Total Cross Sections of the $O^{18}(p,\alpha)N^{15}$ and $O^{18}(p,n)F^{18}$ Reactions*

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The angular distribution of the α particles from the $O^{18}(p,\alpha)N^{15}$ reaction and the total cross section for the $O^{18}(p,n)F^{18}$ reaction have been measured for proton energies between 2.60 and 2.97 Mev. Comparison of the total cross sections for the two reactions eliminates the previously observed differences in resonance energies in these reactions. At most energies the α particles are preferentially emitted in the forward and backward directions and the angular distributions are rapid functions of proton energy.

INTRODUCTION

A PREVIOUS study[1] of the energy levels in the F^{19} nucleus from observations of maxima in the yields of the $O^{18}(p,\alpha)N^{15}$ and $O^{18}(p,n)F^{18}$ reactions resulted in some ambiguity due to small but definite differences in the proton energies needed to produce yield maxima of these reactions. In this earlier work the two reactions were observed simultaneously but at different angles, the α particles at 90° to the proton beam and the neutrons at 0°. In an effort to resolve these ambiguities further measurements have been made in which the total cross section for the (p,n) reaction and the detailed angular distribution of the (p,α) reaction were obtained for certain ranges of proton energy which, from the earlier data, appeared to be interesting.

EQUIPMENT

Due to the different techniques required for the (p,α) and (p,n) measurements the two reactions had to be studied separately in this present work.

The yield of α particles as a function of angles and proton energy was obtained using a target chamber described previously[2] with the following modifications. The magnetic analyzer (H) and nuclear emulsion holder (I,J,K) shown in Fig. 1 of reference 2, were removed and replaced by a proportional counter. The proton beam defining aperature was made 0.125 in. in diameter and the aperature leading into the proportional counter was 0.200 in. in diameter at a distance of 4.25 ins. from the target. The monitor proportional counter (L) was removed. Other equipment used in the (p,α) work was similar to that described in reference 1.

The neutron yield was measured by counting the positron activity of the resulting F^{18}, a technique which has been applied elsewhere[3,4] to this reaction, but with thicker targets and proton beams having a wider energy spread than in the present work.

The target chamber used for the neutron measurements was that described in reference 1 with the target mounting clamp modified so that a 1-mg/cm² aluminum foil, 1.0 in. wide and 1.5 ins. high, could be held at a distance of 0.025 in. from the target foil in the forward direction. This aluminum foil served to catch the F^{18} nuclei emerging from the target in the forward direction, but did not stop the protons which had passed through the target. Therefore, the usual insulated cup could be used for beam current collection and measurement. After a suitable bombardment period, the aluminum foil was removed and the positron activity in it, due to the F^{18} nuclei which have been caught, was measured using a thin-wall Geiger counter. It was found that this procedure gave more reproducible results than counting the F^{18} activity remaining in the target, since the NiO target foils were very fragile and often broke during handling. It was not convenient to count the F^{18} activity in the target in its original position because of the delay in starting the next bombardment. The target foils were prepared by a method described previously.[5] In both target chambers the foils were mounted at a fixed angle of 45° with respect to the proton beam. Several targets were used during the course of these experiments and their thick-

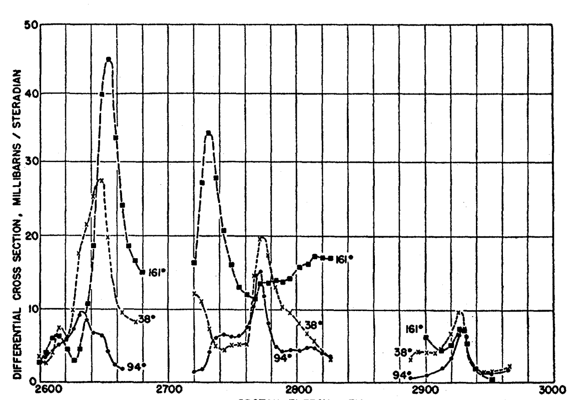

FIG. 1. Differential cross section for the $O^{18}(p,\alpha)N^{15}$ reaction observed at three center-of-mass angles as a function of incident proton energy. Proton energies are for center of target.

