Seven New Isomers with Half-Lives between 10^{-5} and 10^{-1} Second*†

STANLEY H. VEGORS, JR.,‡ AND PETER AXEL
Physics Department, University of Illinois, Urbana, Illinois
(Received October 28, 1955)

Isomers with half-lives greater than 10^{-5} second were sought between the 180-cycle 1-microsecond yield pulses of a 24-Mev betatron. The following new activities were observed:

Bombarded element	Half-life (μsec)	Energy (kev)
As	12 000±3000	305±15
Mo	16.5±1.2	98±5
Pd	33±6	165±15 305±15
W	16.0±1.0	370±15
Tl	65±5	410±15 706±20
Tl	530±50	506±15
Bi	2700±250	500±20 930±30

Additional results include (1) a new half-life determination of Y^{88m} as 287±15 μsec, (2) threshold measurements for several of the activities, and (3) negative results in looking for W^{180m} and Na^{22m}.

INTRODUCTION

THIS paper reports the initial successes of a systematic search for isomers with half-lives between 10^{-5} second and 10^{-1} second. Before this study, only four isomers had been reported in this intermediate half-life range: Ta^{181m} (22 μsec),[1] Pb^{206m} (145 μsec),[2] Y^{88m} (370 μsec),[3] and W^{180m} (5.5 milliseconds).[4] In contrast, there are more than 80 isomers whose half-lives are greater than 10^{-1} second and more than 40 isomers whose half-lives are less than 10^{-5} second.[5]

The disproportionately small number of isomers known with intermediate half-lives might lead one to conjecture about whether there is a scarcity of such isomers due to nuclear structure or whether the apparent absence of these isomers is due to inadequate detecting techniques. The fact that we were able to find seven new isomers in our initial work indicates that the previous techniques were the limiting factors. Even the longest half-lives in the intermediate range (i.e., 10^{-1} second) are too short to permit effectively moving a sample from the place at which it was irradiated to a detector. Thus, it is necessary to have both the sample and detector stationary while the short-lived activity is being formed. A technique which has worked very well with half-lives less than 10^{-5} second involves measuring isomers which are being formed continuously from longer-lived radioactive parents. If the isomeric half-life is sufficiently short, it is easy to measure the time interval between the radiations which announce the formation of the isomer and the decay of the isomer. However, when the isomeric half-life is too long, there may be too many independent radiations between the formation and the decay, and these extraneous radiations contribute a complicating, chance-coincidence, background.

The technique which is described here is more suitable in that a pulsed particle accelerator induces the nuclear reactions which form the isomeric states at a known time. The counting equipment measures the time between this formation and the subsequent decay. Softky[4] used this technique with the 300-μsec yield pulses of a 32-Mev proton linear accelerator, whose yield pulses occurred 15 times per second. Half-lives between 2 and 25 milliseconds should have been detectable using this technique. Using 17 different targets (Be, Mg, A, Ni, Cu, Zn, Mo, Ag, Cd, In, Sn, Ta, W, Pt, Pb, Bi, and U), Softky found an isomer only with the Ta target and he assigned this 5.5-millisecond isomer to W^{180m}.

The work reported here used the 1-μsec bremsstrahlung yield pulses from the University of Illinois 22-Mev betatron which has a repetition rate of 180 pulses per second. However, modifications were made on the betatron so that the repetition rate of the machine could be decreased, when desired, by a factor of 2, 4, or 8, thus increasing the time between yield pulses by a corresponding amount. The NaI scintillation detector could be made sensitive for any time interval except a 30-μsec interval which ended 20 μsec after the yield pulse. The preliminary survey reported in this paper

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† A more complete report of this research was included as a thesis submitted in partial fulfillment of the requirements for the PhD degree.
‡ University of Illinois Predoctoral Fellow.
[1] S. De Benedetti and F. K. McGowan, Phys. Rev. **70**, 569 (1946).
[2] D. E. Alburger and M. H. L. Pryce, Phys. Rev. **95**, 1482 (1954).
[3] Hyde, Florence, and Larsh, Phys. Rev. **97**, 1255 (1955).
[4] S. D. Softky, Phys. Rev. **98**, 736 (1955).
[5] See, for example, M. Goldhaber and A. W. Sunyar, in *Beta- and Gamma-Ray Spectroscopy*, edited by Kai Siegbahn (North-Holland Publishing Company, Amsterdam, 1955), Part II, Chap. 16.

involved 27 different elements as samples. Seven new isomers were identified while using as samples the six elements: As, Mo, Pd, W, Tl, and Bi. These are shown in Table I, together with new lifetime measurements made on four previously known isomers in Zn, Y, Ta, and Pb.

No intermediate-lived activities were observed with 17 elements: O, Na, Mg, Al, Cl, K, Ti, Cr, Mn, Fe, Ni, Zr, Sb, I, Ba, Ce, and Th. Inasmuch as further improvements in techniques are possible, these negative results are not particularly significant; these elements will be reinvestigated with the increased sensitivity of improved techniques.

EXPERIMENTAL PROCEDURE

Samples were placed about 10 feet from the betatron target in a $1\frac{5}{8}$-inch diameter collimated bremsstrahlung beam. A 1 in.×1 in.×2 in. rectangular NaI crystal mounted on a Dumont 6292 phototube was placed as close as possible to the sample without itself being in the x-ray beam. An electronic gating network was used to select the delay time between the x-ray burst and the sensitive time of the counting equipment.

