Title
DECAY STUDIES OF SOME NEUTRON-DEFICIENT ISOTOPES OF ANTIMONY AND TELLURIUM

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Publication Date
1957-08-01

UCRL 3879

UNIVERSITY OF
CALIFORNIA

Radiation

DECAY STUDIES OF SOME NEUTRON DEFICIENT ISOTOPES OF ANTIMONY AND TELLURIUM

BERKELEY, CALIFORNIA

UCRL-3879
Chemistry-General

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

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Ann Rhodes
(Master's Thesis)

August 1957

Printed for the U. S. Atomic Energy Commission

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ABSTRACT

Helium-ion bombardments of indium, and helium-ion, deuteron, and proton bombardments of tin in the Berkeley 60-inch cyclotron have led to the discovery of some new antimony and tellurium activities.

Four new half-lives have been observed in the neutron-deficient antimony region. These are 4.0 ± 0.3 hr, 60 ± 10 min, 30 ± 5 min, and 7 ± 2 min.

New half lives discovered for light tellurium isotopes are 7.5 ± 1.5 hr, 1.4 ± 0.2 hr, and 16 ± 2 min.

Energies of some gamma radiations associated with these activities have been measured.

Discussion of their possible identities is included, but in view of the similarity of half lives and prevalence of isomerism in the region, no definite mass assignments could be made.

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I. INTRODUCTION

A. Purpose of the Research

The information at present available on the lightest isotopes of antimony and tellurium is summarized in the General Electric Chart of the Nuclides as follows.[1]

	Te^{116} ~3h ($\beta^+2.4$)	Te^{117} 2.5h $\beta^+2.5$		Te^{118} 6.0d K ($\beta^+3.1$) ($\gamma.11$)	Te^{119} 16h K $\gamma.56$ e^-	4.5d K $\gamma1.6$ $e^-.2,.5$
		Sb^{116} 15m $\beta^+2.4,..$ $\gamma1.27,.9,$ 2.2 E4.7	60m $\beta^+1.4$ $\gamma1.27,.9,$ .41 E4.7	Sb^{117} 2.8h K $\gamma.16$ e^-	Sb^{118} 3.5m $\beta^+3.1$ IT.11 E 4.1	5.1h K,$\beta^+.7$ $e^-.2$ $\gamma.26,1.5$

It should be possible to prepare yet lighter isotopes of these elements by bombardment of stable indium and tin, using the full energy of the Berkeley 60-inch cyclotron. The object of this research was the preparation and identification of such new isotopes, and the partial determination of their modes of decay.

Because tin has a closed shell of 50 protons, it is probable that the low-lying excited states of tin nuclides are due mainly to excitation of the neutron structure. However, as the region of mass with which we are concerned lies approximately midway between the neutron magic numbers 50 and 82, we may expect some difficulty in making a theoretical interpretation of the energy levels.

B. Previous Work in This Region

The existence of the two isomers of Sb^{116} has until fairly recently caused a certain amount of confusion in this region.

In 1949, Temmer[2] prepared and identified 60-min Sb^{116} by bombardment of In^{115} with helium ions with energies ranging up to 37 Mev. Two years later Blaser, Boehm, and Marmier[3] tried to make the same isotope by a (p,n) reaction on Sn^{116}, and found only an extremely low yield of the 60-min activity. To explain this they hypothesized a semimagic number of 66, corresponding to closure of a subgroup, which would give Sn^{116} unusual stability.

In 1953, Stähelin and Preiswerk,[4] surveying the energies of first excited states of even-even nuclei, found that Temmer's value for Sn^{116} was inconsistent with the general trend they had observed. Therefore they repeated the (p,n) reaction on tin, and thus prepared a 15.5-min isomer of Sb^{116}. To this isomer they assigned gamma rays that had previously been thought to belong to the 14.5-min Sb^{120},[5] and they suggested that Temmer's 60-min antimony may better be interpreted as being Sb^{115}. This, however, must be regarded as extremely unlikely, considering that the production of this isotope from In^{115} would involve an $(\alpha,4n)$ reaction, and the maximum bombardment energy Temmer used was 37 Mev.

The problem appears to have been resolved when Aten, Manassen, and DeFeyer[6] succeeded in making both a 60-min and a 14-min isomer of Sb^{116} at the same time, by alpha bombardment of indium.

