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Beta Decay of N^{16}

DAVID E. ALBURGER
Brookhaven National Laboratory, Upton, New York*

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The positron-electron pair coincidence spectrum occurring in the beta decay of 7.4-sec N^{16} has been examined at 1.25% resolution with an intermediate-image pair specrometer. A line is observed corresponding to internal pair conversion of the 6.14-Mev *E*3 transition from the 3− second excited state to the 0+ ground state of O^{16}. The upper limit on the intensity of a 6.06-Mev nuclear pair line from the 0+ first excited state (electric monopole transition) is 10% relative to the 6.14-Mev line and this corresponds to an upper limit of 1.5×10^{-4} for the fractional beta decay to the 6.06-Mev level. A lower limit of 8.2 is derived for the log*ft* value of this $2- \rightarrow 0+$ beta-ray branch as compared with the known log*ft*=6.7 for the $2- \rightarrow 0+$. 10.4-Mev branch to the ground state.

INTRODUCTION

THE beta decay of N^{16}, half-life 7.4 sec, is known[1] to take place with the emission of beta-ray groups to the ground state and to three excited states of O^{16}. Recent studies of the N^{16} beta-ray spectrum have been made with magnetic spectrometers by Morton and Lewis[2] and by Kern, Kenney, and Brunhart.[3] They found that the 10.4-Mev beta-ray component to the ground state has the unique first-forbidden shape above 4.4 Mev, as expected from the previous 2− spin assignment for N^{16}, and their values for the relative intensity of this branch are 24% and 28%, respectively. The principal inner group, which goes to the 6.14-Mev level in O^{16}, has an end point of 4.3 Mev after subtraction of the high-energy beta-ray component. A further subtraction was made from which a 3.3-Mev beta-ray group going to the 7.11-Mev O^{16} level was resolved, although its relative intensity was in both cases 3–5 times greater than that expected from the gamma-ray data of Toppel[4] who found that the 6.14-Mev gamma ray in N^{16} decay is 14.5 ± 1 times as intense as the 7.11-Mev gamma ray. Toppel's result, which confirms an earlier value of 12.5 ± 3 for the same ratio as measured by Millar, Bartholomew, and Kinsey,[5] may be used to deduce directly the ratio of beta-ray branching to the 6.14- and 7.11-Mev levels in O^{16} inasmuch as the ground-state gamma-ray transitions are the only known modes of decay of these levels and the small amount of feeding from the 8.87-Mev level is negligible. Source thickness effects may have been responsible for the relatively large intensity of the 3.3-Mev group obtained from the beta-ray spectra analyses.

In the decay scheme of N^{16} shown in Fig. 1 the beta-ray branching intensities have been deduced using the average value [2,3] of 26% for the ground state branch and Toppel's result for the ratio of the 4.3- to 3.3-Mev components. The branch[1] to the 8.87-Mev state is 1.1% and this is followed by gamma rays of 2.75, 1.90, or 1.72 Mev of relative intensities 27:1:3 in cascade with the high-energy gamma rays. It has also been shown[6,7] from the $F^{19}(p,\alpha)O^{16}$ reaction that the 2− 8.87-Mev level de-excites 8% of the time by a direct transition to the ground state.

Experimental log*ft* values for the various beta-ray groups may be deduced from the branching intensities discussed above and they are listed in the upper part of Table I together with values calculated from the shell model by Elliott and Flowers[8] making use of Rosenfeld forces and fixed spin-orbit splitting. According to Elliott and Flowers the discrepancy between the experimental and theoretical log*ft* values for the 3.3-Mev beta-ray branch may possibly be connected

