Beta Decay of N^{17} to Bound States in O^{17}†

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The beta decay of N^{17} to bound states of O^{17} has been investigated by observation of the beta-ray and gamma-ray spectra with scintillation spectrometers. A gas target of N_2^{15} was bombarded with 2-MeV tritons from an electrostatic generator to yield 4.2-sec N^{17} by the reaction $N^{15}(t,p)N^{17}$. Gamma rays of 0.87 and 2.19 MeV were observed, corresponding to beta transitions to the 0.87- and 3.06-MeV levels in O^{17}. Analysis of the beta-ray spectrum indicated the presence of a beta-decay branch to the ground state of O^{17}. The branching fractions and log*ft* values for these three beta transitions are: O^{17} g.s.—1.6%, log*ft*=7.3; 0.87-MeV level—2.6%, log*ft*=6.8; and 3.06-MeV level—0.5%, log*ft*=6.9. Uncertainties in these log*ft* values are about ±0.1. The large log*ft* value for the allowed transition to the 3.06-MeV state lends support to previous theoretical calculations which indicate that this low-lying negative parity state in O^{17} consists of a three-particle excitation of the O^{16} core.

I. INTRODUCTION

NITROGEN-17 is known to be a delayed neutron emitter.[1] Its beta decay proceeds predominantly to states in O^{17} which are at excitation energies above the threshold for breakup into O^{16} plus a neutron and, since neutron emission is more probable than gamma-ray emission, the decay process is primarily $N^{17}(\beta^-)O^{17*}(n)O^{16}$. Figure 1 illustrates the decay scheme of N^{17}.

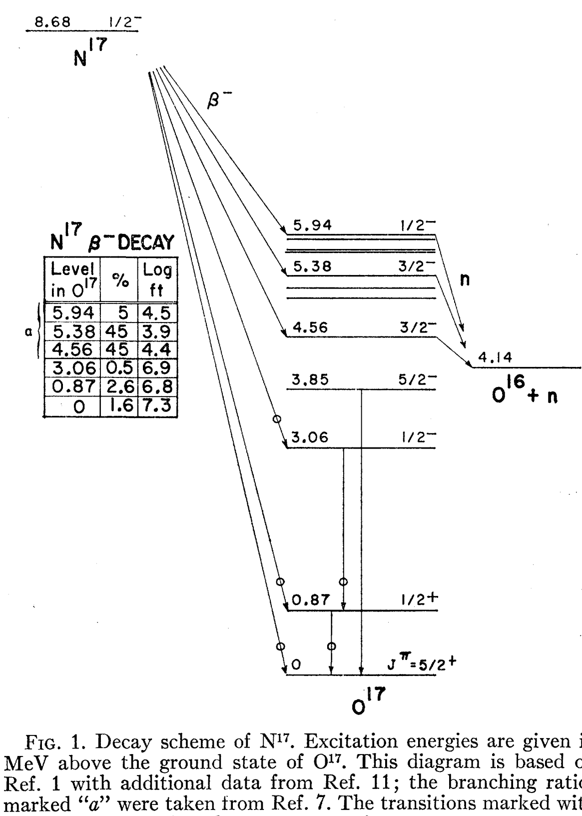

FIG. 1. Decay scheme of N^{17}. Excitation energies are given in MeV above the ground state of O^{17}. This diagram is based on Ref. 1 with additional data from Ref. 11; the branching ratios marked "*a*" were taken from Ref. 7. The transitions marked with circles are reported in the present experiment.

This distinctive delayed neutron emission was originally observed following the bombardment of various light elements by high energy deuterons. Experiments by N. Knable *et al.*[2] and L. W. Alvarez[3] identified the activity as N^{17}, and the half-life and beta-ray and neutron spectra were investigated.[2–4] Determinations of the half-life of the decay, by observation of the delayed neutrons, yielded values between 4.14 and 4.20 sec.[1,5]

The beta spectrum of N^{17} was measured by Alvarez[3] in coincidence with neutron emission. He obtained an end-point energy of 3.7±0.2 MeV for these beta particles. Possible emission of higher energy betas to particle-stable states of O^{17} could not be observed because of background problems.

The neutron spectrum observed by early investigators[3,4] was a broad distribution centered near 1 MeV. More recently, G. J. Perlow *et al.*[6] studied the neutron spectrum from the decay of N^{17} with a proportional-counter recoil spectrometer and found two neutron groups corresponding to beta decay to the known levels in O^{17} at 4.56 MeV (3/2−) and 5.38 MeV (3/2−). J. Gilat, G. D. O'Kelley, and E. Eichler[7] have employed a neutron time of flight system, with the N^{17} beta decay furnishing the time reference, and observed three neutron groups from O^{17*}. Two of these correspond to the groups observed by Perlow *et al.* while the weak third group corresponds to beta emission to the level in O^{17} at 5.94 MeV (1/2−).

