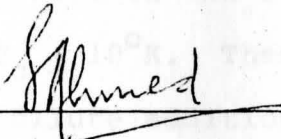


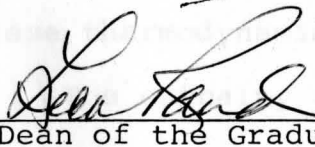
THERMODYNAMIC AND X-RAY STUDIES OF
DILUTE Tl-Sb ALLOYS

by

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ABSTRACT

THERMODYNAMIC AND X-RAY STUDIES OF
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Master of Science in Engineering
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Thallium undergoes a martensitic phase transformation from β -phase to α -phase on cooling. It has been attempted in this investigation to determine the enthalpy changes of both phases from 445^oK to 525^oK, including the enthalpy change associated with the phase transformation and also the crystal structures and lattice parameters of the respective phase at $T_c \pm 10^o$ K. Then it was attempted to determine the effect of dilute additions of antimony to pure thallium on these thermodynamic and x-ray parameters.

The enthalpy change of the phase transformation, $\Delta H_{T_c}^{\alpha\beta}$, the crystal structures and lattice parameters of the respective phase and the volume change associated with the phase transformation bears a linear relationship with additions of antimony in pure thallium. The result supports the basic premise of Ahmed's theory on electronic contribution to phase transformation.

ACKNOWLEDGEMENTS

Here I would like to acknowledge the guidance, help and suggestions from Dr. S. Ahmed, Professor of Metallurgical Engineering, during the entire course of this work, and also Dr. T. K. Slaweki, Chairman of Chemical and Metallurgical Engineering department for his help.

Samuel Vinod Thamboo

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LIST OF SYMBOLS

SYMBOL	DEFINITION	UNITS
α	Alpha Phase	None
β	Beta Phase	None
H	Enthalpy	Joules/gram mole
T	Temperature	Kelvin
v	Volume	\AA^3
λ	Wavelength of X-ray	\AA
C_p	Specific heat at constant pressure	Joules/gram mole degree K

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CHAPTER 1

INTRODUCTION

The diffusionless phase transformation in metals and alloys require the change of the crystal structure of the parent phase to that of the product phase, involving a re-shuffling of the atoms to achieve the transition. This transformation is achieved either upon heating or cooling. The transformation on cooling starts at a definite temperature T_s and ends at a definite temperature T_f . Generally T_s and T_f are different temperatures. Similarly the transformation temperature on heating also starts and ends at different temperatures. This results in a hysteresis loop that is significantly larger in Fe-base alloys than in Au-Cd or In-Tl alloys. The most important point here is that the transformation upon cooling is at a definite temperature, $T_c = (T_s + T_f)/2$.

The temperature, upon cooling, T_c , is always below the equilibrium temperature, T_0 , where the free energy of the parent and the product phases are equal. This indicates that some degree of undercooling is required for the transformation, to provide the chemical free energy change to overcome the non-chemical free energy change associated with such transformations.

It is also well known that the enthalpy change, ΔH , as a function of temperature will change discontinuously at

the transformation temperature on cooling T_c . This change in enthalpy is known as the enthalpy of phase transformation. From the enthalpy versus temperature curve the specific heat at constant pressure can be determined at the temperature under consideration.

Pure thallium is known to undergo a diffusionless phase transformation at 498°K . This was first found by Levin.¹ Senkiti Sekito² reported that the low temperature α -phase has a hexagonal, close-packed structure with the lattice parameters $a=3.65\text{\AA}$ and $c/a=1.600$. He reported the high temperature β -phase has a face centered cubic structure with a lattice parameter of $a=4.841\text{\AA}$. Lipson and Stokes³ studied the crystal structure of pure thallium (99.995% Tl) at room temperature and confirmed the α -phase to have a hexagonal close packed structure with a lattice parameter of $a=3.4496 \pm 2\text{\AA}$, $c=5.5137\text{\AA}$, $c/a=1.5984 \pm$ at 18°C . They determined the crystal structure at 262°C (using a Debye-Scherrer camera) to be body-centered cubic and not face-centered cubic as reported earlier by Sekito. The lattice parameter obtained by them for the body-centered high temperature structure was $a=3.874 \pm \text{\AA}$ at 262°C .

