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Long-Lived Tellurium Isomers

R. D. HILL
Department of Physics, University of Illinois, Urbana, Illinois*

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The internal conversion electron spectra of neutron-activated enriched tellurium isotopes have been studied. It has been shown that each odd mass-number isotope from 121 to 131 exists in a long-lived isomeric state. In all cases the initial isomeric transition is 2^4-pole magnetic, which appears to identify the long-lived isomeric states with a spin of 11/2. The spins of the ground states of Te^{127}, Te^{129}, Te^{131} would appear to be 3/2, and that of Te^{123} 1/2. Information about Te^{121} and Te^{125} ground states is incomplete.

INTRODUCTION

THE observation[1] that Sb when bombarded by energetic deuterons gave rise to a Te activity of about 140-day half-life and a profusion of internal conversion lines appeared to point to a particularly complicated Te^{121} isomeric decay. The assignment of the lines to Te^{121} had been made many times on the basis of the existence of 121 being the only gap which could be filled by a $d-2n$ reaction from Sb^{121} and Sb^{123}, as well as on the existence of only one period of decay of the activity. At the time of these experiments, however, it was felt that there was room for the existence of two isomers Te^{121} and Te^{123}, produced from Sb^{121} and Sb^{123}, which would have very similar lifetimes arising from the very similar 82 and 88.5-kev transitions. Separated Te isotopes were accordingly obtained from Oak Ridge and bombarded for a month in the pile there. This has led to a clarification of the Te^{121} radiations, the discovery of an isomer of Te^{123}, and a general survey of the Te isomers.

EXPERIMENTAL RESULTS

The internal conversion spectra of the activated Te isotopes were determined with a 180° focusing beta-ray spectrograph. The results are set down in Table I. The lifetime of Te^{123} has been inferred from the change in the intensities of the K-conversion lines of the 88.5 and 82-kev transitions over a period of 7 months. Immediately after separation of the Te fraction from the deuteron bombarded Sb, the intensity ratio of the (88.5-K) line to the (82-K) line was equal to 1.25. Approximately 7 months later, the ratio had diminished to 0.75. The half-life of Te^{123}, equal to 90 days, was calculated assuming a half-life for Te^{121} of 140 days. Both of these estimates are probably too low and the activities of the separate Te^{121} and Te^{123} isomers are now being followed.

The spectra from the activated Te isotopes are reproduced in Fig. 1. Certain lines are common to more than one spectrum. For example, the topmost spectrum is from deuteron bombarded Sb and is due to the mixed Te^{121}, Te^{123} isomers. The stable isotope Te^{120} was not obtainable in the enriched form. Analyses of the enriched isotopes which were bombarded are shown in Table II. The lines due to Te^{125} appear in Te^{123} and are due to 2.9 percent impurity of Te^{124}. The question might be raised as to whether the lines of the 88.5-kev transition in Te^{127} are not due to an impurity of Te^{122} in Te^{126}. This appears to be very unlikely since Te^{122} is present only to 0.1 percent in Te^{126} (95.4 percent), whereas the 88.5-kev lines are absent in the Te^{125} spectrum where Te^{122} is present to the extent of 1.5 percent in Te^{124} (84 percent). There is also no evidence for the 159-kev transition in the Te^{127} spectrum. A transition of 86 kev was observed by Helmholtz[4] present in the activity of Te^{127}.

For the 106-kev transition in Te^{129}, Helmholtz observed 102 kev. The value of 177 kev for the transition in Te^{131} is due to Helmholtz. This line was not observed in the present experiments although the irradiated Te^{130} was placed in the spectrograph within about 36 hours of removal from the pile. Activated Te^{130} gave, however, the 80 and 163.6-kev* transitions due to I^{131} (8 day) which grows from Te^{131}. The 80-kev transition provided a useful check on the energy calibration[5] of the spectrograph. A value of 80.4 kev was obtained from the K conversion line and 79.4 kev from the L-line, agreeing well with DuMond's value of 80.1 kev.

TABLE I. Half-lives and transitions of tellurium isomers.