These observations of beta-decay branches from N^{17} to levels of spin and parity 3/2− and 1/2− in O^{17} are

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] F. Ajzenberg-Selove and T. Lauritsen, *Energy Levels of Nuclei: A=5 to A=257, Landolt-Börnstein Tables*, edited by K. H. Hellwege (Springer-Verlag, Berlin, 1961), New Series, Group 1: Nuclear Physics and Technology, Vol. I; and F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **11**, 1 (1959).

[2] N. Knable, E. O. Lawrence, C. E. Leith, B. J. Moyer, and R. L. Thornton, Phys. Rev. **74**, 1217A (1948).
[3] L. W. Alvarez, Phys. Rev. **75**, 1127 (1949).
[4] E. Hayward, Phys. Rev. **75**, 917 (1949).
[5] S. Hinds, R. Middleton, A. E. Litherland, and D. J. Pullen, Phys. Rev. Letters **6**, 113 (1961).
[6] G. J. Perlow, W. J. Ramler, A. F. Stehney, and J. L. Yntema, Phys. Rev. **122**, 899 (1961).
[7] J. Gilat, G. D. O'Kelley, and E. Eichler, Bull. Am. Phys. Soc. **8**, 320 (1963); and Annual Report, Chemistry Division, Oak Ridge National Laboratory, 20 June 1963.

consistent with the value of 1/2− expected for the N^{17} ground-state spin and parity on the basis of the shell model. Nitrogen-17 with seven protons and ten neutrons has one proton hole, presumably $p_{1/2}$, below the eight-particle shell at O^{16}, as well as two neutrons above this shell.

The experimental situation concerning the beta decay of N^{17} at the inception of the present experiment was therefore that the half-life and the predominant decay to neutron emitting states in O^{17} had been studied in some detail but that nothing was known about beta decay to lower excited states in O^{17}. One difficulty in investigating the possibility of other beta-decay branches was that of producing N^{17} relatively uncontaminated by other activities. Since 7.4-sec N^{16} is one contaminant commonly produced, even chemical separation would not produce a pure source of N^{17}. The earlier experiments utilized the distinctive feature of delayed neutron emission, by which common contaminant activities could be ignored. In the present experiment a nearly pure source of N^{17} was produced by the reaction $N^{15}(t,p)N^{17}$, employing a gas target of 99.5% N_2^{15}.

II. EXPERIMENTAL PROCEDURE

The beta decay of 4.2-sec N^{17} was studied by observation of beta-ray and gamma-ray singles spectra and beta-gamma coincidence spectra. The N^{17} was produced by the reaction $N^{15}(t,p)N^{17}$ ($Q=-0.109$ MeV), induced by the triton bombardment of N_2^{15} gas. A beam of 2.4-MeV tritons from an electrostatic accelerator passed through a thin nickel foil into a cylindrical gas cell, the axis of which lay along the beam axis. The gas cell for the gamma-ray observations was stainless steel, 3.8 cm long with 0.038-cm wall thickness. The cell used for the measurements of the beta spectrum was constructed with an aluminum wall section 0.013 cm thick and 7.0 cm long, and had an end plate of tantalum to act as a beam stop. Gas pressures of 50 to 100 Torr were commonly employed. The target gas was commercially available enriched N_2^{15} with a nominal enrichment to 99.5% N^{15}. Mass spectrometric analysis of the gas gave values of (in atom percent): 99.1% N^{15}, 0.5% N^{14}, 0.2% H^1, 0.1% O^{16}, and traces of carbon and other elements.

The gamma spectrometer consisted of a 10.2-cm-thick by 12.7-cm-diam (4-×5-in.) NaI(Tl) crystal mounted on a Dumont 6363 photomultiplier tube, and conventional electronics. Lucite or aluminum disks in front of the NaI crystal served as beta absorbers.

The beta spectrometer was a cylindrical NE-102 plastic scintillator 10.2 cm long and 8.3 cm in diameter mounted on a Dumont 6363 photomultiplier tube, and conventional electronics. The thickness of material between the target gas and the beta scintillation spectrometer was 34.3 mg/cm² in the gas cell wall, 4.7 mg/cm² of air (5 cm), and 4.4 mg/cm² in the light shield for a total of 43.4 mg/cm².

The NaI crystal and the plastic scintillator were positioned, either individually for the singles spectra or on opposite sides of the target for the coincidence spectra, at 90° to the beam direction in the horizontal plane.