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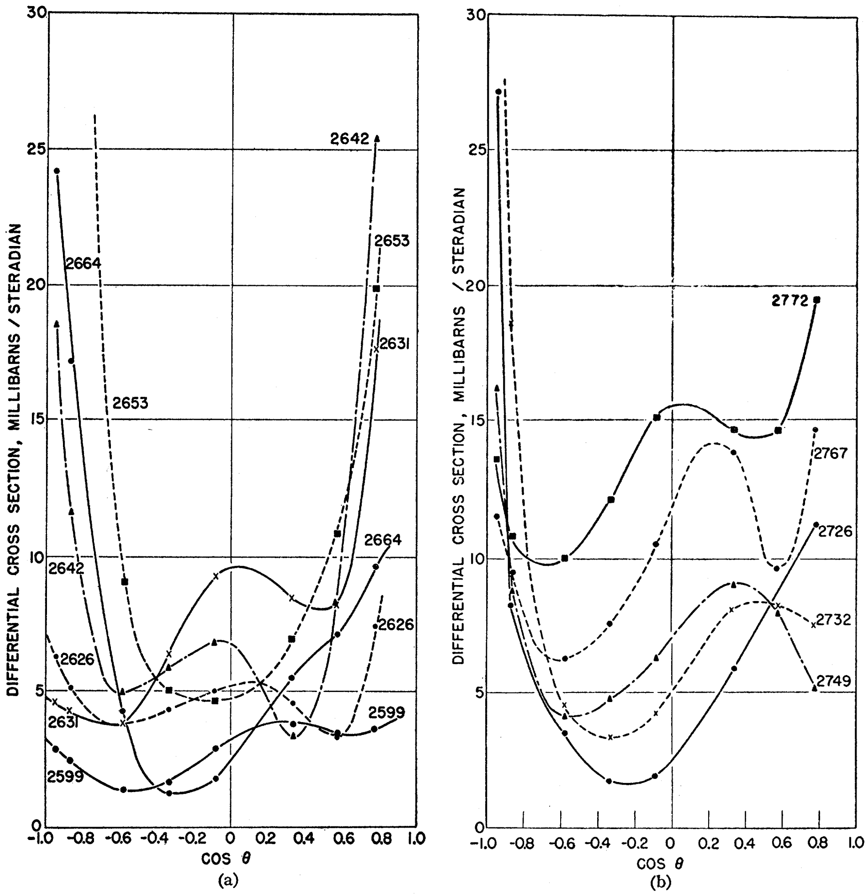

