Confirmation of 8^+ assignment to the 11.86 MeV level in ^{24}Mg†

S. A. Wender, C. R. Gould, and D. R. Tilley
North Carolina State University, Raleigh, North Carolina 27607
and Triangle Universities Nuclear Laboratory, Durham, North Carolina 27706

D. G. Rickel
Northrop Services, Inc., Research Triangle Park, North Carolina 27707
and Triangle Universities Nuclear Laboratory, Durham, North Carolina 27706

R. W. Zurmühle
University of Pennsylvania, Philadelphia, Pennsylvania 19174
(Received 9 November 1977)

Linear polarizations of γ rays from the $11.86 \rightarrow 8.12 \rightarrow 4.12$ MeV decay in ^{24}Mg have been studied with a NaI polarimeter. The 11.86 MeV level was populated via the $^{12}C(^{16}O,\alpha\gamma)^{24}Mg$ reaction. The results are consistent with $J^\pi = 8^+$ for the 11.86 MeV level and in agreement with earlier work, rule against a 6^+ assignment with 85% confidence.

[NUCLEAR REACTIONS $^{12}C(^{16}O, \alpha\gamma)$, $E=42$ MeV; measured linear polarization, $\alpha\gamma$ coincidence. Deduced J^π.]

The properties of the 11.86 MeV state in ^{24}Mg have been the subject of much interest since Branford, Spooner, and Wright[1] reported in 1973 a possible assignment of $J^\pi = 8^+$ for this level. The existence of an 8^+ level at this energy was surprising since it was 1.35 MeV below the known ground-state rotational band 8^+ level at 13.21 MeV.[2] Such ground-state rotational band levels are normally expected to be the lowest levels of a particular J^π in any nucleus.

The 8^+ assignment suggested for the 11.86 MeV level followed from an angular correlation study of the reaction $^{12}C(^{16}O, \alpha\gamma)^{24}Mg$. The 11.86 MeV level is strongly populated in this reaction,[3] and Branford *et al.*[1] found that it decayed exclusively to the 6^+ member to the ground-state rotational band at 8.12 MeV. Their angular correlation and lifetime data were consistent with two possibilities: (a) $8^+ \rightarrow 6^+$, pure $E2$ transition or (b) $6^+ \rightarrow 6^+$, mixed $M1E2$ transition with $\delta = -0.66 \pm 0.06$. The absence of a decay of the 4^+ ground-state rotational level at 4.12 MeV argued against the 6^+ assignment and 8^+ for the 11.86 MeV level was preferred. The decay scheme of Fig. 1 was subsequently confirmed by Fifield, Zurmühle, and Balamuth.[4] These authors also showed that the 11.86 MeV level had negligible α particle decay width to states in ^{20}Ne.

While the 8^+ assignment thus seemed quite reasonable, it appeared desirable to attempt to exclude the 6^+ possibility on other grounds. We have accordingly performed a measurement of the linear polarization of the $11.86 \rightarrow 8.12$ MeV decay under experimental conditions similar to those employed by Branford *et al.*[1] Our results are consistent with $J^\pi = 8^+$ for the 11.86 MeV level and rule against the 6^+ possibility with 85% confidence.

Our experiment consists of a coincidence measurement of the linear polarization of the γ ray from the decay of the 11.86 MeV state, in which the α particles from the $^{12}C(^{16}O, \alpha)^{24}Mg$ reaction are detected at 0°. In this collinear geometry only the $m=0$ substates of the 11.86 MeV level are populated, and the linear polarization of the $11.86 \rightarrow 8.12$ γ ray depends only on the J^π values of the states involved and the multipole mixing ratio of the transition.

The target consisted of a 50 $\mu g/cm^2$ enriched ^{12}C foil. A 25 μm thick Ni foil positioned behind

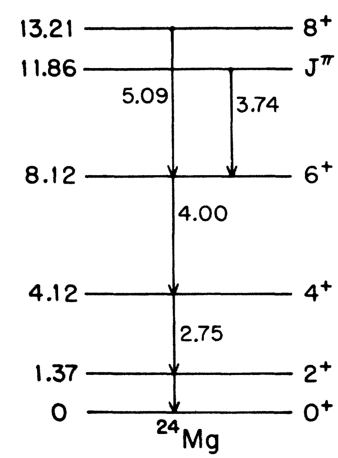

FIG. 1. Partial decay scheme of ^{24}Mg.

the target was used to stop the 42 MeV $^{16}O^{5+}$ beam from the TUNL FN tandem van de Graaff accelerator. The α particles were observed in a 2 mm detector with an acceptance angle of 5° and the γ rays were observed at 90° with respect to the beam direction in a NaI Compton polarimeter positioned 21 cm from the target.

