9.17-Mev State in N^{14}

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The angular distributions of the 9.17-Mev ground state gamma ray and the gamma rays of the 2.73–6.44 Mev cascade resulting from the 1.75-Mev proton resonance on C^{13} ($N^{14*}=9.17$ Mev) have been measured. The spins deduced from the angular distributions for the 9.17-Mev state and the 6.44-Mev state agree with previous assignments. The angular momenta admixtures required are found to be in disagreement with one shell model of N^{14} but it is shown that the model can be brought into accord with experiment by having the 9.17-Mev state wave function include a configuration with a nucleon in the f shell.

INTRODUCTION

THE fact that nuclei in the $1p$ shell (Li^5-O^{16}) appear to be amenable to a shell model description has led to extensive calculations which are to be compared to the wealth of experimental data. A case in point is the nucleus N^{14} where Warburton and Pinkston[1] (W-P) have assigned shell model configurations to many of the states of N^{14} and have then proceeded to calculate various dynamic properties of these states. W-P used a simplified model of N^{14}, rather close to extreme jj coupling about a C^{12} core and found fairly good agreement between theory and experiment. The present study was undertaken in order to investigate certain of the experimental points still doubtful in N^{14} and to test further the W-P model; specifically, the 1.75-Mev proton capture resonance on C^{13} ($N^{14*}=9.17$ Mev) was studied.

The main features of the decay of the 9.17-Mev state have been recently given by Rose.[2] The strength of the predominant ground-state transition ($\omega\Gamma_\gamma=14.1$ ev) and the total width ($\Gamma=77\pm12$ ev) were measured by Hanna and Meyer-Schützmeister.[3] The parity of the 9.17-Mev state was determined to be positive by Strassenburg *et al.*[4] The decays of the 9.17-Mev state of interest in the present work are shown in Fig. 1. The spin assignments for the 6.44- and 9.17-Mev states are from the present work and confirm the previous assignments.

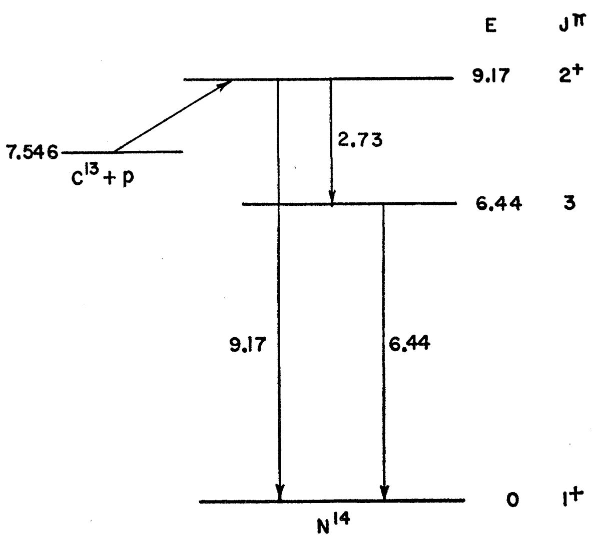

FIG. 1. Energy-level diagram showing those transitions studies in the present work. Many other levels in N^{14} are known (see reference 1).

EXPERIMENTAL RESULTS

30-kev thick carbon targets cracked from methane enriched to 48% C^{13} were bombarded with 1.75-Mev protons from the Aeronautical Research Laboratory Van de Graaff generator. The resonance is strong enough so that nonresonant gamma rays gave a negligible contribution to the spectra.

Gamma-ray spectra taken with a three crystal pair spectrometer are shown in Fig. 2. It can be seen that the 6.44-Mev line is at least as intense at 30° as it is at 0° while it is much weaker at 90°. If these data are fitted with a distribution function of the form

$$W(\theta)=\sum_k A_k \cos^k\theta,$$

it is readily apparent from the strong angular dependence exhibited in Fig. 2 that $W(\theta)$ must contain terms of the order $k>2$. For a well-isolated resonance, as obtained here, the coefficients A_k are nonvanishing only for even values of k, and hence the above requirement becomes $k_{\max}\geqslant4$. Since the 9.17-Mev state must have $j\leqslant2$, k is further restricted to values $k_{\max}\leqslant4$. Data were also taken at $\theta=60°$; the best fit to the data for the 6.44-Mev line is given by

$$W(\theta)=1+(1.6\pm0.4)\cos^2\theta-(1.1\pm0.4)\cos^4\theta,$$

with

$$[W(0)/W(90)]-1=+0.42\pm0.05.$$

The presence of the large $\cos^4\theta$ term has the following immediate consequences:

(1) The 9.17-Mev state must have $j=2$. The strength of the 9.17-Mev radiation to the $j=1$ ground state

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[1] E. K. Warburton and W. T. Pinkston, Phys. Rev. **118**, 733 (1960).
[2] H. J. Rose, Nuclear Phys. **19**, 113 (1960).
[3] S. S. Hanna and L. Meyer-Schützmeister, Phys. Rev. **115** 986 (1959).
[4] A. A. Strassenberg, R. E. Hubert, R. W. Krone, and F. W. Prosser, Bull. Am. Phys. Soc. **3**, 372 (1958).

transition requires it to be predominantly dipole which implies $j \geqslant 2$ while the $\cos^4\theta$ term in the 6.44-Mev angular distribution requires $j \geqslant 2$. Hence $j=2$ is uniquely determined. This spin assignment had been previously deduced by Rose, Trost, and Riess[5] from gamma-ray asymmetry measurements.

