Disintegration of Te^{129}†

WILLIAM E. GRAVES AND ALLAN C. G. MITCHELL
Physics Department, Indiana University, Bloomington, Indiana
(Received August 17, 1955)

The disintegration of Te^{129} has been investigated with the help of a magnetic lens spectrometer, permanent field spectrometer with photographic recording, and scintillation counters. The half-lives of the isomeric states in the parent were found to be 41 days and 74 minutes, respectively. The 74-minute state decays to I^{129} with the emission of beta-ray groups whose end-point energies and relative abundances are 1.453 Mev (71%), 0.989 Mev (15%), 0.69 Mev (4%), and 0.29 Mev (10%). Gamma rays of 0.027, 0.21, 0.475, 0.72, and 1.12 Mev were found. The 41-day state decays, for the most part, to the 74-minute state of Te^{129} with the emission of a highly internally converted gamma ray of energy 106.3±0.1 kev for which the K/L ratio is unity. A beta-ray transition, of low intensity, from the 41-day state of Te^{129} to the ground state of the product is postulated. Gamma-gamma and beta-gamma coincidence experiments using scintillation spectrometers served to indicate the probable level scheme of I^{129}. A discussion of the disintegration scheme is given suggesting probable spins and parities of the levels.

1. INTRODUCTION

TELLURIUM-129 is reported in the literature to have half-lives of 34 days and 72 minutes, indicating an isomeric pair. Hill[1] has shown that the longer-lived state is the isomeric parent and that it makes a transition to the shorter-lived state through a gamma ray whose energy is 0.106 Mev and which is highly internally coverted. He measured the K/L ratio for the internally converted gamma ray and concluded that it was characteristic of an $M4$ transition. No very definitive work has been done on the shorter lived state. Early work[2] indicates that is is accompanied by the emission of a beta-ray group and at least two gamma rays.

We have investigated this disintegration since it goes to I^{129} which has 53 protons and whose low-lying levels should be characterized by $(g_{7/2})^3$ proton configurations. Hebb[3] investigated the disintegration of Te^{131} which goes to I^{131} and found certain regularities between the states of I^{125}, I^{127}, and I^{131}. The states of I^{129} were missing in this sequence and it was for this reason that the present investigation was undertaken.

2. PREPARATION OF THE SOURCE AND METHODS OF INVESTIGATION

Sources were prepared by bombarding separated Te^{128}, obtained from the Stable Isotopes Division of the U. S. Atomic Energy Commission, with 11.5-Mev deuterons in the Indiana University cyclotron. Bombardments of about 1.5 hours duration were used in producing the short-lived isomer and of many hours in producing the long-lived isomer. The tellurium was dissolved in HCl and precipitated as the metal with the use of SO_2 and hydrazine hydrochloride. At least two precipitations were made to make sure that any iodine contaminants were removed.

The beta-ray spectrum of both the short-lived and the long-lived components were measured in a magnetic lens spectrometer. The gamma-ray spectrum, being too weak for measurement with a magnetic spectrometer, was measured with a scintillation spectrometer. With the help of scintillation spectrometers, both gamma-gamma and beta-gamma coincidences were measured.

3. RADIATIONS FROM THE SHORT-LIVED STATE

Using the shorter bombardment times, sources were prepared for measurement in a magnetic lens spectrometer. Owing to the short half-life, several separate bombardments had to be made and a composite of the beta ray spectrum prepared. The beta-ray spectrum is shown in Fig. 1, in which the number of counts per unit current interval, N/I, is plotted against the current, I, through the lens. The insert of Fig. 1 shows (to a different scale) the L and M internal conversion lines for a gamma ray of 26.8 kev in the product iodine. A careful search was made for other internal conversion electrons at positions which were calculated from the results on the gamma-ray spectrum obtained with the help of a

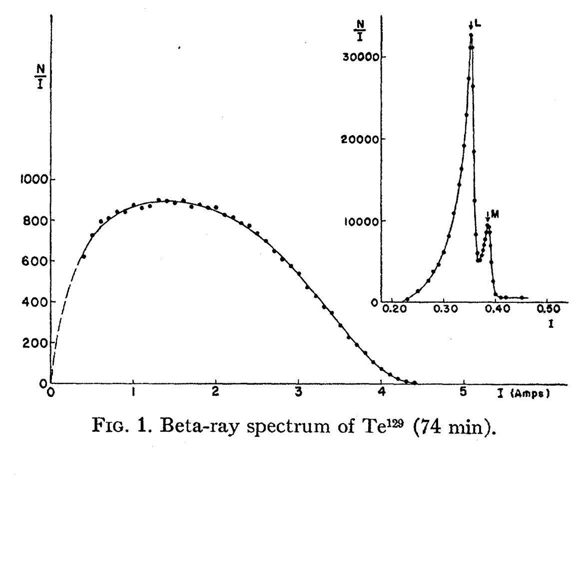

FIG. 1. Beta-ray spectrum of Te^{129} (74 min).

