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Disintegration of Te^{131}†

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Investigations of the nuclear radiations from the 30-hour isomeric state of Te^{131} have been made with the help of magnetic lens spectrometers and scintillation counters. Beta-ray groups of end-point energies 2.46, 2.14, 1.69, 1.35, 0.98, 0.57, and 0.42 Mev have been found. The well-known internally converted 0.180-Mev transition, that from the 30-hour isomeric state of Te^{131} to the 25-minute ground state, was reinvestigated, and its $K/(L+M)$ ratio of 2.4 corresponds to that of an $M4$ transition. Photoelectron spectra show well defined lines corresponding to gamma-ray energies of 0.773, 0.446, 0.331, 0.147, and 1.12 Mev, and weaker lines corresponding to gamma-ray energies of 0.24, 0.275, 0.575, 0.84, and 1.63 Mev. Gray wedge pictures of NaI(Tl) scintillation spectra indicate that the 0.147 and 0.446-Mev transitions are the main lines appearing in the 25-minute tellurium with the 0.773-Mev line also visible. Gamma-gamma scintillation coincidence experiments on the long-lived tellurium are utilized in establishing a possible decay scheme.

I. INTRODUCTION

TELLURIUM-131 shows half-lives of 30 hr and 25 min indicating an isomeric pair, the 30-hr state lying higher. The isomeric transition was investigated by Hill[1] who showed that the 0.180-Mev internally converted gamma ray involved in the transition has the character of $M4$ radiation. The isomeric transition has been shown to take place between an $h_{11/2}$ (30-hr) upper state and a $d_{3/2}$ (25-min) ground state.

The radiations from the 25-min state have been investigated by Geiger[2] using absorption techniques and coincidence counting. He found two beta-ray groups of energies 2.0 and 1.35 Mev together with gamma rays of 0.700 and 0.160 Mev. The two gamma rays were found to be in cascade. Beta-gamma coincidence experiments indicated that all beta rays lead to excited states of the product I^{131}.

Investigations of the radiations from the 30-hr state have been essentially limited to observations of the isomeric transition and no modern determinations of the beta and gamma rays associated with this transition appear to have been made. The present study was undertaken to obtain information on the 30-hr Te^{131} as well as to make a more precise study of the radiations from the 25-min state. Since the 30-hr and 25-min states of the parent are of opposite parity and differ greatly in spin, it is to be expected that two different sets of levels in the product, I^{131}, will be populated by beta transitions depending on the initial state. The spectrometer studies in the present paper were made on the 30-hr state in equilibrium with the 25-min state. Certain studies, of a confirmatory nature, were made with the help of scintillation counters on the 25-min state alone.

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[1] R. D. Hill, Phys. Rev. **76**, 188 and 333(A) (1949). For reference to earlier work see *Nuclear Data*, National Bureau of Standards Publication No. 499 (U. S. Government Printing Office, Washington, D. C., 1950).

[2] K. Geiger, Z. Naturforsch. **7a**, 579 (1952).

II. PARTICLE SPECTRUM

Sources of the 30-hr Te^{131} were prepared by bombarding the magnetically separated isotope Te^{130} with 11.5-Mev deuterons in the Indiana University cyclotron. The tellurium was separated chemically and used as the nitrate for beta-ray sources or as the metal for gamma-ray sources. The chemical separations were carried out after the 25-min Te^{131}, formed in the bombardment, had decayed to insure that during the time of measurement the 30-hr and 25-min periods would be in secular equilibrium and also to insure that any I^{131}, arising as a result of the decay of Te^{131}, would grow from the 30-hr period.

The beta-ray spectrum and that of the attendant internal conversion lines were investigated with the help of a magnetic lens spectrometer. The total beta-ray distribution was measured as a function of the time so that corrections could be made for the decay of Te^{131} and the subsequent growth of the daughter I^{131}. One source was left in the lens for 28 days after bombardment and no long-lived impurity other than the I^{131} was noted. The beta-ray distribution, thus corrected, shows clearly that the spectrum is complex. A Fermi plot of the data was made and is shown in Fig. 1. Table I shows the results of the analysis with the relative intensities and log ft values of the groups. It should be stated that, because of the many subtrac-

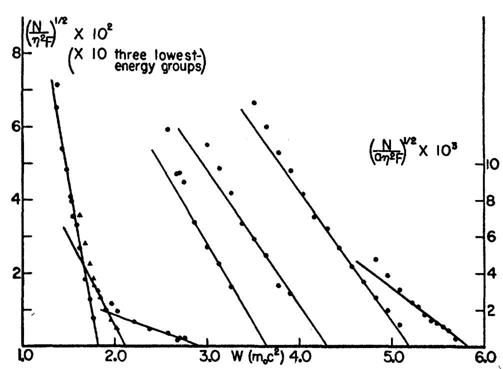

FIG. 1. Fermi plot of the beta rays of Te^{131}.

