The first 4+ level of the axially asymmetric model is, instead, very near the 1.81-Mev Xe^{132} level, which could have spin 4. This model, as well as the extension of this model presented by Davydov and Chaban,[13] does predict a 3+ level which has an energy similar to that of the proposed spin 3, 1.966-Mev level. It might be noted that this 1.966-Mev level and the 1.81- and the 2.10-Mev levels appear to group around an energy which is three times that of the first 2+ level. This is the energy that the pure vibrational model predicts for five degenerate levels. The three levels of Xe^{132} could have spins of three of these levels; i.e., 2, 3, and 4.

In many even-even nuclei a 3- level, which can be explained as due to octupole surface vibrations,[15] has been observed with an energy between 2 and 3 Mev. There are three possible levels with spin 3 in this energy region in Xe^{132}. Unfortunately, it is not possible to say which one if any of these levels arises from octupole surface vibrations, since our results do not establish their parities.

The gamma-gamma angular correlation measurements indicate the 1.392-, 0.953-, and 0.518-Mev transitions consist of a large amount of dipole radiation. Since a transition between levels of even-even nuclei which arise from collective types of nuclear motion is expected to have a predominantly electric quadrupole character, this suggests that the 2.84-, 2.401-, and 1.966-Mev levels may be excitations of the intrinsic structure or at least strongly influenced by it.

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Half-Life of B^{12}, Na^{24m}, and As^{75m}†*

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The following half-lives were measured: B^{12}, $(20.31\pm0.20)\times10^{-3}$ sec; the 472-kev level of Na^{24}, $(19.9\pm0.3)\times10^{-3}$ sec; and the 305-kev level of As^{75}, $(16.8\pm0.4)\times10^{-3}$ sec. The activities were made with a pulsed beam from a Van de Graaff generator. The data were taken with gated radiation-detection circuits in conjunction with a 9-channel time-delay analyzer, and the half-lives were determined by least-squares analysis.

INTRODUCTION

THE need for accurate half-life measurements in the millisecond range has been apparent for some time. The theory of weak interactions is sufficiently advanced to be able to interpret very accurate values for the half-life of some of the light nuclei such as B^{12}. The demand on accuracy for gamma-transition half-lives are not yet as severe; however, in several restricted classes, where empirical systematics have been observed, accuracy of the order of a few percent is significant. The state of experimental half-life determinations just a few years ago may be illustrated with B^{12}, where published values ranged from 18.5 ± 1 msec[1] to 27 ± 2 msec,[2] or with As^{75m}, where values ranged from 12 ± 3 msec[3] to 21 ± 2 msec.[4]

Nuclei or nuclear states with half-lives in this time range are generally produced by activating a sample with the pulsed beam of an accelerator. The activity is then studied between beam pulses. It would appear that many of the earlier measurements were less accurate than had been claimed because of difficulties encountered in measuring the background on which the activity of interest was superimposed. In the work to be described, special precautions were taken to minimize the background due to the accelerator as well as the buildup of activities with intermediate half-lives. By analyzing the same data with different values for the background, an attempt was made to arrive at a realistic estimate of the accuracy of the reported half-lives.

EXPERIMENTAL PROCEDURE

The activities were produced either with the proton or with the deuteron beam of the large Los Alamos electrostatic accelerator. The type of information that could be obtained about these activities depended on the timing of the irradiation-counting cycle. Where the amount of activity was limited or where for background reasons the beam current had to be limited, an efficient

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[1] E. Norbeck, Jr., Bull. Am. Phys. Soc. 1, 329 (1956).
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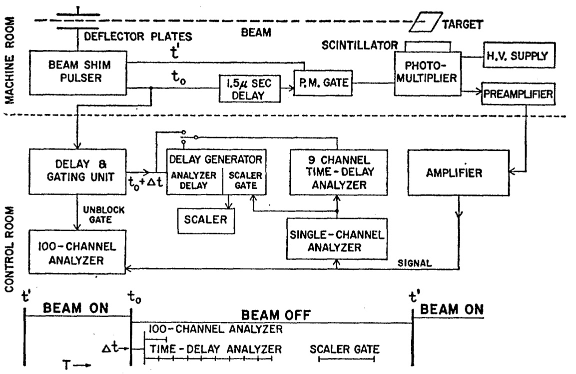

FIG. 1. Block diagram of electronics for gating the electrostatic accelerator and the radiation detector. The timing sequence is illustrated in the lower part of the figure.

way to take data was to irradiate 50% of the time and then to count during the other 50%. If the pulse length was several half-lives, then the short-lived activity was built up to near saturation at the end of each beam pulse. During a run, longer-lived activities in the second-to-minute range would also build up and reach half of their saturation value. Unfortunately, activities in this half-life range were invariably produced in addition to the desired one. A particularly bothersome impurity was 66-sec F^{17}, which could be produced by the (d,n) or even by the (p,γ) reaction on the oxygen contamination of the target. The 50% duty cycle was used in survey work for the purpose of observing all activities that could be activated in a given target.