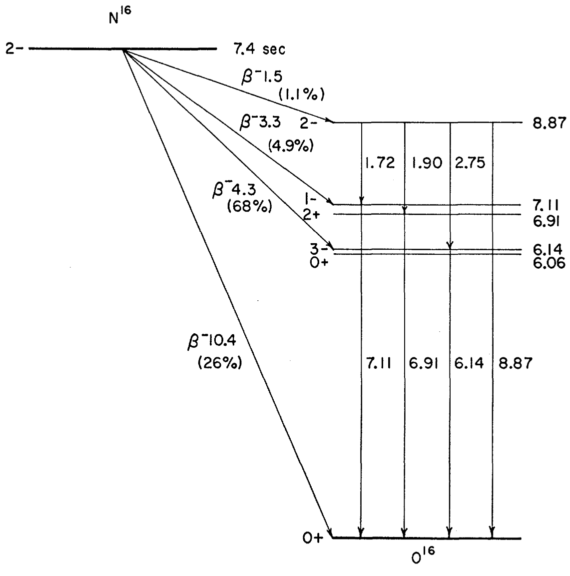

FIG. 1. Decay scheme of N^{16} summarized from the literature.

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* Under contract with the U. S. Atomic Energy Commission.

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[5] Millar, Bartholomew, and Kinsey, Phys. Rev. **81**, 150 (1951).

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with the sensitivity of the calculations to the nature of the spin-orbit forces for this particular level.

There has long been speculation as to the nature of the 0+ first excited state of O^{16}. This level, as well as a number of others below 14 Mev, has been described by Dennison[9] on the basis of an alpha-particle model for O^{16}. However, it has been pointed out[1] that the agreement between the experimentally determined levels and those predicted by the alpha-particle model may be largely fortuitous inasmuch as the alpha-particle model has not been able to account for the dynamical properties of these states, for the existence of $T=1$ states, or for the presence of the 2− level at 8.87 Mev.

More recently attempts have been made to describe the O^{16} levels on the basis of the nuclear shell model, and the calculations of the logft values in the beta decay of N^{16} mentioned above indicate one of the successes of this approach. Thus far it has not been possible to determine the exact nature of the configuration of the 6.06-Mev 0+ level. Very probably it does not result from the excitation of a single particle inasmuch as the lifetime of the ground-state electric monopole transition is long (5×10^{-11} sec) and furthermore the electric dipole radiation to this $T=0$ level from the 13.09-Mev 1− state of $T=1$ is not observed. This transition[10] is $<1.3\times10^{-3}$ as strong as the $E1$ ground-state transition observed in the $N^{15}(p,\gamma)O^{16}$ reaction at the resonance $E_p=1.05$ Mev. An excitation of two or more particles lifted from the $1p$ shell to higher shells could account for the properties of the level.

In order to attempt to throw more light on the nature of the 6.06-Mev 0+ level, one may make use of a highly sensitive method of detecting a beta-ray branch to this particular state. This is based on the fact that once the 6.06-Mev level is formed it decays virtually 100% by nuclear pair emission, whereas when the 6.14-Mev level is reached in the known beta-ray transition the internal pair conversion probability is 1.5×10^{-3} for an $E3$ transition of 6.14 Mev. Thus if the $2-\rightarrow0+$ branch to the 6.06-Mev state were to have the same logft value as the $2-\rightarrow0+$ branch to the ground state, one would expect the branch to the 6.06-Mev level to be 160 times weaker than the allowed beta-ray transition to the 6.14-Mev level according to the logft values of 6.7 and 4.5, respectively. Except for possible differences in the pair detection efficiencies, the 6.06-Mev nuclear pair line would then actually be 4 times stronger than the 6.14-Mev internal pair line in spite of a very much smaller beta-ray branching intensity. A pair spectrometer would appear to be the only instrument with which a very weak branch to the 6.06-Mev level could be detected, and clearly the resolution of the instrument must be sufficient to measure a doublet of lines differing in energy by only 1.3%. The problem is complicated further by the 7.4-sec half-life of N^{16} and by the fact that, if the pairs are to be detected in an instrument which selects positrons and electrons of equal energy, the lines occur at $(6-1)/2=2.5$ Mev or close to the maximum of the 4.3-Mev beta-ray continuum. In order to observe the pair lines in the presence of such a large intensity of beta rays, the detecting system must discriminate against coincidences resulting from scattering as well as random events.