† This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. D. Hill, Phys. Rev. 76, 333 (1949).
[2] See Hollander, Perlman, and Seaborg, Revs. Modern Phys. 25, 469 (1953).
[3] E. Hebb, Phys. Rev. 97, 987 (1955).

TABLE I. Beta-ray spectrum of Te^{129} (74 min).

Energy (Mev)	Abundance (%)	Log ft
1.453 ± 0.005	70.5	5.89
0.989 ± 0.020	15.4	5.93
0.69 ± 0.10	3.7	5.98
0.29 ± 0.06	10.4	4.30

scintillation counter. No internal conversion electrons were found at these positions. The source, however, was quite weak and lines having low internal conversion coefficients would not have been found. This experiment was repeated later using the long-period isomer in equilibrium with the short-lived state and gave a result in agreement. The internal conversion line and the beta-ray spectrum decayed with a half-life of 74 minutes.

A Fermi plot of the beta-ray spectrum was made and from that the end points, relative abundances, and values of log ft for the various groups were computed and are shown in Table I. Owing to the low relative abundance of the two lower energy groups and since several subtractions had to be performed in the analysis, the values for the end-point energies of these groups are subject to a larger uncertainty than for the two higher energy groups. The ratio of the number of internal conversion electrons of the 26.8-kev gamma ray to the total beta ray spectrum is $e(L+M)/\beta\sim0.23$. This value is probably too low as a result of window cut-off effects.

The gamma-ray spectrum of the 74-minute activity was measured with the help of a scintillation spectrometer using a NaI(Tl) crystal. Owing to a small contamination of Te^{130} in the separated isotope, a small amount of activity of the 30-hr Te^{131} was present in the source. After correcting for this activity, lines were found at 0.475 ± 0.005 and 1.12 ± 0.02 Mev which definitely had a half-life of 74 minutes. Another line was found having an energy between 0.75 and 0.80 Mev. The main contribution at this energy comes from the strong line at 0.773 Mev from the 30-hr Te^{131}. After correcting for the Te^{131} contribution, there remained a line at about 0.77 Mev associated with a half-life of 75 to 80 minutes.

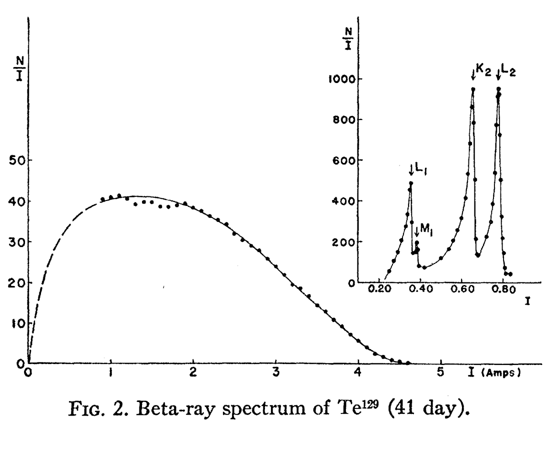

FIG. 2. Beta-ray spectrum of Te^{129} (41 day).

Owing to the corrections, its exact energy is somewhat uncertain.

4. RADIATIONS FROM THE LONG-LIVED ACTIVITY

A bombardment of several days was used to prepare the long-lived activity. The chemical separation was made after waiting a sufficient time for 74-minute activity formed concurrently in the bombardment and any Te^{131} activities to die away, and sources were prepared for the measurement of the half-life, the gamma-ray spectrum and the beta-ray spectrum. The measurement of the half-life gave a value of 41 days.