Actual half-life measurements were made with about a 2.5% duty cycle, the beam-on time being roughly equal to the half-life of interest. The short-lived activity was then built up to about half saturation, while the longer-lived activities ($\sim$1 min) were present to 2.5% of saturation. Under these conditions, the ratio of initial counting rates was more favorable by a factor of 10 than the one found with a 50% duty cycle. It was also possible to count the background during each cycle, after the short-lived activity had died out and before the next beam pulse reactivated the target. A sampling of the background during each cycle was necessary, because the ratio of short-lived activity to background depended on machine operating conditions as well as on the amount of longer-lived activity that was built up on the target.

Figure 1 shows a block diagram of the circuitry[5] and an illustration of the timing cycle employed in most of the work. The beam could be deflected completely off target by applying +1000 v to one of the beam-deflector plates. The beam-deflector pulser determined the basic timing cycle. In addition to providing the deflection voltage, it generated the timing pulse t' when the beam was turned on and the pulse t_0 when the beam was again deflected. These pulses operated a flip-flop circuit which gated the first dynode of the photomultiplier off during the beam on time. Due to the slow time constant of light decay in NaI(Tl) it was found advantageous to introduce a 1.5-μsec delay after the beam pulse and before turning the photomultiplier on.

The beam-off, or t_0, pulse was utilized in the control room to initiate the counting cycle. A delay Δt of 10 μsec or longer was introduced before counting was actually started; during this time the amplifier recovered from the feed-through pulse of the photomultiplier gate. The decay of the activity was followed with a nine-channel time-delay analyzer which recorded the time distribution of pulses selected by a single-channel pulse-height analyzer. The background counts from this single-channel analyzer were recorded with a gated scaler which began a count cycle after the activity of interest had decayed. If the decay of the background was to be investigated, the start of the time-delay-analyzer cycle was delayed with respect to t_0 so that the analyzer covered the latter part of the beam-off cycle. Pulse-height spectra were recorded with a 100-channel pulse-height analyzer which was normally gated on for the duration of one half-life. The pulse-height distributions were always monitored with the 100-channel analyzer for changes in the photopeak position and for the appearance of new peaks due to the buildup of longer-lived activities.

The timing was derived in all cases from phantastron circuits and was stable to better than 1% for periods of weeks. Only the length of the time-delay-analyzer channels and of the scaler gate had to be known accurately. These were calibrated by counting a 1.0000-kc/sec signal from a crystal-controlled oscillator for the order of 10^3 cycles of the beam pulser. A practically random sampling of the standard frequency signal was obtained provided there was no small-number integral ratio between the standard signal and the beam-pulser frequency. Overlap or lack of overlap between the different time channels was checked by comparing the sum of the individual channel counts with the counts recorded by the "total" scaler.[5] For gate length in the millisecond range, the rms deviation of the time-delay-analyzer channels was about 0.2% and slow drifts of the average channel length were less than 0.5% over several hours. Since the rise time of the gates was about 0.5 μsec, the timing was less accurate in the microsecond range. Thus for a 10-μsec channel length the rms deviations were about 2% of the channel length.

Standard high-voltage supplies, amplifiers, and pulse-height analyzers were used. The half-life determination depends critically on the stability of the channel width and of the channel position of the single-channel pulse-height analyzer. If either of these should depend on counting rate, then a systematic error is introduced into the data. For this reason data were taken with

[5] The schematic circuit diagram of most of the circuits used has been described by J. P. Glore, Los Alamos Scientific Laboratory Report, LA-2152 (unpublished). For discussion of the delay and gating unit and of the time-delay analyzer, see also A. W. Schardt, Phys. Rev. **108**, 398 (1957).

both wide and narrow channels over a range of counting rates; no statistically significant effect could be found on the values of the half-life thus determined.