TABLE I. Beta-ray branches in the decay of N^{16}.

Beta end-point energy (Mev)	O^{16} level (Mev)	Spins and parities	Branch in percent	Exp. log ft	Theor. log ft for $V_c=40$ Mev[a]
10.40	ground	$2-\rightarrow0+$	26	6.7	6.5
4.26	6.14	$2-\rightarrow3-$	68	4.5	4.65
3.30	7.11	$2-\rightarrow1-$	4.9	5.1	7.9
1.53	8.87	$2-\rightarrow2-$	1.1	4.4	4.2
4.34	6.06	$2-\rightarrow0+$	≤0.015	≥8.2	...

[a] See reference 8.

PAIR SPECTROMETER DESIGN

The operation and performance characteristics of an earlier version of the intermediate-image pair spectrometer have been described[11] previously. 1P21 side-window photomultiplier tubes were used and the 1½-inch diameter semicircular scintillation detecting crystals were located in air outside of a mica window at the final focus. The optical links between the crystals and the phototubes were made with semicircular acrylic rod 1½ inches in diameter and the optical contacts between the light pipes and both the crystals and tubes were made with Dow-Corning 10^6 centistokes viscosity grease. Several disadvantages of this arrangement were apparent, the main one being the relatively poor light-collecting efficiency of the 1P21 phototube. Difficulties had been experienced with optical separation of the tubes and crystals from the light pipes and with breakage of the mica window. The location of the detecting crystals was poor in two respects. Focused electrons could scatter out of one crystal, off the brass gasket clamp for the mica window, and back into the other crystal. Although the detection of these undesirable coincidence events could be minimized by high pulse-height bias in the coincidence circuit, it was never possible to reject them completely because of the relatively poor pulse-height resolution. Also the effective area of the detector was limited by the mica window opening such that events might be lost when the final image is large, i.e., at spectrometer baffle settings for high transmission.

In the new design illustrated in Fig. 2 these defects have been corrected. RCA-6342 photomultiplier tubes are used because of their good light-collecting efficiency,

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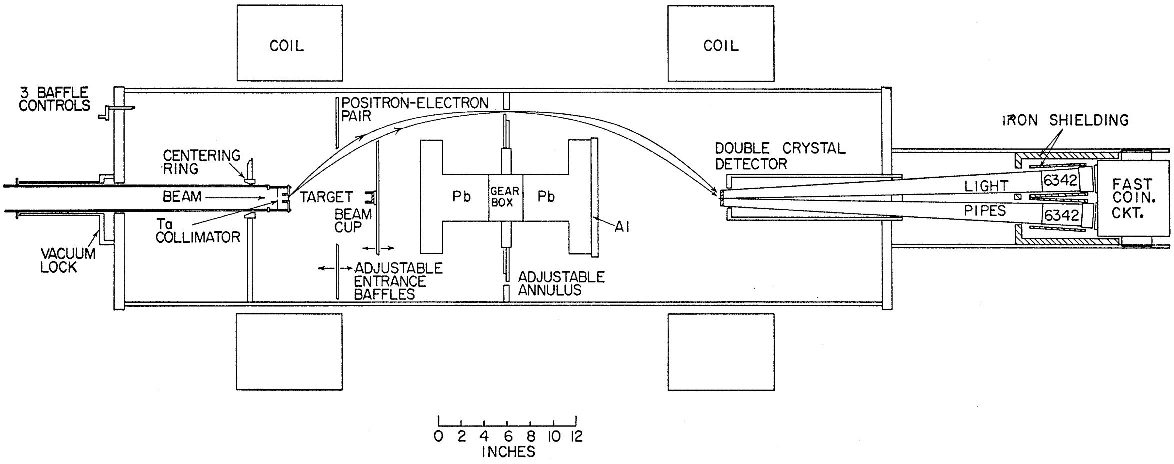