It is the aim of this research to study the phase transformation in pure thallium and the effect of antimony in

¹H. S. Levin, Z. Anorg Chem. Vol.45, (1905), p.34.

²Senkiti Sekito Z. Krist, Vol. 74, (1930), p.p. 189-193.

³D. H. Lipson and A. R. Stokes, Nature, Vol. 148, (1941), p. 175.

very small concentrations on this phase transformation. This research effort involves both thermodynamic and x-ray studies of both phases over a range of temperatures.

EXPERIMENTAL METHOD

Sample Preparation

Pure Inconel (99.99%) and pure titanium (99.99%) were cut into small pieces. The Inconel was first cleaned in boiling water to remove the protective paraffin coating. The pieces were then cleaned in acetone and ether. The proper amounts of the metals were then weighed for each alloy. These pieces were then placed in a clean quartz tube and sealed under vacuum (1.5×10^{-5} torr).

The alloys were then melted within the quartz tube in a furnace. The melted alloys were kept at 2500°C in a furnace for five days. Every 24 hours the tubes were inverted to insure proper mixing. They were then furnace cooled. After cooling, the samples were removed from the furnace and annealed at 250°C for 48 hours.

The alloy samples that prepared were approximately 15 mm long and had a diameter of 2 mm. The average weight of each sample was 50 grams. A 1 mm hole was drilled at the center of the cross-section to a depth of 10 mm. The samples after the heat treatment were electropolished with nickel and chromic to avoid oxidation.

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CHAPTER II

EXPERIMENTAL METHOD

Sample Preparation

Pure thallium (99.999%) and pure antimony (99.99%) were cut into small pieces. The thallium was first cleaned in boiling water to remove the protective paraffin coating. The pieces were then cleaned in acetone and ether. The proper amounts of the metals were then weighed for each alloy. These pieces were then placed in a clean quartz tube and sealed under vacuum (1.8×10^{-5} Torr).

The alloys were then melted within the quartz tube in a furnace. The molten alloys were kept at 350°C in a furnace for five days. Every 24 hours the tubes were inverted to ensure proper mixing. They were then furnace cooled. After cooling, the samples were removed from the furnace and annealed at 250°C for 48 hours.

The alloy samples thus prepared were approximately 15 mm long and had a diameter of 25 mm. The average weight of each sample was 50 grams. A 1 mm hole was drilled at the center of the cross-section to a depth of 10 mm. The samples after the heat treatment were electroplated with nickel and chromium to avoid oxidation.

Alloys of the following compositions were prepared in this manner.

1. Pure thallium
2. Tl-Sb alloy (0.1 atom percent Sb)
3. Tl-Sb alloy (0.3 atom percent Sb)
4. Tl-Sb alloy (0.5 atom percent Sb)
5. Tl-Sb alloy (0.9 atom percent Sb)

Thermodynamic Investigation

Description of Calorimeter

The study of the thermodynamic properties was done in a modified Olsen calorimeter. (Figure 1). The sample held by a thermocouple was contained in a water-tight copper jacket. This jacket was placed in the medium contained in a Dewar's flask, which in turn was surrounded by an adiabatic jacket. A Teflon block was used to cover the flask.

Temperature measurement of the medium was done by a thermopile consisting of seven precision thermocouples connected in series. The thermocouples were introduced through the Teflon block. The cold junction of the thermocouple was maintained at 0°C with the use of a precision electronic cold junction.

The calorimeter medium was kept agitated with the use of a magnetic stirrer unit placed under the calorimeter assembly.

The output E.M.F. of the thermocouple in the thermopile was calibrated by using a quartz digital thermometer with an accuracy of $.0001^{\circ}\text{C}$.

Spectroquality isopropyl alcohol was used as the calorimeter medium.

A measured amount of isopropyl alcohol was weighed in a clean Dewar's flask. This amount was maintained the same for all runs. The magnetic stirrer was placed in the flask carefully after weighing.

The sample was placed on the thermocouple and lowered into the furnace maintained at 500°C . As soon as the sample reached a temperature of 270°C it was quickly removed from the furnace and capsuled. It was then lowered into the calorimeter and capped.