Since the x-ray burst lasted for only 1 μsec, the background present when the counting equipment was sensitive consisted of slow neutrons and long-lived induced radioactivity. The slow neutrons and the capture gamma rays emitted when these neutrons were captured formed the most annoying part of the background and the shielding was designed mainly to minimize these neutron effects. The main collimator made of Pb was 14 in. long and had an exit port $\frac{3}{4}$ in. in diameter. It was placed about $5\frac{1}{2}$ feet from the betatron target. A large concrete wall, $1\frac{1}{2}$ feet thick, was placed between the betatron and the main collimator in order to prevent the noncollimated radiation from leaving the vicinity of the betatron. The main collimator emitted many neutrons due to (γ,n) processes, and was therefore surrounded first by a layer of paraffin and then by a layer of borax.

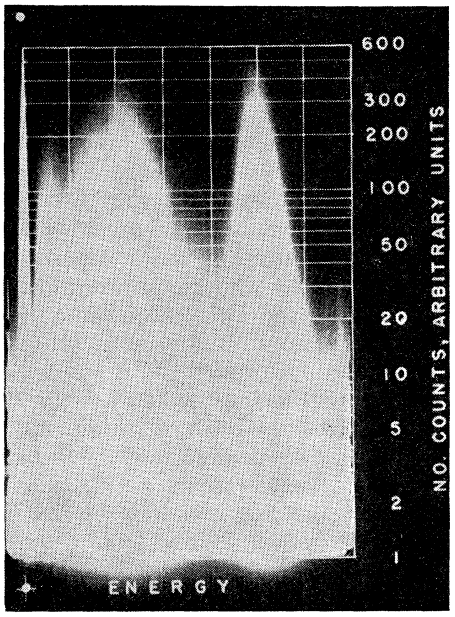

FIG. 1. Y spectrum, $E_\gamma = 393$ kev. The line at the origin of the energy axis marks zero energy. The sudden decrease of intensity at approximately $\frac{1}{4}$ energy divisions is artificial.

TABLE I. Observed isomeric lifetimes.

Element bombarded	Half-life (μsec) This work	Previous reports	Energy of emitted gamma rays (kev)
	New isomers		
As	12 000±3000		305±15
Mo	16.5±1.2		98±5
Pd	33±6		165±15, 305±15
W	16.0±1.0		370±15
Tl	65±5		410±15, 706±20
Tl	530±50		506±15
Bi	2700±250		500±20, 930±30
	Previously known isomers		
Zn^{67m}	8.8±1	8.5, 9	
Y^{88m}	287±15	370±30	
Ta^{181m}	18.5±2.5	22, 20.1±0.7, 18.8±0.5, 16±3	
Pb^{206m}	132±10	145±15	

With this collimation and shielding, the principal delayed background at the detector came from gamma rays emitted when slow neutrons were captured near the collimator or by the walls, ceiling and floor of the room. The sample and detector were therefore placed in the center of a Pb house, 18 in.×21 in.×18 in., which had walls that were 2 in. thick. The region around the beam's entrance hole had a 4-in. thick wall. The Pb house was surrounded by an 8-inch thick layer of borax which in turn was surrounded by an 8-inch thick layer of paraffin in order to minimize neutron capture in the vicinity of the detector. An air ionization chamber was used to measure the yield of the beam after it had left the Pb house.

In the final shielded arrangement, when a 6.9-g/cm^2 Al sample was used about one third of the detected background came from the neutrons it produced. The background per unit yield in the collimated beam was independent of whether the betatron target was made of Pt or Ni, indicating that the neutrons produced in the betatron target did not contribute appreciably to the background. A more favorable count-to-background ratio was obtained when the collimated beam was sent through a hole in the rear wall and the sample and detector were both placed outside of the betatron building. However, because of the higher beam intensity available inside, higher precision could be obtained inside the betatron room despite the higher background.

The residual background had no characteristic gamma rays but did have an apparent half-life of about

200 microseconds. This background could be reduced during any lifetime measurement by selecting only events in the narrow energy range corresponding to lines present in the activity being measured. In addition to this short-lived background, there were long-lived backgrounds arising from induced radioactivities. The effects of these long-lived backgrounds could be measured and subtracted properly. However, backgrounds due to long-lived radioactivities decreased the precision and reduced the sensitivity of the technique for finding new isomers.

The phototube on which the NaI crystal was mounted was gated off during the x-ray burst by a +300-volt pulse applied to its photocathode. This gating avoided both after pulsing in the phototube and excessively large signals which would have resulted from the huge scintillation produced by scattered radiation during the x-ray burst. The gating pulse itself produced an electronic "feedthrough" pulse on the anode of the photomultiplier and a small inverted pulse was applied to the anode to cancel out this feedthrough. The gating pulse was initiated by the "betatron-expander trigger" which preceded the yield pulse by about 10 microseconds; the gating pulse remained on for about 10 μsec after the yield pulse was finished. The preamplifier and amplifier did not recover from the gating pulse and the feedthrough compensating pulse until 20 μsec after the yield pulse. This slow recovery was not studied and may have been due to either the crystal, the phototube, or the electronics.

Two different types of pulse-height selectors were used to determine the energy of the gamma rays. One of these was a modified gray-wedge pulse-height analyzer[6] which was used to search for new activities. The modifications which made it possible to measure half-lives, included (a) a coincidence circuit which required the presence of an externally generated timing gate before a pulse could be displayed, and (b) a pulse-height channel selector which allowed pulses to be displayed only if they came within a preset amplitude range.[7]

The second type of pulse-height selector was a standard single-channel device whose output pulses were sent through either a one-channel or a five-channel coincidence timing network. The coincidence circuits and timing circuits were of conventional design as were the preamplifier, amplifier, power supplies, and scalers. The single timing gate had a duration variable from 10 to 2000 μsec and could be delayed from the yield pulse by from 20 to 3000 μsec. The five-channel timing circuit produced five contiguous gates, each of adjustable duration so that five points of a half-life curve could be taken simultaneously.

