$1s^41p2p^2$, and $1s^41p1f^2$. The matrix elements of Q connecting each of these nine configurations with the ground configuration all vanish and therefore these configurations have little influence on the value of Q. In conclusion it appears that the electromagnetic and beta-decay properties of the $A=7$ nuclei can be satisfactorily understood on the basis of the supermultiplet theory with configuration admixtures that preserve the partition symmetry and LS coupling. We wish to stress the uncertainties in the "experimental" value of Q and in the values of $\langle r^2\rangle_{1p}$ and the radial integrals, which were evaluated with oscillator eigenfunctions, and also the insensitivity of Q to variations in the proportions of the configuration admixture.

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O^{17} and O^{19} Lifetimes by a Particle-Gamma Coincidence Technique

R. E. McDonald, D. B. Fossan,[*] L. F. Chase, Jr., and J. A. Becker
Lockheed Palo Alto Research Laboratories, Palo Alto, California

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Lifetimes of the 96-keV and 1.47-MeV levels in O^{19} produced by the $O^{18}(d,p)O^{19}$ reaction have been measured from the distribution of time delays between protons and the appropriate decaying gamma rays. A solid-state detector was used both as a timing and as an energy-measuring device for the protons. The time-delay distributions were obtained with a time-to-height converter in the normal fast-slow coincidence arrangement. The measured half-lives of the 96-keV and 1.47-MeV levels in O^{19} are 1.39 ± 0.05 nsec and ≤ 75 psec, respectively. These results are compared with intermediate-coupling shell-model calculations. Using this particle-gamma coincidence technique a remeasurement of the lifetime for the 871-keV level in O^{17} produced by the $O^{16}(d,p)$ O^{17} reaction resulted in a half-life of 182 ± 5 psec.

I. INTRODUCTION

LOW-LYING states of the O^{19} nucleus have been studied both theoretically and experimentally. Intermediate-coupling shell-model calculations[1] predict a $\frac{5}{2}^+$ ground state and two states within about 1 MeV of the ground state with spins and parities of $\frac{3}{2}^+$ and $\frac{1}{2}^+$. Experimentally, levels are known to exist at 96 keV and 1.47 MeV.[2]

Stripping angular distributions for the $O^{18}(d,p)O^{19}$ reaction[3,4] indicate the transfer of $l_n=2$ and $l_n=0$ neutrons for the ground state and 1.47-MeV state, respectively, while the 96-keV state did not show a stripping pattern. These l values imply a $\frac{1}{2}^+$ assignment for the 1.47-MeV level and allow either $\frac{5}{2}^+$ or $\frac{3}{2}^+$ for the ground state. Beta-decay studies[2,5] favor the $\frac{5}{2}^+$ assignment for the ground state.

Givens *et al.*[6] determined the parity of the 96-keV level to be positive from a measurement of its K-conversion coefficient which implied an $M1$ transition and hence an even parity relative to the ground state. Angular correlation results of Allen[7] unambiguously assign a spin of $\frac{3}{2}$ to this level. This $\frac{3}{2}^+$ assignment for the 96-keV level is in agreement with the associated shell-model wave functions[1] which predict the observed small stripping width.

Zimmerman[4] has measured the lifetime of the 96-keV level as $t_{1/2}=1.21\pm0.20$ nsec by a recoil technique using the $O^{18}(d,p)O^{19}$ reaction. In this previous experiment, gamma rays were observed from recoiling excited O^{19} nuclei at various distances from the target; the lifetime was determined from a knowledge of the recoil velocity. Rather large uncertainties in the lifetime result from background corrections and the difficulty of determining precisely the stopping power for the O^{19} nuclei in the target. In addition, this measurement requires that the lifetime of the 1.47-MeV state is short relative to that of the 96-keV state, since the 96-keV state is populated predominantly by 1.37-MeV cascade gamma rays. The fact that the lifetime of the 1.47-MeV state satisfies this criterion was based partially on single-particle estimates for this transition.