The gamma rays were measured with the scintillation spectrometer using gain settings approximately the same as those used for the 74-minute activity. Here lines were found at 0.475 ± 0.005, 0.72 ± 0.01, and 1.14 ± 0.02 Mev. On changing the gain setting to bring up the low-energy region, the line at 27 kev was detected. The fact that essentially the same gamma-ray spectrum is exhibited by both the 41-day and the 74-minute activities suggests that the main mode of decay of the 41-day state is via a highly internally converted gamma ray to the 74-minute state. Further work on these gamma rays is discussed in Sec. 5.

TABLE II. Beta-ray spectrum of Te^{129} (41 day).

Energy (Mev)	Relative abundance (%)	Log ft[a]
1.530 ± 0.005	68.2	...
0.972 ± 0.020	15.7	5.92
0.66 ± 0.10	3.2	6.00
0.35 ± 0.06	12.9	4.45

[a] Based on 74-min half-life.

The beta-ray spectrum of the 41-day activity was measured in a magnetic lens spectrometer. The source was weak so that long counting times for each point had to be used. The results are shown in Fig. 2. As in Fig. 1, the beta-ray spectrum and the internal conversion lines are plotted to a different scale. The most prominent new features are the K and L internal conversion lines for a gamma ray at 106 kev (K_2 and L_2). This is the 106-kev gamma ray of the isomeric transition discovered by Hill.[1] The K/L ratio as measured in the present experiment is unity, in agreement with Hill's result. The ratio of the number of internal conversion electrons from this transition to the total number of beta rays was measured and found to be $e(K+L)/\beta=0.95$. The half-life of the isomeric transition and the K/L ratio are compatible with an $M4$ transition.[1] Since the value of $\alpha_K+\alpha_L$ for an $M4$ transition of this energy is approximately 440, essentially all transitions between the two states go via internal conversion electrons. This accounts for the fact that no gamma ray of 106 kev is found in the scintillation spectrum. The other conversion lines are a composite of the L and M lines for the 27-kev gamma ray and K–$2L$ and K–L–M Auger electrons from tellurium, resulting from the internal conversion of the 106-kev gamma ray. The Auger electrons fall, within the limit of error, at the same position as the L and M lines for the 27-kev gamma ray.

In order to check on internal conversion lines a source was placed in a permanent field spectrometer, using photographic recording. On the film, the K, L, and M lines for the 106-kev line and the L and M lines for the 27-kev gamma ray were seen. No other internal conversion lines were seen. The energy obtained for the 106-kev gamma ray from the K, L, and M lines is 106.3 ± 0.1 kev, when calibrated against Th(B+C+C′′).

The beta-ray spectrum was analyzed by making Fermi plots of the data and the results are shown in Table II. The three low-energy groups agree reasonably well with those obtained from the 74-minute activity. The high-energy group poses somewhat of a problem which will be discussed later.

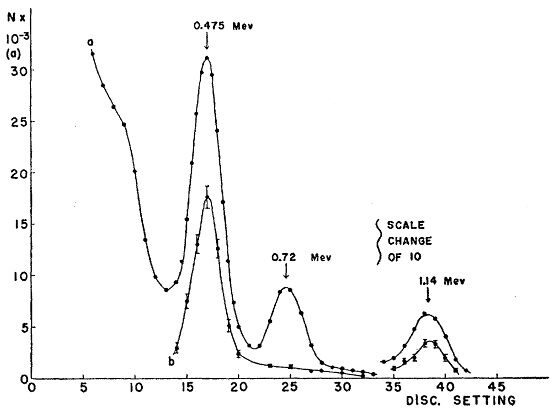

FIG. 3. Gamma-gamma coincidence spectrum of Te^{129}. (a) Singles. (b) Coincidences with channel 1 set on 27-kev line (scale = singles scale/200).

5. COINCIDENCE EXPERIMENTS

In order to get an insight into the nature of the decay scheme, both gamma-gamma and beta-gamma coincidence experiments were performed using scintillation spectrometers. The experiments were carried out using the long-lived activity in equilibrium with its short-lived isomer.

Gamma-gamma coincidences were measured by setting one spectrometer on a given line and sweeping through the spectrum with the other spectrometer. Figure 3 shows the results when one spectrometer is set on the 27-kev line. Coincidences were found with the lines at 0.475 and 1.14 Mev but not with that at 0.72 Mev. Other gamma-gamma coincidence experiments showed that there were no coincidences between (0.475–0.72), (0.475–1.14) or (0.72–1.14). All gamma-gamma coincidences appeared to be prompt with respect to the resolving time of the apparatus (1×10^{-7} sec).

