Beta-Ray Spectrum of N^{16}†

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The beta-ray spectrum of 7.38-second N^{16} has been investigated with a 180-degree magnetic spectrometer. The radioactive nuclei were produced by 1.5-Mev deuterons through the reaction $N^{15}(d,p)N^{16}$, using targets of lead nitrate enriched to 64% in N^{15}. Of the four known beta-ray groups, two with end-point energies 10.40 ± 0.05 Mev and 4.39 ± 0.07 Mev are satisfactorily resolved. The intensity of the 10.40-Mev group relative to that of the remainder of the transitions is in the ratio of 28:72, leading to $\log f_0 t=6.67$. The 10.40-Mev group is shown to proceed as a first-forbidden $\Delta J=2$(yes) transition, and thus the ground state of N^{16} may be uniquely designated as a 2^- level.

INTRODUCTION

THE beta decay of N^{16} has been investigated in the past primarily through the study of the gamma rays[1] which are emitted in the de-excitation of the states of O^{16}. Before the present investigation was begun, the only detailed beta-ray work was an analysis of coincidence absorption data[2] which indicated that three beta-ray groups were present, arising from transitions to the ground state of O^{16}, and to excited states at 6.14 and 7.12 Mev, with relative intensities in the ratio 20:40:40. A recent magnetic spectrometer measurement has been reported[3]; a comparison of this spectrum with the present results will be made in the Discussion section.

Careful measurements of the relative gamma-ray intensities, together with particle reaction data, have led to the conclusion that the ground state of N^{16} is probably a 2^- (spin 2, odd parity) level, and that the relative intensities of the 4.4- and 3.3-Mev beta-ray groups should be in the ratio of approximately 14.5:1. The results of a gamma-ray study of the low-lying levels of N^{16} are consistent with an assignment of 2^- to the ground state.[4] The pertinent portion of the energy level diagram of O^{16} is included as an insert in Fig. 1. The *ft*-values allow the interpretation that the ground state transition is first-forbidden and the other two allowed.

The beta decay of N^{16} has been treated extensively in intermediate-coupling theory by Elliott and Flowers,[5] who have shown that transition matrix elements calculated on the basis of Rosenfeld forces with fixed spin-orbit splittings give an anomalously small transition probability for the decay to the 1^- level in O^{16}. A suggestion that N^{16} decay might proceed from an isomeric doublet of 0^- and 3^- states instead of a single 2^- state, with predicted half lives of approximately 5 and 20 seconds, has been examined by Toppel[6] who found only a single half-life present to within an accuracy of 7%. Identification of the N^{16} ground state as a spin 2, odd-parity level would seem to indicate strongly the necessity of a two-body vector spin-orbit force[5] to account for the strength of the transition to the 1^- state of O^{16}.

It is to be noted that the ground state transition, if from a 2^- level to a 0^+ level, will be of the first-forbidden $\Delta J=2$ type, with a "unique" nonallowed spectral shape.[7] On the other hand a transition from the suggested 0^- level, at this low value of Z and with a high end-point energy, will also produce a distinctive nonallowed spectral shape. The present investigation was initiated as an attempt to observe the spectrum directly and thus determine definitely the spin and parity of the ground state of N^{16}.

EXPERIMENTAL PROCEDURE

The reaction $N^{15}(d,p)$ N^{16} was used to produce the 7.38-second radioactive N^{16}. A deuteron beam of about

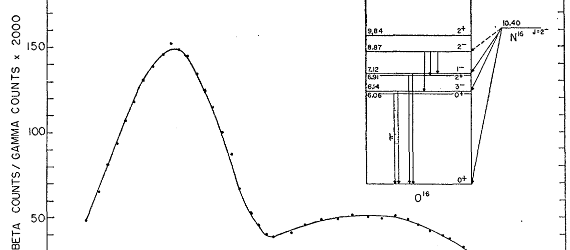

Fig. 1. Spectrum of beta rays from N^{16} decay. The probable error is approximately represented by twice the size of the points. The insert indicates the pertinent known energy levels of O^{16}.

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[1] H. S. Sommers and R. Sherr, Phys. Rev. **69**, 21 (1946); Millar, Cameron, and Glicksman, Phys. Rev. **77**, 742 (1950); Millar, Bartholomew, and Kinsey, Phys. Rev. **81**, 150 (1951); Boehm, Peaslee, and Perez-Mendez, Phys. Rev. **90**, 1119 (1953); Wilkinson, Toppel, and Alburger, Phys. Rev. **101**, 673 (1956).

[2] Bleuler, Scherrer, Walter, and Zünti, Helv. Phys. Acta **20**, 96 (1947).

[3] P. W. Morton and H. W. Lewis, Bull. Am. Phys. Soc. Ser. II, **2**, 286 (1957).

[4] D. H. Wilkinson, Phys. Rev. **105**, 686 (1957).

[5] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London) **A242**, 57 (1957).

[6] B. J. Toppel, Phys. Rev. **103**, 141 (1956).