TABLE I. Beta rays of Te^{131}.

End point Mev	Initial level	Relative abundance % total	% 25 min	Log ft
2.46	30 hr	4.72	....	11.00[a]
2.14	25 min	13.1	60.4	6.22
1.69	25 min	5.4	25.1	6.18
1.35	25 min	3.1	14.5	6.22
0.98	30 hr	4.6	....	7.82
0.57	30 hr	16.9	....	6.45
0.42	30 hr	52.1	....	5.52

[a] $\log[(W_0^2-1)ft]$.

tions involved in completing the Fermi plot, the end points of the lower-energy groups are subject to considerable error. For reasons given below, a forbidden shape correction corresponding to $\Delta j = \pm 2$, yes was applied to the highest-energy beta-ray group. Unfortunately, however, the end point of the second group lies too high to enable one to actually see the shape of the first group.

A plot of the low-energy internal conversion lines is shown in Fig. 2. Here will be seen K and L lines for a gamma ray of energy 0.180±0.002 Mev, K lines for gamma rays at 0.147±0.001 Mev, 0.099±0.001 Mev, and a line which corresponds to a K line for a 0.079-Mev line or an L line for a 0.051-Mev line. The interpretation of the last mentioned line is complicated by the knowledge that there is a 0.080-Mev transition resulting from the decay of I^{131}. The line shown in the figure does not exhibit the growth to be expected for a line from I^{131}. This line is considered to be an L line for a gamma ray of 0.051 Mev even though the corresponding K line, which would occur at an electron energy of 18 kev was not found. Otherwise no place could be found for it in the decay scheme. In addition to the lines shown in Fig. 2, internal conversion electrons appear for gamma rays of energy 0.77, 0.84, and 0.58 Mev. There are indications of internal conversion electrons corresponding to gamma rays at 0.33, 0.28, and 0.24 Mev.

The $K/(L+M)$ ratio for the 0.180-Mev internal conversion line is 2.4, which is in agreement with that empirically predicted for an $M4$ transition.[3] A comparison of the intensity of the 0.180-Mev transition from the isomeric state in tellurium to the ground state of that isotope with that of the beta groups emitted from the 25-minute ground state serves to check on those groups assigned to the 25-min level in Table I. With the decay governed by that of the 30-hr level, the rate of reaching the 25-min level via the isomeric transition must be equal to the rate of leaving by beta transitions. Since the theoretical K internal conversion coefficient[4] for the 0.180-Mev line is 20, it follows that the number of internal conversion electrons from the 0.180-Mev transition should be approximately equal to the number of beta rays coming from the ground state. Within the experimental errors, this was found to be the case for the proposed decay scheme.

III. GAMMA-RAY SPECTRUM

Sources were investigated using lead and uranium radiators to get more information concerning the gamma-ray spectrum emitted in this decay. A typical spectrum taken with a lead radiator is shown in Fig. 3. The decay of the source was followed for several days in order to identify those lines having the half-life of Te^{131} from certain impurity lines which arose in this bombardment. Lines showing the half-life of and attributed to Te^{131} are shown in Table II.

Additional lines are shown which have the half-life of I^{131} and also some from I^{130}. The latter was formed in this experiment from $Te^{130}(d,2n)I^{130}$ and was not removed in the chemical separation. There was no evidence of I^{130} occurring in runs on the beta-ray spectrum which were taken at a later date. The half-life of the line at 0.199 Mev is doubtful so that it is not included in the lines attributed to Te^{131}. It is noted that the K photoelectron line for the 0.842-Mev gamma ray is masked by the L line for the considerably more intense 0.773-Mev line. Qualitative evaluations of the relative intensities of the lines is all that is feasible with the source strength available. The gamma ray at 0.773 Mev is the most intense with those at 0.331 and 0.446 Mev coming next. The transition at 0.147 Mev appears to be quite intense when account is taken of its internal conversion.