The bombardment procedure was to switch the beam, typically 0.2 μA, onto the gas target for five seconds, turn off the beam, wait one second, and switch on the pulse-height analyzer for six seconds (live time). Control of this sequence was manual. Twenty of these bombardments constituted a normal run with a total live counting time of two minutes. It was necessary to restrict the beam intensity to prevent gain shifts in the photomultiplier tubes since the counting rates were high ($\sim 10^5$ per second) during the time the beam was on. The dead time of the RIDL 400-channel pulse-height analyzer during the six-second counting period following bombardment of N_2^{15} was 10–20% for the gamma spectra and 20–40% for the beta spectra.

Background spectra were taken both before each series of 20 bombardments and beginning 30 sec after the final bombardment of each series. These background runs were each two minutes in duration and their average was subtracted from the raw data to obtain net spectra. This procedure eliminated the effects of both constant environmental radioactivity and long-lived activities produced by the bombardment.

Another type of background spectrum was obtained by repeating measurements of the beta and gamma spectra with He^4 in the target cell rather than N^{15}. These He^4 runs measured activities induced in the apertures, target window, and target cell by triton bombardment.

For the bombardments in which gamma spectra were obtained the triton energy at the center of the gas cell was 1.98 MeV; for the beta spectra this energy was 2.15 MeV.

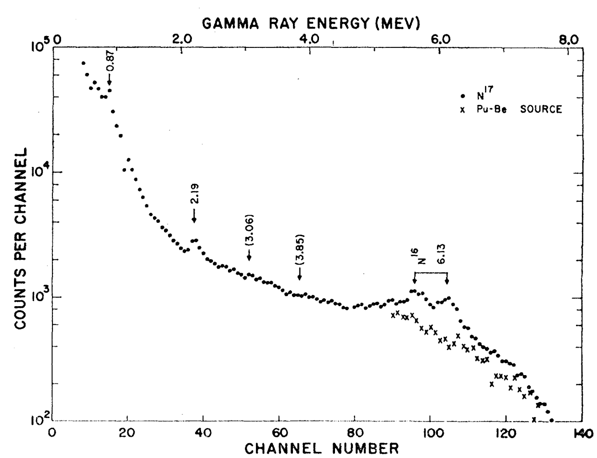

FIG. 2. NaI scintillation detector spectrum observed following the triton bombardment of a target of 99.5% N_2^{15}. Beta absorber: 3.9 g/cm² Al. Response of the NaI detector to neutrons from a Pu-Be source is also indicated. N^{16} is a contaminant activity.

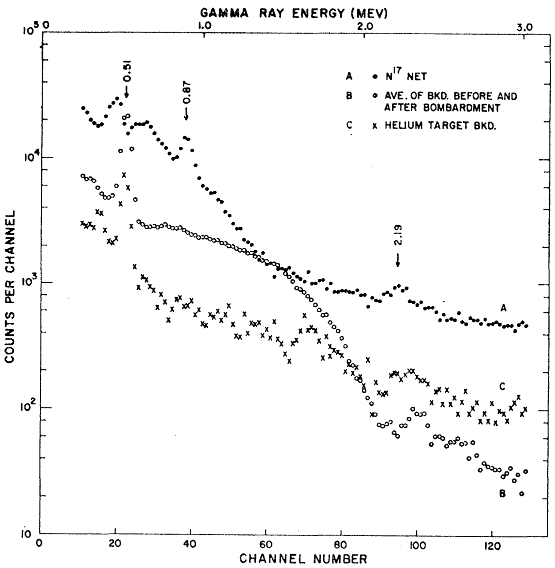

FIG. 3. NaI scintillation detector spectra observed following the triton bombardment of targets of 99.5% N_2^{15} or of He^4. Beta absorber: 2.6 g/cm² Al. Closed circles (A) are the net N^{17} spectrum after subtraction of backgrounds. The 0.87- and 2.19-MeV gamma rays are due to the beta decay of N^{17}; the peaks at 0.45 and 0.63 MeV are attributed to neutron inelastic scattering in I^{127}. Open circles (B) are the averaged background observed before and after bombardment. The beta spectrum (end point: 2.12 MeV) from I^{128} is evident. Crosses (C) indicate the spectrum from a He^4 target bombarded in the same manner as the N_2^{15} target. The three spectra are correctly normalized to each other.

III. RESULTS

A. Gamma-Ray Spectra

1. Background Problems

The gamma-ray singles spectra from the decay of N^{17} are presented in Figs. 2 and 3. The spectrum in Fig. 2 was taken with a gain setting chosen to allow gamma rays up to about 7.5 MeV to be observed. This spectrum illustrates several of the background problems in the gamma ray spectroscopy of N^{17}. The first is the presence of 6.14-MeV gammas from 7.4-sec N^{16}, which is produced by the reaction $N^{14}(t,p)N^{16}$ on the 0.5% of N_2^{14} in the target gas. The Q value for the reaction $N^{15}(t,d)N^{16}$ is -3.8 MeV so that it does not contribute to the yield of N^{16}. The half-life of N^{16} is so close to that of N^{17} that the background subtraction does not remove it from the spectrum.

