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Total Neutron Yield from the Reaction ^{14}C$(\alpha,n)^{17}$O*

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The total neutron yield of the reaction ^{14}C$(\alpha,n)^{17}$O has been measured in the alpha-particle bombarding-energy range of 2.5 to 5.1 MeV. Six new anomalies were observed in the yield curve at alpha-particle energies of 4.030±0.015, 4.07±0.04, 4.17±0.04, 4.434±0.010, 4.70±0.04, and 5.004±0.010 MeV. These would correspond to excitation energies in the ^{18}O compound nucleus of 9.361, 9.39, 9.47, 9.675, 9.88, and 10.119 MeV. The experimental widths vary from 21 to 200 keV. An approximate value of the average alpha-particle strength function was obtained.

INTRODUCTION

LEVELS in ^{18}O at excitation energies between 8 and 9 MeV have been studied primarily by the reactions ^{14}C$(\alpha,\alpha)^{14}$C (Ref. 1) and ^{14}C$(\alpha,n)^{17}$O (Ref. 2). The region below 8.64 MeV has also been investigated by the ^{19}F$(t,\alpha)^{18}$O reaction.[3] No information was available concerning level structure above an excitation of approximately 9 MeV.[4] The ^{14}C$(\alpha,n)^{17}$O reaction appeared to offer a straightforward method of studying the excitation-energy region above 9 MeV.

EXPERIMENTAL TECHNIQUES

Experimental techniques used in the present experiment have been previously described.[5] The alpha-particle beam was obtained from the Oak Ridge National Laboratory 5.5-MV Van de Graaff accelerator and neutrons were detected with the graphite-sphere neutron detector.[6] Targets were produced by the technique of Douglas *et al.*[7] from ^{14}C-enriched acetylene made from enriched barium carbonate using the method described by Monat *et al.*[8] These targets were similar to those used in an earlier experiment at this laboratory.[9] A target thickness of 17 keV was determined by measuring the known[2] 2.55- and 2.64-MeV levels in the ^{14}C(α,n) reaction. The alpha-particle bombarding energy was calibrated relative to the ^{7}Li$(p,n)^{7}$Be threshold which was taken to be 1.881 MeV. As a check on this energy calibration, the energy of the ^{19}F$(\alpha,n)^{22}$Na resonance at approximately 2.6 MeV was measured using a thick target. Our value of 2610±5 keV is in good agreement with the value of 2609±3 keV as obtained by Williamson *et al.*[10]

RESULTS AND DISCUSSION

Figure 1 shows the relative total neutron yield as a function of the bombarding alpha-particle energy, uncorrected for target thickness. The points shown are the count rates in the graphite-sphere neutron detector as a function of incident alpha-particle energy. Also shown is the background obtained by bombarding the reverse side of the target. The yield curve can be normalized to an absolute cross section at the peak of the 2.64-MeV resonance by using the value of 300 mb±60% given by Sanders.[2] Table I gives the corrected peak energies and laboratory widths and compares them to

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TABLE I. Resonance parameters from the present and previous experiments. The resonant energies and widths are in the laboratory system. This table shows: in column 1 the resonant energy obtained in the present work; in column 2 the resonant energy as given in Refs. 2 and 3; in column 3 the width estimated in the present experiment; in column 4 the width obtained previously. Column 5 gives the energy of excitation in ^{18}O obtained from the present work, and column 6 gives the excitation energy from the ^{19}F$(t,\alpha)^{18}$O work of Ref. 3. Our excitation energies are based on $C^{14}+\alpha=6.227$ MeV from Ref. 4.

Resonant energy (MeV)		Width (keV)		Excitation in ^{18}O (MeV)	
Present expt.	Refs. 2 and 3	Present expt.	Refs. 2 and 3	Present expt.	Ref. 3
2.558±0.007	2.553±0.004	1± 1	1.6± 1	8.217	8.19±0.02
2.648±0.007	2.642±0.003	17± 5	10 ± 1	8.287	8.26±0.02
2.801±0.010	2.798±0.011	10± 7	22 ±10	8.406	8.39±0.02
					8.48±0.02
					8.64±0.02
3.320±0.020	3.336±0.020	80±20	100 ±20	8.809	
3.509±0.010	3.508±0.005	65±10	54 ± 5	8.956	
4.030±0.015		35±20		9.361	
4.07 ±0.04		≈150		9.39	
4.17 ±0.04		≈ 70		9.47	
4.434±0.010		80±40		9.675	
4.70 ±0.04		≈200		9.88	
5.004±0.010		21± 5		10.119	

those obtained in previous work. It should be noted that an additional peak may be located at about 4.6 MeV, just visible on the side of the 4.70-MeV anomaly. Other very broad peaks may also exist.