With a uranium radiator both a K and an L photoelectron line are seen for a gamma ray of energy 1.12±0.01 Mev. There is also some evidence for a K photoelectron line corresponding to a gamma ray of energy 1.63±0.02 Mev.

IV. COINCIDENCE EXPERIMENTS ON THE 30-HR Te^{131}

Gamma-gamma coincidence experiments using scintillation counters were able to establish some features of the decay scheme, although lack of resolution coupled with the complexity of the decay left some questions unsolved. The gamma ray at 1.12 Mev is in coincidence with that at 0.773 Mev. The 0.773-Mev

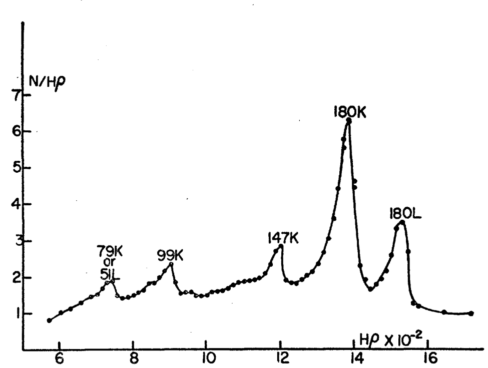

FIG. 2. Low-energy internal conversion lines of Te^{131}.

[3] M. Goldhaber and A. W. Sunyar, Phys. Rev. 83, 906 (1951).
[4] Rose, Goertzel, and Perry, Oak Ridge National Laboratory Publication No. 1023, 1951 (unpublished).

gamma ray is in coincidence with other gamma rays around 0.773 Mev with too great a true-to-chance ratio to be accounted for by coincidences between the Compton distribution of the 1.12-Mev line and the 0.773-Mev line. It is therefore presumed that the gamma rays at 0.773 Mev and 0.84 Mev are in coincidence. Comparison between the singles spectrum and the coincidence spectrum indicate that the gamma ray at 0.773 Mev is not in coincidence with that at 0.331 Mev.

V. EXPERIMENTS ON THE 25-MIN Te^{131} USING SCINTILLATION COUNTERS

In order to investigate the decay of the 25-min state of Te^{131}, sources were prepared by slow neutron bombardment of Te^{130}. No chemical separations were performed before making the measurements. The bombardment time was kept short, since the thermal neutron capture cross section for I^{131} is of the order of 2000 times that for Te^{130}, and I^{132} has a half-life of 2.4 hours. The beta-ray spectrum was run with the help of an anthracene scintillation counter. Corrections

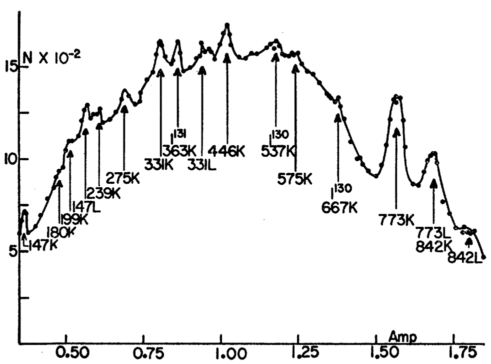

FIG. 3. Photoelectrons from Te^{131}, lead radiator.

were made for the presence of I^{132}, growth of I^{131} and the decay of the 25-minute period before making a Fermi plot Because of poor resolution coupled with a complex spectrum, it was possible only to estimate the end-point energies of the beta-ray groups. These estimates were 1.86 Mev for the highest-energy group and 1.35 Mev for a second group.

The gamma rays from the 25-min Te^{131} were investigated with the help of a NaI(Tl) scintillation counter using the gray wedge technique and compared with a similar experiment using the 30-hr Te^{131}, prepared by a much longer bombardment with deuterons. The 0.147- and 0.446-Mev gamma rays appear on a short exposure of the 25-minute tellurium and in addition the 0.773-Mev line appears on a longer exposure. It is doubtful that any 30-hr Te^{131} was present, since the decay of other sources prepared in the same manner had been followed for the purpose of determining the growth of the iodine daughter and no 30-hr period had been noticed. Pictures of the same source were taken a day following bombardment and no lines from the 30-hr Te^{131} were seen.