Because of the success of the intermediate-coupling shell-model calculations for s-d nuclei, further information and accuracy on the lifetimes of the 1.47-MeV and 96-keV states of O^{19} are important as a closer check on the wave functions for these states. Thus, it is the purpose of this experiment to measure these lifetimes in a direct manner which is capable of ac-

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[*] Present address: State University of New York at Stony Brook, New York.

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curacies to within a few percent. The technique used for these measurements was to determine the distribution of time delays between protons from the $O^{18}(d,p)O^{19}$ reaction and the appropriate decaying gamma rays, with a time-to-height converter. Fast timing pulses for the protons were obtained from a solid-state detector without noticeable deterioration of the energy resolution. The time resolution used for the 1.47-MeV-state measurement was 450 psec full width at half-maximum (FWHM) with a minimum slope corresponding to a 70-psec half-life. As a check on the timing technique, the half-life of the 871-keV state in O^{17} was measured using the $O^{16}(d,p)O^{17}$ reaction. A value of $t_{1/2}=182\pm5$ psec was obtained which is in good agreement with previous measurements[8].

II. EXPERIMENTAL TECHNIQUE

The lifetime results in this experiment were obtained from logarithmic slopes of the distribution of time delays between the formation and the decay of the states under consideration. The formation of the O^{19} states was determined by protons from the $O^{18}(d,p)O^{19}$ reaction as detected in a solid-state detector, while the subsequent gamma rays detected in a plastic scintillator, determined the decay of the states. The time-delay pulses were produced in a fast time-to-height converter along with additional slow-coincidence requirements which isolated particular proton groups and gamma rays and maintained a minimum time resolution. There are several advantages in using a solid-state detector over the conventional pulsed-beam technique. With a solid-state detector, a number of the time-resolution difficulties associated with the pulsed beam are eliminated. Another advantage is in the energy-resolution characteristics of the solid-state detector which allow the study of individual levels even if a number of levels are strongly populated. A schematic diagram of the apparatus is shown in Fig. 1.

In this experiment, deuterons from the Lockheed Van de Graaff accelerator bombarded a 1-cm-thick gas target equipped with 0.002-mm Ni windows at 0°, 90°, and 180°. A gas pressure of about 10 cm Hg was used. The solid-state counter detecting the protons was placed at 90°. Appropriate collimation was employed to allow the proton detector to observe only a small portion of the gas target; this was necessary to minimize transit-time variations and kinematic-energy spreads for the particles. The gamma-ray detector was placed perpendicular to the reaction plane defined by the deuteron beam and the proton counter.

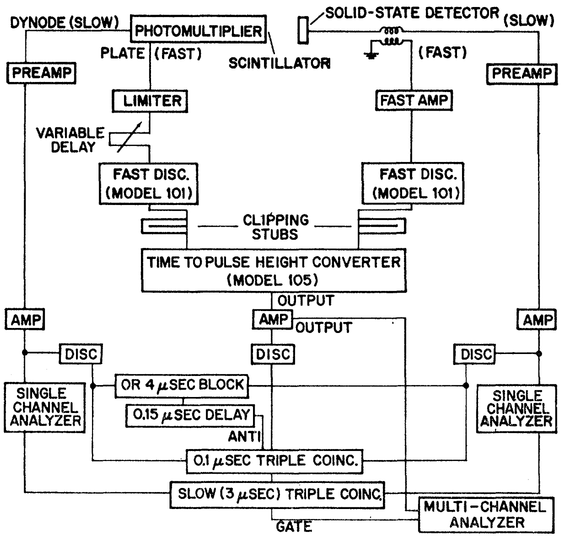

FIG. 1. A schematic diagram of the experimental apparatus.