Isomer	121	123	125	127	129	131
Half-life (day)	140[2]	90	58[3]	90[2]	32[2]	1.2[2]
Transitions (kev)	82	88.5	109.7	88.5	106	177[4]
	213	159	35.4			

Very rough activation isotopic cross sections can be obtained for the capture of slow neutrons and the production of Te^{123} and Te^{125} activities. The following values: $Te^{122}\sim1$ barn, $Te^{124}\sim5$ barn, were obtained from a comparison with Seren's[6] for Te^{130} (0.008), Te^{128} (0.015), Te^{126} (0.073).

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* This work was assisted by the joint program of the ONR and the AEC.

[1] R. D. Hill and J. W. Mihelich, Phys. Rev. 74, 1874 (1948).

* *Note added in proof:* It has since been recognized by Brosi, DeWitt, and Zeldes [Phys. Rev. 75, 1615 (1949)] that this transition arises from a 12-day isomer of Xe^{131}.

[2] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. 20, 616 (1948).

[3] Friedlander, Goldhaber, and Scharff-Goldhaber, Phys. Rev. 74, 981 (1948); Hill, Scharff-Goldhaber, and Friedlander, Phys. Rev. 75, 324 (1949).

[4] A. C. Helmholtz, Phys. Rev. 60, 415 (1941).

[5] Lind, Brown, Klein, Muller, and DuMond, Phys. Rev. 75, 1633A (1949.)

[6] Seren, Friedlander, and Turkel, Phys. Rev. 72, 888 (1947).

DISCUSSION OF ISOMERISM

The similarity between the lifetimes and transition energies of the odd atomic mass isomers of Te is striking. (Only one odd isotope, Te^{125}, was bombarded with neutrons but no activity or transitions were detected, other than those due to the impurities of the already known odd isomers.)

In Table III are set down the relevant experimental and analytical data pertaining to the odd Te isomers. The angular momentum changes l of the long lived transitions were obtained from the relation

$$\tau_\gamma=[3(l!)^2/\rho^{2l}]\cdot(137/W)^{2l+1}\cdot(\hbar/mc^2),$$

where τ_γ is the experimental lifetime multiplied by (1+conversion coefficient in all shells). The estimated conversion coefficient in all shells was obtained using the experimental N_K/N_L ratio and the value of the K-conversion for a trial l value. In all the Te isomer cases, the angular momentum change of the transitions having the lowest N_K/N_L ratios is $l=4$ magnetic and/or $l=5$ electric. As shown by Drell,[7] the amount of magnetic multipole conversion is high, and in all cases amounts to approximately 95 percent.

Second transitions, following the long-lived transitions, occur in the three lowest mass number cases. The lifetime for the 213-kev transition was found[8] to be 5×10^{-8} sec.

From the N_K/N_L ratios, the angular momentum changes[9] of the 213 and 159 transitions are probably 3 electric and 1 magnetic, respectively. Assuming that the ratios of the intensities of the K-electrons of the 213 and 159 transitions to the total electron intensities[1] of the 82 and 88.5 kev transitions may yield the K-conversion coefficients of the former transitions, the values obtained are 0.13 and 0.17, respectively. Using the conversion tables of Rose,[10] then, one obtains for the 213-kev transition, α_K2^2-electric$=0.10$, α_K2^3-electric$=0.39$; β_K2^2-magnetic$=0.39$; and for the 159-kev transition β_K2^1-magnetic$=0.17$. The analysis for the 159 kev transition therefore seems to indicate $l=1$, magnetic, even parity change; but for the 213-kev transition the assignment of an angular momentum change is difficult to specify at present. The identity of the two weak electron lines[1] of 32.5 and 35 kev in the spectrum of Te^{121} also remains to be determined. In the case of Te^{125} only the L- and M-conversion lines have been observed, and values of the N_K/N_L or K-conversions are therefore not available.