[6] Bernstein, Chase, and Schardt, Rev. Sci. Instr. 24, 437 (1953).
[7] R. L. Chase, Brookhaven National Laboratory Report BNL-263(142) (unpublished).

PRECISION OF MEASUREMENTS

Since the work reported here was of a preliminary nature, the precision obtained was that which could be obtained easily and was in no case limited by fundamental difficulties in the technique. In any particular case, both the sample and the detector could be redesigned to give an optimum count-to-background ratio. Since the lifetime measurements were limited by background, the lifetimes could be determined more accurately by a more complete suppression of this background. The energy measurements could also be improved by a more thorough calibration of the scintillation spectrometer. The least precise measurements made thus far are those which involve relative intensities. Because of the thickness of the samples, the poor geometry, and the unknown effective thickness of the crystal, relative intensity measurements may be inaccurate by as much as a factor of two or three for x-rays and 50% for γ rays.

Each half-life and energy value was measured on at least two different occasions.

RESULTS

A. Previously Known Activities

1. Zn^{67m}.—Using a 2.54-g/cm^2 Zn sample, we observed a 90±5 kev gamma ray which decayed with a half-life of 8.8±1 μsec. These results are in good agreement with the previously reported values of 92 kev[8,9] and of 9 μsec[8] and 8.5 μsec.[9] This agreement indicates that this technique is sensitive even to low energy, relatively short-lived radiations.

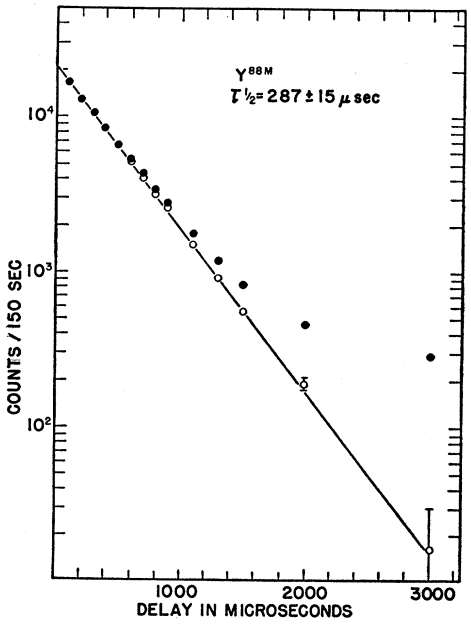

FIG. 2. Y half-life. This measurement gives $\tau_{\frac{1}{2}}=287\pm15$ μsec. Best value is $\tau_{\frac{1}{2}}=287\pm15$ μsec.

[8] Meyerhof, Mann, and West, Phys. Rev. 92, 758 (1953).
[9] Ketelle, Brosi, and Porter, Phys. Rev. 90, 567 (1953).

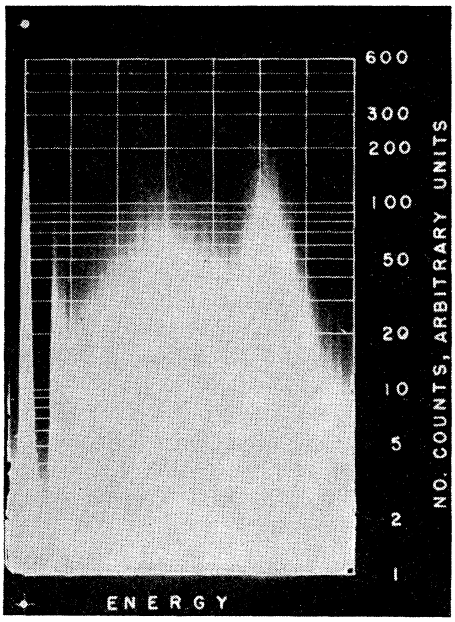

FIG. 3. As spectrum, $E_\gamma = 305$ kev. The line at the origin of the energy axis marks zero energy. The sharp increase in intensity below 1 energy division is due to noise. The sudden decrease of intensity at approximately $\frac{1}{2}$ energy division is artificial.

2. Y^{88m}.—Using a 1.22-g/cm^2 sample of Y_2O_3, we observed a 393±15 kev gamma ray which decayed with a half-life of 287±15 μsec. The scintillation spectrum is shown in Fig. 1, which is illustrative of the type of data obtained with the gated grey-wedge circuit. The outstanding 393-kev photopeak (appearing at the fifth division on the energy axis in Fig. 1) was selected by the auxiliary pulse-height selector for the half-life measurements. The half-life measurement, which was the most precise one made, is shown in Fig. 2. Although the half-life is somewhat shorter than the previously reported 370±30 μsec, the energy is in good agreement with the reported value of 395 kev. After the experiment on Y was completed, evidence for a weak line at 45±5 kev was noticed; its origin will be investigated in the future.