(2) Protons having angular momentum $l \geqslant 2$ must take part in the formation of the 9.17-Mev state. By taking the 9.17-Mev state as 2+ and noting that the C^{13} ground state is $\frac{1}{2}-$, a significant f-wave component in the incoming protons is indicated.

(3) The spin of the 6.44-Mev state is most probably 3. The large $\cos^4\theta$ term in the angular distribution requires the 6.44-Mev radiation to contain significant admixtures of radiation of multipolarity $L \geqslant 2$ which implies $j \geqslant 3$ for the 6.44-Mev state, while the strength of the 9.17–6.44-Mev transition requires $1 \leqslant j \leqslant 3$. This same spin assignment was indicated in the work of Rose *et al.*[5]

On assuming the 6.44-Mev ground-state transition to be pure quadrupole, the measured angular distribution requires the intensity of the f-wave component of the protons forming the 9.17-Mev state to be between 30% and 80% of the total intensity, with the amplitude of the p and the f waves having the same sign. It has been assumed here that the 2.73-Mev gamma ray from the 9.17- to the 6.44-Mev states is pure dipole. This assumption should not seriously detract from the validity of our conclusions, since the strength of the 2.73-Mev gamma ray ($\Gamma_\gamma \sim 0.5$ ev) implies that it is predominantly dipole, and since interference terms from the unobserved radiation do not appear in the angular correlation. Regardless of any higher-multipolarity admixtures in the 2.73- and 6.44-Mev radiations, the size of the $\cos^4\theta$ term in the 6.44-Mev gamma ray angular distribution requires at least a 20% f-wave component in the formation of the 9.17-Mev state.

The partial wave admixture required in order to fit the 6.44-Mev gamma ray angular distributions lead to the following proton reduced widths in single particle units:

$$\theta_f^2 \sim 0.3\%,$$
$$\theta_p^2 \leqslant 10^{-2}\%.$$

The value $\theta_p^2=0$ is allowed if the 6.44-Mev radiation is mixed. For these estimates the proton width has been taken[3] as 70 ev and an interaction radius of 3.41×10^{-13} cm was used.

The angular distribution of the 2.73-Mev radiation was found to be:

$$W(\theta)=1-(0.14 \pm 0.05)\cos^2\theta$$

if any possible $\cos^4\theta$ term is neglected. A large $\cos^4\theta$ term is precluded by the measured angular distribution.

Angular distributions for the 2.73-Mev radiation were

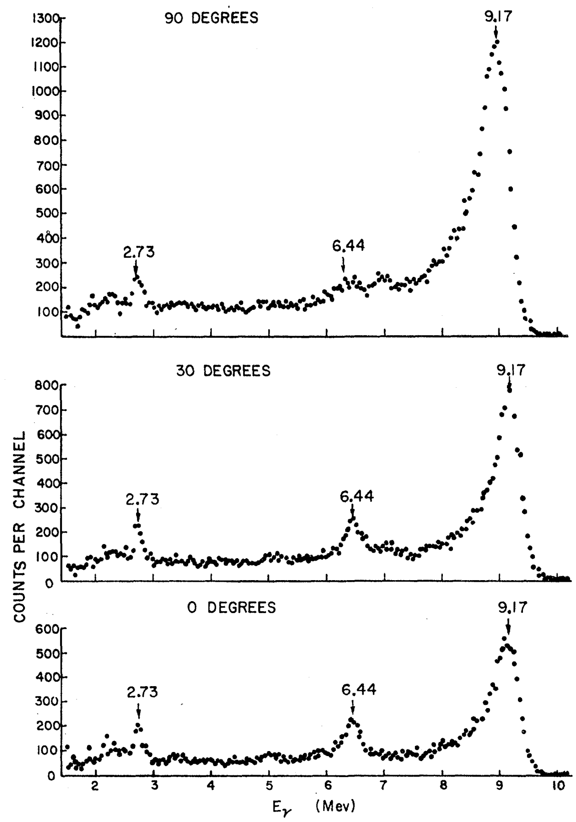

FIG. 2. Spectra taken at the 1.75-Mev $C^{13}(p,\gamma)N^{14}$ resonance with a three-crystal pair spectrometer. The weak peak above the 6.44-Mev line is apparently the same as the 7.05-Mev line seen in reference 2.

calculated for the range of relative partial wave intensities allowed in the formation of the 9.17-Mev state as determined from the measured angular distribution of the 6.44-Mev radiation. It was found that the 2.73-Mev angular distribution could be fitted by assuming a pure dipole transition with an upper limit on the amplitude of any quadrupole admixture given by $|\delta| < 0.05$. By taking $\Gamma_\gamma(2.73)=0.5$ ev as determined from the total gamma widths and the branching ratio for the 2.73-Mev transition,[2] this upper limit for a quadrupole admixture implies $|M|^2<3$ if the 9.17- and the 6.44-Mev states are of the same parity and $|M|^2 < 100$ if these two states are of opposite parity.