On most targets it was possible under continued irradiation to build up activities with half-lives in the minute-to-hour range. This effect was minimized by confining the irradiation to the time that data were actually being taken. A remotely operated tantalum shutter just ahead of the target was closed to permit lining up the accelerator beam and checking the circuits without activating the target. The materials to be irradiated were placed inside a stainless steel target tube with 0.010-in. wall thickness. A piece of 0.010-in. thick gold closed off the end of this tube. Compressed, amorphous boron enriched[6] to 98.1% in B^{11} was used for the B^{12} work. Na^{24m} was produced by the (d,p) reaction on a piece of pure sodium metal (100% Na^{23}). A coating of natural, 99.99% pure Ge metal (36.5% Ge^{74}), evaporated into the gold end of the target tube, served as target for the As^{75m} measurements.

RESULTS

B^{12}. This activity was produced with 2.3-Mev deuterons by the $B^{11}(d,p)$ reaction. The beam was pulsed on for 25 μsec once every 0.6 sec. The β activity was detected with a plastic scintillator on an RCA 6655 photomultiplier. Typical counting data are shown in Fig. 2. A least-squares fit to the data was made on an IBM 704 computer.[7] The values for the half-life as determined from different runs are given in Table I. The errors given were determined from the deviations of ten points from the curve fitted with three adjustable parameters[8] (B^{12} activity, B^{12} half-life, and background). The individual runs, which differed from each other in counting rate and bias level of the detector, were given equal weights in computing the final value

TABLE I. Experimental half-life determinations. (Half-lives are given in units of 10^{-3} sec; errors on individual runs were derived from closeness of fit of data points to calculated curve.)

Run No.	B^{12} (msec)	Na^{24m} (msec)	As^{75m} (msec)
1	20.52±0.10	20.16±0.12	16.93±0.26
2	20.19±0.10	19.65±0.20	16.93±0.21
3	20.30±0.05	19.90±0.18	16.33±0.22
4	20.26±0.16	19.64±0.15	16.58±0.19
5	20.28±0.10	19.85±0.15	16.97±0.37
6		20.01±0.16	16.77±0.34
7		20.10±0.15	
Mean	20.31	19.90	16.75
Rms deviation of mean	0.06	0.08	0.13
Over-all accuracy	±0.20	±0.30	±0.40

[6] The sample was obtained from The Hooker Electrochemical Company, Niagara Falls, New York.

[7] The code for least-squares analysis of the data was prepared by Roger Moore.

[8] This way of determining errors involves small-number statistics and is subject to large fluctuations; thus B^{12} run 3, Table I is not significantly more accurate than the other runs.

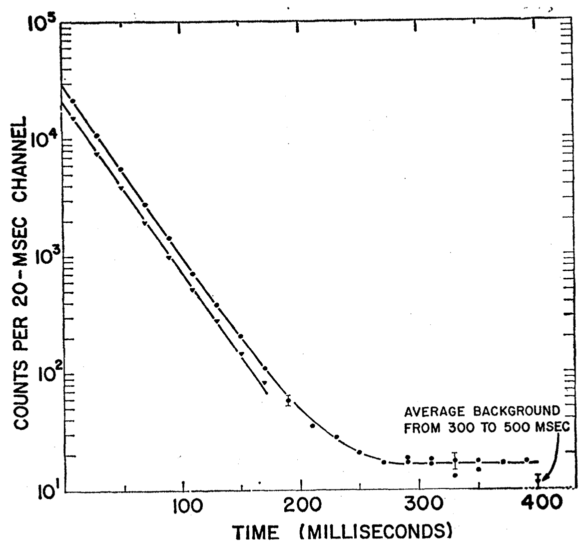

FIG. 2. Beta-decay curve of B^{12} without background corrections. ● These data were taken in three runs with different delays inserted before the start of the time-delay analyzer cycle. A typical run for the half-life determination is illustrated with the symbol ▲; the channel counts were accumulated over 1000 cycles.

of the half-life. The ±0.06 msec represents the rms deviation from the average and is a measure of the consistency of the data. The errors introduced by the absolute calibration of the time-delay analyzer are also small and amount to at most ±0.05 msec.

