Energy Levels in F^{18} from the $O^{17}(p,\alpha)N^{14}$ Reaction*

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A separated isotopic target of O^{17} has been used to study the excitation function of ground-state alpha particles from the reaction $O^{17}(p,\alpha)N^{14}$ for proton energies between 1 and 3 Mev. Thirteen levels in F^{18} have been found, with excitation energies 6.666, 6.820, 7.304, 7.527, 7.552, 7.713, 7.728, 7.889, 7.917, 8.094, 8.216, 8.238, and 8.382 Mev.

INTRODUCTION

BY means of the reaction $O^{17}(p,\alpha)N^{14}$, one can investigate the energy levels of the nucleus F^{18} in the region of excitation above 6 Mev. (The difference in energy between $O^{17}+p$ and F^{18} is 5.618 Mev.) The calculated Q value for the ground-state reaction is 1.197 Mev. The following report gives an account of such a study for a range of proton energy from 1 to 3 Mev.

The lowest part of the same region in F^{18} has been investigated by Heydenburg and Temmer[1] in the reactions $N^{14}(\alpha,p)O^{17}$ and $N^{14}(\alpha,\alpha)N^{14}$. Their work showed two pronounced resonance levels, and a third, broader one was inferred—from the shape of the excitation curve—to lie somewhat higher than the actual range of their measurements. References to some earlier studies of the $N^{14}(\alpha,p)$ reaction, using radioactive alpha sources for bombardment, can be found in reference 1.

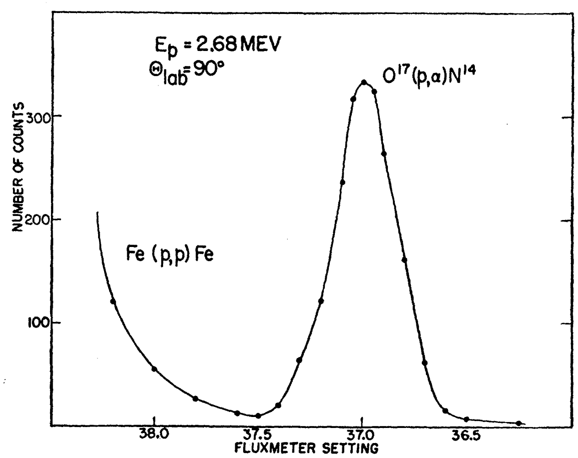

FIG. 1. Momentum profile of ground-state alpha particles from the $O^{17}(p,\alpha)N^{14}$ reaction at proton energy 2.68 Mev. The observation angle was 90°. To the left is seen the scattering edge for protons elastically scattered from the thick target backing of stainless steel. The momentum increases from left to right in the figure.

EXPERIMENTAL APPARATUS AND PROCEDURE

Protons were accelerated by the Kellogg Radiation Laboratory 3-Mev electrostatic accelerator and maintained homogeneous in energy to about 0.1% by an electrostatic analyzer. A proton current of 0.5–1 μa was used to bombard a thin, electromagnetically separated O^{17} target on a thick backing of stainless steel. The target thickness was of the order of 1 kev for 1-Mev protons. The target had been prepared at the Nobel Institute of Physics, Stockholm from enriched oxygen gas by a procedure which has been described earlier[2]: The O^{17} was collected at mass number 31 in the form of the ion $N^{14}O^{17}$. The composition of the mass 31 current was approximately 90% $N^{14}O^{17}$, 7% $N^{15}O^{16}$ and less than 3% $C^{13}O^{18}$.

Secondary particles to be analyzed were ejected from the target at an angle $\theta_{lab}=90°$ to the incident beam, into a 16-inch double-focusing, 180° magnetic spectrometer. The solid angle of the spectrometer was 6.24×10^{-3} steradian. An 0.5-inch slit was used in front of the 0.0007-inch thick CsI-crystal scintillation detector. In this experiment the alpha group leaving the residual nucleus N^{14} in its ground state was isolated and its intensity as a function of the bombarding energy was measured. No other alpha group from the other components of the target or from possible contaminants have energies near to this group and this fact facilitated the identification of the $O^{17}(p,\alpha)N^{14}$ group.

The analyzing system was biased to pass pulses from alpha particles. However, the suppression of pulses from protons elastically scattered from the target backing was not complete. These protons lay quite close in energy to the alpha group studied and an observation angle of 90° was chosen because at this angle a large enough energy separation was obtained between the alpha particles and the protons over the whole range of bombarding energy. At the higher incident energies, a small proton-background had to be subtracted from the measured counting rates. This background was obtained from momentum profile curves like the one shown in Fig. 1.

