Lifetimes of the First Excited States of F^{17} and O^{17*}

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Using the gamma-gamma coincidence method and an electronic time-to-amplitude converter, the lifetimes of the first excited states in the mirror pair O^{17}(0.87 Mev) and F^{17}(0.50 Mev) have been measured. The reactions initiating the gamma cascades were $O^{16}(d,p)O^{17*}$ and direct proton capture in O^{16}. The time resolution of the coincidence circuit was good enough to allow the lifetime measurements to be made by direct observation of the exponential decay, rather than by measurement of the centroid shift. The measured mean life of O^{17*} is $(2.55\pm0.13)\times10^{-10}$ sec; the measured mean life of F^{17*} is $(4.45\pm0.22)\times10^{-10}$ sec. Both of these results are in reasonable agreement with earlier, less accurate values.

1. INTRODUCTION

THE transitions from the first excited state to the ground state in the mirror nuclei F^{17} and O^{17} provide a comparison of the role of an odd neutron and an odd proton in electric quadrupole transitions. It was first shown by Thirion and Telegdi[1] that the transition rate in O^{17} was much faster than that expected for an $E2$ single-neutron transition, and was actually very nearly the rate expected for a single-proton transition. This was explained by postulating a collective excitation of the O^{16} core by means of its interaction with the odd neutron.

Considerable theoretical effort has been expended to explain this transition in O^{17}. The measurement of the O^{17} ground-state quadrupole moment[2] and the F^{17} γ transition rate[3,4] have provided additional experimental data to be incorporated into theoretical treatments[5] of collective effects in these nuclei, which consist of an O^{16} core plus one odd nucleon. The previous measurements of the O^{17*} and F^{17*} lifetimes and of the O^{17} quadrupole moment had rather large experimental uncertainties ($\sim30\%$) so that almost all the theories could be made to be consistent with the data. Thus, a more precise measurement of these quantities seemed to be in order.

The O^{17*} lifetime was originally measured[1] [$\tau_m = (2.5\pm1.0)\times10^{-10}$ sec] using the $O^{16}(d,p\gamma)O^{17}$ reaction and observing the number of γ rays from recoiling O^{17} as a function of distance behind the target.

Two measurements of the F^{17*} lifetime have been made, both with electronic techniques. Lehmann *et al.*[3] used the $O^{16}(p,\gamma)F^{17}$ reaction and γ-γ coincidences [$\tau_m = (4\pm1)\times10^{-10}$ sec]. Holland, Lynch, and Hanna[4] used the same reaction with a pulsed beam to measure the lifetime [$\tau_m = (3.5\pm1.0)\times10^{-10}$ sec]. In neither measurement was the time resolution good enough to allow direct observation of the exponential decay. The lifetime was, instead, obtained by comparing the centroid position of a time spectrum from the F^{17} gamma rays with those from a "prompt" source. The uncertainty in both measurements was primarily due to possible systematic troubles, e.g., the effect of unidentified competing reactions.

Recent improvements in photomultipliers and coincidence circuitry have made it possible to observe the exponential decay for lifetimes of the order 2×10^{-10} sec.[6] Lifetimes measured in this way are relatively insensitive to the systematic errors associated with centroid shift measurements. We have therefore remeasured the O^{17*} and F^{17*} lifetimes to an accuracy of 5% by observing the exponential decays. This paper is a detailed report of our results which have been previously reported in abstract form.[7]

II. EXPERIMENTAL PROCEDURE

Our measurement of the lifetimes were performed using a γ-γ coincidence method. For the measurement of the O^{17*} lifetime, O^{17} in the second excited state was produced by $O^{16}(d,p)O^{17}$ using a 3-Mev deuterons from the Brookhaven National Laboratory Van de Graaff accelerator. This state decays primarily to the first excited state. Direct proton capture in O^{16} at a proton bombarding energy of 1.5 Mev was used to obtain the necessary γ-γ cascade in F^{17}. More details on these and competing reactions are discussed in Secs. IV and V.