The polarimeter consisted of a 10.2 cm diameter, 21.0 cm long NaI crystal surrounded by an NaI annulus of inner diameter 11.0 cm, outer diameter 24.1 cm, and length 24.5 cm. The annulus was split into four optically isolated pieces and was shielded from the direct flux of γ rays from the target by 5.1 cm of lead. The linear polarization of a γ ray incident on the center crystal was found by measuring the asymmetry in the counting rates for Compton scattering events in the vertical versus horizontal planes.[5]

The sensitivity of the polarimeter was calibrated on the ^{12}C 4.43 MeV γ rays produced in the $^{12}C(p,p')^{12}C^*$ reaction at $E_p = 5.0$ MeV. The 4.43 MeV γ rays are known to be strongly polarized at this bombarding energy.[6] The expected polarization was calculated directly from the measured angular distribution and was $P = 0.88 \pm 0.02$. Lower and upper thresholds of 0.7 and 2.0 MeV, respectively, were placed on the side-detector signals of the polarimeter in order to restrict the range of acceptable Compton scattering angles. On the basis of the measured polarization asymmetry, and a number of system anisotropy checks with a Pu-Be γ ray source, we determined a polarization sensitivity of 5% for our polarimeter at 4.4 MeV. The sensitivities at 3.75 and 4 MeV were obtained by normalizing the point scattering geometry values to this experimentally determined value.

Figure 2 shows the γ ray spectra obtained in coincidence with α particles leading to the 11.86 MeV level in ^{24}Mg. The top spectrum corresponds to events in the center detector which were not associated with valid events in the side detectors. Below it are the spectra corresponding to valid events in the side detectors. The middle spectra is the sum spectrum for center-plus-vertical detector events and the lower spectrum is the sum spectrum for center-plus-horizontal detector events. The 11.86 → 8.12 MeV γ ray peak is not completely resolved from the subsequent 8.12 → 4.12 MeV decay and we therefore analyze the unresolved cascade 11.86 → 4.12 as one sum.

For an $8^+ \to 6^+$ transition unresolved from the

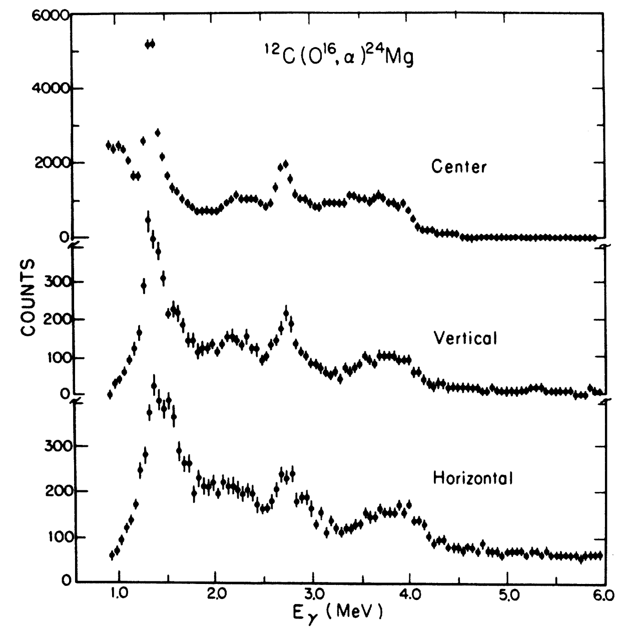

FIG. 2. Spectra of γ rays in coincidence with α particles populating the ^{24}Mg 11.86 MeV level. The upper spectrum corresponds to pulses in the center crystal in anticoincidence with the annulus. The middle and lower spectra correspond to center crystal pulses summed with coincident pulses from vertical and horizontal sections of the annulus, respectively.

subsequent $6^+ \to 4^+$ transition, the expected polarization is 73%. For the $6^+ \to 6^+ \to 4^+$ possibility the expected polarization is $43 \pm 5\%$. The error here is associated with the range of mixing ratios allowed by the results of Ref. 1. Combining the polarization sensitivity obtained from the $^{12}C(p,p)$ experiment with our measured asymmetry gives a polarization of > 75% for the unresolved cascade (> 30% to two standard deviations). The errors are large, but rule against the 6^+ assignment with ~85% confidence.

Our results provide further evidence that the 11.86 MeV level has $J^\pi = 8^+$ and is indeed an 8^+ state lying below the 8^+ member of the $K = 0$ rotational band. Although initially assumed to be made up of configurations outside the s-d shell,[1] the 11.86 MeV level is probably the low-lying 8^+ state recently predicted by Watt, Kelvin, and Whitehead[7] to have predominantly the configuration $(d_{5/2})^8$. Such a state represents an almost pure condensation into the $d_{5/2}$ shell. The location and properties of analogous structures in neighboring nuclei would be of particular interest.

*Work supported in part by U.S. ERDA.

[1]D. Branford, M. J. Spooner, and I. F. Wright, Particles and Nuclei 4, 231 (1972).
[2]R. W. Ollerhead, J. A. Kuehner, R. J. E. Levesque, and E. W. Blackmore, Can. J. Phys. 46, 1381 (1968).
[3]J. L. C. Ford, J. Gomez del Campo, R. L. Robinson, P. W. Stelson, and S. T. Thornton, Nucl. Phys. A226, 189 (1974).
[4]L. K. Fifield, R. W. Zurmühle, and D. P. Balamuth, Phys. Rev. C 8, 2217 (1973).
[5]J. R. Williams, R. O. Nelson, C. R. Gould, and D. R. Tilley, Phys. Rev. C 11, 1111 (1975).
[6]R. Bass, S. Brinkman, C. van Charzewski, and H. Hanle, Nucl. Instrum. Methods 107, 32 (1972).
[7]A. Watt, D. Kelvin, and R. R. Whitehead, Phys. Lett. 63B, 385 (1976).