Of the other energetically possible reactions between tritons and N^{15}, the (t,n) reaction leads to stable O^{17} while the (t,α) reaction leads to long-lived C^{14} which would not be detected. Another source of possible background activity are reactions between the small amounts of $(He^3)^+$ in the accelerated beam and the N_2^{15} target. Of the energetically possible reactions, only $N^{15}(He^3,n)F^{17}$ leads to a radioactive product, the effect of which would be negligible.

As an additional test for the presence of possible contaminant activities, a rough determination was made of the half-life of the activity measured with the NaI detector, following triton bombardment of the N_2^{15} target. The observed half-life of 4.0 ± 0.5 sec was consistent with the accepted value of 4.2 sec for N^{17}.[5]

The second, more serious, background problem arises from the presence of delayed neutron emission from N^{17} itself. Since the beta-decay branching fraction to neutron-emitting states in O^{17} is 95%, the target is an intense source of delayed neutrons. These neutrons interact with the NaI scintillator both by neutron capture and by inelastic scattering to produce background gamma rays.

A major contribution to the background in the NaI spectra comes from neutron capture in the I^{127} of the crystal itself. Since the delayed neutrons are emitted with the same half-life as the gamma rays from N^{17}, the capture gamma rays appear in the net spectrum of Fig. 2. The continuum of pulses extending to approximately 7 MeV is attributed to neutron capture gamma rays from iodine with possibly some contribution above 7 MeV from capture in Pb. For comparison, the response of the NaI crystal to neutrons from a Pu-Be source has been plotted in Fig. 2. The normalization is arbitrary.

The background continuum tends to mask peaks due to weak gamma rays. Of interest would be a search for a possible crossover transition from the 3.06-MeV level to the ground state, for a 3.85-MeV gamma from the next level in O^{17} to the ground state, and for possible gamma rays from the neutron-emitting states in O^{17}. Figure 2 shows no evidence for gamma-ray peaks between 2.19 MeV and the triplet of peaks from the 6.14-MeV gamma from N^{16}. An upper limit of 0.1% of the total number of beta disintegrations can be put on a possible beta branch to the 3.85-MeV level, assuming it de-excites exclusively to the ground state.[8]

Since neutron capture in hydrogen would produce a gamma ray of 2.23 MeV which might interfere with observation of the 2.19-MeV gamma from N^{17}, care was taken to exclude hydrogenous materials from the vicinity of the target during measurements of the gamma-ray singles spectra.

A second effect of neutron capture in iodine is the production of I^{128}. The 25-min half-life of this nuclide is long enough so that it is removed from the gross spectrum by the subtraction of a background measured between 30 and 150 sec after the end of the series of bombardments. This background, actually an average of background spectra taken just before and just after bombardment, is curve B in Fig. 3. It shows a characteristic beta spectrum from I^{128} in the crystal.

Another background effect produced by the delayed neutrons is inelastic scattering in the Na^{23} and I^{127} of the crystal. The neutrons excite the 0.44-MeV first excited state in Na^{23} and levels up to the 1.09-MeV state in I^{127}. The prompt de-excitation gamma rays appear in the gamma spectra with the N^{17} half-life and

[8] S. Gorodetzky, T. Muller, and M. Port, Physica **22**, 1159A (1956).

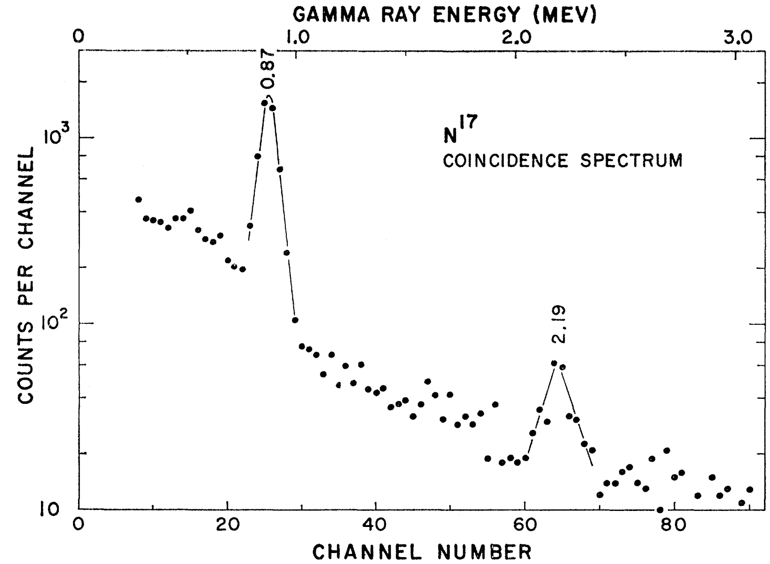

FIG. 4. The NaI spectrum in coincidence with beta rays of greater than 3.2 MeV.