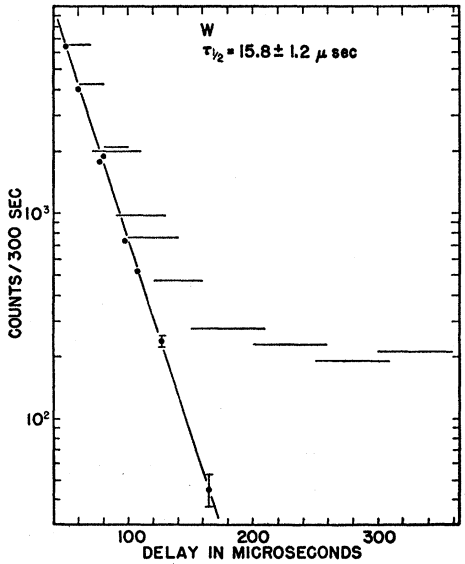

FIG. 4. W half-life. This measurement gives $\tau_{\frac{1}{2}} = 15.8 \pm 1.2$ μsec. Best value is $\tau_{\frac{1}{2}} = 16 \pm 1$ μsec.

3. Ta^{181m}.—Using a 10.1-g/cm^2 sample of Ta, we observed the known lines in Ta^{181m} but no attempt was made to measure the energies accurately. A determination of the half-life gave a value of 18.5±2.5 μsec in good agreement with the precise values of 20.1±0.7 μsec[10] and 18.8±0.5 μsec[11]; measurements by other observers gave 22 μsec[1] and 16±3 μsec.[12]

4. Pb^{206m}.—When an 11.3-g/cm^2 Pb sample was used, the previously reported activity[2] in Pb^{206m} was observed. The measured half-life of 132±10 μsec agrees well with the previously measured value of 145±15 μsec. The spectrum showed a 343-kev peak, unresolved peaks at 516 and 537 kev, and peaks at 803 and 880 kev. Neither the energy nor the intensity measurements were comparable with the much more detailed earlier work[2] but our qualitative results are consistent with the suggested decay scheme. The Pb^{206m} activity has an apparent threshold energy of 10.38±0.45 Mev indicating that most of the observed activity comes from a (γ,n) reaction on Pb^{207} rather than from a (γ,γ') reaction on Pb^{206}. This behavior is similar to that of 0.8-sec Pb^{207m} which was observed to have an apparent threshold of 10.29±0.2 Mev in good agreement with a previous measurement[13] of 10.2 Mev. In both cases, the apparent threshold is well above the true (γ,n) threshold implying that the activity is not formed in significant amounts until the neutron has enough energy to penetrate the centrifugal barrier.[14] A more quantitative study of the implications of these apparent thresholds is planned.

B. New Activities

1. As.—A sample of 7.15 g/cm^2 of As showed a distinctinctive line of 305±15 kev which decayed somewhat in the 5555-μsec interval between x-ray bursts. In order to measure this half-life accurately, the University of Illinois 22-Mev betatron was modified so that the repetition rate of x-ray yield pulses was at $\frac{1}{8}$ of the usual rate, thus giving a time interval of 44 440 μsec between yield pulses. With the betatron thus modified, the As half-life was determined to be 12 000±3000 μsec. A spectrum of the As activity is shown in Fig. 3. This picture was taken for eleven and one-half minutes and includes 40 000 counts; the

[10] Bunyan, Lundby, Ward, and Walker, Proc. Phys. Soc. (London) **A61**, 300 (1948).
[11] H. S. Murdoch, Proc. Phys. Soc. (London) **A66**, 944 (1953).
[12] R. A. Becker and H. N. Brown, Phys. Rev. **90**, 328 (1953).
[13] Bendel, Toms, and Tobin, Phys. Rev. **99**, 672 (1955).
[14] See for example, P. Axel and J. D. Fox (to be published).

timing gate is set at a delay of 1000 μsec and a duration of 1000 μsec.

2. Mo.—When a 2.9-g/cm^2 sample of MoO_2 was used, a 98±5 kev gamma ray was observed with a 16.5±1.2 μsec half-life. The apparent threshold of this activity is 8.4±0.6 Mev. It is hoped that a more precise threshold determination together with a semiquantitative measurement of the yield will help determine the isotopic assignment of this isomer.

3. Pd.—The weakest observed activity was found in a 1.0-g/cm^2 sample of Pd. Two gamma-ray lines of 165±15 kev and 305±15 kev are observable with intensities which, within the 50% precision, may be equal. Each line has a half-life consistent with a value of 33±6 μsec. A thicker Pd sample will be reinvesti-

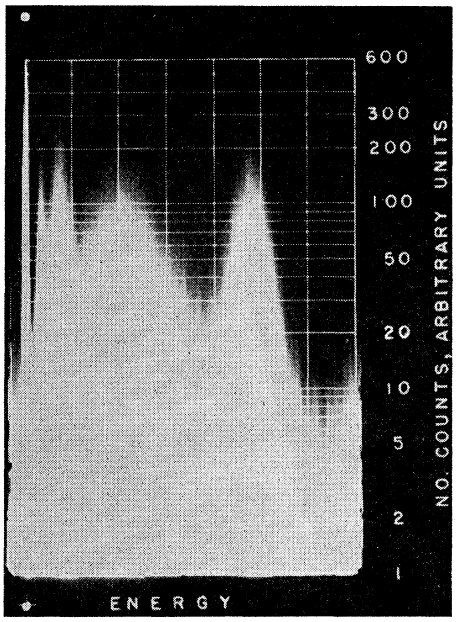

FIG. 5. W spectrum, E_γ=370 kev. A strong K x-ray can also be seen. The line at the origin of the energy axis marks zero energy. The intensity increase below $\frac{1}{2}$ energy division is probably due to noise. The decrease of intensity at approximately $\frac{1}{3}$ energy division is artificial.

gated and more precision will be obtained in order to ascertain whether a single isomeric cascade or two independent isomers are formed in the Pd sample.

