THE

PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, Vol. 136, No. 4B 23 NOVEMBER 1964

Spin and Parity of C^{15}†

D. E. ALBURGER, C. CHASMAN, K. W. JONES, AND R. A. RISTINEN
Brookhaven National Laboratory, Upton, New York

(Received 9 July 1964)

The energy of the 5.3-MeV gamma ray produced in the beta decay of C^{15} was measured with a lithium-drifted germanium detector. An energy of 5.301 ± 0.005 MeV was found. This value is in agreement with the value of 5.299 ± 0.006 MeV found by Alburger, Gallmann, and Wilkinson and verifies the basis of their arguments for the assignment of $\frac{1}{2}^+$ for the spin and parity of the ground state of C^{15}. The techniques used in the gamma-ray energy determination are discussed in detail.

INTRODUCTION

A 5.3-MeV gamma ray is emitted in the beta decay of C^{15}. One accurate measurement of its energy has been reported,[1] a result which was obtained by means of a magnetic pair spectrometer operated at a resolution of 1.5%. Combining this result with N^{15} level energies from reaction Q values[2] shows that the inner beta-ray group in C^{15} decay leads to the upper member of the 5.275- to 5.299-MeV doublet in N^{15}. This result, when considered with other experimental evidence, makes it most probable that both the N^{15} 5.299-MeV level and the ground state of C^{15} have spin $\frac{1}{2}$ and even parity. Because of the effective gamma-ray energy resolution of 80 keV in the pair spectrometer measurement, the determination of the transition energy to an accuracy of ± 6 keV was difficult, but it was considered firm. The recent introduction of lithium-drifted germanium gamma-ray detectors has provided a device with a linewidth many times smaller than that of the magnetic pair spectrometer. It was felt that a remeasurement of the gamma-ray energy with this device would be worthwhile to confirm the energy value found by Alburger *et al.*,[1] and hence to confirm the basis of their arguments for the assignment of $\frac{1}{2}^+$ for the spin and parity of the ground state of C^{15}.

EXPERIMENTAL PROCEDURES

C^{15} was produced by the $C^{14}(d,p)C^{15}$ reaction at $E_d = 3.2$ MeV using an 80% enriched C^{14} target 0.7 mg/cm^2 thick. This was cemented onto one side of a tantalum holder. A thick TiN^{15} target was deposited on the other side. The target was mounted so that either side could be bombarded by the beam. A brass absorber with a thickness of $\frac{1}{4}$ in. was placed between the target and the germanium detector to absorb high-energy beta rays. A beam chopper was placed in the path of the beam upstream from the target. The procedures for forming and counting activities with the chopper and timing system have been described previously.[3]

The lithium-drifted germanium detector was 2.7 cm^2 in area and had a sensitive depth of 2.4 mm. It was fabricated at this laboratory by a method similar to that of Tavendale and Ewan,[4] but a constant power supply was used for drifting. At liquid-nitrogen temperature, the resolution for the 662-keV gamma ray in Cs^{137} was 6.5 keV full width at half-maximum height with 200-V detector bias. For the double-escape peak in the 6.132-MeV transition in O^{16}, the resolution was 13 keV full width at half-maximum height with the low-energy side of the line about twice as broad as the high-energy side. For this line the energy resolution is about 0.25%.

Figure 1 shows a composite of the gamma-ray spectra from the decay of C^{15} and the N^{16} calibration source obtained in one of three final sets of data. All three of

---

† Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] D. E. Alburger, A. Gallmann, and D. H. Wilkinson, Phys. Rev. **116**, 939 (1959).

[2] F. Ajzenberg-Selove and T. Lauritsen, Technical Report (unpublished).

[3] D. E. Alburger, Phys. Rev. **131**, 1624 (1963).

[4] A. J. Tavendale and G. T. Ewan, Nucl. Instr. Methods **25**, 185 (1963); G. T. Ewan and A. J. Tavendale, *ibid.* **26**, 183 (1964).