The time-to-pulse height converter and associated circuitry shown in the block diagram of Fig. 1 are very similar to that described by Green and Bell.[8] Improved photomultipliers made it possible to use relatively large plastic scintillators without loss of time resolution. The width at half maximum of the time spectrum for Co^{60} was approximately 4×10^{-10} sec. The sides of the curves

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

[1] J. Thirion and V. L. Telegdi, Phys. Rev. **92**, 1253 (1953).
[2] M. J. Stevenson and C. H. Townes, Phys. Rev. **107**, 635 (1957).
[3] P. Lehmann, A. Lévêque, T. Grjebine, J. L. Picou, and R. Barloutaud, Compt. rend. **245**, 2259 (1957).
[4] R. E. Holland, F. J. Lynch, and S. S. Hanna, Phys. Rev. **112**, 903 (1958).
[5] R. J. Blin-Stoyle, Proc. Phys. Soc. (London) **A66**, 1158 (1953); R. D. Amado and R. J. Blin-Stoyle, Proc. Phys. Soc. (London) **A70**, 532 (1957); R. D. Amado, Phys. Rev. **108**, 1462 (1957); A. de-Shalit, Phys. Rev. **113**, 547 (1959); G. Barton, Nuclear Phys. **11**, 466 (1959); G. Barton, D. M. Brink, and L. M. Delves, Nuclear Phys. **14**, 256 (1959), S. Fallieros and R. A. Ferrell, Phys. Rev. **116**, 660 (1959).
[6] R. E. Bell and M. H. Jorgensen, Nuclear Phys. **12**, 413 (1959).
[7] J. V. Kane, R. E. Pixley, R. B. Schwartz, and A. Schwarzschild, Bull. Am. Phys. Soc. **5**, 239 (1960).
[8] R. E. Green and R. E. Bell, Nuclear Instr. **3**, 127 (1958).

had exponential slopes which decreased by a factor of 2 in 6×10^{-11} sec. Other details of the circuit and its operation are discussed in the Appendix.

Care was taken to ensure that the γ-γ delayed coincidence lifetime measurements were not affected by the presence of other γ-γ cascades. This was done by inspecting the radiations emitted from the target with a NaI(Tl) γ-γ coincidence spectrometer. The results of these investigations enabled us by proper choice of target materials and particle bombarding energies to reduce the number of unwanted cascade transitions, and to identify the remaining ones as known transitions corresponding to prompt cascades. Their intensities were sufficiently small in comparison with the cascade of interest so that their contribution to the exponential decay region of the delayed coincidence curve could be neglected.

III. TARGETS

Oxygen targets were used for both the O^{17} and F^{17} measurements.

A differentially pumped gas target at $\sim1/50$ atm pressure was used for the O^{17} measurements. The deuteron beam was introduced into the target (without foils) through three collimators successively 2 mm, 2 mm, and 1 mm diameter. The spaces between the collimators were evacuated by 200-liter/sec Heraeus pumps.[9] The gas was 99.6% oxygen, passed through a liquid nitrogen trap to remove any residual CO_2 impurity. The target pipe was 10 in. long with a tantalum beam stopper.

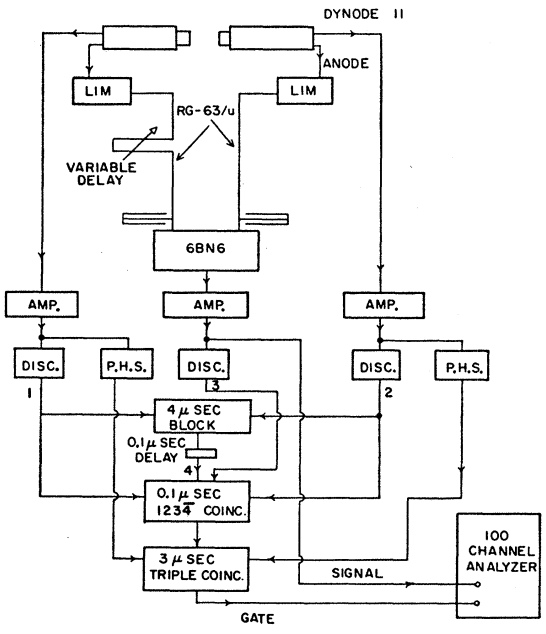

FIG. 1. Block diagram of fast-coincidence system.

[9] We are indebted to Mr. Charles Gould and the Brookhaven Accelerator Design and Development Department for the use of their Heraeus pumps.

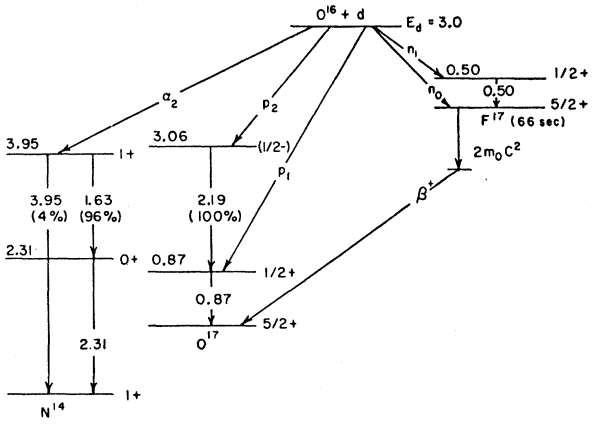

FIG. 2. Energy level scheme for nuclei formed in the deuteron bombardment of O^{16}. Data are taken from reference 10. Energies are in Mev.

