Lifetimes of the First Excited States of F^{17} and B^{10}†

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The mean life of the first excited state of F^{17} has been measured using a pulsed-beam technique. The mean life is definitely <0.5 mμsec. The result obtained is (0.35 ± 0.15) mμsec with the upper limit more firmly established than the lower. A value of 495 ± 15 kev was obtained for the excitation energy in F^{17}. A measurement of the mean life of the first excited state of B^{10} gave a value of (0.90 ± 0.1) mμsec.

INTRODUCTION

THE mirror nuclei O^{17} and F^{17} have been treated extensively because of the essential simplicity of a structure which consists of a closed shell plus a single nucleon. A sensitive measure of the validity of this simple picture for these nuclei is provided by a knowledge of transition probabilities for the low-lying levels. If the core is relatively inert, the lifetime of the first excited state in F^{17} or O^{17} should be approximated closely by the pure $E2$ lifetime for transition of a proton or neutron between the single-particle levels $s_{\frac{1}{2}}$ and $d_{\frac{5}{2}}$. Hence, the lifetime for F^{17} would be very much shorter than for O^{17}. At the other extreme, a large interaction with the core would tend to equalize and shorten both lifetimes. These effects have been treated quantitatively by a number of authors.[1,2]

From the measured mean life[3] of (0.25 ± 0.1) mμsec for the first excited state in O^{17}, it was already apparent that some collective motion must be invoked to explain the very short lifetime. To test the explanations advanced for this case, a measurement on the mirror level in F^{17} is very desirable. Unfortunately, any recoil technique such as the one used for O^{17} is difficult to apply since the energy of the radiation from F^{17*} ($\sim$500 kev) coincides so closely with the energy of the annihilation radiation which results from the positron decay of the ground state of F^{17}. In the hope that the lifetime might lie in the region accessible to an electronic technique, which would effectively suppress this background, a measurement was attempted with the timing method available in this laboratory. During the course of this work a successful measurement of the lifetime was reported by Lehmann *et al.*[4]

The nucleus B^{10} does not present the structural simplicity of F^{17} and O^{17}, but the success achieved in describing the location and character of the low-lying levels has stimulated a study of their transition probabilities.[5,6] In this case also, the reported measurements on the lifetime of the first excited state indicate the presence of collective motion in the $E2$ transition. These measurements have used both recoil and electronic techniques. As seen in Table I, the results are in qualitative agreement but there is possibly a quantitative disagreement, especially between the results of the two different techniques. Because of the importance of this lifetime, we present here a measurement utilizing the same method as used for F^{17}.

EXPERIMENTAL PROCEDURE

The excited state in F^{17} was produced by proton capture in O^{16} which is followed by a cascade through the level of interest. A thick target of ice (H_2O) was mounted at the end of the proton beam tube on a gold foil which was in contact externally with a reservoir of liquid nitrogen. The radiation was detected in a NaI crystal, 0.5 in. thick by 1.0 in. in diameter, mounted as close as practicable to the target and shielded from radiation from the accelerator.

The technique of measurement is described in more detail elsewhere.[7] The proton beam, $E_p=3.0$ Mev, was pulsed by passing it through an oscillating electric field which swept it back and forth across a slit situated at a distance of 200 cm from the field. The frequency of

TABLE I. Measurements of the mean life of the first excited state of B^{10}.

Mean life (mμsec)	Method	Reference
$0.7\ \pm0.2$	Recoil (collimator)	a
0.85 ± 0.2	Recoil (stopper)	b
1.05 ± 0.1	Electronic (p,γ)	c
1.16 ± 0.3	Electronic (γ,γ)	d
0.90 ± 0.1	Electronic (p,γ)	Present work
0.94 ± 0.06	Weighted average	

[a] See reference 3.
[b] J. C. Severiens and S. S. Hanna, Phys. Rev. **104**, 1612 (1956).
[c] See reference 10.
[d] S. Gorodetzky and A. Knipper, J. phys. radium **19**, 83 (1958).

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[5] D. R. Inglis, Revs. Modern Phys. **25**, 390 (1953).

[6] D. Kurath, Phys. Rev. **101**, 216 (1956), and **106**, 975 (1957).

[7] R. E. Holland and Frank J. Lynch, Argonne National Laboratory Report ANL-5818, 1957 (unpublished), p. 11. The method is similar to the one used and described by Weber, Johnstone, and Cranberg, Rev. Sci. Instr. **27**, 166 (1956).