The angular distribution of the 9.17-Mev ground state transition was also measured. For this measurement a single 3-in. diam, 3-in. thick NaI(Tl) crystal was used. After correcting for finite solid angle, absorption in the target chamber walls, and Doppler shift, the angular distribution was found to be

$$W(\theta)=1-(0.59 \pm 0.03)\cos^2\theta+(0.03 \pm 0.03)\cos^4\theta,$$

with the asymmetry

$$[W(0)/W(90)]-1=-0.56 \pm 0.01.$$

[5] H. J. Rose, W. Trost, and F. Riess, Nuclear Phys. 12, 510 (1959).

The asymmetry and angular distribution data require that the ratio of the $E2$ to the $M1$ amplitude for the 9.17-Mev transition be

$$-0.02<\delta<0.$$

This small value of δ requires an undetectably small $\cos^4\theta$ term in the angular distribution which is in agreement with the present data but disagrees with the results of Strassenburg *et al.*[4] We find the upper limit in Weisskopf units for the $E2$ matrix element in the 9.17-Mev radiation to be $|M|^2<0.03$.

All of the above analysis is based upon the 9.17-Mev state having positive parity. Should this assignment be incorrect, which would contradict the experimental evidence as well as the W-P model, the following would result:

6.44-Mev angular distribution: These data could then be fit by having an octupole mixture of amplitude $\delta=0.1$, and a ratio of channel spin 1 to channel spin 0 of about 1:2. The size of the octupole admixture required in this eventuality (9.17-Mev state negative parity) would imply a negative parity for the 6.44-Mev state.

2.73-Mev radiation: These data could then be fit if an $E2$ admixture $-0.04<\delta<0.01$ were present.

9.17-Mev radiation: Assigning negative parity to the 9.17-Mev state requires the 9.17-Mev ground state transition to be primarily $E1$. Our angular distribution would require $0<\delta<0.02$ which is a reasonable range for an $M2$ competing with an $E1$.

Thus, all of the present data are consistent with the 9.17-Mev state having negative parity and the data can be fit with reasonable multipole admixtures providing also that the 6.44-Mev state has negative parity.

In the ensuing discussion we take the 9.17-Mev state to have positive parity which is, of course, also consistent with all of the present data. Positive parity for the 9.17-Mev state is required by the W-P model as well as by the gamma-ray polarization measurement.[4]

DISCUSSION

In their model of N^{14}, Warburton and Pinkston take the 9.17-Mev state to be $j=2+$, $T=1$ as indicated by experiment. Taking some small liberties with the W-P model, it can be said that they attribute the 9.17-Mev state to the configuration $C^{12}(s,d)^2+C^{12}(p_{\frac{3}{2}}{}^{-1}p_{\frac{1}{2}}{}^3)$. This shell model assignment is most appealing, as the state cannot be made by simply attaching a proton to C^{13} ($C^{12}p_{\frac{1}{2}}$) which explains the small proton width, while the large gamma width would arise from a $p_{\frac{1}{2}}\rightarrow p_{\frac{3}{2}}$ transition. However, the W-P calculations disagree with the data presented here on two counts:

(1) W-P predict that the $E2$ component of the ground state radiation should be of strength $|M|^2\sim 0.1$ while we find as an upper limit $|M|^2<0.03$.

(2) The state described by the configuration of W-P given above would be formed primarily by p-wave protons and W-P calculate the proton reduced width on this basis. However, we find that a sizeable f-wave component is present and, in fact, the f-wave reduced width, $\theta_f{}^2$, is at least 10 times the p-wave reduced width.

The W-P model can be brought into agreement with the experimental data if the 9.17-Mev state is taken to also include the configuration $C^{12}p_{\frac{1}{2}}f_{\frac{5}{2}}$. The magnitude of $\theta_f{}^2$ measured here indicates that this portion of the wave function constitutes a few percent of the total wave function. The small $E2$ reduced width could then be explained as being caused by a cancellation between the $p_{\frac{1}{2}}\rightarrow p_{\frac{3}{2}}$ and the $f_{\frac{3}{2}}\rightarrow p_{\frac{1}{2}}$ amplitudes of the $E2$ matrix element.

This "fixing-up" of the W-P model that is required in order to fit the experimental data illustrates the fact that a simplified model can explain many of the main features of the N^{14} nucleus but that more detail is required in order to account for some of the more subtle dynamic properties.

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