The counters were well shielded from the collimators and the beam stopper.

For the F^{17} measurements, a 0.5-mm thick $\times$1.5-cm diameter tungsten plate was baked in a hydrogen atmosphere and then heated to redness in a 99.9% oxygen atmosphere. The oxidized plate was enclosed in a water-cooled copper target holder. No target deterioration was found during 24 hours of bombardment at 1.5 Mev with 50 μa of protons.

IV. O^{17} MEASUREMENTS

The gamma-ray cascade for the O^{17} measurement was obtained from the $O^{16}(d,p_2)O^{17}$ reaction.

The deuteron bombardment of oxygen yields the following radiations (see Fig. 2): $O^{16}(d,n_{0,1})F^{17}$ produces 0.51-Mev annihilation radiation from the β^+ decay of 66-sec F^{17}, as well as a 0.50-Mev gamma ray from the first excited state to the ground state; $O^{16}(d,\alpha_2)N^{14}$ results in 1.6 Mev-2.3 Mev γ-γ coincidences; $O^{16}(d,p_1)O^{17}$ gives the 0.87-Mev gamma ray to the ground state; $O^{16}(d,p_2)O^{17}$ gives the 2.2 Mev -0.87 Mev coincidences with which we are concerned. No other gamma rays were noted.

The $O^{16}(d,\alpha_2)N^{14}$ radiation was particularly troublesome when using plastic scintillators since the pulse-height selectors set for the Compton electrons of the 2.2$-$0.87 Mev cascade in O^{17} also admit with high efficiency the γ rays of the N^{14} cascade. An excitation function for the ratio of these two cascades was therefore measured using 3-in.$\times$3-in. NaI(Tl) detectors. Happily we found that the ratio of the $O^{16}(d,p_2)$ to $O^{16}(d,\alpha_2)$ yields showed a sharp maximum, equal to 10, near 3 Mev. At 50 kev on either side of this energy the ratio dropped to 5, and it dropped to 1 at 2.8 Mev. The NaI(Tl) coincidence spectrum taken at 3-Mev bombarding energy is shown in Fig. 3.

Singles and coincidence spectra (channeled from 1.5$-$2.0 Mev) using the plastic scintillators are shown in Fig. 4. The rise in singles counts at low pulse height

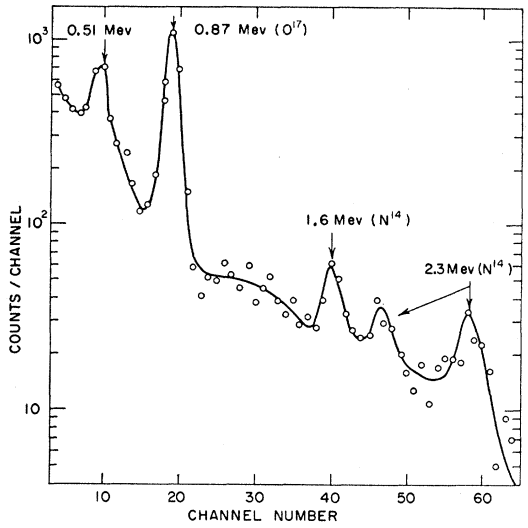

FIG. 3. NaI coincidence gamma-ray spectrum from the $O^{16}+d$ reaction. The second NaI detector is channeled between 1.3—2.5 Mev. The deuteron bombarding energy was 3.0 Mev.

is due to the $O^{16}(d,n)$ reactions and accounts for almost half of the singles counting rate. The pulse heights for the neutrons and for the 0.5-Mev radiation from these reactions are, however, below the pulse-height selector windows used for both γ rays in the O^{17*} lifetime measurement. The 0.87-Mev radiation is the next largest component of the singles spectrum; however, most of it is produced in the $O^{16}(d,p_1)$ reaction and so is not in coincidence with any other gamma ray. In fact, only 10% of the 0.87-Mev radiation is preceded by the 2.2-Mev gamma ray. The high-energy gamma rays ($\sim$2.3 Mev) seen in the coincidence spectrum are due to the $O^{16}(d,\alpha_2)N^{14}$ reaction. Since the lifetime of N^{14*} is $<2\times10^{-13}$ sec,[10] this radiation has no effect on the delayed part of the time spectrum, but does cause a 10% contribution to the prompt part.