FIG. 2. Revised design of the intermediate-image pair spectrometer.

small transit-time spread, and the possibility of applying up to 2000 volts to the tube. These tubes are more sensitive to stray magnetic fields than the 1P21's so that greater care must be taken with magnetic shielding. With the triple magnetic shielding arrangement shown in Fig. 2, consisting of a standard mu-metal shield and a concentric iron cylinder over each tube, and a box made of $\frac{1}{2}$-inch-thick soft iron plate surrounding both tubes, the gain shift is 10% between zero field and a field focusing 4-Mev electrons. The light pipes have a diameter of 2 inches at the phototubes and they taper down, with a circular cross section, to $1\frac{1}{2}$ inches diameter at a point just outside the vacuum chamber end plate. Each of the pipes then passes through an O-ring seal into the vacuum. The $1\frac{1}{2}$-inch diameter is maintained between the O-ring and the crystal but one side of each pipe is milled flat so that the cross section, starting from circular at the O-ring, becomes semicircular at the crystal. All surfaces are of course highly polished. The light pipes project through a hole at the end of the re-entrant brass tube which acts as a centering support. This arrangement places the crystals well in front of any near-by scattering material and the final effective detecting area is larger than in the previous design. Both the crystals and the phototubes are cemented to the light pipes by means of Biggs R-313 bonding cement. With Pilot-B crystals the stability of the detector in the vacuum is very good. Each light pipe and crystal unit is wrapped with aluminum foil and a $\frac{1}{16}$-inch-thick tungsten absorber is located between the crystals. Outside of the vacuum, aluminum foil and black Scotch tape are used to cover the light pipes and phototubes. Just as in the original design the axial position of the crystals is adjusted to be on the source side of the final focal plane such that the electrons enter the crystals mainly over an annular region before they would cross the spectrometer axis.

The performance of the light-piping system is shown in Fig. 3 which gives the pulse-height distribution from one of the photomultiplier tubes when 2.5-Mev electrons are focused onto the $\frac{1}{2}$-inch-thick by $1\frac{1}{2}$-inch diameter semicircular Pilot-B scintillator. The peak has a full width at half maximum of 8% and the peak-to-valley intensity ratio is 100. 85% of the pulses are contained within the range 33 to 43 volts. In the previous arrangement using 1P21's, the width of the line when 2.5-Mev electrons were focussed onto an *anthracene* crystal was 18% and the peak-to-valley ratio was 24. Allowing for the fact that Pilot-B has only half the integrated light output as anthracene for a given electron energy, the improvement is actually better than the comparison of 8% with 18% resolution would suggest. It may be estimated that the resolution for the same type detecting crystal has improved by a factor of 3 and that the over-all light-collecting efficiency is a factor of 10 greater than for the old arrangement.

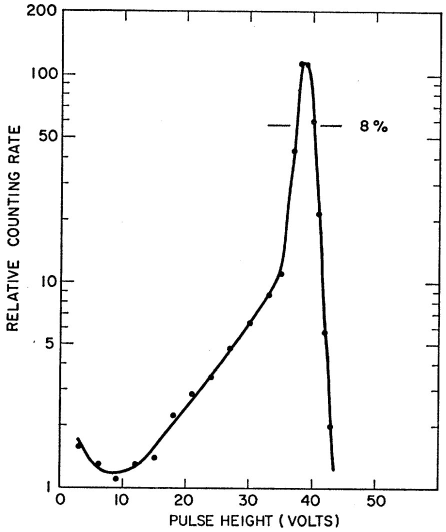

FIG. 3. Pulse-height spectrum when 2.5-Mev electrons are focused onto a $\frac{1}{2}$-in.-thick by $1\frac{1}{2}$-in. diameter Pilot-B scintillator with the light-piping geometry shown in Fig. 2.