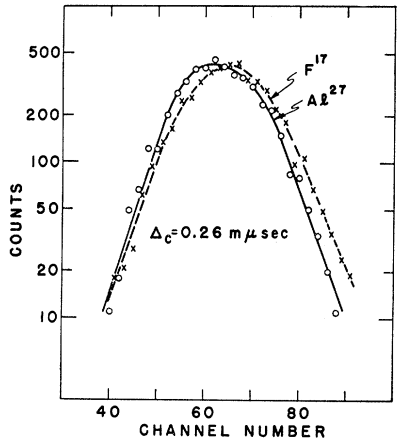

FIG. 1. The time spectrum for radiation from the first excited state of F^{17} in the reaction $O^{17}(p,\gamma)F^{17}$, compared with the time spectrum for radiation from the proton bombardment of aluminum. The difference in the centroids of the two curves is denoted by Δ_c and the value is given in millimicroseconds. The ordinate is logarithmic. Each channel is equivalent to 0.15 mμsec.

oscillation was 7.50 megacycles/sec and the maximum value of the field was 9.5 kilovolts/cm. The pulses thus produced on the target were separated in time by 62 mμsec, their width was approximately 0.6 mμsec, and the average current on the target was usually 0.2 μa.

The measurement consists essentially in determining the time of arrival of a gamma ray in the detector, on a time scale established by the pulsing of the beam. The characteristic time for each event is converted into a pulse height which can then be used with conventional circuits to obtain a variety of information.

The following spectra, all displayed on a 256-channel analyzer, were obtained:

(1) The total, ungated spectrum of pulse heights from the detector. This spectrum consisted chiefly of the capture radiation from $O^{16}(p,\gamma\gamma)F^{17}$, the annihilation radiation from the positron decay of F^{17}, and x-radiation from the accelerator. The radiation from the first excited state of F^{17} and the annihilation radiation produced a strong photopeak at 500 kev.

(2) The spectrum consisting only of those gamma rays which are produced promptly in the target (within about 4.0 mμsec) after the arrival of each proton pulse. This spectrum was obtained by gating the output of the detector with "time pulses" whose amplitudes were selected so as to correspond to prompt radiation. From this spectrum, in which the annihilation radiation was greatly suppressed, an energy of (495±15) kev was obtained for the radiation from F^{17*}.

(3) The spectrum of those gamma rays which are essentially uncorrelated with the proton pulse. In this case the spectrum was gated by time pulses with amplitudes corresponding to some time delay (>4 mμsec). In this spectrum the annihilation radiation appears with the random background since the lifetime of F^{17} is very much longer than the interval between proton pulses.

(4) The spectrum of the time pulses for those gamma rays which produce 495-kev pulses in the detector. In this case, pulses from the detector which pass a channel set at 495 kev were used to gate the output of the time-to-pulse-height converter. It is the analysis of this time spectrum which yields the value of the mean life.

(5) A spectrum similar in every way to (4) except that the oxygen (H_2O) target was replaced by an aluminum target. This time spectrum of prompt radiation[8] (chiefly from $Al^{27}(p,p'\gamma)Al^{27}$) was used as a standard with which the curve for F^{17} was compared as shown in Fig. 1. In order to minimize possible electronic drifts, the data were accumulated by interchanging the H_2O and Al targets many times without otherwise altering the experimental arrangement. Both targets were mounted in the target chamber, which was hinged to the main beam tube by means of a Sylphon bellows, so that either target could be readily rotated into position.

Before obtaining the final spectra in Fig. 1, a series of tests was carried out to investigate the distortions produced by excessive counting rates or by the variation of pulse height over the channel of acceptance. By stringently limiting the counting rate and using a very narrow channel, spanning a pulse-height interval equivalent to about 24 kev, spurious shifts in the time spectrum were reduced so that they were small, though not negligible, compared to the shift observed for F^{17}. As a test of the criteria which were used, the time spectrum for radiation from the first excited state of Na^{23}, obtained from the reaction $Na^{23}(p,p'\gamma)Na^{23}$, was compared with the time spectrum from the aluminum reaction, as shown in Fig. 2. Since the lifetime

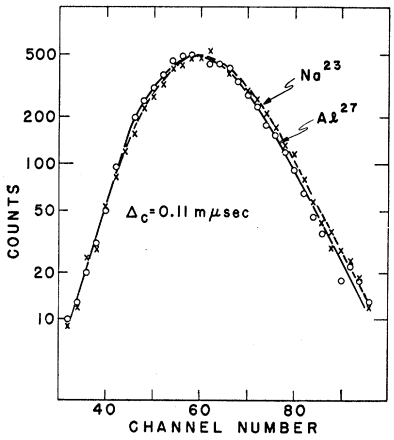

FIG. 2. The time spectrum for radiation from the first excited state of Na^{23} in the reaction $Na^{23}(p,p'\gamma)Na^{23}$ compared with the spectrum for radiation from the proton bombardment of aluminum.