According to Feenberg and Hammack,[11] on the basis of a one-particle nuclear shell structure theory, a region of isomerism should occur in the isotope table around Z or $N=63$ to 81 (approximately) where the $1h$, $2d$, $2p$ and $3s$ levels may cross.[12] The isotopes of Te^{121} to Te^{131} lie in this region with N equal to 69, $71\cdots79$, and the

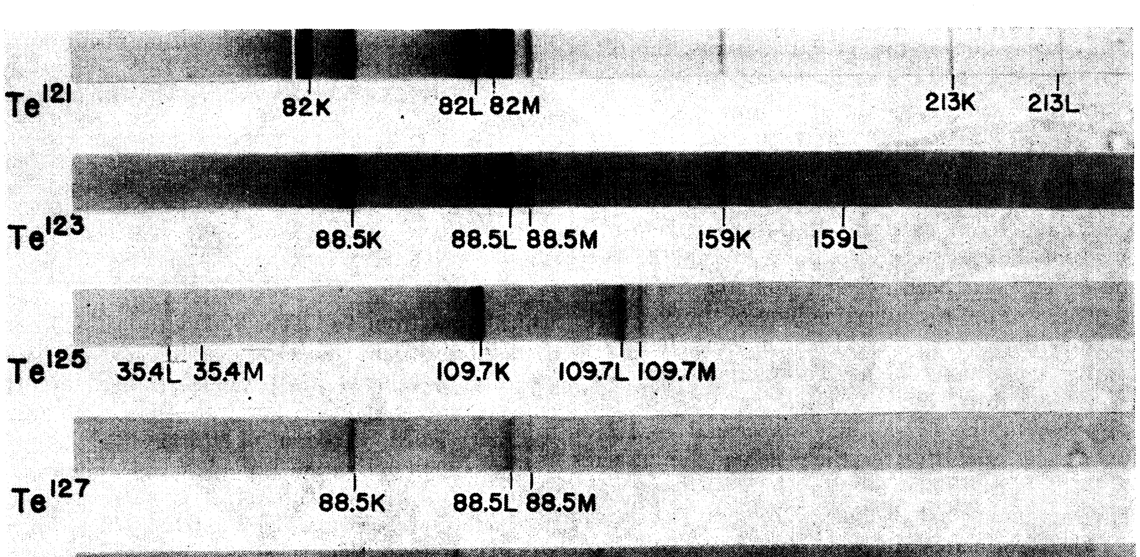

FIG. 1. Internal conversion spectra of Te isomers. The weak lines, caused by the following transitions, which are clearly visible on the original film, have been retouched for the purposes of reproduction: Te^{121} (213 kev), Te^{125} (35.4 kev), Te^{127} (88.5 kev), Te^{129} (106 kev).

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[7] S. D. Drell, Phys. Rev. **75**, 132 (1949).

[8] P. T. Bittencourt and M. Goldhaber, Phys. Rev. **70**, 780 (1946).

[9] M. H. Hebb and E. Nelson, Phys. Rev. **58**, 486 (1940).

[10] M. E. Rose and others, "Tables of K-shell Internal Conversion Coefficients."

[11] E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949). See also L. Nordheim, Phys. Rev. **75**, 1894 (1949).

[12] The nomenclature is according to M. G. Mayer, Phys. Rev. **75**, 1969 (1949).

TABLE II. Isotopic abundances of enriched tellurium samples.

Stable isotope	Sample (1)	Sample (2)	Sample (3)	Sample (4)	Sample (5)	Sample (6)
122	79.4	1.5	0.1	0.1	<0.1	<0.1
123	1.4	0.7	0.3	0.0	<0.1	<0.1
124	2.9	83.9	1.4	0.6	<0.1	<0.1
125	2.6	4.7	87.9	0.7	0.2	<0.1
126	4.6	4.6	6.8	95.4	1.5	0.3
128	4.9	3.0	2.4	2.6	94.4	2.3
130	4.0	1.9	1.1	0.6	3.9	97.4

TABLE III. Angular momentum changes of telliurium isomer transitions.

Isomer	Te^{121}	Te^{123}	Te^{125}	Te^{127}	Te^{129}	Te^{131}
Half-life (days)	140	90	58	90	30	1.2
γ_1-transition (kev)	82	88.5	109.7	88.5	106	177
N_K/N_L	0.77	0.92	1.5	0.75	1	2
Ang. mom. change	4 mag.	4 mag.	4 mag.	4 mag.	4mag.	4 mag.
γ_2-transition (kev)	213	159	35.5			
N_K/N_L	4.2	7.7	?			
K-conv. coeff.	0.13	0.17	?			
Ang. mom. change	?	1 mag.				

required values of angular momentum changes for the isomeric transitions are also possible on the theory.