The major error in this half-life determination is due to the possibility of slight pulse-height shifts with counting rate and to possible time-dependence of the background. Since the different runs were taken with widely differing counting rates, it is safe to say that any error due to pulse-height shifts is less than 0.15 msec. The effect of background on the final half-life was computed for B^{12} run No. 4. In this run the gate length was 14.98 msec; data were taken over 1000 cycles. A total of 13 051 counts were accumulated in channel No. 1, and a background of 10.2±0.9 counts per 14.98 msec was measured during the time interval from 300 to 500 msec after the irradiation. If this background is ignored, then the computed half-life is 0.10 msec longer; on the other hand, if this background was due to an activity with a 0.2-sec half-life, the B^{12} half-life would be 0.16 msec smaller. In view of these effects an uncertainty of ±0.20 msec has been assigned to the final B^{12} half-life.

The 20.31±0.20 msec found for the half-life of B^{12} in this work may be compared with two recent measurements of comparable accuracy, namely, 20.6±0.2 msec[9] and 20.4±0.4 msec.[10] It should be noted that the error assigned in reference 9 does not cover any systematic error that might have been introduced by neglecting background corrections to the raw data.

[9] James F. Vedder, University of California Radiation Laboratory Report, UCRL-8324, 1958 (unpublished).

[10] B. J. Farmer and C. M. Class, Bull. Am. Phys. Soc. 4, 278 (1959).

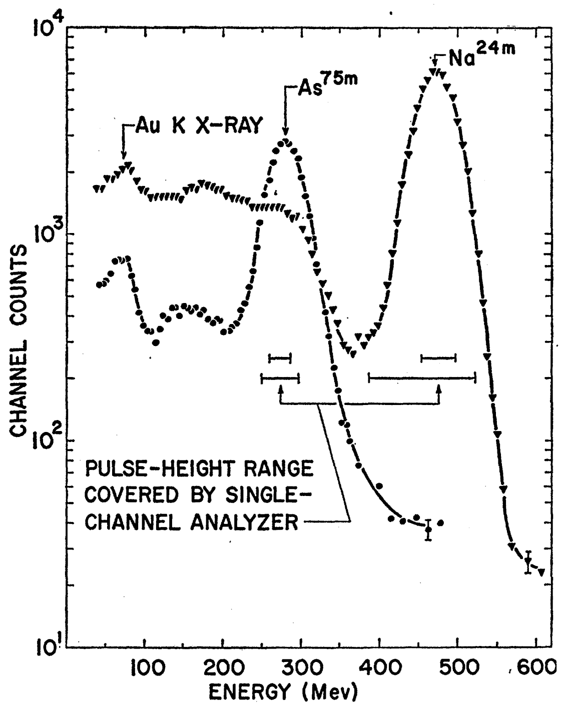

FIG. 3. Gated scintillation spectra of gamma rays in the Na^{24m} and As^{75m} decays. The cycle employed in taking the Na^{24m} data was as follows: beam on, 50 μsec; beam off, 500 msec; delay before gating on the 100-channel analyzer, 1 msec; and counting period, 20 msec. The corresponding numbers for the As^{75m} data were 20 msec, 400 msec, 1 msec, and 20 msec, respectively.

Na^{24m}. The sodium isomer was formed by the $Na^{23}(d,p)$ reaction with 4.0-Mev deuterons. The 472-kev gamma ray by which the isomer decayed was detected with a $1\frac{1}{2}$ in. diam by 1 in. long NaI(Tl) crystal. The values of half-life given in Table I were obtained by following the decay of the photopeak with the single-channel pulse-height analyzer covering the interval shown in Fig. 3. The background was counted from 250 to 350 msec after the beam pulse. Depending on operating conditions, the background per channel fell between 0.5 and 1.5% of the counts in the first time channel. The half-life found is 19.9 ± 0.3 msec, consistent with the value of 20 ± 2 msec reported elsewhere.[11]

As^{75m}. Protons with an energy of 2.6 Mev were used to activate As^{75m} by the $Ge^{74}(p,\gamma)$ reaction. The target was placed at the center of a NaI(Tl) well-type crystal, $2\frac{1}{2}$ in. diam by $2\frac{7}{8}$ in. long. A 280-kev gamma ray follows promptly after the 25-kev isomeric transition (Fig. 3). The values of the half-life, as determined from the decay of this gamma ray, are given in Table I. The background fell in the range from 3.5 to 7% of the counts in the first time channel, and again the half-lives obtained from runs with different backgrounds do not differ significantly from each other. The average, 16.8 ± 0.4 msec, is consistent with other more recent measurements.[12]

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[11] E. C. Campbell and P. F. Fettweis, Nuclear Phys. **13**, 92 (1959).

[12] These studies have been summarized by the author, Phys. Rev. **108**, 398 (1957).