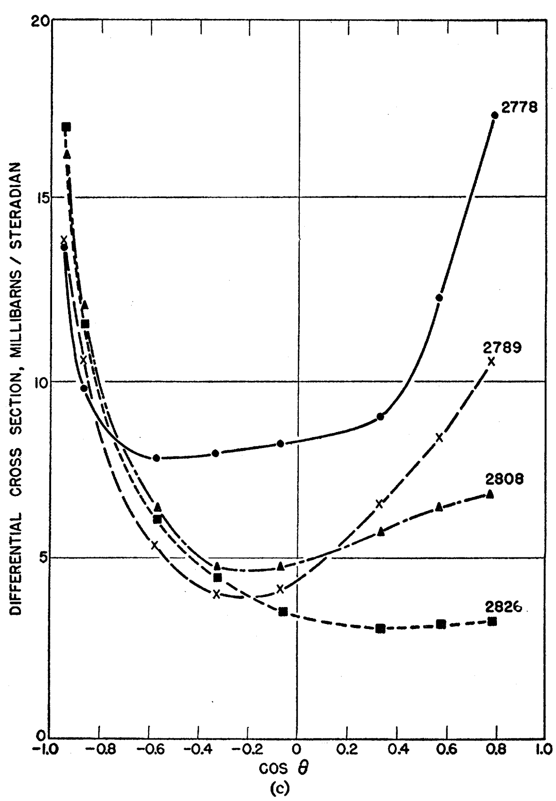

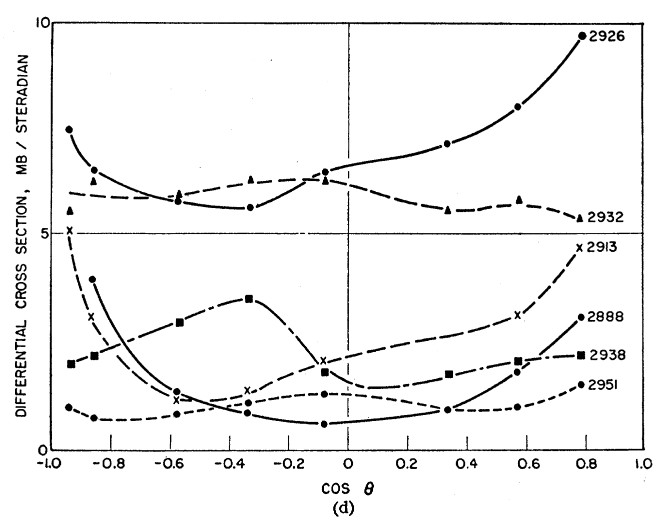

FIG. 2(a), (b), (c), and (d). Angular distribution of the α particles from the $O^{18}(p,\alpha)N^{15}$ reaction for various proton energies. Cross sections and angles are in center-of-mass system. Numbers on the curves give incident proton energies at center of target in kev.

nesses ranged between 10 and 15 kev for 2.7-Mev protons.

EXPERIMENTAL PROCEDURE

The yield of the (p,α) reaction was measured as a function of proton energy with the proportional counter at laboratory angles of 36°, 52°, 66°, 90°, 105°, 121°, 147°, and 160°. The upper and lower angular limits were determined by the structure of the target chamber and counter. The proton energy was varied in steps of approximately 6 kev over three ranges of energy which were thought to be interesting due to the considerations mentioned in the introductory section above. As in the previous (p,α) work,[1] the counter window thickness and filling pressure were adjusted so that the α particle pulses were easily separated from those due to other causes.

As a preliminary to taking the (p,n) data, tests were made to determine the fraction of F^{18} atoms which reached the aluminum catcher foil, the fraction which remained in the target foil and the fraction recoiling in the backward direction. It was found that 42% of the F^{18} atoms reached the catcher foil, 55% of them remained in the target foil and 3% of them left the target in the backward direction. None of the F^{18} atoms passed through the catcher foil. Since the dimensions of the catcher foil were large compared with the proton beam diameter (0.065 inch) and the spacing between target and catcher, essentially all of the F^{18} atoms leaving the target in the forward direction were caught by the aluminum foil.

Due to the large number of protons scattered by the aluminum catcher foil into the proportional counter attached to the target chamber, it was not feasible to count the α particles produced during a bombardment with the catcher in place. Therefore, preliminary runs with no catcher present were made before each series of F^{18} measurements and the resulting α particle yield at 90° was used to confirm the condition of the target and to check the consistency of the energy calibration of the machine by comparison with our previous (p,α) data.

During each bombardment with the catcher in place the proton beam intensity was checked periodically and the F^{18} activity was later corrected for its decay during the bombardment, taking into account the observed variations in beam current. After a bombardment the active catcher foil was removed from the target chamber and placed under a calibrated, thin-wall Geiger counter. The time (about 5 minutes) required for this operation was long enough to permit the complete decay of any F^{17} activity ($T_{\frac{1}{2}}=66$ seconds[6]) due to the $O^{16}(p,\gamma)F^{17}$ reaction. The decay of the F^{18} activity in each catcher was followed for about one hour, during which time other bombardments could be made.

[6] C. Wong, Phys. Rev. 95, 765 (1954).

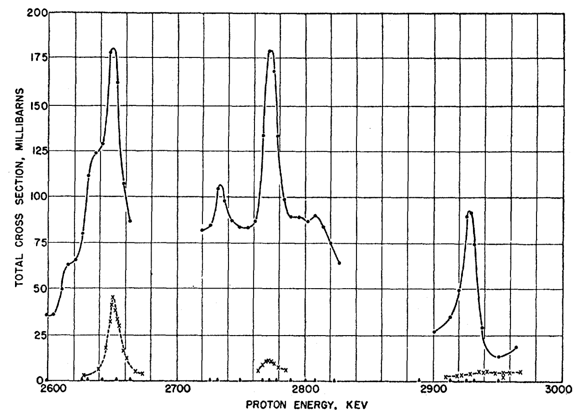

FIG. 3. Total cross sections for the $O^{18}(p,\alpha)N^{15}$ reaction (solid curve) and the $O^{18}(p,n)F^{18}$ reaction (dashed curve) as a function of proton energy in kev. Triangular dots along the energy scale designate proton energies for which angular distribution curves are presented in Fig. 2.