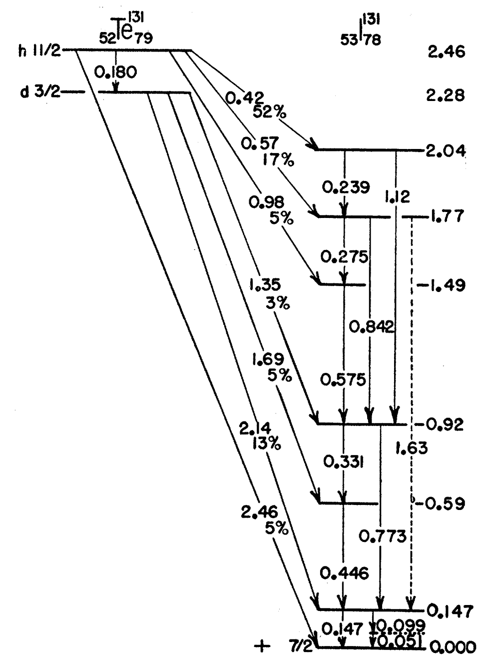

FIG. 4. Tentative decay scheme for Te^{131}.

VI. DISCUSSION OF RESULTS—A PROPOSED DECAY SCHEME

A decay scheme which is compatible with the information obtained is shown in Fig. 4. It is very difficult, with such a complicated situation, to be sure that the decay scheme is unique. The tentative scheme presented here fits well from the point of view of energetics and is substantiated by coincidence experiments. A detailed discussion of the reasons for proposing this scheme is given in the Appendix.

The ground state of I^{131} with 53 protons is expected to have the configuration $(g_{7/2}{}^3)_{7/2}$. The highest-energy beta-ray transition, from the $h_{11/2}$ state of Te^{131} would be expected to be characterized by $\Delta j=\pm 2$, yes, with a value of $\log(W_0{}^2-1)ft\approx 10$, in agreement with experiment. Aside from the highest-energy beta-ray group and that of lowest energy, which appears to be

TABLE II. Gamma rays from the decay of Te^{131}.

From photoelectron spectrum E_γ Mev	From internal conversion spectrum E_γ Mev
1.63 ±0.02	....
1.12 ±0.01	....
0.842±0.013	0.84
0.773±0.008	0.77
0.575±0.012	0.58
0.446±0.004	....
0.331±0.005	(0.331)
0.275±0.009	(0.275)
0.239±0.009	(0.239)
0.147	0.147±0.001
	0.180±0.002
	0.099±0.001
	0.051±0.002

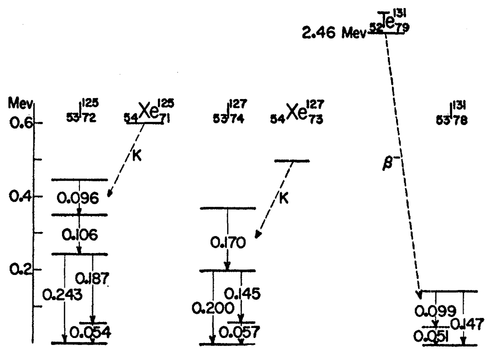

FIG. 5. The low-lying states of I^{125}, I^{127}, and I^{131}.

allowed, it is difficult to gain much information about spin and parity change in these transitions since the values of log *ft* lie in the intermediate range.

It is interesting to compare the low-lying states of I^{131} with those of I^{125} and I^{127}. The information on the states[5] of I^{125} and I^{127} is plotted together with the low-lying states of I^{131} in Fig. 5. The three lowest states bear a remarkable similarity in that they are characterized by two low-energy gamma rays and a crossover transition. The energy of the crossover transition decreases as the neutron number increases. This similarity suggests that a $g_{7/2}{}^3$ proton configuration is primarily responsible for the low-lying levels.

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APPENDIX

The 0.147- and 0.446-Mev gamma rays are assigned to the lowest levels of the decay scheme as shown because of their appearance in the disintegration of the 25-minute tellurium. The 0.147-Mev gamma ray is thought to lead to the ground state of the iodine because of the energy difference between the first two beta groups. The second beta-ray group of end-point energy 2.14 Mev originates from the 25-minute level of the tellurium, and the 0.147-Mev gamma ray follows this group and leads to the ground state of the iodine. If the 2.14-Mev beta group came from the 30-hour level of Te^{131}, it would lead to a level in the iodine at 0.32 Mev above the ground state. However, the gamma ray of 0.331 Mev, which would then be the transition from this state to the ground state, is not seen in the 25-minute decay.