Te^{116} and Te^{117} have not been so thoroughly investigated. Dropesky and Wiig[7] report that proton bombardment of I^{127} yields a 2.5 ± 0.1-hr tellurium activity, which decays to 2.8-hr antimony (presumably Sb^{117}), and another 2- to 4-hr tellurium isotope which decays to a 10- to 20-min antimony. This work has not been published.

II. EXPERIMENTAL PROCEDURES

A. Bombardment Techniques

In the research described here, bombardments of four types were carried out in the 60-inch cyclotron. Indium was bombarded with helium ions, and tin with deuterons and protons, to produce antimony isotopes directly. Also, tin was bombarded with helium ions to produce tellurium isotopes, which then decayed to antimony.

Approximately 0.5 mg of In_2O_3 powder was used for target material. This was placed in a small depression at the center of a 10-mil platinum disc, covered with 0.25-mil platinum foil, and mounted in a water-cooled microblock assembly.

Bombardments were generally of one hour's duration, using a beam current of 8 μamp. In most cases the full energy available was used, that is, approximately 48 Mev for helium ions, 24 Mev for deuterons, and 12 Mev for protons. A few lower-energy bombardments were also carried out.

Samples of In_2O_3 enriched in In^{113} and of SnO_2 enriched in Sn^{112} and Sn^{114} were obtained from Oak Ridge National Laboratory.[8] Their chemical purity was states to be better than 99%, and their isotopic compositions to be as listed on page 8 under "Abbreviations used in Table of Data."

B. Chemical Procedures

In view of the relatively short half lives involved, speed was one of the most important factors to be considered in the chemical separations. It was this factor which ruled out the otherwise very convenient anion-exchange method described by Smith and Reynolds,[9] in which tellurium, antimony, and tin are successively eluted from Dowex-l resin with oxalic acid, ammonium oxalate, and sulfuric acid, respectively.

A solvent extraction method using isopropyl ether, suggested by Pappas,[10] suffers from the same disadvantage. Actually, separation times of a few minutes were reported by Pappas, but attempts to repeat this were unsuccessful.

The procedure found to be most generally useful was a simple one involving precipitation of tellurium as the metal and antimony as the sulfide. The SnO_2 target, weighing approximately 0.5 mg, was dissolved in 5 ml of 6 $\underline{M}$ NaOH. The solution was slightly acidified with concentrated HCl and evaporated down to a small volume. Five mg each of antimony and tellurium carriers in 3 $\underline{M}$ HCl were added, and the volume made up to 20 ml with 3 $\underline{M}$ HCl. Te metal was precipitated by adding 10 ml of 15% $NH_2NH_2 \cdot HCl$ solution and saturating with SO_2 gas. The tellurium was filtered off. The filtrate was boiled to remove excess SO_2, diluted to 2 $\underline{M}$ HCl, and saturated, while hot, with H_2S to precipitate antimony as its sulfide. At this acidity, tin and indium remain in solution.

In_2O_3 targets were treated in a similar way except that they were initially dissolved in hot 3 $\underline{M}$ H_2SO_4, and the steps involving tellurium were emitted. The tin was held in solution by complexing with HF, after first reducing the antimony to the trivalent state to avoid losing any of it by complexing.

This procedure was completed in about half an hour.

C. Counting Equipment

Over-all decay curves of antimony and tellurium samples were followed on a Geiger-Müller counter.

Gamma-scintillation spectroscopy was carried out on three types of instruments. In the early experiments a single-channel gamma analyzer with a Speedomax recorder and a 50-channel pulse-height analyzer were used. Most of the work was done, however, with a Penco 100-channel gamma analyzer, using a NaI (Thallium-activated) scintillation crystal.[11]

For beta spectroscopy, a magnetic-lens spectrometer employing an anthracene scintillation detector was used. This spectrometer has been described elsewhere.[12]

III. SUMMARY OF RESULTS

Results are presented in Table I; some typical spectra are shown in Figs. 1 and 2.

Abbreviations Used in Table I

Instruments

G-M = Geiger-Müller counter.
1-ch = Sincle-channel gamma analyzer.
50-ch = 50-channel gamma analyzer.
Penco = 100-channel gamma analyzer.
ML = Magnetic-lens beta spectrometer.