Temperature of the sample and the medium was simultaneously recorded using an x-y recorder.

X-Ray Investigation

Description of High-Temperature X-Ray Camera

An MRC high-temperature x-ray camera was used for the high temperature x-ray studies. A view of the camera is shown in Figure 2. This attachment was mounted on a Norelco x-ray diffractometer. Heating of the specimen was achieved by electric resistance heating of a Tantalum element held between two water cooled blocks. The temperature was controlled by

controlling the current passing through the heating element, through a Variac. The temperature was measured by using a precision chromel-alumel thermocouple. The upper surface temperature of the sample was measured for various settings of the amperage and a calibration curve was obtained.

The specimen chamber could be closed by an air-tight cover. This permitted the use of helium atmosphere in the chamber.

A rate-meter with a strip chart recorder was used to get a diffraction pattern.

Experimental Method

Samples for x-ray studies were cut from the calorimeter samples in slices 0.1 mm thick. The sample was mounted on the tantalum element after filing and cleaning with acetone. The attachment cover was replaced and the chamber was purged with helium for 2 minutes at a moderate flow rate. The exhaust valve was then closed and the flow of helium stopped. A chamber pressure of 10 psi was maintained. The temperature was then raised to the required value and a scan was obtained on the strip chart.

For the thallium alloys, only selected 2θ values were scanned by the oscillating crystal method.

The results were indexed by analytical methods. For hexagonal crystals the $\sin^2 \theta$ values are given by equation (1)

$$\sin^2 \theta = A (h^2 + hk + k^2) + Cl^2 \quad (1)$$

$$\text{Where } A = \frac{\lambda^2}{3a^2} \text{ and } C = \frac{\lambda^2}{4c^2}$$

The permissible values for $(h^2 + hk + k^2)$ are 1, 3, 4, 7, 9 etc. The lattice parameters were calculated by solving equation (2)

$$\sin^2\theta = \frac{\lambda^2}{4} \left[\frac{4}{3} \frac{(h^2 + k^2 + hk)}{a^2} + \frac{1}{c^2} \right] \quad (2)$$

Similarly for cubic system the $\sin^2\theta$ values satisfy equation (3)

$$\frac{\sin^2\theta}{(h^2 + k^2 + l^2)} = \frac{\lambda^2}{4a^2} \quad (3)$$

The sum $(h^2 + k^2 + l^2)$ is always integral and the permissible values for the body-centered cubic structure are 2, 4, 6, 8, 10, 12, etc.

CHAPTER III

RESULTS AND DISCUSSION

The thermodynamic results consisted of changes in temperature of the calorimeter medium as a function of the change in the temperature of the sample. From these results the enthalpy change, ΔH , was calculated by using the following equation;

$$\Delta H = W \cdot C_p \cdot \Delta T$$

where $\Delta H = H_T - H_{525}$

W = The weight of the calorimeter medium

C_p = The specific heat of the calorimeter at T_{OK}

ΔT = The change in calorimeter temperature with respect to the reference point at $525^{\circ}K$.

The results of the above calculations are shown in Tables 1 through 5 and also in Figure 3 through 7. The results definitely indicate that pure thallium and the Tl-Sb alloys exhibit a first order phase transformation. The initial temperature to start the transformation (T_s) and the final temperature of the transformation (T_f) are listed in Table 6. From these values the mean transformation temperature on cooling (T_c) are determined and listed in this Table. The enthalpy change accompanying the phase transformation, $\Delta H^{\alpha\beta}$, is determined at T_c by simple extrapolation of

the high temperature and low temperature curves. The results are shown in Table 7 and Figure 8.

It is interesting to note that both T_c and $\Delta H^{\alpha\beta}$ exhibit a linear relationship with concentration in all cases. Both the enthalpy and transformation temperature decrease with the increase in antimony content.