On considering possible decay schemes, it was felt that there should be a line at around 0.2 Mev which

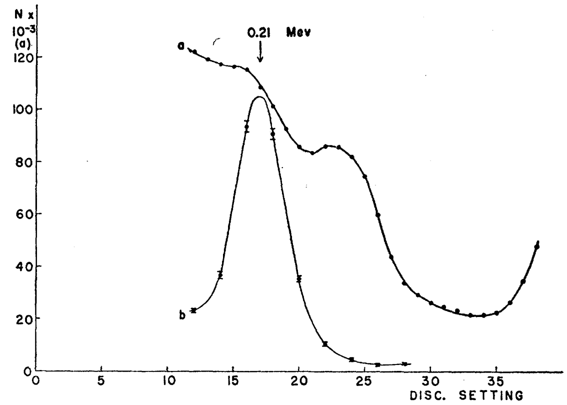

FIG. 4. Portion of gamma-gamma coincidence curve. (a) Singles. (b) Coincidences with channel 1 set on 475-kev line (scale = singles scale/1000).

should be in coincidence with the one at 0.475 Mev. Again setting on the 0.475-Mev line with one spectrometer, a line at 0.21 ± 0.01 Mev was found in coincidence with it. This is shown in Fig. 4.

In order to obtain a better insight into the relationship between the various beta-ray groups and the gamma rays, coincidence experiments were performed with the help of two scintillation spectrometers in which an anthracene crystal was used to detect beta rays and a NaI(Tl) crystal to detect gamma rays. The Cs^{137} internal conversion line at 0.624 Mev was used to calibrate the anthracene crystal. With the scintillation spectrometer measuring gamma rays set on a given gamma ray (Channel 1), the beta-ray distribution in coincidence with this gamma ray was measured with the scintillation spectrometer using the anthracene crystal. Fermi plots were made of the beta-ray distribution in coincidence with various gamma rays as well as of the singles distribution. Figure 5 shows such Fermi plots for the singles distribution and for the beta rays in coincidence with the 0.475-, 0.72-, and 1.14-Mev gamma rays, respectively. In each case, a recalibration was made to satisfy the condition that the singles end point be 1.45 Mev. Table III gives the results for the end points when Channel 1 was set on those gamma rays shown in Column 1.

The experiments show that most of the beta rays are in coincidence with the 27-kev line which suggests that the highest energy group leads to the 27-kev state and that all gamma rays are prompt with respect to the

TABLE III. Results of beta-gamma coincidence experiments (41-day activity).

Channel 1 set on gamma ray (Mev)	Channel 2 beta-ray end points (Mev)
0.027	1.45
0.475	0.96
0.72	0.82
1.14	0.35

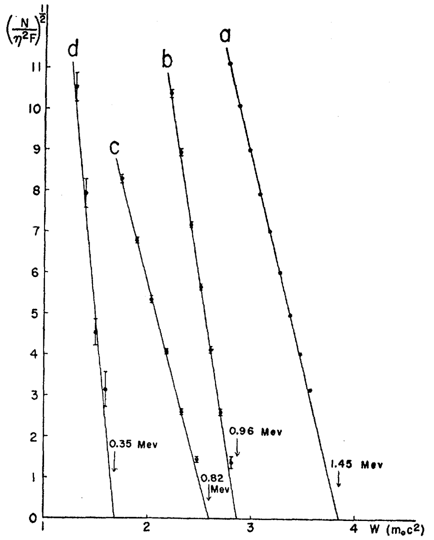

FIG. 5. Fermi plots for beta rays in coincidence with various gamma rays. The ordinate scales are arbitrary. (a) Singles. (b) Coincidences with 0.475-Mev gamma ray. (c) Coincidences with 0.72-Mev gamma ray. (d) Coincidences with 1.14-Mev gamma ray.

resolving time of the apparatus (1×10^{-7} sec). The remaining beta-ray end points are in reasonably good agreement with the results of the analysis of the beta-ray spectrum obtained with the help of the magnetic lens. The rather poor agreement for the two low-energy groups is to be expected from the low relative abundance of these groups.

6. DISCUSSION

The parent, Te^{129}, consists of a pair of isomeric states which are connected by a highly internally converted gamma ray whose energy is 106 kev and the radiation is of an $M4$ character. The upper state has a half-life of 41 days and, according to the shell model, a configuration $h_{11/2}$ while the lower state has a half-life of 74 minutes and a configuration $d_{3/2}$.