Target materials

Nat. In = 95.8% In^{115}, 4.2% In^{113}.
$In^{113,115}$ = 65.4% In^{113}, 34.6% In^{115}.
50% Sn^{114} = isotope mixture of composition.

Isotope	Atomic %
112	2.63
114	50.03
115	2.84
116	19.42
117	4.40
118	8.56
119	2.55
120	7.24
122	1.08
124	1.26

72% Sn^{112} = isotope mixture of composition.

Isotope	Atomic %
112	72.49
114	2.76
115	0.48
116	6.64
117	2.11
118	5.23
119	1.77
120	5.83
122	1.20
124	1.49

Table I. Table of Data

Bombardment number	Target and type of bombardment	Counting instrument	Observed half lives, energies		Activity to which assigned in discussion.
1	Nat. In + 48-Mev α	G-M	50 min. (and longer)		Sb^{116} and A
		1-ch	4 peaks, energies uncertain, $t_{1/2} = 60$ min		Sb^{116} and A
			1 peak, $t_{1/2} = 2.2$ hr		Sb^{117}
3	"	G-M	50 min		Sb^{116} and A
			2.5 hr (and longer)		Sb^{117}
		50-ch	3 peaks, energies uncertain, $t_{1/2} = 55$ min		Sb^{116} and A
5 and 6	"	50-ch	γ-ray energy (kev)	$t_{1/2}$	
			90 ± 10	1 hr	Sb^{A}
			120 ± 10	73 min	Sb^{116}
			155	2.5 hr	Sb^{117}
			385	73 min	Sb^{116} or A
			510	composite.	
7	"	ML	Conversion line ~1.3 Mev		Sb^{116}
			β^{+} 0.75, 1.10, and 1.5 Mev (resolution of Fermi plot)		Sb^{A} Sb^{116}

Table I (continued)

Bombardment number	Target and type of bombardment	Counting instrument	Observed half lives, energies		Activity to which assigned in discussion.
7	Nat. In + 48-Mev α	Penco	γ-ray energy (kev)	$t_{1/2}$	
			60	60-71 min	Sb^{A}
			90	63-65 min	
			120	62-70 min	Sb^{116}
			160	-	Sb^{117}
			400	52-60 min	Sb^{116}
			510	50-60 min	Sb^{A} and Sb^{116}
			950	-	
			1350	-	Sb^{116}
22	Nat. In + 33-Mev α	Penco	γ-ray energy (kev)	$t_{1/2}$	
			75	-	
			110	-	Sb^{116}
			160	-	Sb^{117}
			250	4.3 hr	Sb^{D}
			1070	complex	Sb^{116} and ?
			1260	1-4 hr	
4	$In^{113,115}$ + 25-Mev α	G-M	40 min. (and longer)		Sb^{A}
		1-ch	γ-ray energy (kev)	$t_{1/2}$	
			160	2.7 hr	Sb^{117}
			540	47 min	Sb^{A}
			250	complex	Sb^{D}

Table I (continued)

Bombardment number	Target and type of bombardment	Counting instrument	Observed half lives, energies		Activity to which assigned in discussion.
9	$In^{113,115}$ + 48-Mev α	G-M	35 min (and longer)		$Sb^{A,D}$
		Penco	γ-ray energy (kev)	$t_{1/2}$	
			30	93 ± 5	?
			75	157 ± 7 min	Sb^{117} ?
			105	57 ± 10 min	Sb^{116}
			160	3 - 4 hr	Sb^{117}
			400	50 min	Sb^{116}
			510	42 ± 8 min	Sb^{A} and Sb^{116}
10,14, 15, and 17	50% Sn^{114} + 48-Mev α	G-M	Te:	1.7 hr	Te^{C}
				9 hr	Te^{G}
		Penco	Te: γ-ray energy (kev)	$t_{1/2}$	
			95	1.2-2.5 hr	Te^{C}
			115	-	Sb daughter?
			510	1.5 hr	
			750	1.1 hr	Te^{C}
			960±10	1.8 hr	
			1070±10	-	
			1320±10	2 hr	Te^{C}
		G-M	Sb (daughter of above Te)*	26 min	Sb^{B}
				1.5 hr	?

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*Chemically separated from active tellurium fraction 90 min after bombardment and 60 min after tellurium purification.