The enthalpy of an α -phase at a temperature T_c is given by:

$$H_{T_c}^{\alpha} = H_0^{\alpha} + \int_0^{T_c} C_p^{\alpha} dT \quad (1)$$

Where H_0^{α} = The enthalpy at 0°K

C_p = The specific heat of α -phase at constant pressure

In case of thallium the β -phase which is the high temperature phase transforms to the α -phase which is a low temperature phase. Thus the total enthalpy of pure thallium at temperature T will be given by the following expression:

$$H_T = H_0^{\alpha} + \int_0^{T_c} C_p^{\alpha} dT + \Delta H_{T_c}^{\alpha\beta} + \int_{T_c}^T C_p^{\beta} dT$$

Where H_T = The enthalpy of pure thallium at $T^\circ\text{K}$.

H_0^{α} = The enthalpy of α -phase at 0°K .

$\Delta H_{T_c}^{\alpha\beta}$ = The enthalpy of phase transformation.

C_p^{α} & C_p^{β} = The specific heat at constant pressure of the respective phases.

It should be noted that the high temperature phase does not exist physically at low temperatures but the extrapolated values can be obtained from the data at high temperatures.

The x-ray studies involve the determination of the crystal structures of each phase of pure thallium and its alloys and also the determination of lattice parameters by oscillating crystal method. The x-ray results indicate that the crystal structure of the β -phase is body centered cubic and the crystal structure of the low temperature, α -phase of pure thallium is hexagonal close packed. The alloying additions do not change these crystal structures, but cause a change in the lattice parameter. The results are shown in Tables 8 through 20 and Figures 10 and 11. From these results the volume of each phase is calculated at the indicated temperature which in all cases are at $T_c \pm 10^\circ\text{K}$ and the results are listed in Table 21. The difference in temperature at which these values were obtained is 20°K . If it is assumed that such a small change in temperature will not substantially change the lattice parameters, one may calculate the volume change accompanying the transformation. The results are shown in Table 22 and Figures 13 and 14. The volume change represents the difference in volumes of the parent and product phases and will result in contributing to the strain free energy change which obviously will be volume related.

Ahmed has presented a theory relating the electronic contribution to the phase transformation in pure thallium. In this theory it is suggested that the free energy change associated with the phase transformation consists of a volume dependent part and a volume independent part. The volume dependent part results from the volume changes between the

parent and product phases. The associated strain energy will be volume dependent. The volume independent part is related to the electronic contribution (A complete paper on this subject will be published soon by S. Ahmed). If one plots $\Delta H^{\alpha\beta}$ versus V^* (defined as $V^* = (\Delta V_{All}^{\alpha\beta} - \Delta V_{T1}^{\alpha\beta}) / (\Delta V_{T1}^{\alpha\beta})$) then one gets a fairly good straight line as shown in figure 15. This result confirms the basic premise of the theory.

TABLE 1

THERMODYNAMIC RESULTS

Pure Thallium	Calorimeter Medium	Isopropyl Alcohol
Alloy No B-11 Run No. 1	Medium Temperature Room Temperature	23.0°C 23.117°C
Temperature (°K)	ΔH (Cals/Mole)	ΔH (J/Mole)
525	0	0
519	62.33	261.79
513	146.39	614.84
507	199.38	837.40
505	215.16	903.67
502	222.30	933.66
502	261.01	1096.24
502	299.22	1256.72
502	314.50	1320.90
501	322.15	1353.03
495	360.36	1513.51
488.5	390.92	1641.86
482.0	436.77	1834.43
476	452.06	1898.65
470	505.55	2123.31

TABLE 2

THERMODYNAMIC RESULTS

Tl-Sb Alloy (.1 atom percent Sb) Run No. 4		Isopropyl Alcohol Calorimeter Media Room Temperature 23.114°C Media Temperature 23.226
Temperature (°K)	ΔH Cals/Mole	ΔH Joules/Mole
525	0	0
519	329.00	1381.80
513	552.66	2321.17
507	657.59	2761.88
506	683.84	2872.13
505	710.07	2982.29
503.5	792.43	3328.21
502	871.26	3659.29
502	989.52	4155.98
501	1028.94	4321.55
500	1055.22	4431.92
498	1068.36	4487.11
497	1098.82	4615.04
496	1125.14	4725.59
495	1138.31	4780.90
488.5	1190.96	5002.03