Agreement between the present work and previous experiments is seen to be good, with some exceptions. We do not see any rise in the region between 3.6 and 3.8 MeV whereas at the most backward angle (164°) the highest energy elastic-scattering data show a pronounced rise. The ^{19}F$(t,\alpha)^{18}$O data[3] seem to show two levels at excitations of 8.48 and 8.64 MeV which do not appear in the present experiment. It is quite possible that these are "unnatural parity states" which cannot be formed by alpha-particle bombardment of ^{14}C. Excitation energies from the ^{19}F$(t,\alpha)^{18}$O work are consistently lower than those found from any of the ^{14}C$+\alpha$ work.

Using Sanders'[2] value of the absolute cross section and following the techniques used in previous work at this Laboratory[5] which were in turn based on the work of Schiffer and Lee[11] and Clarke, Almqvist, and Paul,[12] we have averaged the cross-section data over an energy interval $\Delta E=700$ keV as a function of the incident alpha-particle energy. These results are shown as the points in Fig. 2. Under the assumption that $\Gamma_n \gg \Gamma_\alpha$ and that all other widths are negligible [the (α,p) reaction has a $Q=-9.8$ MeV], a value of the average alpha-particle strength function $\bar{S}_\alpha$ was caluclated for each

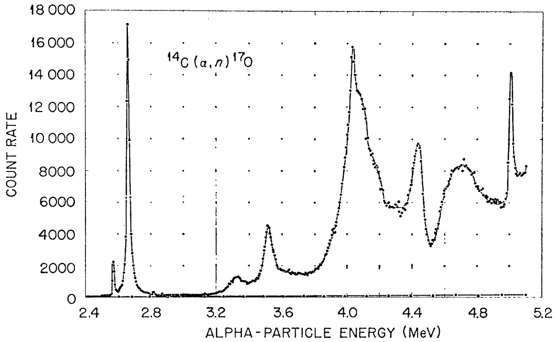

FIG. 1. The relative total neutron yield as a function of the bombarding alpha-particle energy (uncorrected for target thickness). The lower points are the background obtained by bombarding the reverse side of the target. The yield curve can be normalized to an absolute cross section at the peak of the 2.64-MeV resonance by using the value of 300 mb±60% given by Sanders.

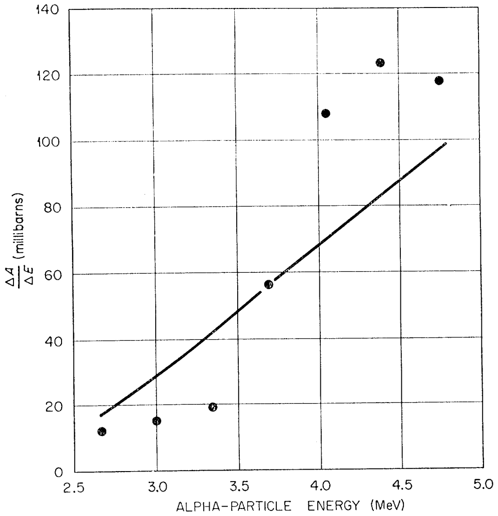

FIG. 2. We have averaged the cross-section data over an energy interval ΔE of 700 keV and plotted the area per unit ΔE as a function of the incident alpha-particle energy. The points are values from the experiment. The solid line is the theoretical curve calculated for the average value of the alpha-particle strength function $\bar{S}_\alpha=0.006_6$.

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energy increment from the expression

$$A_{\Delta E}/\Delta E = 2\pi^2\bar{\lambda}^2[\Sigma_l(2l+1)2kR/A_l^2]\bar{S}_\alpha,$$

where $A_{\Delta E}/\Delta E$ is the unit area under the averaged yield curve. This expression is based on the assumption that the net effect of interference terms in the total cross section is zero when averaged over the levels, and a simple summation of single-level Breit-Wigner terms may be used. The reaction radius was taken to be $1.4(A^{1/3}+1.59)\times10^{-13}$ cm. The $\bar{S}_\alpha$ defined is an average over the possible alpha-particle orbital angular momenta. Values of $\bar{S}_\alpha$ calculated for each energy increment were within a factor of 2 of the average value of 0.006_6.[13] Since very few levels are involved, this spread is reasonable. This average $\bar{S}_\alpha$ must be considered to be of limited accuracy.