Table I (continued)

Bombardment number	Target and type of bombardment	Counting instrument	Observed half lives, energies		Activity to which assigned in discussion.
11,21	50% Sn^{114} + 24-Mev d	G-M	30 ± 10 min (and longer)		Sb^A and ^{B}
		Penco	γ-ray energy (kev)	$t_{1/2}$	
			105		
			155		Sb^{117}
			245	3-4 hr	Sb^D
			400	1.7-2.3hr	Sb^{116}
			510	1 hr	Sb^{116} and Sb^A
			970		
			1250	1-2 hr	Sb^{116}
18	50% Sn^{114} + 13-Mev d	G-M	37 min		Sb^A or ^{B}
			4.5 hr		Sb^D
		Penco	γ-ray energy (kev)	$t_{1/2}$	
			105	-	Sb^{116}
			165	-	Sb^{117}
			510		
			1,000	complex	?
			1,280		
			250	4.5 hr	Sb^D

Table I (continued)

Bombardment number	Target and type of bombardment	Counting instrument	Observed half lives, energies		Activity to which assigned in discussion.
19	50% Sn^{114}	G-M	17 min		?
	+ 12-Mev p		1.6-2.0 hr		Sb^{116}
		Penco	γ-ray energy (kev)	$t_{1/2}$	
			60	-	Sb^A
			100	1.5 hr	Sb^A
			150	-	Sb^{117}
			255	4 hr	Sb^D
			511	22 min	Sb^B
			960	50 min	Sb^A or Sb^{116}
			1320	36 min	Sb^A or B
13,16	72% Sn^{112}	G-M	Te: 15 ± 3 min		Te^F
	+ 48-Mev α		2-3 hr		$Te^{116,117}$
		Penco	Te:		
			γ-ray energy (kev)	$t_{1/2}$	
			80	-	
			110 ± 5	3 hr	$Te^{116,117}$
			130	-	
			165	-	
			280	-	
			510	-	
			670	6 hr	Te^G
			750	1.3 hr	Te^C
			920	-	
			960	-	
			1060	-	
			1350	30 min	Sb^A or D

Table I (continued)

Bombardment number	Target and type of bombardment	Counting instrument	Observed half lives, energies		Activity to which assigned in discussion.
12	72% Sn^{112} + 24-Mev d	G-M	7 min		Sb^E
			35 min		Sb^D
			2.5 hr (and longer)		Sb^{117}
		Penco	γ-ray energy (kev)	$t_{1/2}$	
			90	-	Sb^A
			110	-	
			170	1-3 hr	Sb^{117}
			210	-	?
			230	-	
			510	shorter	
			670	-	
			1090	-	
			1300	-	Sb^{116}