TABLE 3

THERMODYNAMIC RESULTS

Tl-Sb Alloy (0.3 atom percent Sb) Run No. 7		Calorimeter Media	Isopropyl Alcohol
		Room Temperature	23.4°C
		Media Temperature	23.8°C
Temperature (°K)	ΔH Cals/Mole	ΔH Joules/Mole	
525	0	0	
519	685.08	2877.34	
513	915.66	3845.75	
507	1065.46	4474.93	
501	1211.32	5087.54	
495	1308.57	5495.99	
492	1357.19	5700.20	
491	1381.51	5802.34	
490	1410.59	5924.48	
486	1568.88	6589.30	
485	1581.06	6640.45	
483.5	1605.41	6742.72	
476	1666.29	6998.42	
470	1751.53	7356.43	
463.5	1800.29	7561.01	
457	1873.29	7867.82	

TABLE 4

THERMODYNAMIC RESULTS

Tl-Sb Alloy (.5 atom percent Sb) Run No. 8		Calorimeter Media	Isopropyl Alcohol
		Room Temperature	23.6°C
		Media Temperature	24.1°C
Temperature °K	ΔH Cals/Mole	ΔH Joules/Mole	
525	0	0	
519	244.66	1027.57	
513	379.02	1591.88	
507	537.82	2258.84	
501	1075.28	4516.18	
495	1392.87	5850.05	
488.5	1490.59	6260.48	
482	1563.88	6568.30	
476	1637.17	6876.11	
473.5	1661.60	6978.72	
472	1686.03	7081.33	
471	1771.53	7440.43	
470	1783.75	7491.75	
468.5	1808.18	7594.36	
467.0	1820.39	7895.64	
463.0	1857.04	7799.57	

TABLE 5

THERMODYNAMIC RESULTS

Tl-Sb Alloy (.9 atom percent Sb)

Room Temperature: 23.8°C

Run No. 9

Media Temperature: 24.4°C

Calorimeter Media Isopropyl Alcohol

Temperature (°K)	ΔH Cals/Mole	ΔH Joules/Mole
525	0	0
519	209.61	880.36
513	377.12	1583.90
507	494.31	2076.10
501	586.39	2462.84
495	837.53	3517.63
488	1063.55	4466.91
482	1130.52	4748.18
476	1180.75	4959.15
470	1247.72	5240.42
463	1297.94	5451.35
457	1348.17	5662.31
451	1377.96	5787.43
448	1415.14	5943.59
447	1431.88	6013.90
446	1465.37	6154.55
445	1473.74	6189.71
443	1515.59	6365.48
442	1535.74	6450.11
432	1569.28	6590.98
426	1619.59	6802.28

TABLE 6

VARIATION OF TRANSFORMATION TEMPERATURES WITH ALLOY CONTENT*

Alloy Composition	Transformation Temperatures on Cooling		
	Start	End	Mean
Pure Thallium	502	502	502
Tl-Sb (.1 a % Sb)	503	501	502
Tl-Sb (.3 a % Sb)	488	486	487
Tl-Sb (.5 a % Sb)	472	470	471
Tl-Sb (.9 a % Sb)	450	442	446

*This was determined by thermodynamic results.

TABLE 7

THERMODYNAMIC PROPERTIES OF THE INDICATED ALLOYS
AT THE INDICATED TEMPERATURES

Alloy Composition	Temperature of Determination ($^{\circ}$ K)	$\Delta H_{f,c}$ (Joules/Mole)	$C_{p\alpha}$	$C_{p\beta}$
1. Pure Thallium	502	346.5	36.75	38.35
	502			
	502			
2. Tl-Sb (.1 a % Sb)	503	924.00	85.34	114.03
	501			
	505			
3. Tl-Sb (.3 a % Sb)	487	525.00	50.98	60.31
	486			
	488			
4. Tl-Sb (.5 a % Sb)	471	399.00	50.16	56.57
	470			
	472			
5. Tl-Sb (.9 a % Sb)	446	373.80	42.00	30.46
	442			
	450			