RESULTS

Three of the (p,α) yield curves taken with the angular distribution chamber are shown in Fig. 1. The proton energies have been corrected for target thickness and represent the average energy at the center of the target. The cross sections have been converted to the center-of-mass coordinate system and the angles given for the three curves are center-of-mass angles with respect to the direction of the proton beam.

A representative selection of angular distribution curves are presented in Figs. 2(a), (b), (c), and (d). The cross sections have been converted to the center-of-mass coordinate system and they have been plotted against the cosine of the angle of observation, converted to the center-of-mass coordinate system. The numbers designating each curve represent the proton energies at the center of the target in kev.

The total cross sections for the (p,α) reaction, the solid curves in Fig. 3, were obtained by graphical integration of the angular distribution curves. The smaller triangular marks along the bottom edge of Fig. 3 designate the proton energies for which curves are given in Fig. 2. The curves not given in Fig. 2 were omitted to avoid confusion due to the large number of overlapping lines.

The dotted curves in Fig. 3 represent the total cross section for the $O^{18}(p,n)F^{18}$ reaction. The F^{18} activities measured in the catcher foils are considered to be proportional to the total cross section for this reaction without regard to possible variations in the angular distribution of the neutrons. This should be true since this reaction was studied over an energy range of no more than 400 kev above its threshold energy (2577 kev[1]), and in this region the F^{18} nuclei should all have initial directions within 12° of the direction of the proton beam. During their passage through the target the fluorine atoms will make collisions with the nickel and oxygen atoms in the target so that some diffuse out of the target and some remain in it, as was experimentally confirmed. However, the velocity and direction of the fluorine atoms are mainly determined by the velocity of the center-of-mass of the reaction system, which changes only slightly over the range of this experiment, so that the fraction of fluorine atoms reaching the catcher should not be a strong function of the incident proton energy.

The relative errors between the points on the (p,α) curves in Figs. 1 and 2 are thought to be between 2% and 4%, as determined by counting statistics and the reproducibility of data. Because of uncertainties in the number of O^{18} atoms in the targets the cross section scales may be in error by $\pm 25\%$. Some of the points in Fig. 3 giving the total cross section of the (p,α) reaction have an additional uncertainty up to $\pm 5\%$ due to the need for extrapolation of the curves of Fig. 2 to 0° and 180°. The maximum error due to this cause occurs at those proton energies where the yield rises most rapidly at high and low angles.

The individual points on the (p,n) curves in Fig. 3 are thought to have relative errors of $\pm 5\%$ with the cross section scale being uncertain by as much as $\pm 50\%$, due to target conditions and the uncertainty in the absolute efficiency of the positron counters.

DISCUSSION OF RESULTS

The 94° curves in Fig. 1 closely resemble the pertinent portions of the solid curve in Fig. 1 of reference 1, with the addition of some finer details, apparently due to the thinner targets used in the present work. However a comparison of the 38° and 161° curves with the 94° curve show that there are many features of this reaction which the curve for any single angle cannot show. The apparent excess of yield in the backward direction, as illustrated by the 161° curve being higher than the 38° curve, is an illusion due to the fact that these two angles are not symmetric about 90°. As the proton energy is varied, the angular distribution of the α particles emitted varies widely, as can be seen from Fig. 2. On the whole, the yield per unit solid angle near 90° is less than that in the forward or backward direction.

The curves in Fig. 3 showing the total cross section for the (p,α) reaction indicate that there are more energy levels in the F^{19} nucleus than was evident from the 90° curve in the older work.[1] In the older data there was a displacement in energy between the neutron peak at 2649 kev and the α-particle peak at 2635 kev, whereas the total cross section curves now show that the neutron maxima at both 2772 kev and 2650 kev correspond within one or two kev to maxima in α-particle yield. As in the earlier data, the neutron cross section does not appear to have a maximum in the neighborhood of the maximum of the (p,α) cross section at 2928 kev.

An inspection of the curves in Fig. 2 shows that the angular distributions on the low-energy sides of the resonances at 2650 kev and 2772 kev are more complex than those on the high-energy sides, and that the chief contributions to the peaks are the strong yields in the forward and backward directions. In contrast to these, the resonance at 2928 kev has much less complex angular distributions on either side of the peak and is most nearly isotropic at the peak. It is possible that these differences in the α-particle distributions are related to the fact that the 2650-kev and 2772-kev resonances appear in both (p,α) and (p,n) reactions, while the 2928-kev resonance appears only in the (p,α) interaction.

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