cannot be separated from the gamma rays from N^{17} decay. Fortunately, none of the gamma rays from I^{127} is so close in energy to the 0.87-MeV gamma from N^{17} that they cannot be easily distinguished from it. The peaks near 0.45 and 0.63 MeV in Fig. 3 are due to inelastic scattering.

The net gamma spectrum (A) of Fig. 3 has been obtained from the raw data by the subtraction of two backgrounds. The first of these (B) is the average of background runs taken just before and just after each series of 20 bombardments. The second background that has been subtracted (C) is the spectrum taken and analyzed in the same manner as the N^{17} spectrum but with He^4 in the gas target instead of N_2^{15}.

2. *Net Spectra*

Two gamma-ray peaks in the net spectrum (A) of Fig. 3 have been attributed to the decay of N^{17}. These gamma rays at 0.87 and 2.19 MeV correspond to the de-excitation of the first and second excited states in O^{17}. Other experiments indicate that the second excited state at 3.06 MeV in O^{17} decays exclusively to the first excited state. In this experiment no evidence for a 3.06-MeV gamma ray was found.

Figure 3 shows that the 2.19-MeV gamma ray is weak compared to the 0.87-MeV gamma ray and that there are therefore two beta-decay branches involved, to both the first and second excited states of O^{17}. Analysis of the data gives a value of $(6.8\pm0.9):1$ for the ratio of the intensities of the 0.87- and 2.19-MeV gamma rays. Assuming the 3.06-MeV level de-excites only by cascade through the 0.87-MeV level, this gamma-ray intensity ratio leads to a value of $(5.8\pm0.9):1$ for the branching ratio for beta decay to the first excited state as compared to decay to the second excited state.

The relative photopeak efficiency of the NaI crystal plus beta absorber for the two gamma rays was determined experimentally with Y^{88} and Na^{24} sources. A correction of 4.5% for accidental summing in the NaI crystal was applied in the analysis of relative gamma intensities.

B. Beta-Gamma Coincidences

Beta-gamma coincidence spectra were obtained with the plastic scintillation detector in conjunction with the NaI crystal. A beta spectrum measured by the plastic scintillator without the coincidence requirement was compared with a beta spectrum taken under the same conditions except that the beta rays were required to be in coincidence with pulses above about 0.15 MeV in the NaI detector. The energetic end point of the coincidence beta spectrum was about 900 keV lower than the end point of the singles spectrum, demonstrating the presence of a ground-state beta group in the latter spectrum but not in the former.

Several gamma-ray spectra were taken in coincidence with beta rays. The discriminator level which determined the lower limit of beta energies accepted by the coincidence system was varied between 0.7 and 4.8 MeV for this series of spectra. Since the neutrons from N^{17} which produced serious backgrounds in the NaI singles spectra were in coincidence with low-energy beta particles, the gamma-ray coincidence spectra showed a progressive improvement in background level as the beta-ray bias level was increased. Figure 4 shows the NaI spectrum in coincidence with beta particles of greater than 3.2 MeV. Determination of the relative intensities of the gamma rays from the coincidence spectra would not have been as straightforward as the determination from the singles spectra, however, and the coincidence spectra were not analyzed for the relative intensities.

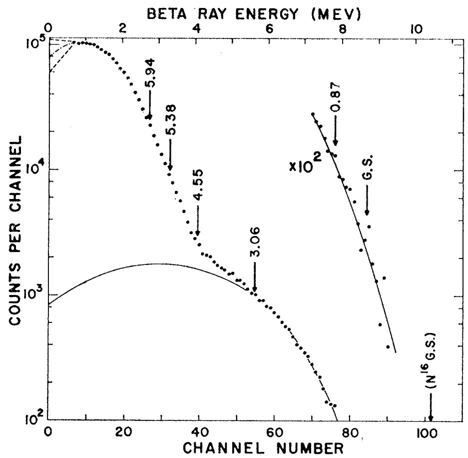

FIG. 5. Net beta-ray spectrum, obtained with a plastic scintillation detector, following the triton bombardment of a 99.5% N_2^{15} target. An averaged before-and-after bombardment background and a He^4 target background have been subtracted from the raw data to yield this spectrum. Calculated end point energies for the beta groups are labelled with the excitation energies of the corresponding O^{17} levels. The solid line is the computer fit to the high-energy beta groups. The dot-dash line is our extrapolation to zero energy of the beta spectrum; the dashed lines indicate the extremes considered in the uncertainty of this extrapolation.