The O^{17} lifetime measurement was made with a 1.6—2.0 Mev γ-ray energy window on the counter for the high-energy gamma ray and a window for the other counter in the region of the 0.87-Mev gamma. The lower edge of the 0.87-Mev window was set to exclude 0.5-Mev gamma rays. Both windows were approximately 30% wide. The beam current ($\sim$0.4 μa) was adjusted to give a total singles rate without pulse-height selection in each counter of $\sim$20 000 counts/sec. A coincidence rate of $\sim$0.2 count/sec was observed. Figure 5 shows the time spectrum obtained after 20 hours of counting. The prompt curve was obtained with a Na^{24} source of the proper strength to approximately reproduce the total singles rate due to the beam. This was done periodically to monitor circuit drifts. A second time spectrum with a singles rate approximately double the first (40 000 counts/sec) was also taken and was similar to that obtained at the lower rate.

[10] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. **11**, 1 (1959).

V. F^{17} MEASUREMENTS

The reaction $O^{16}(p,\gamma)F^{17}$ was used to produce the gamma cascade for the F^{17*} lifetime measurement. Gamma rays from this reaction have been studied by Warren *et al.*,[11] using a thin target. They found gamma rays corresponding to direct ground-state transitions and to the cascade through the first excited state, with the cascade transition being ten times stronger than

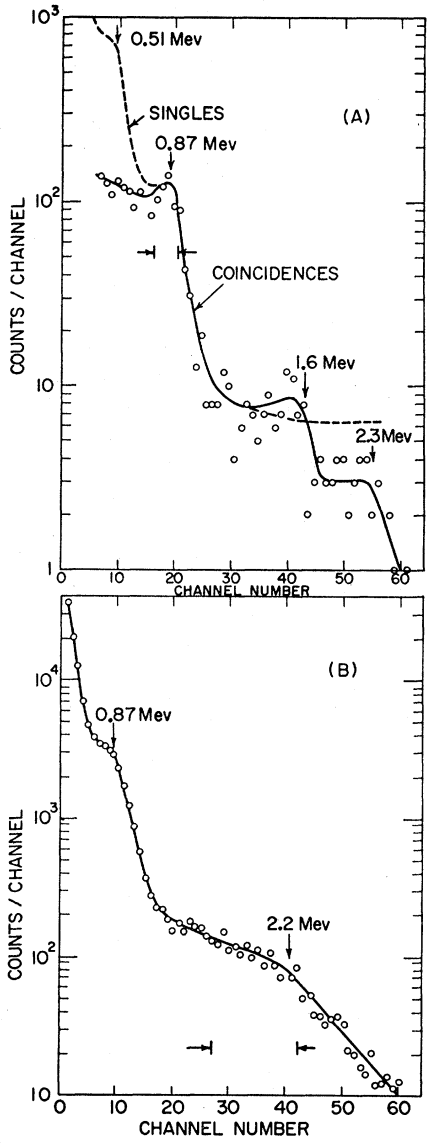

FIG. 4. Gamma rays from the $O^{16}+d$ reaction, using plastic scintillators. In (*A*), the solid line is the spectrum in coincidence with a channel between 1.6 and 2.0 Mev. The singles rate has been normalized to the coincidence rate at the Compton edge of the 0.87-Mev gamma ray. In (*B*) the spectrum in coincidence with a channel for the 0.87-Mev gamma ray is shown. The channels used in the lifetime measurement are indicated by the arrows. In all the plastic scintillation spectra the energies indicated refer to the Compton edge of the specified γ ray.

[11] J. B. Warren, T. K. Alexander, and G. B. Chadwick. Phys. Rev. **101**, 242 (1956).

the direct ground-state transition. The cross section was relatively constant above 1.3 Mev ($\sim 6\,\mu$b). The radiation to the first excited state had a $\sin^2\theta$ angular distribution. Since the Q value for the reaction leading to the 0.50-Mev state is 0.10 Mev, the capture gamma ray feeding this state has an energy approximately equal to the proton energy.