4. W.—At the time of this investigation, the only convenient W sample we had was a 0.7-g/cm^2 sample of $NaWO_4 \cdot 2H_2O$. A gamma ray of 370±15 kev and an x-ray (presumably from W) were observed to decay with a half-life of 16.0±1.0 μsec. The approximate relative intensity of the x-ray and gamma ray imply a conversion coefficient of about 0.25. The conversion coefficient and the half-life lead to the probable assignment of the 370-kev gamma ray as an $M2$ transition. Three half-life measurements were made and agreed within 8%. A typical curve is shown in Fig. 4, and a spectrum is shown in Fig. 5.

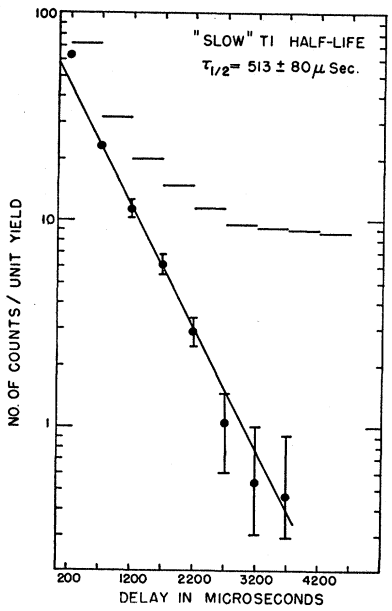

FIG. 6. "Slow" Tl half-life. The first point is high due to the contribution from the "fast" Tl activity. This measurement gives $\tau_{\frac{1}{2}}$=513±80 μsec. Best value is $\tau_{\frac{1}{2}}$=530±50 μsec.

A search was made for the reported[4] 5.5-millisecond W^{180m} activity we hoped to make with a $W^{182}(\gamma,2n)$ reaction. The threshold for this reaction is at 15 Mev, which is 9 Mev below the energy at which we attempted to find it. A 2000-μsec delay was used so that there was no interference from the 16-μsec isomer. We were

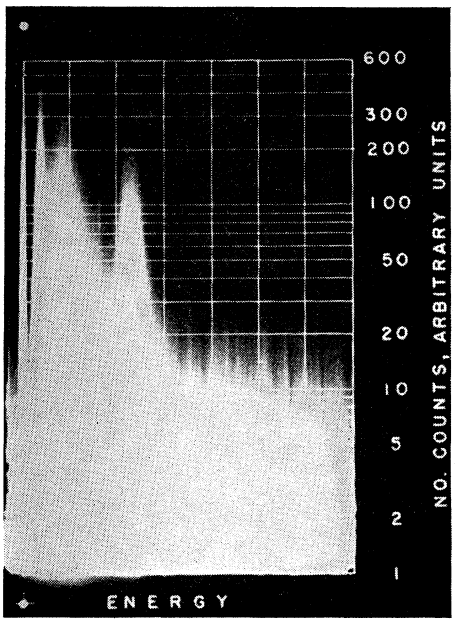

FIG. 7. "Slow" Tl spectrum, E_γ=506 kev. Tl K x-ray can be seen at $\frac{1}{3}$ energy division. The line at the origin of the energy axis marks zero energy. The decrease of intensity below $\frac{1}{3}$ energy division is artificial.

unable to see either the 220-kev or 350-kev lines that have been reported.[4] However, due to thinness of the sample, and the presence of O_2 which produced a comparatively long-lived 510-kev positron annihilation line, the absence of the 5.5-millisecond isomer cannot be interpreted as a definite refutation of the assignment of this isomer to W^{180m}.

5. Tl.—At least two different activities were observed when 0.6 g/cm² of Tl was used as a sample. The longer-lived activity had a half-life of 530±50 μsec (as shown in Fig. 6) and a gamma-ray energy of 506±15 kev (as shown in Fig. 7, which was taken with a 1000-μsec delay and a 1000-μsec gate). The relative intensity of the x-ray (presumably from Tl) and the 506-kev gamma ray implies a K conversion coefficient of about 0.25. The lifetime and conversion coefficient of the 506-kev gamma ray are in best agreement with an $M3$ transition, although it is impossible to rule out anomalously slow $E3$ or $M2$ transitions.

The shorter-lived activity seemed to consist of two gamma rays each of which had a half-life of 65±5 μsec. A typical half-life curve is shown in Fig. 8. The two gamma rays, whose energies were 410±15 kev and 706±20 kev, had about the same intensity which tends to support the assignment of both of these gamma rays to a cascade decay of a single isomer. A typical spectrum taken with a delay of 60 μsec and a gate duration of 200 μsec is shown in Fig. 9; an indication of the 506-kev line present in the 530-μsec activity can be seen on the high-energy edge of the 410-kev gamma-ray peak. The data are consistent with either gamma ray being the first one in the cascade. If the 410-kev gamma ray occurs first, it is probably an $M2$ transition; whereas, if the 720-kev gamma ray occurs first, it is probably an $M3$ or an $E3$ transition. Once again the possibility of anomalously slow $M2$, 720-kev transitions or anomalously slow $E2$, 410-kev transitions cannot be ruled out.