The 1.69-Mev beta-ray group is presumed to originate at the ground state of the tellurium with the subsequent emission of cascade gamma rays of 0.446 and 0.147 Mev. The 0.446-Mev gamma ray is considered to arise from a level at 0.59 Mev because of the beta energetics. The third beta-ray group, end-point energy 1.69 Mev, would lead to a level in the iodine at 0.77 Mev if it started from the upper level of the tellurium, or to a level at 0.59 Mev if it started from the lower level. If the 0.446-Mev transition led to the ground state of the iodine, there would be no beta group feeding it directly.

The 0.773-Mev gamma ray would appear to arise from a lower level of the decay scheme because it is seen in the 25-minute decay and also because it is intense in the 30-hour decay. Since it is known that it is in coincidence with the 1.12-Mev gamma ray, which appears to lie higher up in the decay scheme, it cannot also be in coincidence with the 0.446-Mev gamma ray. These gamma-gamma coincidence measurements as well as Geiger's measurements therefore substantiate the assignment of the 0.773-Mev gamma ray as shown. It is then assumed that the beta-ray group of end-point energy 1.35 Mev originates at the 25-minute level of tellurium and feeds the 0.92-Mev level in iodine. The 0.331-Mev gamma ray is interpreted as a transition between the 0.92 and 0.59-Mev levels on the basis of the energy difference between these two levels. It is not surprising that this 0.331-Mev gamma ray was not seen in pictures of the 25-minute gamma spectrum, since on the basis of the 30-hour gamma spectrum the branching ratio of the gamma rays from the 0.92-Mev level favors the 0.773-Mev transition. This level is populated by only 14.5 percent of the 25-minute disintegrations and by approximately 70 percent of the disintegrations governed by the 30-hour level.

Two factors lead to the decision that the three lowest energy beta-ray groups originate at the 30-hour level of the tellurium. In the first place, no gamma rays which could lead from these levels were seen in the gray wedge pictures of the 25-minute tellurium. Furthermore, from the data in Table I and the assignment of the four higher-energy beta groups given in Fig. 4, 22 percent of the total disintegrations come from the 25-minute level. If the beta group of end point 0.98 Mev, the lowest in intensity of the three remaining groups, is also considered to come from the 25-minute level the *K*-internal conversion coefficient for the 0.180-Mev transition in tellurium is calculated to be 6.2, whereas that theoretically[4] predicted for this *M*4 transition is 20. Obviously if either of the higher intensity, low-energy groups came from the lower level in tellurium, the calculated value of the internal conversion coefficient would be even smaller. With these last three groups proceeding from the upper level in tellurium, the 1.12-Mev gamma ray most logically follows the beta group of highest intensity. Of the remaining gamma rays yet to be discussed only that at 1.12 Mev is of sufficient intensity to follow the 0.42-Mev beta-ray group. While other assignments cannot be excluded, the position of the 1.12-Mev transition as shown in Fig. 4 seems most consistent with the gamma-gamma coincidence results and the beta-ray energetics.

Arguments similar to those used in assigning the 1.12-Mev gamma ray are used to assign the 0.842-Mev gamma ray following the 0.57-Mev beta-ray group. The position of the 0.575-Mev gamma ray in the decay scheme is suggested solely on the basis of energy considerations. However, this assignment is consistent with the fact that both the beta-ray group and the photoelectron line of the gamma ray are weak. The 0.275- and 0.239-Mev gamma rays are assigned the positions shown in the decay scheme because of the energy fit with the gamma rays already placed. The placement of the 1.63-Mev gamma ray is doubtful particularly since it is not certain that this transition is present in the decay of Te^{131} to I^{131}. It should be pointed out again that the many subtractions involved in completing this Fermi analysis of seven groups leave considerable doubt as to the accuracy of the lower energy groups. The assignment of the 0.099- and 0.051-Mev gamma rays is not certain. Coincidence work using scintillation counters, which was attempted with these lines, was inconclusive because of the large number of counts at these energies due to the many higher-energy gamma rays.

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[5] See *Nuclear Data*, National Bureau of Standards Publication No. 499 (U. S. Government Printing Office, Washington, D. C., 1950), and subsequent Nuclear Data Cards.