A STUDY OF THE EFFECT OF THE 3.10-MEV STATE OF F^{17} ON THE $O^{16}(p,\gamma)F^{17}$ REACTION

Thesis by

John J. Domingo

In Partial Fulfillment of the Requirements

For the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

1963

ACKNOWLEDGMENTS

The author would like to express his gratitude to the staff of the Kellogg Radiation Laboratory for their assistance during the course of this work. He is especially indebted to Dr. Neil Tanner now of the Clarendon Laboratory, Oxford, England for suggesting the problem, and to Professor T. Lauritsen for his constant interest and guidance. The author would also like to thank Dr. T. Tombrello for providing the computer program for the computation of the capture matrix elements, and to Barbara Zimmerman for her help in the analysis of the experimental data. It is a pleasure to acknowledge the assistance of Mr. J. D. Pearson without whose unfailing aid during the weary months of accelerator maintenance this experiment could never have been brought to fruition.

The author is also grateful for the graduate fellowships received from the National Science Foundation and for the financial support of this research project by a joint program of the Office of Naval Research and the U.S. Atomic Energy Commission.

ABSTRACT

The yield of the two capture gamma rays in the $O^{16}(p,\gamma)F^{17}$ reaction has been measured at 90° to the beam for bombarding energies in the range 2.56 - 2.76 MeV. An anomaly was observed in the yield of the capture gamma ray leading to the .500 MeV $\frac{1}{2}^{+}$ state of F^{17} for a bombarding energy of approximately 2.66 MeV corresponding to the 3.10 MeV state of F^{17}. No anomaly was observed in the yield of the capture gamma ray leading to the $\frac{5}{2}^{+}$ ground state of F^{17}. The experimental results were found to be in good agreement with theoretical calculations made on the basis of the extra-nuclear capture model of Christy and Duck (1961). On the basis of the experimental results and the theoretical calculations, the single particle reduced widths for the $\frac{1}{2}^{+}$ .500 MeV state and the $\frac{5}{2}^{+}$ ground state of F^{17} were obtained. Using the definition of Lane (1958), these single particle reduced widths were found to be:

$$\theta^2_{\frac{1}{2}+sp} = .57 \pm .10 \qquad \theta^2_{\frac{5}{2}+sp} = .38 \pm .08$$

From the shape of the anomaly observed in the yield of the capture gamma ray leading to the $\frac{1}{2}^{+}$ state and the extranuclear calculations, an upper limit was placed upon the width of the gamma ray transition leading from the resonant $\frac{1}{2}^{-}$ state at 3.10 MeV to the $\frac{1}{2}^{+}$ .500 MeV state. This limit was: $\Gamma_\gamma < .03$ eV

TABLE OF CONTENTS

I. INTRODUCTION

In many light nuclei the cross section for the (p,γ) reaction consists of a slowly varying background upon which the various resonances in the reaction are superposed. The characteristic magnitude of this slowly varying background is approximately 1 microbarn for 1 MeV protons, and in many cases the gamma-ray angular distribution has the simple $\sin^2\theta$ form characteristic of a dipole transition with no change of magnetic quantum number. In several cases this $\sin^2\theta$ distribution can be attributed to a P to S electric dipole transition with no spin flip, and this simple angular distribution together with the smoothly varying character of the cross section leads to the description of the reaction as a direct capture process.

Christy and Duck (1961) have shown that in several cases a simple extranuclear model for the electric dipole capture shows good agreement with the experimental data. In this model the capture matrix elements are approximated by only that portion contributed by configurations in which the proton is outside the nuclear potential of the capturing nucleus. For these configurations the only interaction between the two particles is just the Coulomb one, and the wave functions involve only the well known Coulomb functions. The absence of a nuclear interaction in the initial state accounts for the smoothly varying character of the cross section and also for the absence of spin flip and the resultant $\sin^2\theta$ distribution in the case of P to S capture.