[7] E. Konopinski, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Amsterdam, 1955), Chap. 10, p. 292 ff.; and C. S. Wu, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Amsterdam, 1955), Chap. 11, p. 315 ff.

3 to 4 microamperes at an energy of 1.5 Mev was used to irradiate targets of lead nitrate enriched in N^{15} to 64%.[8] The target was bombarded for about four half-lives in a weak-field region near a 180-degree shaped-field magnetic spectrometer with a basic radius of 12 cm,[9] then moved on a carriage within the vacuum system to the spectrometer source position. A thin-window Geiger counter was used as the detector. A counting period of 18 seconds was used, with three or four irradiations being carried out at each spectrometer setting. Each irradiation was normalized by monitoring the intensity of the 6.14- and 7.12-Mev gamma rays which accompany the beta decay. In addition, the source intensity after each irradiation was measured with a "leaky integrator."

About 15 000 gamma-ray counts and from 200 to 1000 beta-ray counts were recorded in each counting cycle. Before counting, the electrostatic accelerator voltage was lowered in order to reduce the background count. The background was determined periodically after the radioactivity had been allowed to decay; a small correction for gamma rays reaching the Geiger counter was determined by recording the count with a slit before the counter completely closed to stop the beta rays.

In making the targets, an aqueous solution of lead nitrate was placed on copper foils varying in thickness from 2.5 mg/cm^2 to 15 mg/cm^2 and allowed to crystallize; relatively thick layers of 25 to 48 mg/cm^2 (average) were needed to give an adequate radioactive intensity. As such a layer was thicker near the edges, the central area struck by the collimated beam was somewhat thinner than the average value.

The magnetic field was measured by a null-balance method with one coil rotating in the spectrometer field and one rotating in a Helmholtz coil field.[10]

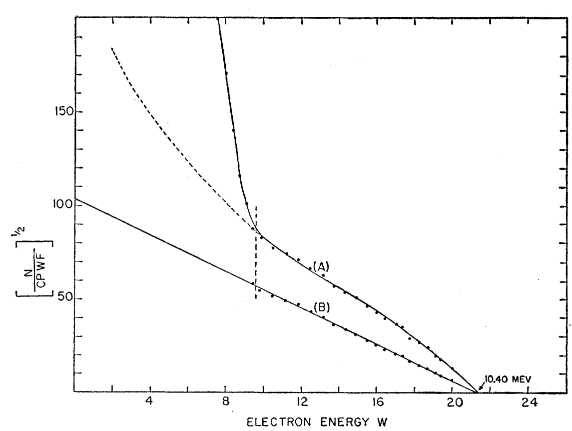

FIG. 2. Fermi-Kurie plot of the highest-energy group. Energy is in relativistic units (units of mc^2). (A) has $C=1$; (B) has $C_1^{(2)}=p^2+q^2$. In (A) the dashed line is a reconstruction of the highest energy group.

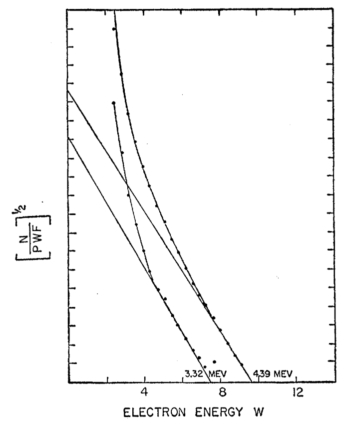

FIG. 3. Fermi-Kurie plots for the two lower-energy groups. Energy is in relativistic units (units of mc^2). See reference 11.

RESULTS

A typical spectrum is shown in Fig. 1; the Fermi-Kurie plots shown in Fig. 2 include in (A) an "allowed" correction factor $C_0=1$ and in (B) the first-forbidden "unique" factor $C_1^{(2)} \propto p^2+q^2$, where p and q are the electron and neutrino momenta, respectively.[7] The straight line of (B) gives an end-point energy value for the highest-energy group of 10.40 ± 0.05 Mev. Extrapolation of the straight line to momenta values below the point corresponding to the transition to the second excited state of O^{16} permits the plotting of the latter in the Fermi-Kurie plot of Fig. 3; the end-point energy of this group is determined to be 4.39 ± 0.07 Mev. The third known beta-ray group is discussed below[11]; a

[8] Obtained from Eastman Kodak Company, Rochester, New York.

[9] H. I. Israel, Ph.D. dissertation, Department of Physics, Indiana University, 1952 (unpublished); C. H. Pruett and R. G. Wilkinson, Phys. Rev. **96**, 1340 (1954).

[10] L. M. Langer and F. R. Scott, Rev. Sci. Instr. **21**, 522 (1950).