The differential cross section at each bombarding energy is directly proportional to the area under the profile peak. However, the ratio of peak height to area

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
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[1] N. P. Heydenburg and G. M. Temmer, Phys. Rev. 92, 89 (1953).
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varies in a regular fashion with the bombarding energy. This function was determined by taking complete profiles at eight different proton energies. Thus, for the majority of points on the excitation curve, it was only necessary to establish the peak of the momentum profile instead of the whole profile. To obtain the counting rate at the maximum, one had to take five to ten points at each profile. The proton bombardment for each of these points was 50 μcoul for the lower proton energies and 15 μcoul for the higher. A small correction for decrease in the number of target nuclei during the bombardments was applied to the measured values. No correction for target thickness has been made.

RESULTS

The measured excitation curve is shown in Fig. 2. The resonant character of the yield is apparent—in all, thirteen resonances are visible. Table I shows

TABLE I. Resonances in $O^{17}(p,\alpha)N^{14}$ ($\theta_{lab}=90°$).

Notation in Fig. 2	E_p(Mev)	$\Gamma_{(c.m.)}$(kev)	$E(F^{18*})$ (Mev)	$d\sigma/d\Omega$ (relative)[a]
1	1.110	9	6.666	0.7
2	1.273	90	6.820	1.2
3	1.786	~65	7.304	1.1
4	2.021	11	7.527	2.3
5	2.048	90	7.552	1.5
6	2.218	11	7.713	1.4
7	2.235	100	7.728	1.3
8	2.406	~25	7.889	3.7
9	2.435	~25	7.917	2.9
10	2.623	~40	8.094	1.1
11	2.753	~15	8.216	1.4
12	2.775	~10	8.238	2.0
13	2.928	~50	8.382	0.9

[a] These values correspond to the maximum counting rate at each peak and hence include both the resonance itself and the background.

proton energy, level width, and excitation of the compound nucleus F^{18} for the various resonances, as well as the absolute differential cross section at the maximum of each resonance. The three former quantities were obtained after reducing the yield curve to a more specifically nuclear function by division by the penetration factors for protons and alphas as computed for s-wave particles, and multiplication by the proton energy, which is inversely proportional to $\pi\lambda^2$.

Comparisons with one-level resonance formulas have been possible for the resonances in the lower part of the region covered and from them the level widths in Table I were obtained. For the higher resonances only approximate limits are indicated.

Levels 1 and 2 were also reported in reference 1. The level widths which were given by the study of the inverse reaction $N^{14}(\alpha,p)O^{17}$ are 27 and 93 kev. The resonance positions in F^{18} were given as respectively

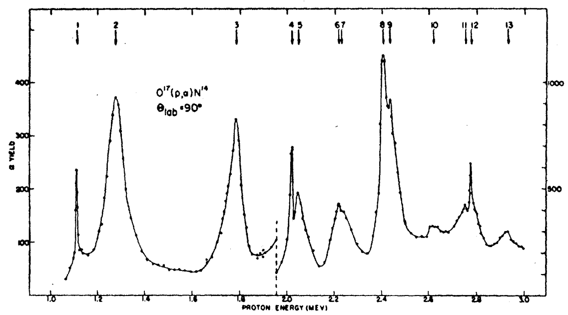

FIG. 2. Excitation function for $O^{17}(p,\alpha)N^{14}$ (ground state) as a function of bombarding energy at the observation angle 90°. 100 counts corresponds to an absolute differential cross section of 0.04 mb/steradian. Note the change of scale at about 2-Mev proton energy.

6.704 and 6.863 Mev. (These energies have been recalculated here using the latest atomic mass data available[3] and differ slightly from the values given in reference 1.) We see that the relative distance between the two peaks is the same as in the present work (160 kev compared to 156 kev) but that the excitation energies differ by as much as 40 kev. No explanation for this discrepancy has been found in the present experimental procedure. An external layer on the O^{17} target would of course work in the opposite direction. Heydenburg and Temmer's third resonance has not been found in the present investigation.

Note added in proof.—In a recent publication, Herring, Chiba, Gasten, and Richards [Bull. Am. Phys. Soc. **1**, 326 (1956)], report resonance energies for $N^{14}(\alpha,p)$ corresponding to levels 1, 2, and 3 in Table I which are respectively 36, 50, and 24 kev lower than those reported here. It is possible that part of this discrepancy can be accounted for by surface contamination on the O^{17} target used in our experiments.