As consequences of these changes, it has become possible to lower the coincidence resolving time and to achieve a more favorable rejection of scattering coincidences. A measure of the rejection of scattering coincidences may be obtained from the yield of true net counts in excess of the random rate at a magnetic field setting just above the 6.06-Mev nuclear pair line relative to the pair line intensity in the $F^{19}(p,\alpha)O^{16}$ reaction (see reference 11). With the previous arrangement the greatest ratio of the 6.06-Mev line to the true net background was 600 even at very high pulse-height bias. The peak-to-background ratio with the present design is still bias sensitive but at biases corresponding to 33 volts in Fig. 3 the ratio is $\sim$3000. It has not been possible to establish whether or not the residual background coincidence rate is caused by electron scattering.

The coincidence circuit is very similar to the original design except for layout improvements which allow the coincidence resolving time and the time-matching cables to be changed easily. Tests of the coincidence efficiency were made by comparing the slow and fast coincidence yields of the 6.06-Mev nuclear pair line in the $F^{19}(p,\alpha)O^{16}$ reaction. With 1750 volts on each phototube and with the pulse-height biases corresponding to 33 volts in Fig. 3, a coincidence efficiency close to 100% was obtained at a resolving time $\tau = 1.0\times10^{-9}$ sec as determined by a 5-inch-long shorted stub of RG-62/U cable. The stability over a period of a few weeks was such as to require no changes in the length of the time matching cables in the fast coincidence portion of the circuit.

Because of a possible improvement in transmission the absolute pair transmission for the 6.06-Mev pair line was measured in the manner described previously.[11] At an annulus opening of 3 mm, corresponding to 0.70% pair resolution, the transmission is 0.25 counts per 10^5 6.06-Mev transitions, which is the same as for the earlier design. However, the curve of transmission *versus* resolution (see reference 11, Fig. 8) now rises more rapidly such that at the full annulus opening of 17 mm width, the peak yield is 11.2 counts per 10^5 transitions as compared with the previous figure of 6.3. These measurements were taken in slow coincidence and with low pulse-height bias so as to detect all pairs reaching the respective crystals. At the largest annulus opening (2.5% pair resolution) the yield of pairs is 1750 counts per microcoulomb of 2.0-Mev protons on a CaF_2 target several mg/cm^2 in thickness. The observation of a relatively larger yield than before (by a factor of about 2) at higher transmission settings is probably connected with the greater effective diameter of the detector in its present location.

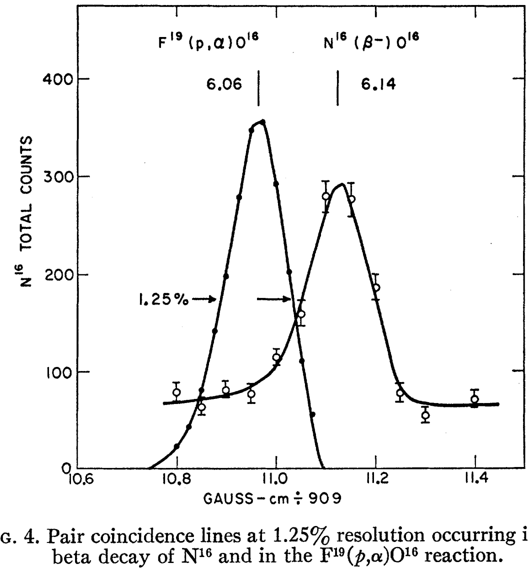

FIG. 4. Pair coincidence lines at 1.25% resolution occurring in the beta decay of N^{16} and in the $F^{19}(p,\alpha)O^{16}$ reaction.

N^{16} EXPERIMENTS

N^{16} activity was made in solid targets of TiN^{15} by means of the $N^{15}(d,p)N^{16}$ reaction using 2.5-Mev deuterons from the Van de Graaff accelerator. The target material was prepared[12] by nitriding Ti metal powder in the presence of nitrogen gas enriched to 95.6% N^{15}. 75% of the Ti was nitrided after 4 hours at 1000°C. A deposit of the TiN^{15} several mg/cm^2 in thickness was stuck to a 0.00005-inch-thick Ni foil located at the normal source position of the spectrometer.