TABLE 8

Calibration Run 1
Calorimeter Medium Isopropyl Alcohol
Room Temperature 22.51°C

Y-Axis Position	Quartz Thermometer Reading (°C)
.1	21.697
2.1	21.825
3.4	21.906
5.0	22.009
6.9	22.132
7.8	22.191
8.8	22.252
9.6	22.313
11.3	22.416
12.5	22.495

TABLE 9

Calibration Run II
Calorimeter Medium Isopropyl Alcohol
Room Temperature 26.25°C

Y-Axis Position	Quartz Thermometer Reading °C
1.3	22.55
2.0	22.604
3.4	22.694
5.6	22.838
7.8	22.976
9.0	23.055
11.4	23.206
13.1	23.309
15.3	23.456
17.0	23.564
18.5	23.650
20.5	23.783
23.7	23.983
26.5	24.162
29.8	24.37
32.0	24.567
35.3	24.74
37.6	24.889

TABLE 10

X-RAY RESULTS

Pure Thallium
 Temperature of Measurement 26°C

Line No.	I/I ₀	2θ	sin ² θ	hkl
1	10	29.78	.0660	100
2	100	32.23	.0771	002
3	35	34.08	.0859	101
4	20	44.56	.1437	102
5	2	53.05	.1995	110
6	35	58.82	.2411	103
7	5	63.35	.2757	112
8	5	64.40	.2840	201
9	20	67.91	.3119	203
10	10	75.89	.3775	210

Phase α
 Crystal Structure - HCP
 Average Lattice Parameter -

TABLE 11

X-RAY RESULTS

Pure Thallium
 Temperature of Measurement 225°C

Line No.	I/I ₀	2 θ	Sin ² θ	hkl
1	10	29.60	.0653	100
2	100	32.17	.0768	002
3	20	33.95	.0852	101
4	15	44.31	.1423	102
5	35	52.65	.1965	110
6	5	58.55	.2390	103
7	30	63.15	.2739	112
8	10	63.95	.2803	201

Crystal Structure HCP
 Average Lattice Parameter a = 3.4744
 c = 5.5718
 Volume of HCP phase = 58.2469

TABLE 12

X-RAY RESULTS

Pure Thallium 260°C

Line No.	2θ	$\sin^2\theta$	s	$\lambda^2/4a^2$	hkl	a
1	28.36	.0600	*	*	*	*
2	32.66	.0791	2	.0396	110	3.8740
3	56.9	.2269	6	.0378	211	3.9718
4	58.3	.2373	6	.0395	211	3.8756
5	67.4	.3079	8	.0385	220	3.9355
6	68.36	.3156	8	.0395	220	3.8756
7	77.85	.3948	10	.0394	311	3.8838
8	86.45	.4690	12	.0391	222	3.8954
9	112.8	.6938	18	.0385	330	3.9289

Average a=3.9051

Vol. (BCC) = 59.5509

* Due to thallium oxide

TABLE 13

HIGH TEMPERATURE X-RAY RESULTS

Tl-Sb (0.1 atom percent Sb)

Temperature 222°C

Crystal Structure

HCP

Phase α

Line No.	I/I ₀	2 θ	sin ² θ	hkl
2	100	32.07	.0763	.002
3	15	33.75	.0843	.101
5	35	52.55	.1960	.110
7	20	63.87	.2798	.112

TABLE 14

HIGH TEMPERATURE X-RAY RESULTS

Tl-Sb (0.3 atom percent Sb)

Temperature 209°C

Phase α

Crystal Structure HCP

Line No.	I/I ₀	2 θ	Sin ² θ	hkl
2	100	31.95	.0757	002
3	25	33.52	.0832	101
5	30	52.43	.971	110
7	20	63.57	.2774	112

TABLE 15

HIGH TEMPERATURE X-RAY RESULTS

Tl-Sb (0.5 atom percent Sb)

Temperature 190°C

Phase α Crystal Structure HCP

Line No.	I/I ₀	2 θ	Sin ² θ	hkl
2	100	31.76	.0749	002
3	20	33.49	.0830	101
5	30	52.15	.1932	110
7	20	62.97	.2728	112

TABLE 16

HIGH TEMPERATURE X-RAY RESULTS

Tl-Sb (0.9 atom percent Sb)