The gamma-ray spectra from our target were examined at several bombarding energies using two 3-in.×3-in. NaI(Tl) detectors, the detector for the high-energy radiation being positioned at 90° with respect to the beam. The two counters were shielded from each other by 1 in. of lead. A considerable amount of 6-Mev radiation is present due to the $F^{19}(p,\alpha)O^{16}$ reaction, the F^{19} being present as an impurity in the target. This 6-Mev radiation is not associated with any coincidences, except those due to the escape of an annihilation quantum from one crystal followed by its absorption in the other. The ratio of the $O^{16}(p,\gamma)$ to the $F^{19}(p,\gamma)$ yields decreased for $E_p > 1.5$ Mev; hence 1.5 Mev was the bombarding energy chosen for the lifetime measurement. It is to be noted that at 1.5-Mev bombarding energy the target was considerably thicker than the energy resolution of the NaI crystal, resulting in a rather smeared photopeak. Figure 6 shows the singles spectrum and the spectrum in coincidence with the window on the 0.5-Mev photopeak in the other counter.

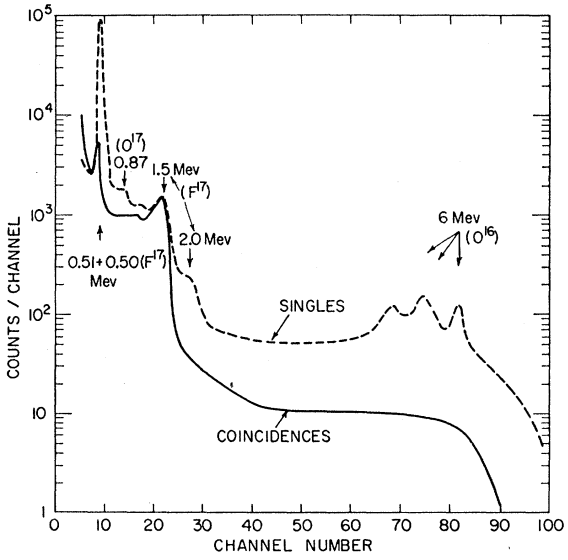

FIG. 6. Gamma rays from the $O^{16}+p$ reaction, using a NaI(Tl) detector. The singles spectrum (dashed curve) also shows the 6-Mev photopeak and two escape peaks from $F^{19}(p,\alpha)O^{16}$, and a small peak at 0.87 Mev from $O^{17}(p,p')O^{17}$. The solid curve is the spectrum in coincidence with a channel on the 0.5-Mev gamma. Since the proton bombarding energy was 1.5 Mev, the capture gamma rays to the ground and first excited states were 2.0 and 1.5 Mev, respectively.

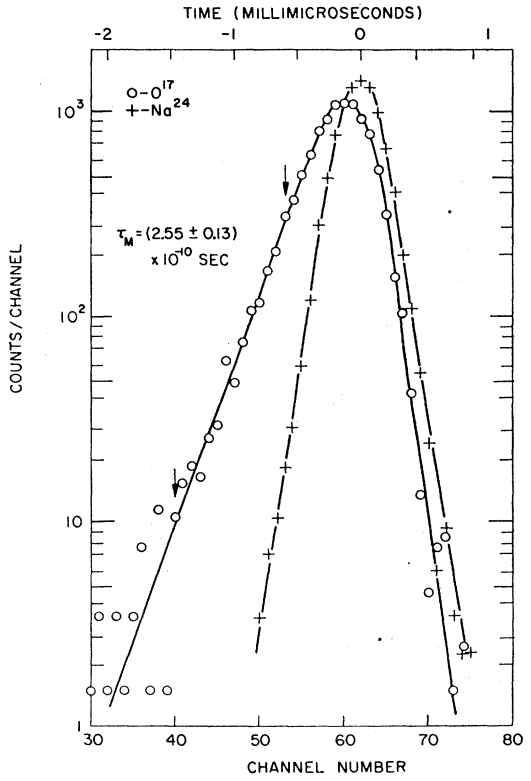

FIG. 5. Time distribution of coincidences in the 2.2 Mev −0.87 Mev cascade in O^{17}. The lifetime of the 0.87-Mev state in O^{17} is given by the slope of the least-squares fit to the data in the region between the two arrows. A (prompt) time spectrum from Na^{24} is included for comparison.