C. Beta-Ray Spectra

Figure 5 presents the net beta-ray spectrum observed with the plastic scintillator following the bombardment of N^{15} with tritons. These data are the sum of 20 bombardment-count cycles for a total bombardment time of 100 sec and a total count time of 120 sec. Background runs taken before and after the series of 20 cycles have been subtracted. A background spectrum, taken under the same conditions except that the target cell was filled with He^4, has also been subtracted from the raw data. The contribution from gamma rays, as determined by runs with a beta absorber in front of the plastic scintillator, was negligible. Proton recoil pulses due to the neutrons from N^{17} would have pulse heights well under 1 MeV on the beta energy scale.

The spectrum of Fig. 5 exhibits two obvious features: a strong beta group or groups with an end-point energy between 4 and 5 MeV and a weak group or groups with an end-point energy between 9 and 10 MeV. Since it was known[7] that N^{17} decays to the levels in O^{17} at 5.94, 5.38, and 4.55 MeV with end-point energies of 2.83, 3.39, and 4.21 MeV, respectively, the intense low-energy part of the spectrum was assumed to be due to these three beta branches. The first part of our analysis was therefore confined to that part of the spectrum above 5 MeV. The gamma spectra (Sec. IIIA.) had indicated the existence of beta branches to the levels in O^{17} at 3.06 and 0.87 MeV; the possibility of a branch to the ground state was open. Analysis of the gamma spectra had shown that the beta branch to the 3.06-MeV level was only $\frac{1}{6}$ as intense as that to the 0.87-MeV level. Furthermore, the tail of the strong beta spectrum from the lower energy groups extended into the region of the group to the 3.06-MeV level. Our analysis was therefore further restricted to include only those data above channel 60 (Fig. 5) in an effort to determine the relative intensities of beta branches to the 0.87-MeV level and to the ground state, if the latter existed.

The beta-ray spectrum was analyzed into its component groups with the aid of a computer program.[9] The first step in the analysis of the beta-ray spectrum from N^{17} was the recording of calibration spectra from a Rb^{88} source and from N^{16}, immediately following the measurements on N^{17}. The Rb^{88} provided a calibration spectrum with 5.25-MeV maximum beta-ray energy. This source was placed at the target position and was covered with Al absorber of the same thickness as the target cell wall. The N^{16} (7.4 sec) was produced by replacing the N_2^{15} target gas by naturally occurring nitrogen and repeating the same sequence of triton bombardments as in the N^{17} runs. This activity provided a calibration spectrum with 10.41-MeV maximum beta-ray energy. Both of these calibration spectra were analyzed, with the aid of the computer program, from the highest energetic end point of each down as far as was possible without interference from lower energy beta groups. This analysis provided, firstly, a reliable energy scale for the subsequent N^{17} analysis so that the end points of the beta groups could be calculated from the known masses and energy levels and held fixed and, secondly, information on the response function of the detector.

The computer program idealized the response of a plastic scintillator to monoenergetic electrons as a Gaussian peak plus a plateau extending from the peak position down to zero energy. The adjustable parameters for the detector response function were then the "resolution" (fractional full-width at half-height of the peak) and the "base" (the ratio of plateau height to peak height). The resolution was assumed to be inversely proportional to the square root of the beta-particle energy, while the base was assumed to be independent of energy. The computer program also took into account the spectrum shape factor for first-forbidden unique transitions. The Rb^{88} and N^{16} calibration beta groups were unique first-forbidden transitions ($\Delta I=2$, yes) as was the N^{17} decay to the ground state of O^{17}. The decay to the 0.87-MeV state of O^{17} was nonunique first forbidden ($\Delta I=0$, yes) and was assumed to have the allowed shape.

It was feasible to analyze the beta spectrum from N^{17} with the aid of the energy scale and response function information provided by the Rb^{88} and N^{16} spectra. In the energy region of interest, above 6.2 MeV, only beta particles from transitions to the 0.87-MeV level and ground state of O^{17} were possible. It was found necessary, however, to include the ground-state branch of the

[9] P. C. Rogers, doctoral thesis, Massachussetts Institute of Technology, 1962 (unpublished), Appendix D.

contaminant N^{16} activity, so that the spectrum was analyzed into three beta groups. The best fit to the experimental points is illustrated in Fig. 6. In this case the fixed parameters were the three end-point energies and the response function. The calculated quantities were the relative intensities of the the three beta groups. The calculated N^{16} contaminant spectrum could be compared in intensity to the spectrum observed with a natural nitrogen target; this comparison agreed well with the known amount (0.5%) of N^{14} in the N^{15} target gas.