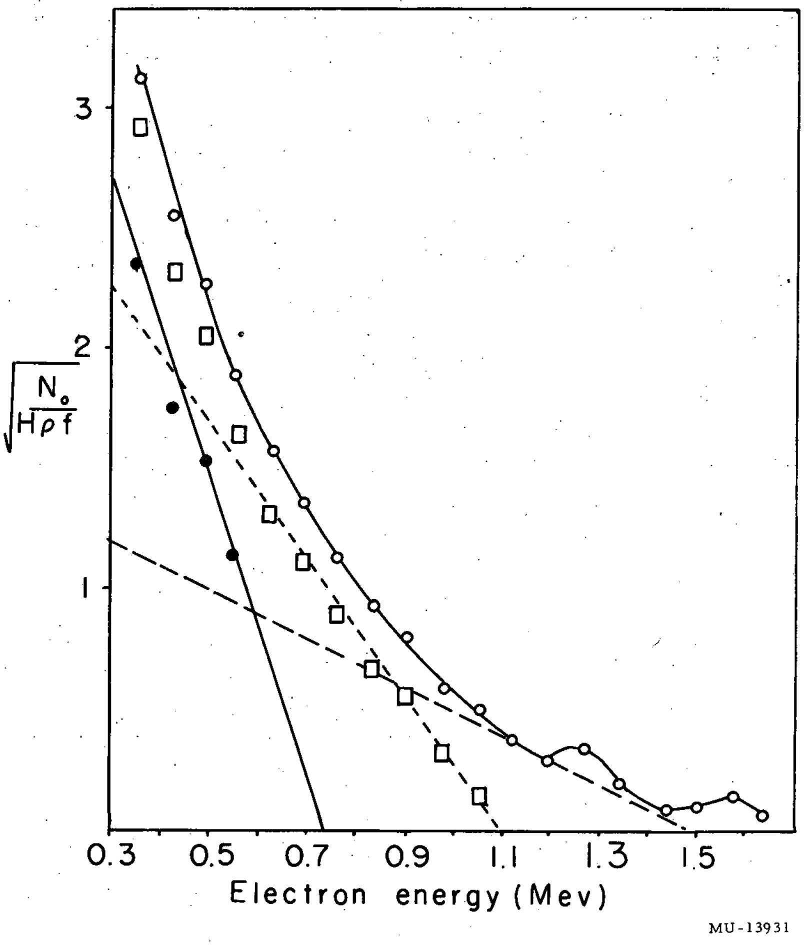

Fig. 1. Resolution of Fermi plot, Bombardment 7.

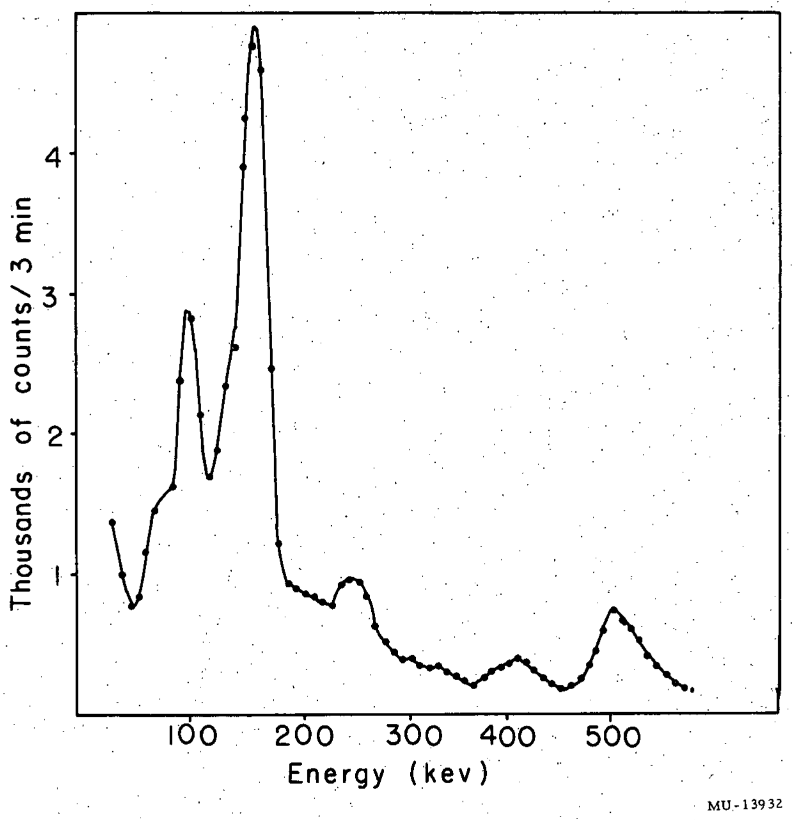

Fig. 2a. Gamma spectrum, Bombardment 21, low-energy region.