In order to produce the activity and then count it, a tantalum beam interceptor was operated pneumatically by a timing system which turned off the scalers during the irradiation. The cycle consisted of a 7-sec irradiation, a $\frac{1}{2}$-sec changeover, and a 7-sec counting interval. The procedure was to count the total number of coincidences for various magnetic field settings, normalizing to a fixed number of accumulated counts in the channel output of one of the crystals. This method of normalizing is suitable since the N^{16} beta-ray continuum is nearly constant over the small interval covered in these measurements. Adjustments of the beam were made so that the monitor count accumulated in each 7-sec period was nearly constant. The average random coincidence contribution is then expected to be the same for all points.

The right-hand curve in Fig. 4 shows one of the N^{16} pair spectrum runs taken at 1.25% spectrometer resolution. The irradiating beam was collected in a Faraday cup after passing through the target. Its strength was 0.25 microampere at the beginning of the run and it was increased thereafter, on account of loss of target material, so that $\sim$18 000 channel counts were recorded in each 7-sec period of counting. Each of the N^{16} points in Fig. 4 is the total for 5×10^6 channel counts taken in five separate passes over the region during a 15-hour run. Approximately 4/10 of the background lying under the peak results from random

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[12] The author is indebted to Dr. O. A. Schaeffer for the preparation of the TiN.

coincidences, as calculated from the average channel counting rates, and the 1.0×10^{-9} sec coincidence resolving time. Another contribution comes from the fact that the positron-electron pairs of the 6.14-Mev transition are in coincidence with the strong 4.3-Mev beta-ray group and this would be expected to result in a continuum of real coincidences. By a consideration of all of the necessary factors, this effect could account for $\sim\frac{1}{4}$ of the total background. There may also be a small multiple-scattering contribution.

Calibration of the spectrometer was taken from the 6.06-Mev nuclear pair line[11] occurring in the $F^{19}(p,\alpha)O^{16}$ reaction at 2-Mev proton energy on a CaF_2 target several mg/cm^2 in thickness. The line was run both before and after the N^{16} data and with the same collimation (2-mm diameter beam aperture), spectrometer settings and target position as for the TiN^{15} target. One of these curves is included in Fig. 4.

A series of runs was made on the N^{16} pairs to determine the absolute transmission for the 6.14-Mev pair line and to establish the way in which the pair transmission varies with spectrometer resolution for this $E3$ transition. Transmission is here defined as the number of pair counts at the peak of the line per pair emitted from the source. The total number of pairs emitted from the source may be calculated after first finding the accumulated number of N^{16} beta-ray disintegrations. A determination of the fraction of the N^{16} spectrum accepted at the pair line momentum setting was made by area measurements of the complete N^{16} spectrum and of the window curve at 2.5 Mev. It was found that at the 9-mm annulus setting, corresponding to 2.4% singles resolution, 2.0% of the N^{16} spectrum is detected. By dividing the accumulated count of both crystal detectors, corrected for ~5% loss in the W absorber, by the singles transmission of 6.1% and by the 2% momentum slice factor, the total number of N^{16} disintegrations is found. This number, multiplied by the branching ratio of 0.68 and by the theoretical internal pair conversion probability[13] of 1.5×10^{-3}, leads to the total number of 6.14-Mev source pairs emitted in the standard counting interval. The recorded pair count divided by the number of pairs emitted is the pair transmission. The transmission curve of yield *versus* resolution for the 6.14-Mev pairs was found to lie approximately parallel to that for the 6.06-Mev $E0$ line mentioned in the preceding section and it is higher by a factor of 1.5.