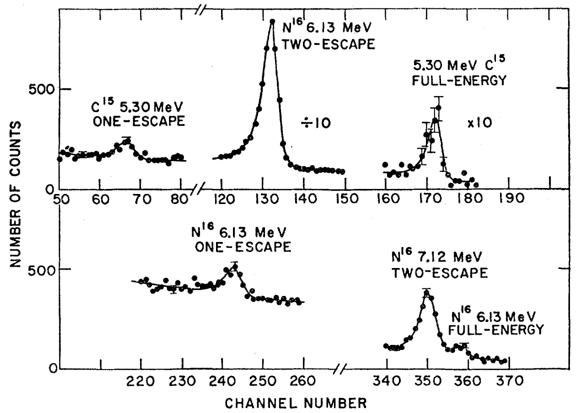

FIG. 1. Composite drawing showing the pulse-height spectra obtained for the N^{16} calibration gamma rays and the 5.3-MeV C^{15} gamma ray. The full-energy, one- and two-escape peaks are seen for the 6.13-MeV N^{16} gamma ray and the two-escape peak of the 7.12-MeV N^{16} gamma ray. The energy calibration was based on the two-escape peaks only. The full-energy and one-escape peaks of the 5.3-MeV C^{15} gamma ray are shown. The two-escape peak was eliminated by the post-amplifier bias. The energy measurements of the C^{15} gamma ray were made relative to the 6.13-MeV calibration line. The energy calibration is 4.48 keV per channel.

the peaks associated with pair production by the 6.132-MeV gamma ray are observed, the full-energy-loss peak lying just above the 7.116-MeV two-escape peak. In the case of C^{15}, only the full-energy-loss and one-escape peaks of the 5.3-MeV gamma-ray appear in the figure. The two-escape line is below the amplifier bias level. Although comparatively much stronger, this line was considered to be too remote from the N^{16} calibration peaks to be used for the energy determination. All lines observed are Doppler shifted by about 1 keV. The shift is nearly the same for all lines considered here, and consequently the uncertainties introduced are much smaller than the uncertainties which are discussed later.

The procedures used in determining the energy of the 5.3-MeV gamma ray will be described in detail in order to point out the capabilities of the Li-Ge gamma detectors in the precise measurement of gamma-ray energies, and to show the limitations on the precision.

For each run, the gain and stability of the charge-sensitive preamplifier, post-bias amplifier, and multichannel pulse-height analyzer were determined with a precision pulser. The pulser voltage, with the chopping relay turned off, was measured with a Leeds and Northrup potentiometer. The channel corresponding to the centroid of the pulser distribution for each pulser setting was then found, and a plot was made of the equivalent potentiometer value against the channel number. Points were spaced closely enough together to make differential nonlinearities negligible. The stability of the system was also checked by measuring the position and width of the pulser line with the beam on and off the targets. No gain shifts or degradation of the resolution by the strong flux of prompt neutrons and gamma rays occurring during the activation of the target were observed.

Calibration gamma rays were observed before and after each run on the C^{15} gamma ray. Since there are no convenient sources of gamma rays from naturally radioactive sources, it was decided to use the 6.13- and 7.12-MeV gamma rays produced in the beta decay of N^{16}. The N^{16} was produced with the N^{15}(d,p)N^{16} reaction. The energies of these gammas were taken as a weighted mean of the proper O^{16} level energies quoted by Ajzenberg-Selove and Lauritsen[2] and the recent values quoted by Browne and Michael.[5] The energies are 6.132±0.003 and 7.116±0.003 MeV. We were able to conveniently observe the full-energy and the one- and two-escape peaks for the 6.13-MeV line, and the two-escape peak for the 7.12-MeV line. In the present experiment the peak position was taken to be that point where the extrapolated sides of the peak intersected. It was felt that this would most closely approximate the method used in the pulser calibration. The use of the centroid is influenced by the asymmetric line shape observed, but the use of an extrapolated cutoff on the high-energy side would be difficult to correlate with the pulser line shape.

Once the channel numbers for the calibration lines were found, the values of the corresponding potentiometer readings were determined from the pulser calibration graph. A plot was then made of energy versus potentiometer reading. It was found that the points could be fitted very accurately with a straight line and that the straight line passed through the origin of the curve to within the accuracy of our experiment. The average intercept was 16±32 keV. The excellent linearity of the device is somewhat surprising, since a large fraction of the electrons produced in the counter by high-energy gamma rays is certainly not stopped in the counter.

The 5.3-MeV C^{15} gamma ray was observed between the two N^{16} calibration runs. The full-energy and one-

TABLE I. Results of the energy measurements. The column headed Δ is the energy of the C^{15} gamma-ray full-energy peak less the energy of the 6.132-MeV reference gamma-ray two-escape peak at 5.110 MeV. The column headed δ is the energy of the reference peak less the energy of the C^{15} gamma-ray one-escape peak.