Figure 7 shows the singles and coincidence spectra from the plastic scintillators. Since one counter must

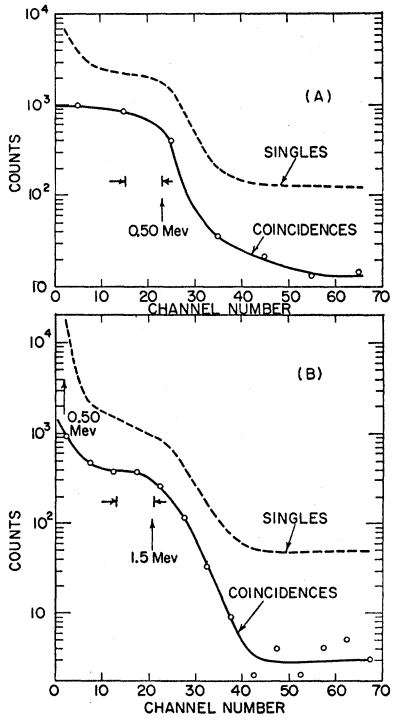

FIG. 7. Gamma rays from the $O^{16}+p$ reaction, using plastic scintillators. In (A) the dashed curve is the singles spectrum and the solid curve is the spectrum in coincidence with a channel set for the 1.5-Mev gamma. In (B), the dashed curve is the singles spectrum (on another energy scale), and the solid curve is the spectrum in coincidence with a channel set for the 0.50-Mev gamma. The channels used are indicated by the arrows.

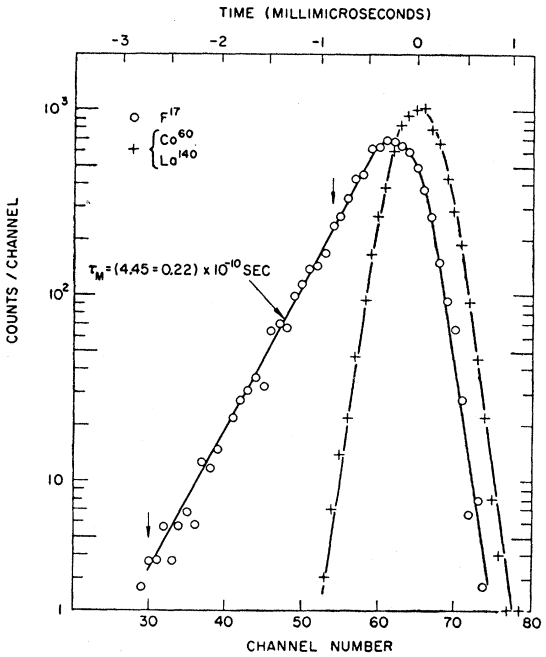

FIG. 8. Time distribution of coincidences in the 1.5 Mev -0.50 Mev cascade in F^{17}. The lifetime of the 0.50-Mev state in F^{17} is given by the slope of the least-squares fit to the data in the region between the two arrows. Prompt time spectra from Co^{60} and La^{140} are included for comparison; these two prompt spectra proved to be identical.

be channeled to include the 0.50-Mev ground-state transition, a number of precautions were taken to decrease the number of coincidences due to 0.51-Mev annihilation quanta being detected in that counter. The scintillators were located below the target so that no straight-line path through the target joined the two scintillators. In addition a tapered Hevimet (W-Cu) absorber $\frac{1}{2}$ inch thick shielded one counter from the other. While a few percent of the counts in the 0.5-Mev window were nevertheless due to secondary processes from the high-energy transition in O^{16}, it can be seen from Figs. 6 and 7 that they are sufficiently few in number that their effect on the lifetime measurement should be very small.

The total ungated singles rate with 50 μa of 1.5-Mev protons was approximately 4000 counts/sec. The coincidence rate was about 0.1 count/sec. Figure 8 shows the time spectrum obtained after 16 hours of running.

VI. CALIBRATION

Periodically during each O^{17} or F^{17} run a time scale calibration (mμsec/channel) was obtained by measuring the centroid position of a prompt time spectrum from a Na^{24} or La^{140} (0.815—1.6 Mev γ cascade) source, respectively, for two different settings of the variable, air-dielectric 125-ohm delay line.[12] During the course of

[12] A so-called "trombone." The design was obtained through the courtesy of N. Winningstad of the University of California Radiation Laboratory.

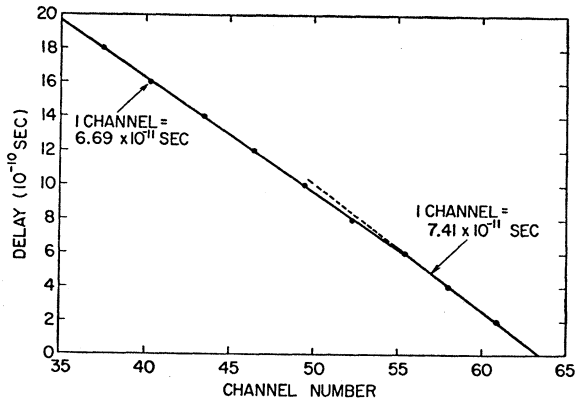

FIG. 9. Calibration of the time to amplitude converter. There is a change in slope near channel 55, amounting to a 10% change in the time delay-per-channel calibration.

the experiment, the calibration drifted by no more than 1% (rms deviation). In addition, a detailed calibration curve was taken for many different settings of the variable delay line. The result is shown in Fig. 9. A nonlinearity, amounting to a 10% change in slope, was noted. The calibration is linear, however, over the range of delays involved in the decaying part of the lifetime curves.