DISCUSSION

From Fig. 4 it is apparent that only a single pair coincidence line is visible in the N^{16} curve near 6-Mev transition energy. Relative to the 6.06-Mev $F^{19}+p$ calibration line, the N^{16} peak occurs at an electron energy 42 kev higher or at a transition energy 84 kev higher than the 6.06-Mev line. Source thickness effects are expected to be negligible for both lines. This energy separation is in agreement with the value 85 ± 10 kev established from particle group analysis[14] and it shows that the N^{16} pair line is associated with the 6.14-Mev second excited state of O^{16}. At the 6.06-Mev position, the net height of the smooth curve through the N^{16} points is down to about 6% of the peak which is just the value it would have for a single component, as expected from the shape of the $F^{19}(p,\alpha)O^{16}$ curve. It is estimated that a 6.06-Mev line contribution 10% as strong as the 6.14-Mev line would be observable in the N^{16} pair spectrum of Fig. 4. This limit, expressed in counts per standard number of accumulated monitor counts, may be used to derive the upper limit for the beta-ray branching intensity to the 6.06-Mev level. The calculations are similar to those described in the preceding section in which the absolute pair transmission for the 6.14-Mev $E3$ pairs was derived, i.e., the total number of beta disintegrations is deduced from the singles count divided by the transmission and momentum slice factors in order to obtain the limit of 6.06-Mev pair counts per N^{16} disintegration. By making use of the measured absolute transmission for 6.06-Mev $E0$ pairs, determined from the $F^{19}(p,\alpha)O^{16}$ reaction as described in the second section, the upper limit on the number of 6.06-Mev $E0$ transitions per N^{16} disintegration is found. An upper limit of 1.5×10^{-4} is thus obtained for the fractional beta decay to the 6.06-Mev level in O^{16}. This corresponds to a lower limit of 13 hours for the partial half-life and therefore to a lower limit of 8.2 for the logft value of the beta-ray branch.

A separate check on the limiting beta-ray branching intensity may be made from a consideration of the 10% limit on the intensity of a 6.06-Mev peak relative to the 6.14-Mev line, together with the theoretical internal pair conversion coefficient of 1.5×10^{-3} for the 6.14-Mev transition and the 6.14- to 6.06-Mev pair transmission ratio of 1.5. The product of these three factors leads directly to an upper limit of 2.2×10^{-4} for the ratio of $E0$ to $E3$ transition intensities. Since 68% of the beta decays go to the 6.14-Mev level, the upper limit of the number of 6.06-Mev $E0$ transitions per N^{16} disintegration is 1.5×10^{-4} which is the same as obtained above.

In the second of these two calculations of the limit of beta-ray branching, it is of interest to ask whether the measured ratio of 1.5 of the $E3/E0$ transmissions is reasonable in view of the differences of angular correlation between pairs in the two cases. The correlation for the $E0$ pairs has been measured[15] as $1+0.98\cos\theta$ for pairs of all energies and we may assume that it is about the same for pairs of equal energy. On the other hand, the pairs from the 6.14-Mev $E3$ transition are certainly more strongly correlated in the same di-

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[14] W. W. Buechner, Massachusetts Institute of Technology Laboratory of Nuclear Science, Progress Report, April, 1950 (unpublished).

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rection, as shown by Rose[13] who has calculated the ratio of pairs at 0° to those at 90° for pairs of all energies in transitions of various energies and multipole orders. For a 6.14-Mev $E3$ transition this ratio is 35. When the energy division is equal, the ratio of pairs at 0° to those at 90° is probably higher than 35 as indicated from the calculations of Horton[16] for $E1$ and $E2$ transitions. Consider the pair spectrometer transmissions for the following three assumed angular correlations between pairs of equal energy:

(1) positron and electron always coinciding in direction,
(2) $1+\cos\theta$,
(3) isotropic.