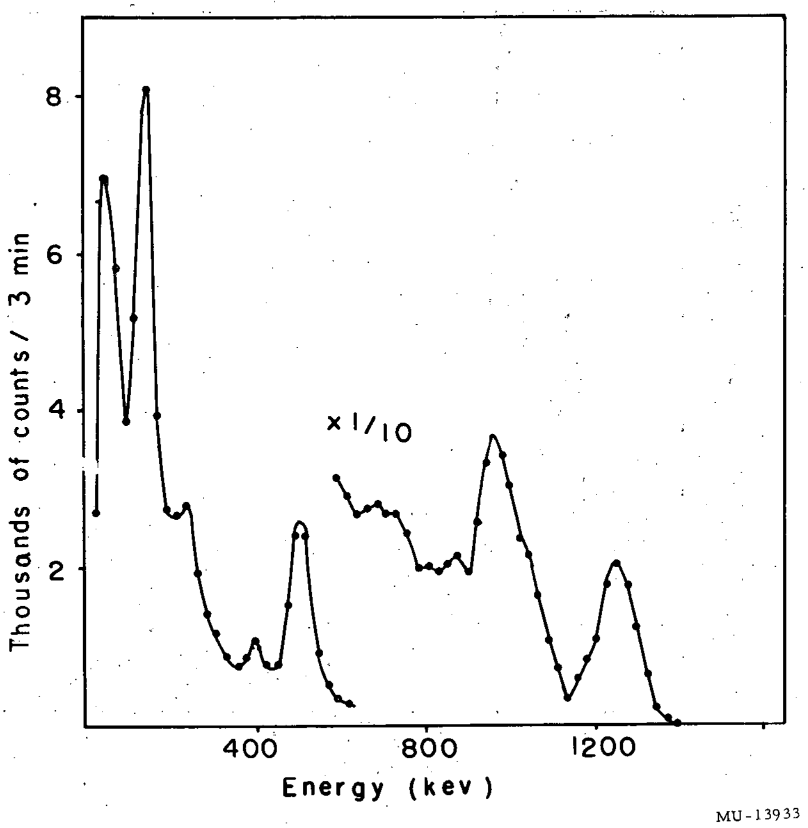

Fig. 2b. Gamma spectrum, Bombardment 21, high-energy region.

IV. DISCUSSION OF RESULTS

From the results of these bombardments it seems possible to extract seven new activities. As the mass assignments are by no means clear, these activities are represented by letters, as follows:

Activity	Half life	Characteristic radiation observed and energy (Mev)
Sb^A	60 ± 10 min	γ:0.06, 0.09, (0.12 ?); β^+0.75,1.10
Sb^B	30 ± 5 min	β^+: (1.3 ?)
Sb^D	4.0 ± 0.3 hr	γ:0.25
Sb^E	7 ± 2 min	-
Te^C	1.4 ± 0.2 hr	β^+; γ:0.75,(0.10, 0.12, 1.0, 1.3)
Te^F	16 ± 2 min	β^+
Te^G	7.5 ± 1.5 hr	γ:0.67

The difficulty in mass assignment is due to two features. One, which is unavoidable, is the presence of many metastable isomeric states in this region, which prevents one from assuming that each half life belongs to a different mass number. The other is that even the isotopically enriched samples of tin contain such a mixture of isotopes that one could never be sure which starting material was responsible for a given product.

The possible identities of the new activities are briefly considered here.

Sb^A. When natural indium was bombarded with 48-Mev helium ions, no new half life was seen, although at this energy one would expect a high yield of Sb^{115}, the $(\alpha,4n)$ product.

One has a choice of three explanations of this negative result. Sb^{115} may be too long-lived to see, or too short-lived, or it may have the same half life as another isotope which is also produced in the bombardment. This last explanation is favored by the fact that three new gamma rays of 1-hour half life have been observed. Of these, two (at 60 kev and at 90 kev) were seen only in bombardments in which Sb^{115} was expected to be produced in reasonable yield (e.g., In^{115} $(\alpha,4n)$. The third, at 120 kev, was seen whenever Sb^{116} was produced, and its intensity relative to other known gamma rays of Sb^{116} did not vary under different bombarding conditions (e.g., in Bombardments 7 and 22). This suggests that the 120-kev gamma ray belongs to Sb^{116} and that the other two may belong to Sb^{115}. The 0.75-Mev and 1.10-Mev positron groups seen in Bombardment 7 would also seem to be attributable to this isotope. Temmer[2] examined the electron spectrum of Sb^{116}, using a magnetic lens spectrometer, and reported only a 1.4-Mev positron group.

<u>Sb^{B}</u>. A 20- to 30-min activity was seen several times in the complex Geiger-Müller decay curves for antimony samples. The only gamma ray that might be associated with it is at 1.3 Mev. This gamma was seen twice, once in antimony resulting from proton bombardment of the 50% Sn^{114} mixture, and once in a tellurium sample from 48-Mev helium-ion bombardment of 72% Sn^{112}. As the (p,n) reaction is the predominant one at the energies available at the 60-inch cyclotron, Sb^{114} is indicated as the most likely choice for this activity. However, the existence of a gamma ray in 60-min Sb^{116} of approximately the same energy makes one hesitate to draw any definite conclusion.