6. Bi.—Using a 10.6-g/cm² sample of Bi, we observed two gamma-ray lines whose energies were 500±20 kev and 930±30 kev. A typical spectrum taken with a delay of 2000 μsec and a gate duration of 2000 μsec is shown in Fig. 10. With the betatron modified so that the repetition rate was decreased by a factor of 4, giving an interval between yield pulses of 22 220 μsec, the Bi half-life was determined to be 2700±250 μsec. A typical half-life curve is shown in Fig. 11. To within the obtainable precision, the data are consistent with a two-step gamma-ray cascade with either gamma ray coming first. It is rather surprising that Softky[4] did not observe this activity when he bombarded either Pb or Bi with 32-Mev protons.

NEGATIVE RESULTS

Although negative results were obtained with 17 samples, only one of them—a 5.6-g/cm² sample of Na—will be discussed in any detail. Na is particularly interesting because the (γ,n) reaction on the only stable isotope, Na^{23}, leads to Na^{22}, which has been the subject of several investigations.

Na^{22} has a ground state of spin parity of 3^+ and an isotopic spin of $T=0$. Charge independence and the systematics of nuclear energy levels lead to the predic-

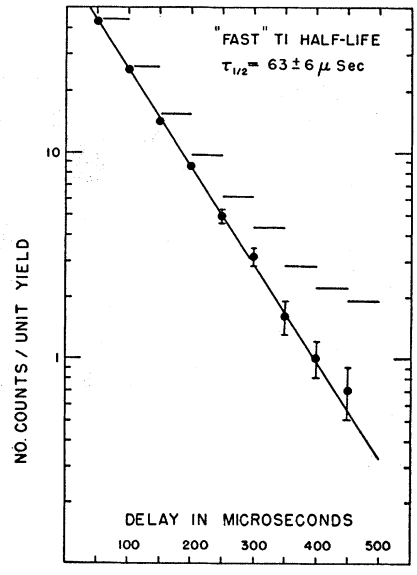

FIG. 8. "Fast" Tl half-life. This measurement gives $\tau_{\frac{1}{2}}=63\pm6$ μsec. Best value is $\tau_{\frac{1}{2}}=65\pm5$ μsec.

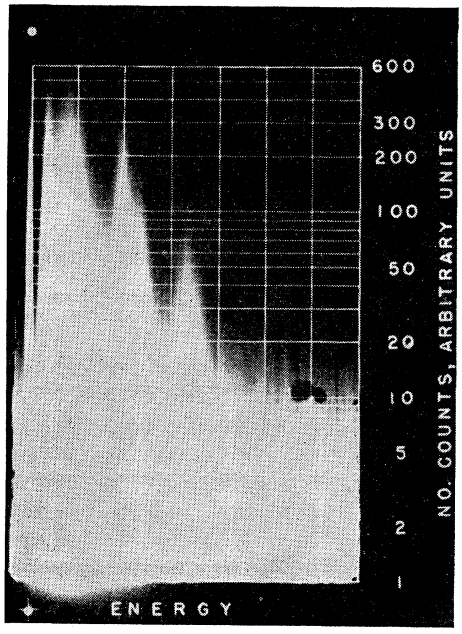

FIG. 9. "Fast" Tl spectrum, $E_\gamma=706$ kev and 410 kev. An indication of the 506-kev "slow" Tl gamma can be seen on the high energy side of the 410-kev peak. Tl K x-ray is at $\frac{1}{3}$ energy unit. The line at the origin of the energy axis marks zero energy. The sudden decrease of intensity below $\frac{1}{3}$ energy division is artificial.

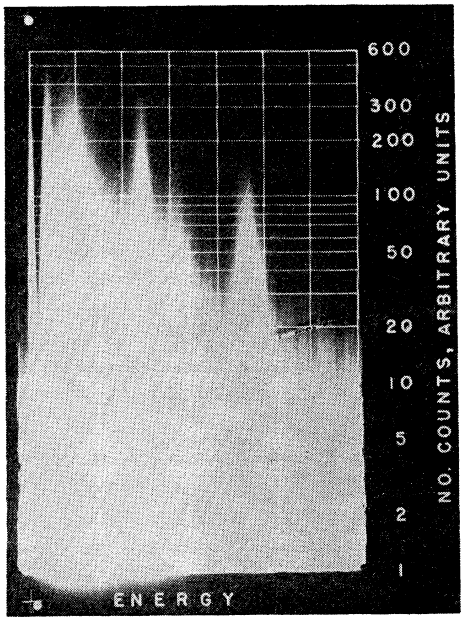

FIG. 10. Bi spectrum, $E_\gamma=930$ kev and 500 kev. Bi K x-ray appears at approximately $\frac{1}{3}$ energy division. The line at the origin of the energy axis marks zero energy. The decrease of intensity below $\frac{1}{3}$ energy division is artificial.

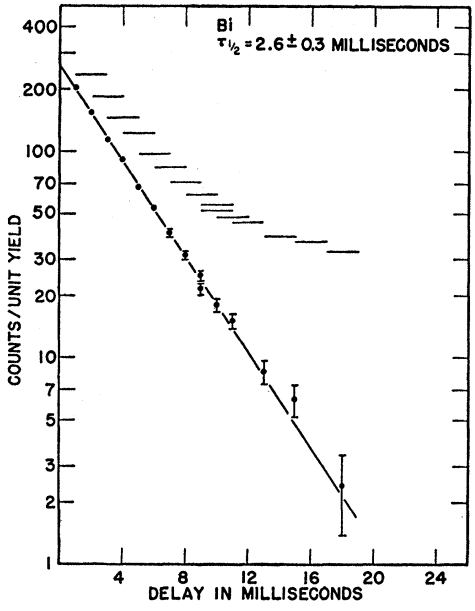

FIG. 11. Bi half-life. This measurement give $\tau_{\frac{1}{2}}=2.6\pm0.3$ milliseconds. Best value is 2.7 ± 0.25 milliseconds.

tion that the first $T=1$ level of Na^{22} has a spin-parity of 0^+ and an energy between 700 kev and 800 kev.[15–17]

Predictions based on similar reasoning for Cl^{34} and K^{38} have been verified experimentally.[15] If the $T=1$ level were the first excited state, the transition to the ground state would be $M3$ and the $T=1$ level would therefore be an isomer. Furthermore, a level in Na^{22} had been found at 592 kev[18] and there was a question of whether this was the predicted $T=1$ level. Stähelin[19] had looked for an isomer in Na^{22} and had not been able to find one even though he could have detected half-lives greater than 1000 μsec.