At the full opening of the spectrometer the singles transmission is 8.1% and thus one would expect that the ratio of pair transmissions (1)/(3) would be one solid angle factor, or 12. An exact calculation has not been made but it may be estimated from the two distributions that the ratio of transmissions (2)/(3) is 3 or 4. Consequently it follows that the ratio (1)/(2) is also 3 or 4. The effect of the correlation of the 6.14-Mev $E3$ pairs would place its transmission somewhere between the extreme of (1) and the $E0$ correlation (2). A rough guess is that the $E3/E0$ transmission ratio is 2 ± 1 which is consistent with the observed ratio of 1.5 for all annulus settings from 6 to 17 mm width.

The lower limit of 8.2 for the logft value of a N^{16} beta-ray branch to the 6.06-Mev level in O^{16} is included in Table I for comparison with the other branches. That this $2-\rightarrow0+$ beta-ray transition is more than 30 times slower than the $2-\rightarrow0+$ branch to the ground state probably could not be explained if the 6.06-Mev level were to be described as the excitation of a single particle, in spite of a possible relative enhancement of the ground-state beta ray by virtue of its going into a closed shell. A number of 2-particle excitations are possible, some of which would introduce inhibiting factors and some of which would not. The present result is consistent with a description of the 6.06-Mev state as the excitation of 2 or more particles from the $1p$ shell and it suggests that if the state is a 2-particle excitation the configuration is not predominantly one such as $1p^{-2}(2s,1d)^2$ which would not be expected to further inhibit the beta-ray transition.

One may estimate how much feeding of the 6.06-Mev level would occur in N^{16} decay by paths other than beta-ray emission, although such considerations would be essential only if a 6.06-Mev pair line had indeed been observed. A transition from the 8.87-Mev level would be an $M2$ radiation of 2.83 Mev in competition both with the 2.75-Mev (predominantly $M1$) gamma ray to the 3− level at 6.14 Mev and with the $M2$ ground-state transition. From the transition probabilities calculated[17] by Moszkowski on the basis of the single-particle model, the 2.75-Mev $M1$ transition would be favored over a 2.83-Mev $M2$ by a factor of $\sim$4000. However, the relative strength[1] of the $E2$ component of the 2.75-Mev transition suggests that the $M1$ component may be slowed down by as much as two orders of magnitude from the single-particle estimate. Feeding of the 6.06-Mev level via the 8.87-Mev level would thus be between $3\times10^{-4}\%$ and $3\times10^{-2}\%$ per disintegration if no allowance is made for further inhibition connected with the configuration of the 6.06-Mev state. Another contender for feeding of the 6.06-Mev level would be an $E1$ transition of 1.05 Mev from the 7.11-Mev level in competition with the 7.11-Mev $E1$ ground-state transition. If the isotopic-spin forbiddenness were the same for both $E1$ transitions and if no other inhibiting factors were operating, one would expect the transition probabilities to depend on the energy cubed, or a factor of 310 in this case. Relative feeding of the 6.06-Mev level would then be 0.016% per disintegration. Beta-ray transitions to the 6.91-Mev 2+ state would be first forbidden and for a logft value assumed to be 6.7, for the sake of argument, the beta-ray branching intensity would be 0.03%. This state decays by $E2$ radiation to the ground state. By taking the E^5 energy dependence into account, the relative amount of feeding of the 6.06-Mev level via a 0.85-Mev $E2$ radiation would be $\sim3\times10^{-3}\%$ per 6.91-Mev state formed, or $\sim10^{-6}\%$ per disintegration. A similar consideration of feeding via a 0.080-Mev $E3$ transition from the 6.14-Mev state shows that this mode must be many orders of magnitude smaller than those discussed above. It may be concluded that even under the most favorable assumptions as to the various gamma-ray transition probabilities, the greatest amount of feeding of the 6.06-Mev level from higher states is either in the neighborhood of or well below the experimentally determined limit of the number of 6.06-Mev states formed.

ACKNOWLEDGMENTS

The author is indebted to Dr. Denys Wilkinson for suggesting this problem and to Dr. Wilkinson and Dr. J. P. Elliott for helpful discussions in connection with it.

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