The solid-state detector used was a 500-Ω cm silicon surface-barrier detector of 100-μ thickness and 25-mm^2 area. Observed rise-time characteristics for solid-state detectors are dependent on the charge-carrier collection time and on the input circuit of the amplifier. Collection-time contributions to the rise time are minimized with low resistivity; theoretical calculations[9] for this detector place this contribution as being less than 1 nsec. The equivalent circuit rise time[10] for the amplifier input is given by $R_sC_aC_d/(C_a+C_d)$, where R_s is the series resistance arising in the undepleted silicon and contacts, C_a is the input capacitance of the amplifier plus any stray capacitances, and C_d is the capacity of the detector. By totally depleting the detector to minimize R_s and with a small area to keep C_d small, this rise-time contribution was made sufficiently small that it was not the limiting factor in the time resolution.

Pulses from the solid-state detector were fed through the primary of a small transformer to a charge-sensitive preamplifier which produced the normal slow energy pulse. The fast pulse for timing purposes was picked off the secondary at the transformer and amplified by a fast circuit.[11] The energy resolution of the solid-state detector was not noticeably affected by this timing technique. In this experiment, a detector with 50-keV energy resolution was used.

The gamma rays were detected in a 5 cm diameter by 5 cm long NE102 plastic scintillator that was mounted on a RCA 7264A phototube. Fast pulses were obtained from the anode while the slow energy pulses were taken from a dynode.

A time-to-height converter[12] was used for the time-delay measurements in the conventional fast-slow

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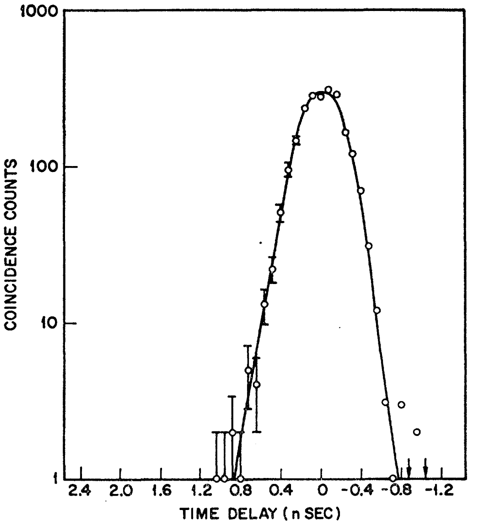

FIG. 2. An experimental decay curve for the 1.47-MeV level in O^{19}. The left slope corresponds to a half-life $t_{1/2} \leq 75$ psec.

coincidence arrangement. For the slow-coincidence requirements, a multi-coincidence circuit was employed along with a 4-μsec blocking circuit for the elimination of pile-up effects. The time-delay spectra were recorded on an 800-channel pulse-height analyzer. A time resolution of about 450 psec FWHM was achieved with this system, of which a large fraction was associated with the gamma-ray detection. The minimum half-life slope with this resolution was about 70 psec. Time calibration of the time-to-height converter was made with air-dielectric lines.

III. EXPERIMENTAL MEASUREMENTS AND RESULTS

1.47-MeV State of O^{19}

For the lifetime measurement of the $\frac{1}{2}^+$ 1.47-MeV level in O^{19}, the slow-coincidence conditions of the solid-state detector were adjusted to accept the narrow group of protons which correspond to the population of the 1.47-MeV level from the $O^{18}(d,p)O^{19}$ reaction. On the gamma-ray side, a 20% channel was set at the Compton edge of the 1.37-MeV gamma ray. The deuteron bombarding energy for this measurement was 2.5 MeV. One of several experimental decay curves for this state is shown in Fig. 2. Since the left slope is equivalent to that expected from the resolution function, only an upper limit of $t_{1/2} \leq 75$ psec can be obtained for the half-life of the 1.47-MeV state.