The experiments on the short-lived activity together with the coincidence experiments suggest that portion of the disintegration scheme, shown in Fig. 6, connected with the 74-minute state.

The fact that the same gamma rays appear with both the long-lived period and the short-lived period and that the ratio of internal conversion electrons of the 106-kev line to the number of beta rays from the long-lived disintegration is approximately unity, strongly suggests that the main mode of decay of the long-lived state is through the 106-kev transition to the 74-minute state and thence by beta-ray transitions to the product I^{129}. The discrepancy between the beta-ray end point found for the highest energy group of the 74-minute and the 41-day isomers could be due to experimental errors in measuring the long-lived spectrum, owing to the low activity of the sources. However, two complete runs were made on one source and the end points obtained for the high-energy group (by the method of Fermi plots) agreed to within 10 kev. The discrepancy is 80 kev.

It is possible that there is a transition from the $h_{11/2}$ state of Te^{129} to the ground state of I^{129}, whose spin is known to be 7/2 and whose parity is even. Such a transition would be characterized by $\Delta I=2$, yes and should have a value of $\log(W_0^2-1)ft\sim10$. Such a transition would have to satisfy two criteria: (1) it would have to give the correct half-life for the 41-day state, and (2) it would have to insure that the ratio of the number of conversion electrons from the 106-kev transition to the total number of beta rays observed would correspond to the observed facts. To estimate this let A_γ, A_{e^-}, and A_β be the probabilities of leaving the 41-day state by a gamma ray, internal conversion electrons, and direct beta-ray transitions respectively. Since the beta-ray end point is known, $\log(W_0^2-1)ft$ can be calculated. Assuming $\log(W_0^2-1)ft_\beta\sim10$, t_β can be calculated. A_γ can be estimated from the formulas of Moszkowski[4] or Weisskopf[5] for multipole transitions and A_{e^-} from the conversion coefficients of Rose.[6] Reversing the process, one can use the two criteria mentioned above, together with the experimental data,

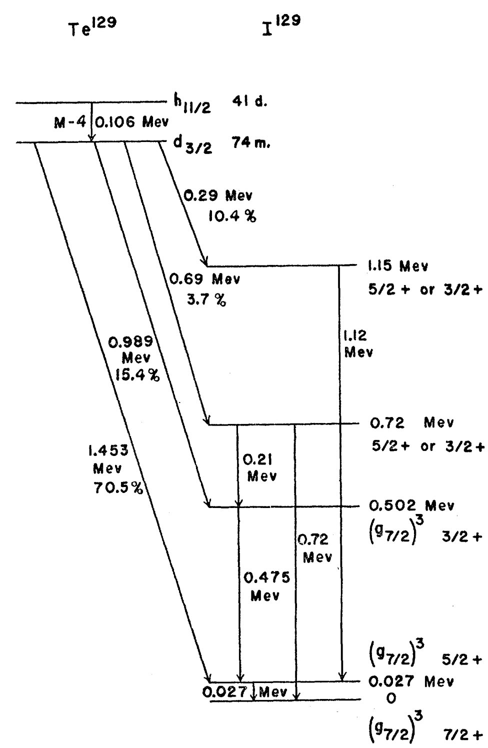

FIG. 6. Tentative disintegration scheme of Te^{129}.

[4] S. A. Moszkowski, Phys. Rev. **83**, 1071 (1951).
[5] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).
[6] M. E. Rose, in *Beta and Gamma Ray Spectroscopy*, edited by K. Siegbahn (North Holland Publishing Company Amsterdam, 1955).

and calculate an A_γ and A_β. Thus:

$$(A_\gamma+A_{e^-}+A_\beta)=0.195\times10^{-6}\ \text{sec}^{-1}\quad\text{(half-life 41 days)},\quad(1)$$