The solid line on Fig. 2 is a calculated curve based on $\bar{S}_\alpha=0.006_6$. It is seen that all points above about 3.75 MeV lie well above the solid curve whereas below this energy all points lie well below the curve. It is possible that this is due to a contribution from neutrons leaving the residual ^{17}O nucleus in its first excited state. The threshold for this channel occurs at about 3.45 MeV. Since the ^{17}O ground-state spin has the value $\frac{5}{2}$, whereas the first-excited-state spin is only $\frac{1}{2}$, the neutron penetrability would tend to enhance the effect.

As a means of determining whether the value of $\bar{S}_\alpha$ calculated above is a reasonable one the following calculation was made. The experimental yield curve was fitted with a sum of simple Breit-Wigner terms. From the parameters used in this fit a set of values for $(2J+1)\Gamma_\alpha=\sigma_{\max}\Gamma_{\text{total}}/4\pi\bar{\lambda}^2$ was then obtained. If one assumes that all the levels have a particular value of J, one may then calculate Γ_α, the corresponding reduced widths γ_α^2, and finally an average reduced width $\langle\gamma_\alpha^2\rangle$ for the interval studied. With the further assumption that the level spacing varies as $(2J+1)^{-1}$ one may calculate the strength function S_α for the assumed value of J. Statistically, not many $J=0$ levels would be expected and the penetrability would reduce the yield for $J\geq3$. The result of the calculation is that for $J=1$, $S_\alpha=0.005$ and for $J=2$, $S_\alpha=0.008$.

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[13] Where the notation indicates that the second 6 is not reliable.

PHYSICAL REVIEW VOLUME 144, NUMBER 3 22 APRIL 1966

Excitation Energies of Bound States of O^{17} and B^{12}†

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The energy of the O^{17} 0.871-MeV gamma ray was measured with a lithium-drifted germanium detector using the $O^{16}(d,p)O^{17}$ reaction to populate the first excited state of O^{17}. A result of 870.81±0.22 keV was obtained using various radiactive sources for energy calibration. Using this line and various others for energy calibration, the energies of gamma rays from transitions in B^{12} were measured and excitation energies of 953.14±0.60 and 1673.65±0.60 keV were deduced for the first two excited states of B^{12}. Strong but non-conclusive evidence is presented for an excitation energy of 2618.5±3.5 keV for the third excited state of B^{12}.

INTRODUCTION

The 871-keV gamma ray from the decay of the first excited state of O^{17} is almost always observed to some extent in gamma-ray spectra from deuteron-induced nuclear reactions. Its presence results from the $O^{16}(d,p)O^{17}$ reaction due to oxygen present in the target in natural form or as an impurity. A precise measure of its energy is therefore desirable in order that the gamma peak may be readily identified and also that it may be used for an energy calibration. In the latter respect it is particularly valuable because the level has a lifetime long $(2.5\times10^{-10}$ sec)[1] compared to the stopping time $(\sim2-6\times10^{-13}$ sec) of the recoiling O^{17} ions in solids, hence the line energy is not shifted by the Doppler effect. Further, its omnipresence should prove convenient in view of the dearth of calibration lines in the energy region of 750–1000 keV. Accordingly, we have used a lithium-drifted germanium [Ge(Li)] gamma-ray detector to measure the energy of the O^{17} 871-keV gamma ray and have used it as one calibration line in energy measurements of several B^{12} gamma rays.

The O^{17} 871 keV level was populated by bombardment of a SiO_2 target with 2.1-MeV deuterons. A 3.5-cc Ge(Li) detector was placed at 90° to the beam and 10 cm from the target. Pulses from the gamma-ray detector were amplified by a Tennelec model 100C preamplifier and by an ORTEC model 220 biased amplifier system and were recorded in one 1024-channel slice of a TMC 16384-channel analyzer. The relationship between energy and channel was determined from gamma-ray peaks of accurately known energies recorded simultaneously with the O^{17} spectra by placing radioactive

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