96-keV State of O^{19}

Because of the small reduced width for the $O^{18}(d,p)O^{19}$ reaction to the $\frac{3}{2}^+$ state at 96 keV, it was not feasible to use the protons which correspond to the population of this state for a lifetime measurement. However, since the lifetime of the 1.47-MeV state was found to be very short, it was possible to use its large gamma-ray branching[7] (96.7%) to the 96-keV state as a means of populating this level in a prompt manner relative to the protons feeding the 1.47-MeV state. Thus, the lifetime of the 96-keV state could be measured by observing the distribution of time delays between the protons which populate the 1.47-MeV state and the 96-keV gamma rays. The slow-channel requirements for the solid-state detector were therefore the same as in the previous measurement for a deuteron bombarding energy of 2.5 MeV. The gamma-ray channel, however, was adjusted to a 20% pulse-height window at the Compton edge of the 96-keV gamma ray. Because of the large energy difference in the Compton edges for the 96-keV and 1.37-MeV gamma rays, only about 3% of the latter were observed in this gamma-ray channel; furthermore, the time-delay pulses resulting from this small percentage of 1.37-MeV gamma rays fell into the prompt region without affecting the measured lifetime. The observed decay curve is shown by the open circles in Fig. 3. From a least-squares fit of a straight line to the logarithmic slope, the half-life of the 96-keV state is determined to be $t_{1/2} = 1.39 \pm 0.05$ nsec. These error limits include statistical uncertainties and an estimated 2% time-calibration uncertainty.

Since the Compton edge of the 96-keV gamma ray is only 27 keV, the time resolution under these conditions is expected to be considerably larger than in the previous measurement. To measure this prompt-resolution function, the O^{18} gas in the target was replaced by O^{16} gas. Also, the deuteron energy was changed such that the proton group which populated the 871-keV state in O^{17} by the $O^{16}(d,p)O^{17}$ reaction, fell in the same slow channel for the solid-state detector. The unchanged

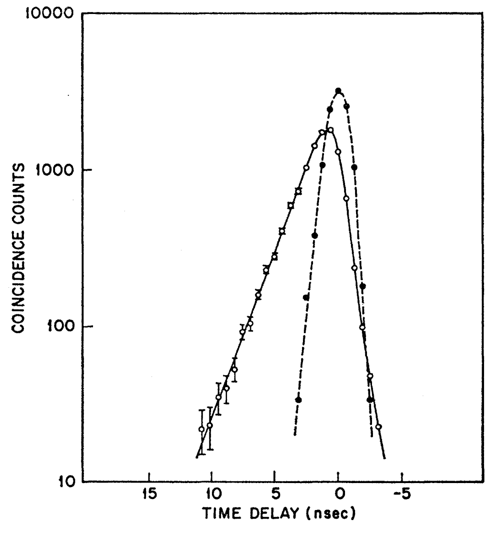

FIG. 3. The experimental decay curve for the 96-keV level in O^{19} as shown with open circles. Darkened circles represent the prompt-resolution function. The left slope of the decay curve corresponds to a half-life, $t_{1/2} = (1.39 \pm 0.05)$ nsec. An arbitrary zero time is used.

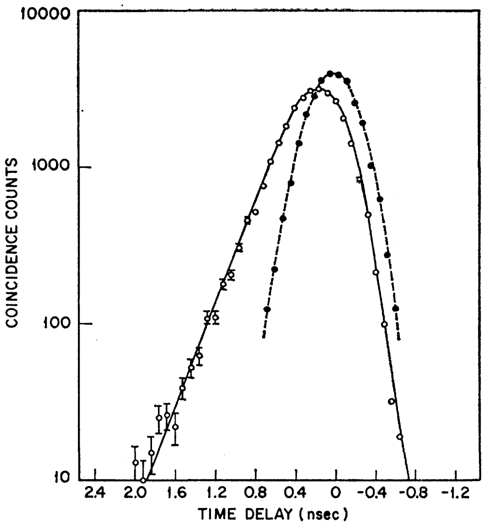

FIG. 4. The experimental decay curve for the 871-keV level in O^{17} as shown with open circles. Darkened circles represent the prompt-resolution function. The left slope of the decay curve corresponds to a half-life, $t_{1/2}=(182\pm5)$ psec. An arbitrary zero time is used.