Unfortunately, only a limited region of the spectrum could be analyzed, the end points of interest differed by only 10% in energy, and the resolution of the detector was poor (15% at 10 MeV). The uncertainties in the branching ratios quoted below therefore include not only the statistical uncertainty associated with the fit of Fig. 6 but also our estimate of the effect of uncertainties in the parameters chosen for that fit, on the basis of fits made with a wide variety of parameters. Chi square for the fit of Fig. 6 was 32 with 28 degrees of freedom. Attempts to fit the data by omitting the O^{17} ground-state group were not successful.

We conclude from the analysis of the beta-ray spectra that a transition to the ground state exists and that the branching fraction to the 0.87-MeV level is 1.7 ± 0.4 times the branching fraction to the ground state.

By combining the results of the gamma-ray and beta-ray analyses, the relative branching fractions to the 3.06-MeV, 0.87-MeV, and ground states were obtained. In order to put these relative branching fractions on an absolute basis it was necessary to determine the fraction of all beta decays represented by these three weak, high energy groups. This fraction was determined by further analysis of the spectrum of Fig. 5, taking into account the N^{16} contaminant and the weak beta group to the 3.06-MeV level. The solid line is the computer fit to the high energy beta groups; the dot-dash line is an extrapolation of the total spectrum to zero energy. The ratio of the intensity of the three high energy groups to the total spectrum was calculated to be 0.0466 ± 0.0075. From this value and the relative branching fractions of the three high energy beta groups the branching fractions were calculated to be: O^{17} ground state, $(1.55\pm0.47)\%$; 0.87-MeV level, $(2.64\pm0.47)\%$; and 3.06-MeV level, $(0.46\pm0.011)\%$.

The $\log ft$ values for these transitions are, using the calculations of Feenberg and Trigg[10] and assuming a half-life for N^{17} of 4.20 sec, 7.26, 6.82, and 6.93, respectively. The standard deviations in these values are approximately ±0.1.

By combining the observed number of counts in the 0.87-MeV gamma-ray peak with our value of 3.1% for the fraction of decays which yield this gamma ray, it was possible to calculate a cross section for the reaction $N^{15}(t,p)N^{17}$, for tritons of 1.98 MeV, of 14 ± 3 mb.

[10] E. Feenberg and G. Trigg, Rev. Mod. Phys. **22**, 399 (1950).

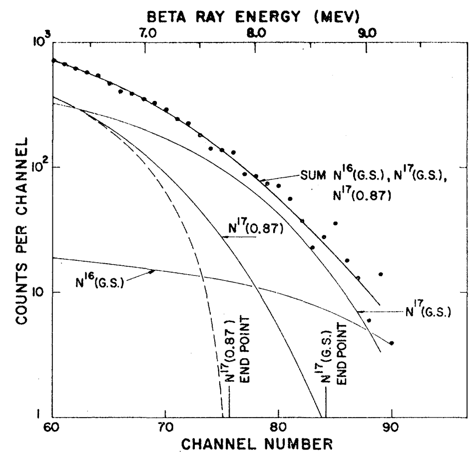

FIG. 6. The high energy part of the beta-ray spectrum of Fig. 5. Dots are the data points. The heavy line is the computer fit to the data. The analysis of the spectrum into three beta groups is indicated by the light lines which are labeled by the parent nucleus and the level in the daughter nucleus to which the decay proceeds. The dashed line is the calculated spectrum of the $N^{17}(0.87)$ group with a correction applied for the response function of the detector. Comparison of the dashed line with the light solid line for the same transition illustrates the effect of the resolution correction.

IV. DISCUSSION

The three beta-decay branches to neutron-emitting states in O^{17} have $\log ft$ values in the range 3.9 to 4.5, indicating that these are allowed transitions. Since the spins and parities of the three O^{17} states involved are $1/2-$ and $3/2-$, the ground state of N^{17} is either $1/2-$ or $3/2-$. The absence of an observable gamma ray of 3.85 MeV from N^{17} decay allows an upper limit of 0.1% of all beta decays to be placed on a beta branch to the 3.85-MeV level of O^{17}, assuming this level de-excites exclusively by gamma emission to the ground state. This value corresponds to a lower limit of 7.4 for the $\log ft$ value for such a beta transition. This relatively high $\log ft$ value, while not ruling out an allowed transition, suggests that the transition is not allowed and, since the 3.85-MeV level is $5/2-$,[11] the spin and parity of the ground state of N^{17} are therefore $1/2-$.