For the F^{17} runs, calibrations were taken with Co^{60}, in addition to the La^{140} source, to determine the extent to which the calibration of the time-to-amplitude converter depended upon the energy of the gamma rays (keeping the same window positions). There was no measurable difference in the calibrations obtained with the two sources, and the prompt curve shown in Fig. 8 was identical for both sources.

An auxiliary experiment was performed to measure the velocity of propagation of pulses in the variable line, using a Cu^{64} annihilation radiation source. The two counters were spaced $\sim$1 m apart, and the Cu^{64} source placed on the axis between them. The source was moved along this axis, and the "trombone" shifted by whatever amount was necessary to keep the centroid of the time spectrum stationary. An additional, auxiliary source was used to keep the singles count rate in the two counters equal and constant, although the measurement turned out to be not count-rate sensitive. This method of calibrating the "trombone" has the advantage, compared with methods involving rf resonance measurements, of using the same kind of pulses that are used in the actual experiment. Hence, any dispersion in the line is automatically included in this calibration. The calibration showed that the velocity of propagation of pulses in the line was (0.99 ± 0.01) times c, the velocity of light. In our calculations the velocity of propagation was assumed to be actually equal to c.

ANALYSIS AND RESULTS

The results of the O^{17} and F^{17} runs are plotted in Figs. 5 and 8, respectively. The lifetimes are given di-

rectly by the slope of the decay; the values quoted are obtained from a least-squares fit to the data in the region between the two arrows on the figures. Considerations of the time resolution of the instrument as described by Newton[13] indicates that the delay curve should be almost exponential in this region. Other least-squares fits were made using slightly different portions of the curve and, within statistics, the value of the slope did not depend upon the exact region of the fit.

The principal source of error is the counting statistics of the delay curve; this amounts to a standard deviation of $3\frac{1}{2}\%$ in lifetime. Another 2% is taken for calibration uncertainties, primarily to allow for the possibliity of small, undetected, nonlinearities in the time-to-amplitude converter (other than the 10% discussed in Sec. VI), as well as for the possibility of the velocity of propagation of the pulses in the variable delay line being different than c. An additional 3% is allowed for possible systematic errors resulting from coincidences of unknown origin. These errors are all assumed to be independent.

The values for the mean lives of the first excited states of O^{17} and F^{17} are, then,

$$\tau_m(O^{17*}) = (2.55 \pm 0.13) \times 10^{-10} \text{ sec},$$
$$\tau_m(F^{17*}) = (4.45 \pm 0.23) \times 10^{-10} \text{ sec}.$$

It should be noted in Figs. 5 and 8 that the maximum of the delay curve occurs at its intersection with the prompt curve, and further, that the centroids of the prompt curve and delayed curve are shifted by just one mean life, in the F^{17} case, and also in the O^{17} decay case when the 10% prompt component from the N^{14} cascade is removed. The proper centroid shifts are to be interpreted as a further check on the lifetimes derived from the exponential decays.

It was also noted that there was no difference between the O^{17} lifetimes measured at the two different counting rates mentioned in Sec. IV, indicating that the data are relatively free of any difficulties that may be caused by high counting rates. The results quoted and the data shown in Fig. 5, however, were taken only from the runs at the lower counting rate.

Finally, from the least-squares fit, both the "internal" (counting statistics) and "external" (deviation of the data points from the least-squares line) errors were computed. The two errors were approximately equal, implying that within the statistical accuracy, the single exponential line represents the most reasonable fit to the data points.

DISCUSSION

It is usually assumed that neutrons do not contribute directly to electronic multipole transitions. Thus the properties of transitions in O^{17} and F^{17} may be obtained from a description of the proton wave functions in these nuclei. In the particular case of O^{17} the transition rate is obtainable from the wave functions of the protons in the core, the odd neutron contributing nothing. For the transition in F^{17}, however, the odd particle is a proton; the transition matrix element is the sum of the matrix elements of the core protons and the matrix element of the extra proton. Theoretical treatments of this problem have been presented by several authors.[5] A review of the theoretical situation is presented by Raz in the introduction to the following paper.[14]

All analyses of these transitions have this feature in common; an explicit separation of the transition probability into the extra nucleon and core nucleon contribution is introduced as a simplifying concept.