<u>Sb^{D}</u>. The existence of a 4-hr antimony activity is based on the observation of a well-defined 250-kev gamma ray having this half life. It was seen in various different types of bombardment, and its half life is sufficient to distinguish it from Sb^{116}, Sb^{117}, and Sb^{118}. We may compare its intensity with that of known gamma rays of Sb^{116} and Sb^{117} in different bombardments.

Table II

Comparative abundances of Sb^{D} and Sb^{116} radiations (in arbitrary units)

	250-kev γ	1.3-Mev γ of 60-min Sb^{116}
Bombardment 21 (50% Sn^{114} + 24-Mev d)	3.1	1.0
Bombardment 22 (Nat. In + 33-Mev α)	0.6	1.0

Sb^D is thus something that is formed in relatively low abundance in Bombardment 22. As the energy is too low to permit (α,4n) reactions, the only explanation seems to be that it is a product resulting from the 4% of In^{113} in the target. The results are consistent with the assignment of Sb^D as an isomer of Sb^{114}.

A further rough comparison may be made as shown in Table III.

Table III

Comparative abundances of Sb^D and Sb^{117} radiations (in arbitrary units)

	250-kev γ	160-kev γ of Sb^{117}
Bombardment 21 (50% Sn^{114} + 24-Mev d)	1.0	1.0
Bombardment 18 (50% Sn^{114} + 13-Mev d)	1.0	2.3
Bombardment 12 (72% Sn^{112} + 24-Mev d)	1.0	0.3

One should not attach too much importance to this comparison. We would be justified in regarding the difference in relative intensities as significant only if we knew how to compare the amount of Sb^{117} formed in each bombardment. But Sb^{117} may be made by various different reactions, e.g., Sn^{119} (d,4n), Sn^{118} (d,3n), Sn^{117} (d,2n), Sn^{116} (d,n). These tin isotopes are present in different abundances in the two isotopic mixtures. As we do not know what proportion of the product is due to a given reaction, we are unable to take this into account. However, of one thing we may be sure. As Sb^D was seen in Bombardment 22, it can be no lighter than 114.

<u>Sb^E</u>. This isotope is apparently more neutron-deficient than any of the other isotopes so far considered. It was seen as an approximately 7-min component of the Geiger decay curve of the antimony products of Bombardment 12 (72% Sn^{112} + 24-Mev deuterons) and on no other occasion. This would indicate that it is no heavier than Sb^{112}.

$\underline{Te}^C$. This was made when 50% Sn^{114} was bombarded with 48-Mev helium ions. Its most distinctive gamma ray, at 750 kev, was also seen in Bombardment 16 (72% Sn^{112} + 48-Mev helium ions). The other 1.5-hr gamma rays in the tellurium sample have energies that are distribingly similar to those of Sb^{116}, which might suggest that we are dealing with a very short-lived isomer of Te^{116}. Be that as it may, however, the 750-kev gamma does not coincide with any of the antimony gammas, and therefore one feels justified in regarding the "1.5 hr-tellurium" as being in fact tellurium and not antimony. Te^{114} or Te^{115} appears to be the most probable assignment.

$\underline{Te}^F$. This is probably the least well substantiated of the new activities. It appears only once, when 72% Sn^{112} was bombarded with 48-Mev helium ions. No gamma rays having this 15-min half life were seen. As it did not appear among the products of helium-ion bombardment of 50% Sn^{114}, we may gather that it is no heavier than Te^{112}.

$\underline{Te}^G$. In the Geiger decay curves of the products of Bombardments 10, 14, 15, and 17, Te^G was found with Te^F. Its half life each time appeared to be close to 9 hours. The 670-kev gamma ray which has been provisionally associated with it was seen only in Bombardments 13 and 16 (72% Sn^{112} + 48-Mev helium ions) and not in the Sn^{114} bombardments. The half life measured for this gamma ray was closer to 6 hours, which could conceivably be regarded as agreeing within the limit of experimental error. If it is the same isotope, however, we are left wondering why the gamma ray was not seen in the Sn^{114} experiments.

ACKNOWLEDGMENTS

I wish to express my thanks and appreciation to Professor John O. Rasmussen for his supervision and guidance of this work, to Dr. Eugene Huffman for helpful chemical discussions, to the 60-inch cyclotron crew, to the Health Chemistry monitors, and to everyone else who has offered advice and encouragement on this project.

This work was done under the auspices of the U. S. Atomic Energy Commission.

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