[8] C. P. Swann and W. C. Porter, Bull. Am. Phys. Soc. Ser. II, 1, 29 (1956); Krone, Everett, and Hanna, Bull. Am. Phys. Soc. Ser. II, 1, 329 (1956).

of Na^{23*} is much less than 0.1 mμsec,[8] the shift observed in this case is presumed to be instrumental and sets a lower limit on the capabilities of the equipment as presently constituted.

The measurements on B^{10} were obtained in a completely anologous fashion to those on F^{17} and the final data are shown in Fig. 3.

RESULTS

The centroid of each time spectrum was computed and for each pair of curves in Figs. 1–3 the shift in the centroid Δ_c is tabulated in millimicroseconds. In Figs. 1 and 3 the shifts[9] are taken as a measure of the mean lives of the excited states of F^{17} and B^{10}. The spurious shift in Fig. 2 is indicative of the error in the measurements.

In the case of F^{17}, it is necessary to correct for the prompt background of primary capture radiation of higher energy which produces pulses in the acceptance channel through Compton scattering in the crystal. First, the spectrum described in (3) above was subtracted from the spectrum in (2), after suitable normalization, in order to obtain a prompt spectrum free of any random component. This spectrum was then analyzed to determine the fraction f of pulses in the acceptance channel produced by the 495-kev radiation from the first excited state. Then

$$\tau=\Delta_c/f,$$

where Δ_c is the measured shift of the centroid in Fig. 1 and τ is the shift with the background removed. With the value 0.75 found for f, we obtain $\tau=(0.35\pm0.15)$ mμsec. The error covers the uncertainty in f as well as the uncertainty in the measurement of the centroids. Since the measured shift Δ_c is only about 2 or 3 times the value of a possible spurious shift, as seen in Fig. 2, we feel that the upper limit given by the error is more reliable than the lower limit.

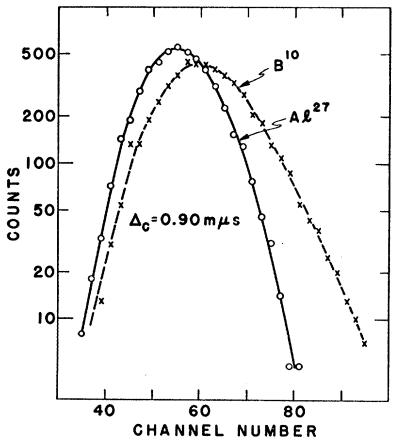

FIG. 3. The time spectrum for radiation from the first excited state of B^{10} in the reaction $B^{10}(p,p'\gamma)B^{10}$ compared with the spectrum for radiation from the proton bombardment of aluminum.

[9] T. D. Newton, Phys. Rev. **78**, 490 (1950); Bay, Henri, and Kanner, Phys. Rev. **100**, 1197 (1955).

For B^{10*} the correction for background is negligible and hence we take $\tau=\Delta_c=(0.90\pm0.1)$ mμsec.

DISCUSSION

The mean life obtained for F^{17*} is in reasonable agreement with the value of (0.25 ± 0.07) mμsec obtained by Lehmann *et al.*[4] These investigators observed gamma-gamma coincidences in the same capture process and measured a delayed coincidence curve. The two experiments are therefore similar; in one case the time of emission of the second gamma ray is determined relative to the emission of the first gamma ray and in the other it is determined relative to the proton capture.

A weighted average of the two results for F^{17*} is $\tau=(0.29\pm0.07)$ mμsec, and the ratio of the lifetimes for F^{17*} and O^{17*} is then 1.2 ± 0.6. Of more interest is the ratio of the reduced matrix elements, which is equal to 3.7 ± 1. This result emphasizes the deviation from a pure single-particle model for which the ratio would be

$$A^2/Z\approx36.$$

Barton[2] gives for this ratio a value of 3 for the collective model and 2.4 when configuration mixing is assumed. The matrix element for the transition in F^{17} is roughly equivalent to four Weisskopf units.

All the results which have been obtained for the transition in B^{10} are summarized in Table I. The present result appears to reduce the possibility that there is a systematic difference between the results of the two different techniques. The weighted average (0.94 ± 0.06) mμsec is in fair agreement with the various measurements. If the value obtained by Thirion and Telegdi[3] is actually too low, there might also be a systematic deviation in their measurement of the shorter lifetime of O^{17*}. It would therefore be very desirable to have a comparison of the lifetimes of O^{17*} and F^{17*} based on the same technique.

As pointed out in earlier papers,[6,10] the lifetime of B^{10*} is too short to be entirely compatible with a model based on intermediate coupling in the p shell. The strength of the $E2$ transition from this level as well as from some of the higher levels[6,11] indicates the presence of collective motion even in such a light nucleus as B^{10}.

ACKNOWLEDGMENTS

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