We were unable to detect any isomer in Na^{22} even though we could have detected any isomer with a half-life above 10 μsec provided that its integrated cross section up to 19.5 Mev was greater than 0.0024 Mev-barns. This sensitivity limit is based on a calibration made using the $Al^{27}(\gamma,n)Al^{26}$ reaction as a standard. The total integrated cross section of $Na^{23}(\gamma,n)Na^{22}$ up to 19.5 Mev is about 0.055 Mev-barns, which is 20 times greater than the upper limit set by our experiment. Since there is no reason to expect the (γ,n) reaction to discriminate strongly against the $T=1$ level, it is unlikely that the $T=1$ level actually forms an isomer. This result implies that there is another level between the 0^+, $T=1$ level and the 3^+, $T=0$ ground state.[20] After this work was completed, Browne and Cobb[21] showed that the 592-kev level in Na^{22} was probably a $T=0$ level because it was formed from the $Mg^{24}(d,\alpha)Na^{22}$ reaction in which no change in isotopic spin is expected. If the 592-kev level is indeed this 1^+, $T=0$ state, the predicted 0^+, $T=1$ level would decay to it by means of an $M1$ transition with a half-life too short to have been detected. Thus, assigning 1^+, $T=0$ to the 592-kev level explains the experimental results[18,19,21] without interfering with the predictions based on charge independence.[15–17]

ACKNOWLEDGMENTS

We wish to thank Mr. John D. Fox for experimental assistance particularly insofar as shielding problems were concerned and for many stimulating discussions. We also should like to thank Mr. T. J. Keegan and his assistants who operated and adjusted the betatron for our use.

[15] P. Stähelin, Helv. Phys. Acta **26**, 691 (1953).
[16] P. Stähelin, Phys. Rev. **92**, 1076 (1953).
[17] S. A. Moszkowski and D. C. Peaslee, Phys. Rev. **93**, 455 (1954).
[18] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **94**, 1252 (1954).
[19] P. Stähelin (private communication).
[20] In predicting the existence of the $J=0$, $T=1$ level the possibility of a $J=1$, $T=0$ level lying between the $T=1$ level and the ground state is mentioned.[17]
[21] C. P. Browne and W. H. Cobb, Phys. Rev. **99**, 644 (1955).
Note added in proof.—More recent measurements of the gamma-ray energies using simultaneous exposures of both the standards and unknown on the grey-wedge pulse-height analyzer have shown that three of the energies should be revised. The better values are: As, 283 ± 15 kev; "slow" Tl, 485 ± 20 kev; and the low-energy Pd line, 180 ± 15 kev. All the other values were confirmed.

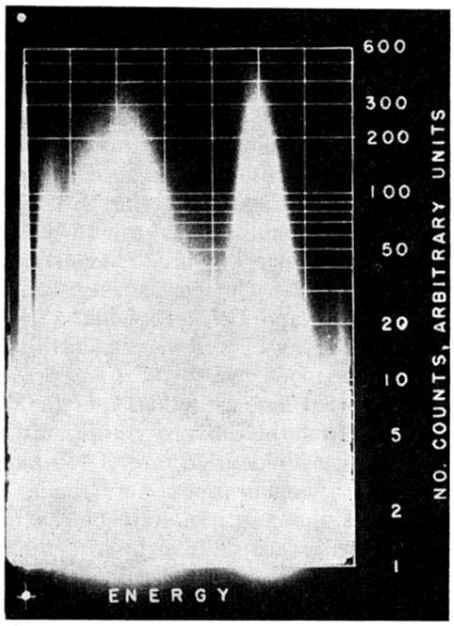

FIG. 1. Y spectrum, $E_\gamma = 393$ kev. The line at the origin of the energy axis marks zero energy. The sudden decrease of intensity at approximately $\frac{1}{4}$ energy divisions is artificial.

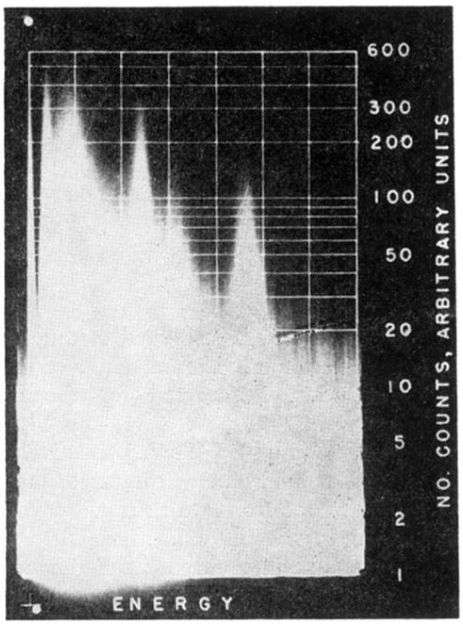

FIG. 10. Bi spectrum, $E_\gamma = 930$ kev and 500 kev. Bi K x-ray appears at approximately $\frac{1}{3}$ energy division. The line at the origin of the energy axis marks zero energy. The decrease of intensity below $\frac{1}{3}$ energy division is artificial.