[11] A plausible argument can be made for the further separation of the third beta-ray group as shown in Fig. 3, where the subtraction of the 4.39-Mev group leaves another with end point 3.32 ±0.05 Mev. In order to check the possible spectrum distortion caused by the thick targets, the F^{20} spectrum with a 40-mg/cm^2 source of NaF on an 8-mg/cm^2 copper backing was obtained. This spectrum was compared with that from a N^{16} source of 25 mg/cm^2 of $Pb(NO_3)_2$ on 2.5 mg/cm^2 of copper backing. The source thicknesses were determined by weighing a measured area of target. The lead nitrate targets always crystallized in a "concave downward" manner, and since the central area struck by the collimated beam was thinner than the area measured and weighed, the surface densities given should be regarded as upper limits. A rough estimate of the thickness of the area actually in the beam is $\frac{1}{3}$ of the average value, or 8 mg/cm^2. The fluorine target crystallized with a uniform surface density. Assuming the energy loss of the electrons to be approximately independent of energy in the range 1–10 Mev, the energy loss in these targets should be approximately proportional to the thickness. The F^{20} Fermi-Kurie plot (end-point energy, 5.4 Mev) was found to deviate upward from a straight line at 1.7 Mev. One would expect an equally thick target of N^{16} to give a deviation at about 3.5 Mev. For a source thickness of about $\frac{1}{5}$ that of the F^{20} source and a backing of about $\frac{1}{3}$, one might expect a deviation at about 1 Mev if only scattering in the sources is considered. The N^{16} deviation occurs in Fig. 3 at about 1.74 Mev. Using the results of the analysis, the relative intensities of the three groups are in the ratio of 28:54:18, in the order of decreasing energy. The ratio of the intensity of the 4.39-Mev group to the 3.32-Mev group is 3.0:1, is reasonable agreement with Morton and Lewis,[3] who report 2.6:1. The gamma-ray work[1] indicates that the ratio should be about 14.5:1. It may well be that this very large discrepancy is a result of scattering effects in the present

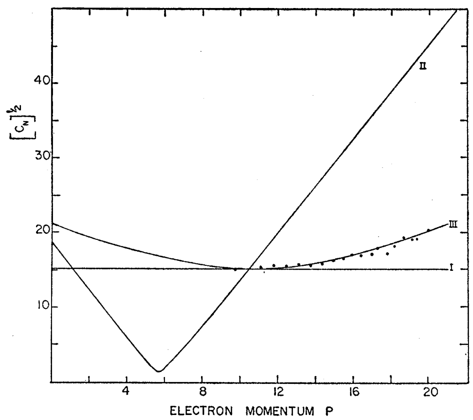

FIG. 4. The square roots of the "shape factors" are plotted *vs* the momentum. Momentum is in relativistic units (units of *mc*). Curve I represents the shape factor for an allowed spectrum; Curve II, for a first-forbidden spectrum with $\Delta J=0$; Curve III, for a first-forbidden spectrum with $\Delta J=2$. The scales are adjusted to give an intersection point at $p=10.5$. The circles represent the empirical correction factors.

fourth beta-ray group of end-point energy 1.53 Mev and relative intensity 1.1% has been established on the basis of gamma-ray spectra,[12] but such a group would not be resolvable in the present work. The source thicknesses used cannot by any means be considered thin; however, a variation of the thickness by a factor of two did not cause a difference in end-point energies nor did it affect the shape of the Fermi-Kurie plots.

The intensity of the 10.40-Mev group relative to that of the remainder of the transitions was found to be in the ratio of 28:72. The corresponding log f_0t value is 6.67 and the log f_1t value is 8.0, using Feenberg and Trigg's values for f.[13]

The half-life of the beta activity was determined early in the work by simultaneously photographing a scaler register and a clock, for points on the spectrum corresponding to 2.5- and 7.0-Mev beta rays. At these points the half-lives were the same at the value 7.4±0.2 sec.

data. When this point was investigated by varying source thickness by a factor of two, no change was seen in the intensity ratios or end-point values, as previously noted.

[12] Wilkinson, Toppel, and Alburger, Phys. Rev. **101**, 673 (1956).

DISCUSSION

The forbidden-shape correction factor may be obtained experimentally by determining the factor by which the points on the Fermi-Kurie plot must be multiplied to transform the curve to a straight line. This result is displayed in Fig. 4; there are also shown the theoretical curves for an allowed transition and for the first-forbidden case with spin changes of 0 and 2. In computing the $\Delta J=0$ curve,[14] the value of the parameter z_3 is taken as zero; a choice of $z_3=1$ merely shifts the point of minimum value. The best agreement is reached with the $\Delta J=2$ curve, and the ground state of N^{16} is therefore to be designated as definitely of spin 2 and odd parity.

The theoretically deduced value[5] of log $f_0t=6.5$ for the 10.40-Mev beta-ray group stands in even better agreement with experiment than before when compared with the present value of 6.67. Upon using the gamma-ray data,[6,12] the intensities of the 4.39-, 3.32-, and 1.53-Mev groups are very nearly in the ratio of 66:5:1, with log f_0t values of 4.5, 5.2, and 4.3, in the same order.

ACKNOWLEDGMENTS

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[13] E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).

[14] H. M. Mahmoud and E. J. Konopinski, Phys. Rev. **88**, 1266 (1952).