gamma-ray channel observed a portion of the Compton spectrum from the 871-keV gamma ray. Since the 871-keV state has a lifetime which is small relative to that of the 96-keV state,[8] the resulting decay curve represented the prompt-resolution function. This resolution function as shown by the darkened circles in Fig. 3, indicates by comparison the validity of the lifetime measurement of the 96-keV state in O^{19}.

871-keV State of O^{17}

As a check on the experimental technique, the lifetime of the 871-keV state of O^{17} was remeasured. The proton group from the $O^{16}(d,p)O^{17}$ reaction which corresponds to the population of this state was accepted in the slow channel for the solid-state detector along with a narrow gamma-ray window at the 871-keV Compton edge. The resulting decay curve is shown by open circles in Fig. 4. The half-life obtained from a least squares fit to the logarithmic slope is $t_{1/2}=182\pm5$ psec. Statistical and time-calibration uncertainties are included in the error limits. This measurement is in agreement with two previous results[8] for this state where gamma-gamma and pulsed-beam techniques were used, but is in disagreement with another measurement.[13] The prompt-resolution function for this measurement shown in Fig. 4 by darkened circles was obtained with similar channel settings, but with an O^{18} gas target and the decay of the prompt 1.47-MeV state of O^{19}.

IV. DISCUSSION AND CONCLUSIONS

In this experiment, the half-life of the 96-keV level of O^{19} has been measured to be $t_{1/2}=1.39\pm0.05$ nsec. The measured upper limit for the half-life of the 1.47-MeV level is $t_{1/2}\leq75$ psec. From a comparison of the present result for the 96-keV level with that of Zimmerman,[4] $t_{1/2}=(1.21\pm0.20)$ nsec, it is seen that the difference between the two results is allowed for by the uncertainty limits. No definite previous experimental value exists for the lifetime of the 1.47-MeV state.

Theoretical considerations regarding the lifetime of the 96-keV level have been made with the j-j coupling shell-model wave functions.[1] Matrix elements for an $M1$ transition between the $\frac{3}{2}^+$ first excited state and the $\frac{5}{2}^+$ ground state were computed and since the three nucleons outside the core are neutrons, only the contribution from the spin part of the $M1$ operator was included. The $(d_{5/2})^3$ configuration is dominant in both the $\frac{3}{2}^+$ and $\frac{5}{2}^+$ states; respective amounts of the $(d_{5/2})^3$ configuration in these two states from the Inoue *et al.* wave functions are 53 and 80%, and those from the j-j coupling analysis of Elliott and Flowers are 62 and 82%. The interesting feature of this calculation is that the $M1$ matrix element between the antisymmetric wave functions $|(d_{5/2})^3\frac{3}{2}\rangle$ and $|(d_{5/2})^3\frac{5}{2}\rangle$ is zero, which means that the dominant parts of both wave functions contribute to the $M1$ transition only by several cross terms with weak configurations. Since the wave functions were determined from an energy-level fit which in the case of O^{19} is not very good, large uncertainties in the small percentages of these additional configurations are expected. With the $M1$ transition probability depending sensitively on these small percentages, the accurate lifetime measurement of the 96-keV level thus serves as a good check on the weak configurations of the ground-state and first-excited-state wave functions for the O^{19} nucleus.

The experimental upper limit obtained for the 1.47-MeV level lifetime is not a good basis for theoretical comparisons since the lifetime is expected to be considerably smaller than this limit. A calculation for an $M1$ transition to the 96-keV level using the wave functions of Inoue *et al.*[1] implies a half-life of 5×10^{-14} sec which is a factor of 10^3 shorter than the measured experimental limit.

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