The success of the model at low bombarding energies is not surprising since calculations show that the integrand of the capture matrix element has a maximum at a distance considerably larger than the nuclear radius. Thus, the behavior of the correct wave functions in the vicinity of the nuclear surface is not very important, and the approximation made in replacing them with Coulomb functions up to some cutoff radius is reasonably good. At higher bombarding energies the model might be expected to deviate from the experimental data since the maximum in the integrand of the matrix elements will move closer to the nuclear surface and the behavior of the correct wave functions in the vicinity of the nuclear surface will therefore become more important. Thus, once the validity of the model had been reasonably well established at low bombarding energies, it was interesting to test it at higher energies.

The extranuclear calculations are in good agreement with the low energy measurements of the $O^{16}(p,\gamma)F^{17}$ cross section (Tanner, 1959; Christy, 1961; Lal, 1962), and the possibility of clarifying a rather puzzling situation concerning the interference between the direct and resonant capture made this a particularly interesting case to investigate at a higher bombarding energy. The energy levels of F^{17} are shown in Fig. 1 which was taken from the compilation of Ajzenberg-Selove and Lauritsen (1959). Analysis of the elastic scattering of protons from O^{16} has shown (Salisbury and Richards, 1962) that the 3.10-MeV state of F^{17} has a spin and parity of $\frac{1}{2}^-$. In this analysis it was found possible to obtain good agreement with the elastic scattering data in the region of the 3.10-MeV state by using only a resonant $P_{\frac{1}{2}}$ phase shift and slowly varying $P_{\frac{3}{2}}$ and $S_{\frac{1}{2}}$ phase shifts. Capture to the .500-MeV $\frac{1}{2}^+$ state proceeds mainly by E1 radiation from the $P_{\frac{1}{2}}$ and $P_{\frac{3}{2}}$ partial waves; capture to the $\frac{5}{2}^+$ ground state proceeds mainly by E1 radiation from the $P_{\frac{3}{2}}$, $F_{\frac{5}{2}}$, and $F_{\frac{7}{2}}$ partial waves. Thus, even on the basis of a purely extranuclear transition, one would expect an anomaly in the γ_2* cross section in the region of the 3.10-MeV state since the $P_{\frac{1}{2}}$ partial wave contains an additional term due to the resonant scattering. The γ_1* cross section, on the other hand, should show no anomaly since it does not proceed through the $P_{\frac{1}{2}}$ partial wave and there will be no additional resonant term in its matrix element.

The experimental results of Laubenstein et al. (1951), appear to be in disagreement with these conclusions since, within their experimental uncertainty, no anomaly was observed in the total capture cross section in the region of the 3.10-MeV state of F^{17}. The extranuclear model, however, predicts a definite anomaly calculable from the $O^{16}(p,p)$ elastic scattering phase shifts and the value of the F^{17} nuclear radius, and in general it is very difficult to see how some sort of anomaly could fail to be present. A preliminary calculation of the expected γ_2 anomaly showed that it would be mainly of the interference type, and that the magnitude of the anomaly should be approximately $\pm$ 25% of the nonresonant yield. The width of the 3.10-MeV state of F^{17} state as deduced from the resonance observed in the $O^{16}(p,p)$ elastic scattering at a bombarding energy of 2.66 MeV is approximately 20 keV. A study of the yield of the

---

*In the following discussion the capture gamma ray leading to the $\frac{5}{2}^+$ state of F^{17} will be denoted by γ_1; the capture gamma ray leading to the $\frac{1}{2}^+$ .500-MeV state of F^{17} will be denoted by γ_2, and the gamma ray leading from the $\frac{1}{2}^+$ state to the ground state of F^{17} will be denoted by γ_3.

two capture gamma rays at $\theta = 90°$ was therefore undertaken for bombarding energies in the range 2.56—2.76 MeV. Sufficiently long bombardments were used so that the expected statistical fluctuation in the γ_2 yield between the data points was only about 2% or less than 10% of the expected anomaly.

An anomaly of the type predicted by the extranuclear model was observed in the γ_2 yield, and, within the statistical uncertainty of approximately 10%, no anomaly was present in the measured γ_1 yield (see Figs. 8 and 9). Parts II and III of this thesis describe the measurement and analysis of the yield of the two capture gamma rays. In Part IV the experimental results are compared with the results predicted on the basis of the extranuclear model.