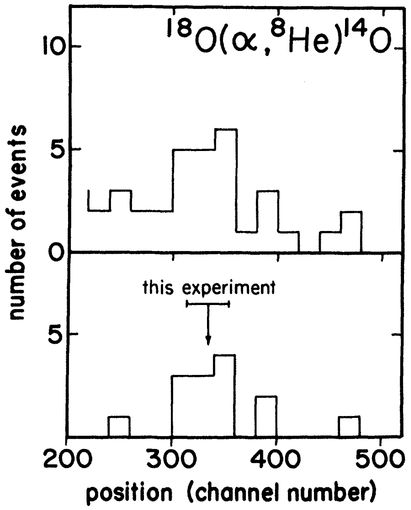

FIG. 1. A spectrum of ^{8}He particles observed at $\theta_{lab} = 8°$ from the bombardment of ^{18}O with 17 mC of 58 MeV α particles. The upper part shows the uncorrected spectrum. The lower part shows the spectrum corrected for background (see text) with the peak position determined in this experiment (1 bin = 20 channels ≅ 25 keV).

~35 nb/sr (^{26}Mg, 80 MeV, 14°, Ref. 1); ~10 nb/sr (^{26}Mg, 110 MeV, 10°, Ref. 7); 50 ± 20 nb/sr (^{64}Ni, 58 MeV, 8°, Ref. 8).

The small cross sections and the relative independence on target mass observed for the various (α, ^{8}He) four-neutron transfer reactions are in contrast to those observed for α-particle transfer reactions such as (*d*, ^{6}Li) and (α, ^{8}Be).[9,10] Furthermore, the cross sections for α-particle transfer reactions, as expected for a direct reaction, generally decrease rapidly with increasing target mass approximately[9] as A^{-3}, whereas the (α, ^{8}He) cross sections apparently do not. Thus, the (α, ^{8}He) data do not appear to exhibit characteristics similar to those found for known direct four-nucleon transfer reactions. It should be noted, however, that the $^{18}O(\alpha, {}^6He)^{16}O$ and $^{16}O(\alpha, {}^6He)^{14}O$ reactions,[3] although apparently direct, also have rather small cross sections (≈50 μb/sr and ≲0.5 μb/sr, respectively). A possible mechanism for (α, ^{8}He) might be the two-step process (α, ^{6}He) (^{6}He, ^{8}He). Simple semiclassical calculations using available $^{16,18}O(\alpha, {}^6He)$ data[3] yield estimates of 0.1 to 10 nb/sr for such a process with a relatively weak dependence on target mass ($\approx A^{-1}$) for $A \lesssim 70$. Coherence effects could increase the cross sections for such two-step processes sufficiently to explain the magnitude and mass dependence of existing (α, ^{8}He) data.

Another possible mechanism is evaporation of ^{8}He subsequent to compound nucleus formation. Hauser-Feshbach cross sections were calculated for the (α, ^{8}He) reaction on ^{18}O, ^{26}Mg, and ^{64}Ni at bombarding energies of 58 MeV, 80 MeV, and 58 MeV, respectively. The Fermi-gas level density expression and parameters of Cameron *et al.*[11] were used, together with the analytic expressions for the compound nucleus level width and the sum over the transmission coefficients for all decay channels of Eberhard *et al.*[12] Compound nucleus level widths Γ were also calculated and compared to experimental level width extrapolations[13] to test the reliability of the estimated level densities at the rather high excitation energies. The agreement for ^{18}F and ^{68}Zn is very good. A discrepancy observed for ^{30}Si (factor of about 5) yields an uncertainty in the estimated cross section by a factor of about 10. The calculated cross section at 8° in the reaction on ^{18}O is about 30 nb/sr, which could explain all or an appreciable fraction of the observed cross section. The calculated cross sections for the reactions[1,8] on ^{26}Mg at 14° and ^{64}Ni at 8° are about 5×10^{-2} nb/sr and 8×10^{-8} nb/sr, respectively. This result essentially excludes any compound nucleus contributions.

It is concluded that the observed (α, ^{8}He) cross sections (Refs. 1, 2, 7, 8, and this work) appear to be incompatible with a direct four-nucleon transfer and, except for the reaction on ^{18}O, also incompatible with a statistical compound nucleus mechanism. Two-step mechanisms or preequilibrium compound nucleus decay may be important.

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[1] J. Cerny, S. W. Cosper, G. W. Butler, R. H. Pehl, F. S. Goulding, D. A. Landis, and C. Detraz, Phys. Rev. Lett. 16, 469 (1966).

[2] R. G. H. Robertson, S. Martin, W. R. Falk, D. Ingham, and A. Djaloeis, Phys. Rev. Lett. 32, 1207 (1974).

[3] J. Jänecke, A. VanderMolen, L. Chua, and F. D. Becchetti, in *Reactions Between Complex Nuclei*, edited by R. L. Robinson *et al.* (North-Holland, Amsterdam, 1974), Vol. 1, p. 46; A. VanderMolen, F. D. Becchetti, J. Jänecke, and L. Chua, Phys. Rev. C 11, 734 (1975).

[4] W. C. Parkinson, J. F. Petersen, R. H. Day, D. C. DuPlantis, W. S. Gray, and J. Bardwick, Nucl. Instrum. Methods 119, 61 (1974).

[5] Annual Report, Cyclotron Laboratory, The University of Michigan, June 1974 (unpublished), p. 6.

[6] D. R. Bach *et al.*, Rev. Sci. Instrum. 27, 516 (1956); G. F. Trentelman and E. Kashy, Nucl. Instrum. Methods 82, 304 (1970).

[7] J. Cerny, in *Reactions Between Complex Nuclei* (see Ref. 3), Vol. 2, p. 483; J. Cerny *et al.*, Phys. Rev. C 10, 2654 (1974).

[8] R. T. Kouzes, Ph.D. thesis, Princeton University, 1974 (unpublished).

[9] A. M. VanderMolen, F. D. Becchetti, and J. Jänecke, in *Reactions Between Complex Nuclei* (see Ref. 3), Vol. 1, p. 36; F. D. Becchetti, L. T. Chua, J. Jänecke, and A. M. VanderMolen, Phys. Rev. Lett. 34, 225 (1975).

[10] R. E. Brown, J. S. Blair, D. Bodansky, N. Cue, and C. G. Kovalasky, Phys. Rev. 138, B1394 (1965); G. J. Wozniak, N. A. Jelley, and J. Cerny, Phys. Rev. Lett. 31, 607 (1973).

[11] A. Gilbert and A. G. W. Cameron, Can. J. Phys. 43, 1446 (1965); J. W. Truran, A. G. W. Cameron, and E. Hilf, in Proceedings of the International Conference on the Properties of Nuclei Far From the Region of Beta-Stability, Leysin, Switzerland, 1970, CERN Report No. CERN 70-30, 1970 (unpublished), Vol. 1, p. 275.

[12] K. A. Eberhard, P. von Brentano, M. Böhning, and R. D. Stephen, Nucl. Phys. A125, 673 (1969).

[13] D. Shapira, R. G. Stockstad, and D. A. Bromley, Phys. Rev. C 10, 1063 (1974); L. Milazzo-Colli and M. G. Braga-Marcazzan, in *Progress in Nuclear Physics*, edited by D. M. Brink and J. H. Mulvey (Pergamon, New York, 1970), Vol. 2, p. 145.