	Δ	δ
Run 1	195.4±3.5 keV	325.2±3.4 keV
Run 2	191.8±3.5 keV	320.3±3.4 keV
Run 3	192.4±3.5 keV	320.5±3.4 keV
Average	193.3±2.0 keV	322.0±2.0 keV
Energy of C^{15} gamma ray	5.3033±0.0020 MeV	5.2990±0.0020 MeV
Average energy of C^{15} gamma ray	5.3012±0.0014 MeV	
Uncertainty in energy of 6.132-MeV two-escape reference peak	±0.0033 MeV	
Final energy and total uncertainty in energy of C^{15} gamma ray	5.301±0.005 MeV	

---

[5] C. P. Browne and I. Michael, Phys. Rev. **134**, B133 (1964).

TABLE II. Summary of errors.

Location of calibration peaks	±0.5 channels or ±0.0013 V on potentiometer
Difference between potentiometer values for the two calibration peaks	±0.35% of the difference
Energy separation of calibration peaks	±0.43% of the difference
Energy calibration in MeV/V	±0.56%
Location of C^{15} gamma-ray full-energy and one-escape peaks	±0.5 channels or ±0.0013 V on potentiometer
Difference between potentiometer values for C^{15} full energy and the 5.110-MeV reference peak, and for C^{15} one-escape and the reference peak	±1.81% of the difference (full energy) ±1.08% of the difference (one escape)
Difference in energy between C^{15} peaks and reference peak	±3.5-keV full energy ±3.4-keV one escape
Uncertainty in average of 6 measurements	±1.4 keV
Uncertainty in energy of reference line	±3.3 keV
Final uncertainty in energy of C^{15} gamma ray	±4.7 keV

escape peaks were close to the two-escape peak of the 6.13-MeV calibration line and were used for the energy determination. The peak positions were found in the same way as for the calibration peak. The channel numbers were then used to find the corresponding values of potentiometer reading. The calibration curve gives the relationship between the potentiometer reading and keV. Hence, the difference in energy between the C^{15} gamma ray and the calibration line can be found easily and accurately. Table I gives a summary of the energy-difference measurements made in the present experiment and shows the calculation of the final gamma-ray energy. Table II gives a detailed summary of our estimates of error. The final average value obtained for the C^{15} gamma-ray energy is 5.301 ±0.005 MeV. This result is to be compared with the energies of 5.275±0.006 and 5.299±0.004 MeV listed for the N^{15} doublet levels in the most recent complilation.[2]

We note that the accuracy of energy determinations with the Li-Ge counter seems to be seriously limited by the accuracy of the available calibration lines. It appears that it will be possible by further work to measure such lines, and to use Li-Ge counters for gamma-ray energy measurements up to several MeV with uncertainties in the energy of less than 1 keV.[6]

DISCUSSION

Our results are in excellent agreement with the results of Alburger *et al.*,[1] and confirm the basis for their arguments for the assignment of $\frac{1}{2}^+$ for the ground-state spin and parity of C^{15}.

The problem of the spin and parity of C^{15} can also be attacked by a measurement of the stripping distribution for $C^{14}(d,p_0)C^{15}$. Moore and McGruer[7] have reported a value of $l=0$ at a deuteron energy of 14.8 MeV, which also gives a value of $\frac{1}{2}^+$ for the ground state of C^{15}. Wilkinson[8] has pointed out, however, that measurement of l values for low-Q reactions at high bombarding energies is difficult because of the small differences in the angular distributions for different l values. For this reason the result of Moore and McGruer is consistent with $l=0$, but does not establish it. Pullen and Wilkinson[9] have recently carried out further measurements on the same reaction at lower energies where the differences between l values are larger, and they conclusively find $l=0$.

The results of all measurements on the spin and parity of C^{15} are in agreement, and it is now well established that the spin parity of the C^{15} ground state is $\frac{1}{2}^+$.

---

[6] Work on the precise measurement of suitable calibration lines is now in progress at Brookhaven.

[7] W. E. Moore and J. N. McGruer, Bull. Am. Phys. Soc. 4, 17 (1959).

[8] D. H. Wilkinson, *Proceedings of the International Conference on Nuclear Structure* (University of Toronto Press, Toronto, Canada, 1960), p. 41.

[9] D. H. Wilkinson (private communication).