It is of interest to compare the $\log ft$ values for the six beta transitions involved in the decay of N^{17} with the ranges of values compiled[12] from the literature for beta decays of known order of forbiddenness. Assuming the level assignments of Fig. 1, four of the branches are allowed transitions while two are first forbidden. The branch to the O^{17} ground state is a unique first forbidden transition. It has been found[12,13] that the range of $\log ft$ values for known cases of unique shape first forbidden transitions is considerably reduced by comparing the

[11] C. Broude, T. K. Alexander, and A. E. Litherland, Bull. Am. Phys. Soc. **8**, 26 (1963).

[12] O. M. Kofoed-Hansen and C. J. Christensen, "Beta Decay," in *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1962), Vol. XLI/2, p. 41.

[13] C. S. Wu, *Nuclear Spectroscopy*, edited by F. Ajzenberg-Selove (Academic Press Inc., New York, 1960), Part A, p. 151.

values of $\log f_1 t$, the calculation[14] of which takes into account the unique shape of the beta spectrum. The value for $\log f_1 t$ of 8.5 for the ground-state transition can then be compared with the range of values 7.5 to 9.5 for 37 known cases. The $\log ft$ value of the nonunique first forbidden branch to the first excited state is well within the range expected for these transitions.

Of the four allowed transitions, those to the levels at 5.94 MeV (1/2−), 5.38 MeV (3/2−), and 4.56 MeV (3/2−) have rather low $\log ft$ values while the transition to the level at 3.06 MeV (1/2−) has a $\log ft$ value of 6.9 and is therefore somewhat hindered. This indication of a configuration for the 3.06-MeV state different from the configurations of the higher negative parity states in O^{17} is of interest in the light of theoretical attempts to describe this low-lying negative parity state. On the other hand, the large $\log ft$ value may merely reflect an accidental cancellation in the matrix element, as in several well known cases.[12]

The nucleus O^{17} is of special interest since it has but a single neutron outside the doubly closed O^{16} shells. The ground (5/2+) and first excited (1/2+) states of O^{17} are considered to be single-particle states with the odd neutron in the $1d_{5/2}$ and $2s_{1/2}$ orbits, respectively, with the level at 5.08 MeV (3/2+) having the odd neutron in the $1d_{3/2}$ orbit. These three states, as expected for configurations consisting of $O^{16}+n$, exhibit large stripping widths in the reaction $O^{16}(d,p)O^{17}$.[1,15] The negative parity states, on the other hand, exhibit small stripping widths and probably represent excitations of nucleons from the p shell of the O^{16} core. Unna and Talmi[16] have carried out calculations of the positions of energy levels in the nuclei above C^{12} and concluded that excitation of a single $1p_{1/2}$ neutron in O^{17} would lead to a 1/2− level ($1p_{1/2}{}^3 2s_{1/2}{}^2$) near 7 MeV while excitation of three $1p_{1/2}$ nucleons would give a 1/2− state ($1p_{1/2} 2s_{1/2}{}^4$) even lower in energy, near 4 MeV, because of the large attraction of the four nucleons in the $2s_{1/2}$ orbit. This configuration with four particles in the s,d shell was suggested by Christy and Fowler[17] to explain the 6.06-MeV (O^+) level in O^{16} and the 0.11-MeV (1/2−) level in F^{19} as well as the 3.06-MeV (1/2−) level in O^{17}. This problem has also been considered by Harvey,[18] who reached similar conclusions. A different approach to the structure of O^{17} and F^{17} is that of Matthies, Neudachin, and Smirnov,[19] who considered a nucleon coupled to a core of four alpha particles.

The hindered beta transition to the 3.06-MeV level lends support to the description of this level as a three nucleon excitation of the O^{16} core since such a state could be formed from the N^{17} ground state only by a radical rearrangement of the nucleons. It is possible that the 1/2− state at 5.94 MeV has the $1p_{1/2}{}^3 2s_{1/2}{}^2$ structure; the configurations of the two 3/2− states and the 5/2− state are an open question.[18]

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V. SUMMARY

(1) Gamma rays of 0.87 and 2.19 MeV have been observed accompanying the beta decay of N^{17}. The intensity ratio of these gamma rays determined the ratio of the numbers of beta transitions to the 0.87- and 3.06-MeV levels in O^{17}. No gamma rays of 3.85 MeV were observed.

(2) The high-energy part of the beta spectrum was analyzed to determine the relative intensities of beta transitions to the ground state and to the 0.87-MeV state.

(3) The relative numbers of high-energy and low-energy beta transitions was determined from the beta spectrum.

(4) The preceding information was combined to yield absolute branching fractions for the ground, first, and second excited states of O^{17} of 1.6, 2.6, and 0.59, respectively.

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