$$A_{e^-}/(A_\gamma+A_{e^-}+A_\beta)=0.95.\quad(2)$$

This gives $A_\beta=0.01\times10^{-6}$ sec^{-1} and $t_\beta=6.93\times10^7$ sec. From this, $\log(W_0^2-1)ft_\beta=11.3$, which is a fairly reasonable value. Similarly $A_{e^-}=1.85\times10^{-7}$ sec^{-1}. Using $A_{e^-}/A_\gamma=(A_K+A_L)/A_\gamma=440$, one obtains a value for A_γ of 4.21×10^{-10} sec^{-1}. This is to be compared with the following theoretical results for A_γ: Moszkowski (no spin) $A_\gamma=1.87\times10^{-10}$; Moszkowski (with spin), $A_\gamma=2.96\times10^{-8}$; Weisskopf, $A_\gamma=5.62\times10^{-10}$. Considering the inexact nature of the calculation of the half-lives of multipole radiation, the results appear to be in satisfactory agreement with what would be expected. The beta-ray results can be partially explained, therefore, by a weak transition from the $h_{11/2}$ state of the parent to the ground state of the product together with the stronger transitions observed in the 74-minute decay.

We now turn to a discussion of the energy level scheme of I^{129}. According to Ford,[7] the spins and parities of the low states of the iodine isotopes should be dictated by the 3-proton configuration. Owing to the close proximity of g and d states in this region, one would expect considerable configuration interaction. The lowest configurations would be expected to be $(g_{7/2})^3$, $(g_{7/2})^2 d_{5/2}$, $(g_{7/2})(d_{5/2})^2$, and $(d_{5/2})^3$. These configurations give rise to some 41 states, all of even parity and with spins from 1/2 to 17/2. The lowest states would have spins of 7/2 and 5/2.

The spin of the ground state of I^{129} has been measured by Livingston, Gilliam, and Gordy[8] and found to be 7/2 and to have even parity, indicating the configuration $[(g_{7/2})^3]_{7/2}$. The values of log ft for the beta-ray groups feeding the states at 0.027, 0.502, and 0.72 Mev are characteristic of l-forbidden transitions.[9] The experiments would suggest the configurations $[(g_{7/2})^3]_{5/2}$ and $[(g_{7/2})^3]_{3/2}$ for the states at 0.027 and 0.502 Mev. The state at 0.72 Mev would have to have a spin of 3/2 or 5/2 and even parity. The transition to the highest state appears to be allowed and this suggests $d_{5/2}$ or $d_{3/2}$ for this state.

An indication of the multipolarity of the 27-kev gamma ray can be obtained from the half-life. As mentioned previously, it was found that coincidences between the 475- and 27-kev gamma rays are prompt with respect to the resolving time of the apparatus (10^{-7} sec). Since the 27-kev state and the ground state have the same parity, the radiation must have the character of $M1$ or $E2$. Using the results of Moszkowski (with spin), the half-life for an $M1$ transition is about 8.1×10^{-10} sec and for an $E2$, 1.0×10^{-4} sec. All higher multipole orders, of course, give longer half-lives and are therefore ruled out by the experimental data. The only shorter half-life would be $E1$, which seems highly unlikely since the transition takes place between two low-lying levels in the same shell and these levels are expected to have the same parity. The evidence suggests that this line is of an $M1$ character, which agrees with the assignment made on the basis of ft values.

Of the many possible states of I^{129} predicted by theory, the present experiments, taken together with the experiments of Livingston, Gilliam, and Gordy on the spin of the ground state, are consistent with the assumption that the level order is $[(g_{7/2})^3]_{7/2}$, $[(g_{7/2})^3]_{5/2}$, and $[(g_{7/2})^3]_{3/2}$ for the ground state and first two excited states. The two higher states appear to have spins of 5/2 and 3/2 and are of even parity.

ACKNOWLEDGMENTS

The authors are indebted to Dr. M. B. Sampson and the cyclotron group for making the bombardments, and to Mr. Fred Vratny for making the chemical separations.

[7] K. W. Ford (private communication).

[8] Livingston, Gilliam, and Gordy, Phys. Rev. **76**, 149 (1949).

[9] While the difference in log ft values for allowed and l-forbidden transitions is not large, it is in general true that the l-forbidden transitions have a higher value of log ft. It is to be remembered, of course, that the empirical classification of beta transitions according to log ft values has been made on the assumption of the single particle shell model. See Mayer, Moszkowski, and Nordheim, Revs. Modern Phys. **23**, 315 (1951), and also M. G. Mayer, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North Holland Publishing Company, Amsterdam, 1955), Chap. 16. Most of the transitions of the type $d_{\frac{3}{2},\frac{5}{2}}$ to $d_{\frac{5}{2},\frac{3}{2}}$ have log ft from about 4.7 to 5.6 and none are as high as 5.9. It is for this reason that these transitions are considered to be l-forbidden.