Owing to the negative Q value, -1.11 Mev, of the reaction giving alpha particles to the first excited level in N^{14}, a similar excitation function for this reaction cannot be studied with the bombarding energies available here, except over the highest part of the region. A comparison of which F^{18} levels are excited in the two cases could, if the partial widths Γ_p are not very small, give some information on the strength of isotopic spin selection rules, since to a first approximation, the ground-state alphas should come from $T=0$ states and the next group from $T=1$ states in F^{18}. Protons on O^{17}, for which $T=\frac{1}{2}$ in the ground state, can excite both singlet ($T=0$) and triplet ($T=1$) states in F^{18}, but as the ground state of N^{14} has $T=0$, only the singlet states of F^{18} can decay by emission of long-range alpha particles ($T=0$). On the other hand, the first excited state in N^{14} is a $T=1$ state and should preferably be reached by decay of the $T=1$ states in F^{18}.

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Optical-Model Analysis of the Elastic Scattering of Alpha Particles*

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The elastic scattering of 22- and 40-Mev alpha particles on a variety of elements has been analyzed in terms of an optical model. The nuclear optical model potential assumed in this work has the form: $(V_R+iV_i)/\{1+\exp[(r-r_1)/d]\}$. The diffuse character of the electrical charge distribution in nuclei was also taken into account. The four parameters in the nuclear optical model potential were varied so as to obtain the best fit to the data. The diffuseness parameter is found to be $d\approx0.5\times10^{-13}$ cm and the parameter r_1, which represents an "average" radius of the nucleus-alpha particle system, is found to be $r_1\approx(1.35A^{\frac{1}{3}}+1.3)\times10^{-13}$ cm. The average values of V_R and V_i are -45 Mev and -10 Mev, respectively, at 40 Mev. Exceptions to this are the lightest elements, C, Al, and Ti, which require -30 Mev for V_R. At 22 Mev, V_R is found to be -31 Mev. Other parameters have the same values obtained at 40 Mev.

I. INTRODUCTION

DURING the past few years, there has been a steady increase in the information available concerning the elastic scattering of various particles from nuclei in the 10–50 Mev energy range. The proton and neutron elastic-scattering data have been analyzed in terms of an optical model.[1] The results of the proton analysis[2] indicate that the interaction potential must have a sloping edge in order to fit the small cross section, observed at large scattering angles. The nuclear potential considered by Saxon and Woods has the form $(V_R+iV_i)/\{1+\exp[(r-r_1)/d]\}$. The parameter d is found to be approximately 0.5×10^{-13} cm, and when r_1 is taken to be $1.4A^{\frac{1}{3}}\times10^{-13}$ cm, V_R is found to be approximately -39 Mev and V_i to be -10 Mev. However, recent work has indicated that equally good fits can be obtained with a radius of $1.20A^{\frac{1}{3}}\times10^{-13}$ cm with $V_R\sim-60$ Mev.[3]

The qualitative features of the alpha-particle data suggest the possibility of fitting these data through the use of an optical-model potential. The success of similar calculations for nucleon-nucleus scattering encourages such a point of view. While it is *a priori* not so clear for alpha-particle scattering as for nuclear scattering that this model should apply, there is the advantage afforded in the alpha-particle analysis that the bombarding particle has zero spin. Thus, unlike the optical-model analysis of nucleon-nucleus scattering, no uncertainty arises from the possibility that a spin-orbit force plays an important role.[4]

Analyses of alpha-particle elastic scattering data from heavy elements only have been made by Porter,[5] by Blair,[6] by Wall *et al.*,[7] and by Oda and Harada.[8] Porter used a classical model which took into account the nuclear absorption of alpha particles in the surface. Blair employed a partial-wave analysis in which it was assumed that all partial waves which have classical impact parameters less than or equal to the interaction radius were totally absorbed. Wall *et al.* performed the same analysis on their data but assumed that the partial waves with classical impact parameters approximately equal to the interaction radius were only partially absorbed. Oda and Harada use the boundary condition model of Feshbach and Weisskopf[9] and the optical model with a complex potential of exponential shape. These analyses were not successful in reproducing the elastic scattering data where the differential cross section deviated markedly from the Coulomb cross section. Three of these analyses[6–8] compelled the use of an anomalously large radius for the alpha-particle-nucleus system.

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