In order to obtain the large angular momentum changes associated with the long-lived isomeric states it is necessary to attribute the first transitions to ones to or from a (1*h*) level. The possible transitions between the available levels are:

$$(1h_{11/2})\rightleftarrows(2d_{3/2});\quad (1h_{11/2})\rightleftarrows(2p_{3/2});$$
$$(1h_{9/2})\rightleftarrows(2p_{\frac{1}{2}});\quad (1h_{9/2})\rightleftarrows(3s_{\frac{1}{2}}).$$

Two of these transitions, those to the 2*p* level, can be ruled out since the selection rule for a 2^4-magnetic transition requires an odd parity change.

The second transitions must evidently be treated independently for each isotope. No second transitions have been observed at all for Te^{127}, Te^{129}, and Te^{131} but these cannot be ruled out entirely as the transitions might be low energy ones or might possibly be weakly converted. If we consider the best known case at present of Te^{123}, it appears that the second transition, between the available levels according to theory, may be one of the following:

$$(2d_{5/2})\rightleftarrows(2p_{3/2});\quad (2d_{3/2})\rightleftarrows(2p_{\frac{1}{2}});\quad (2d_{3/2})\rightleftarrows(3s_{\frac{1}{2}});$$
$$(2p_{3/2})\rightleftarrows(3s_{\frac{1}{2}});\quad (2p_{\frac{1}{2}})\rightleftarrows(3s_{\frac{1}{2}}).$$

All of the transitions to or from the 2*p* level are again ruled out on account of the selection rule for a 2^1-magnetic transition which requires an even parity change.

The transitions in Te^{123} thus indicate the existence of the $(1h_{11/2})$, $(2d_{3/2})$ and $(3s_{\frac{1}{2}})$ levels. These are just the levels which are being filled in the region of Te, $N=69-79$, according to Mayer's theory.[12]

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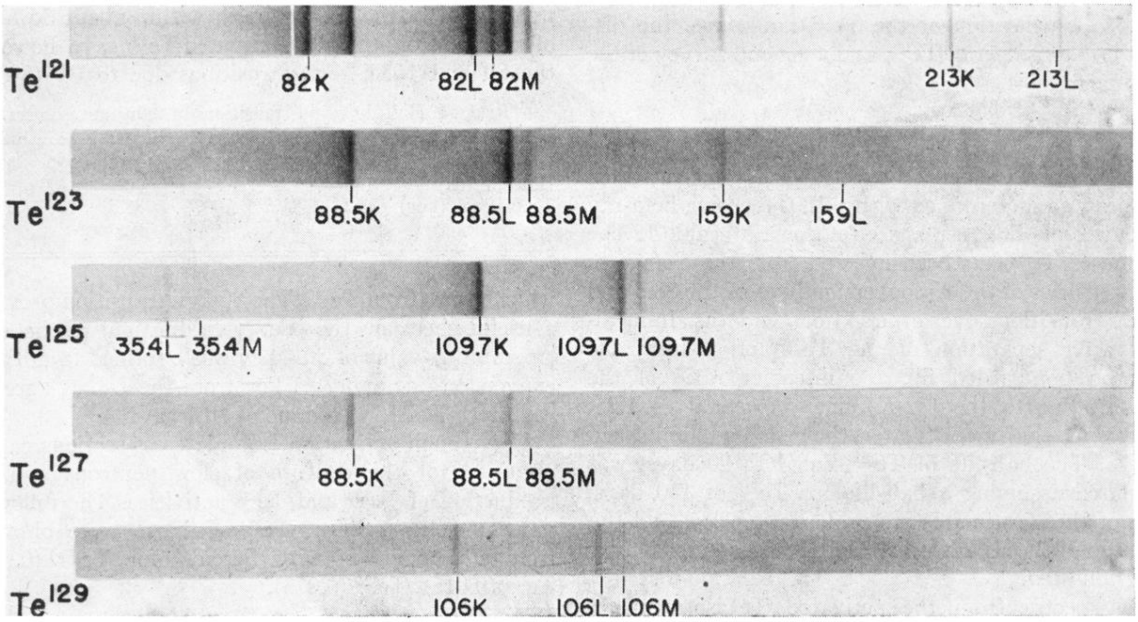
Thanks are due M. Goldhaber for discussion of many points associated with the problem.



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