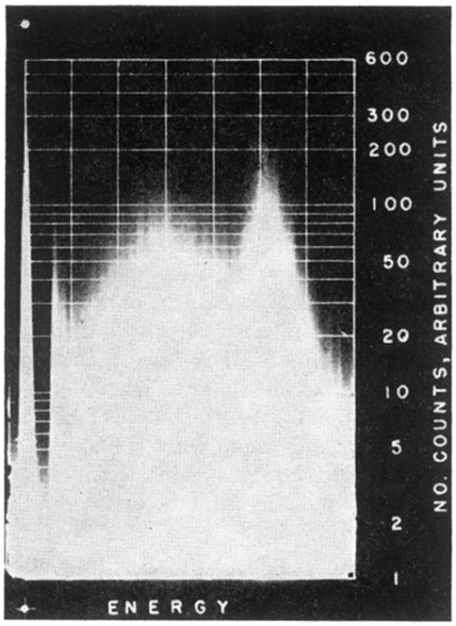

FIG. 3. As spectrum, $E_\gamma = 305$ kev. The line at the origin of the energy axis marks zero energy. The sharp increase in intensity below 1 energy division is due to noise. The sudden decrease of intensity at approximately $\frac{1}{2}$ energy division is artificial.

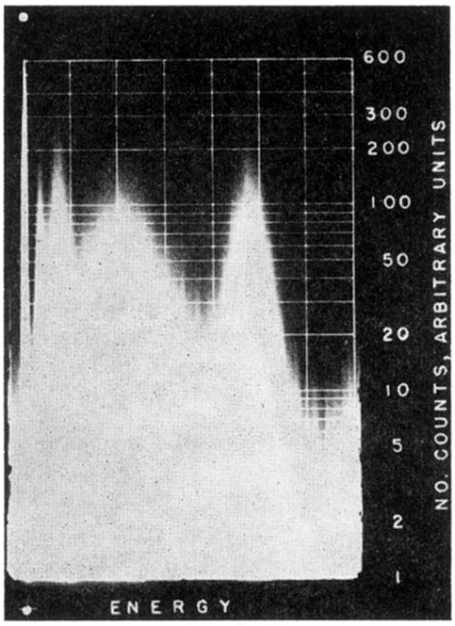

FIG. 5. W spectrum, $E_\gamma = 370$ kev. A strong K x-ray can also be seen. The line at the origin of the energy axis marks zero energy. The intensity increase below $\frac{1}{2}$ energy division is probably due to noise. The decrease of intensity at approximately $\frac{1}{3}$ energy division is artificial.

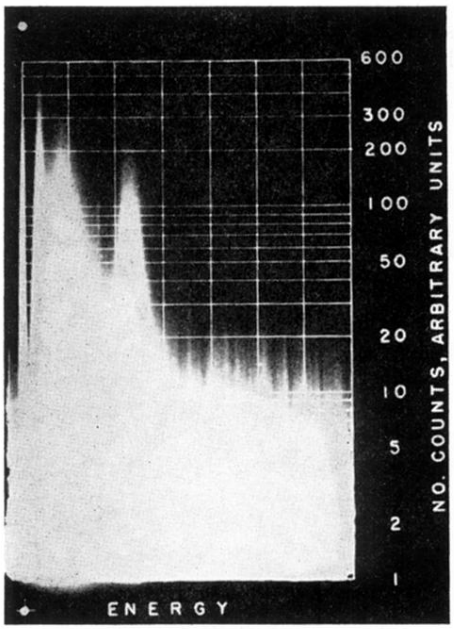

FIG. 7. "Slow" Tl spectrum, $E_\gamma = 506$ kev. Tl K x-ray can be seen at $\frac{1}{3}$ energy division. The line at the origin of the energy axis marks zero energy. The decrease of intensity below $\frac{1}{3}$ energy division is artificial.

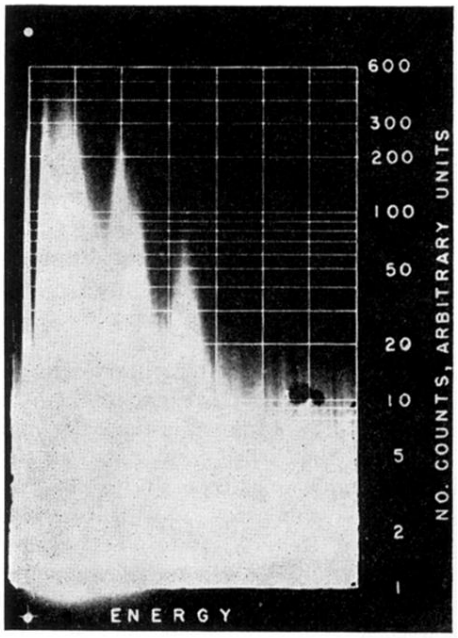

FIG. 9. "Fast" Tl spectrum, $E_\gamma = 706$ kev and 410 kev. An indication of the 506-kev "slow" Tl gamma can be seen on the high energy side of the 410-kev peak. Tl K x-ray is at $\frac{1}{3}$ energy unit. The line at the origin of the energy axis marks zero energy. The sudden decrease of intensity below $\frac{1}{3}$ energy division is artificial.