The measured values of the lifetimes of the first excited states of O^{17} and F^{17} allow an exact experimental determination of the odd-nucleon and core-nucleon contributions, provided it is assumed that the wave functions of all particles are the same in these two nuclei. This represents an additional simplifying approximation and it is shown by Raz[14] that these simplifying assumptions permit a consistent description of some of the properties of these and of neighboring nuclei. If it is assumed that the wave functions of O^{17} and F^{17} differ in some way (other than the difference in the type of the last particle), the odd-nucleon and core contributions may be evaluated using theoretically determined parameters. This procedure introduces more than two nuclear transition matrix elements and hence these matrix elements cannot be uniquely determined from the measurement of two transition probabilities. A more complete test of the theories awaits a comprehensive survey of the electric properties of nuclei in this mass region.

ACKNOWLEDGMENTS

The authors are indebted to Professor D. H. Wilkinson for suggesting this problem. Special thanks go to R. Lindgren, A. Timpe, E. Reilly, and F. Rumph of the Van de Graaff crew.

APPENDIX. THE FAST COINCIDENCE CIRCUIT

As mentioned in Sec. II, the time-to-amplitude converter was essentially a standard one and has been described before.[8] We wish to report here a few modifications in this system, chiefly in the direction of getting high counting rates and high counting efficiency without loss in time resolution.

Three pairs of phototubes were tested: two Amperex type 56AVP's, two RCA type 7264's and two RCA type 6810A's. The 6810A's gave considerably poorer time resolution than either of the other two types and hence were not tested in detail. Using 7264's or 56AVP's with Co^{60} gamma rays, an over-all high voltage of 1700 to 1900 volts, plastic scintillators $1\frac{1}{2}$-in. diam$\times 1\frac{1}{8}$-in. long (Pilot B), and pulse-height selection windows 10%

[13] T. D. Newton, Phys. Rev. **78**, 490 (1950).

[14] B. J. Raz, following paper [Phys. Rev. **120**, 169 (1960)].

wide at the upper end of the Compton distribution, the time spectrum had a width at half maximum of about 4×10^{-10} sec, and the sides of the curves had exponential slopes which decreased by a factor of two in 6×10^{-11} sec. Increasing the window widths to 30% caused the width of the time curve to increase to 5×10^{-10} sec, but did not affect the slopes. Higher energy sources (Na^{24}) did not appreciably improve either the width or the slope, but lower energy windows did give both poorer widths and poorer slopes. There was essentially no difference in performance between the 56AVP and the 7624, and, in fact, during the actual experiment we used one of each of these tube types. Increasing the operating voltage beyond 1900 volts actually worsened the time resolution; we have no convincing explanation for this rather unexpected behavior. The time resolution did not improve significantly when smaller scintillators were used.

The anode signals from each phototube were fed to a Western Electric type 404A pentode limiter. The pulses were clipped at the input to the 6BN6 using ~1-m shorted RG63U stubs. The pulses were applied to grids 1 and 3 of a type 6BN6 gated beam tube, operated with a plate voltage of 30 volts, accelerator voltage of 20 volts, limiter grid bias of −0.9 volt, and quadrature grid bias of −1.1 volts. All voltage supplies were well regulated.

This circuit arrangement is essentially identical to that described by Green and Bell except that the supervisory coincidence circuit described by them was not employed.

In addition to the fast anode signal, a dynode signal from each phototube was used to give pulse-height selection. The amplified dynode signals and 6BN6 signals were fed into a standard triple fast-slow coincidence circuit[15] ($\tau_1=10^{-7}$ sec, $\tau_2=3\times10^{-6}$ sec) where pulse-height selection was made in the slow circuit. The fast-slow circuit also incorporated a "block" circuit, which, working on the fast circuit, assured that a second pulse from either phototube which came within 4 μsec of a preceding pulse would not be analyzed. This assures that all dc voltages, especially in the limiter and coincidence tube, had returned to their normal equilibrium level before the arrival of the next pulse to be analyzed. This enabled us to work at rates of 50 000 counts/sec with no loss of time resolution. Without the block circuit, the time resolution was about 20% worse at these high rates.

[15] This unit (EH1-950-1) was designed by R. L. Chase, Instrumentation Division, Brookhaven National Laboratory.