Temperature 165°C

Phase α

Crystal Structure

HCP

Line No.	I/I ₀	2 θ	Sin ² θ	hkl
2	100	31.53	.0738	002
3	20	33.02	.0808	101
5	30	51.76	.1905	110
7	25	62.52	.2693	112

TABLE 17

CRYSTAL STRUCTURE AND LATTICE PARAMETER OF
LOW TEMPERATURE PHASE

Temperature 225°C 498°K

Alloy Composition	Crystal Structure	Lattice a	Parameter c
1. Pure Thallium	HCP	3.4744	5.5718
2. Tl-Sb (.1 a % Sb)	HCP	3.4829	5.5817
3. Tl-Sb (.3 a % Sb)	HCP	3.4903	5.6021
4. Tl-Sb (.5 a % Sb)	HCP	3.5077	5.6348
5. Tl-Sb (.9 a % Sb)	HCP	3.5323	5.6748

TABLE 18

Tl-Sb (.1 atom percent Sb)
 Temperature of Measurement 250°C

Line No.	I/I ₀	2 θ	sin ² θ	hkl	a
2	100	32.73	.0794	110	3.8693
4	25	58.04	.2353	211	3.8706

TABLE 19

Tl-Sb (.3 atom percent Sb)
 Temperature of Measurement 260°C

Line No.	I/I ₀	2 θ	sin ² θ	hkl	a
2	100	32.42	.0799		3.9054
4	30	57.65	.2325		3.9166

TABLE 20

Tl-Sb (.5 atom percent Sb)
 Temperature of Measurement 260°C

Line No.	I/I ₀	2 θ	sin ² θ	hkl	a
2	100	32.17	.0768	110	3.9449
4	30	57.51	.2314	211	3.9553

TABLE 21

Tl-Sb (.9 atom percent Sb)

Line No.	I/I ₀	2 θ	sin ² θ	hkl	a
2	100	31.63	.0743	110	4.0003
4	27	56.43	.2235	211	3.9940

TABLE 22

CRYSTAL STRUCTURE AND LATTICE PARAMETER OF
HIGH TEMPERATURE PHASE

Alloy Composition	Crystal Structure	Lattice Parameter 'a'
1. Pure Thallium	BCC	3.9051
2. Tl-Sb (0.1 a % Sb)	BCC	3.9110
3. Tl-Sb (0.3 a % Sb)	BCC	3.9255
4. Tl-Sb (0.5 a % Sb)	BCC	3.9501
5. Tl-Sb (0.9 a % Sb)	BCC	3.9972

TABLE 23

VOLUME OF EACH PHASE AT THE INDICATED TEMPERATURE

Alloy Composition	Phase	Temperature (°K) T	Crystal Structure	Lattice Parameter Å		Vol. of each phase %
Pure Thallium	α	498	HCP	3.4744	5.5718	58.2469
	B	533	BCC	3.9051	---	59.5509
Tl-Sb (0.1 a % Sb)	α	498	HCP	3.4829	5.5817	58.6363
	B	533	BCC	3.9110	---	59.8223
Tl-Sb (0.3 a % Sb)	α	463	HCP	3.4903	5.6021	59.1009
	B	513	BCC	3.9255	---	60.4302
Tl-Sb (0.5 a % Sb)	α	447	HCP	3.5077	5.6348	60.0401
	B	497	BCC	3.9501	---	61.4302
Tl-Sb (0.9 a % Sb)	α	425	HCP	3.5323	5.6748	61.3174
	B	450	BCC	3.9972	---	63.8557

TABLE 24

VOLUME CHANGE ACCOMPANYING THE TRANSFORMATION

Alloy Composition	$(V^B - V^{\alpha}) / V^{\alpha} \times 100$	$V^* = \frac{100 (V_{al}^{.3\alpha} - V_{tl}^{B\alpha})}{V_{tl}^{B\alpha}}$
Pure Thallium	2.24	0
Tl-Sb (0.1 a % Sb)	2.02	10.77
Tl-Sb (0.3 a % Sb)	2.25	27.59
Tl-Sb (0.5 a % Sb)	2.65	44.40
Tl-Sb (0.9 a % Sb)	4.13	78.02

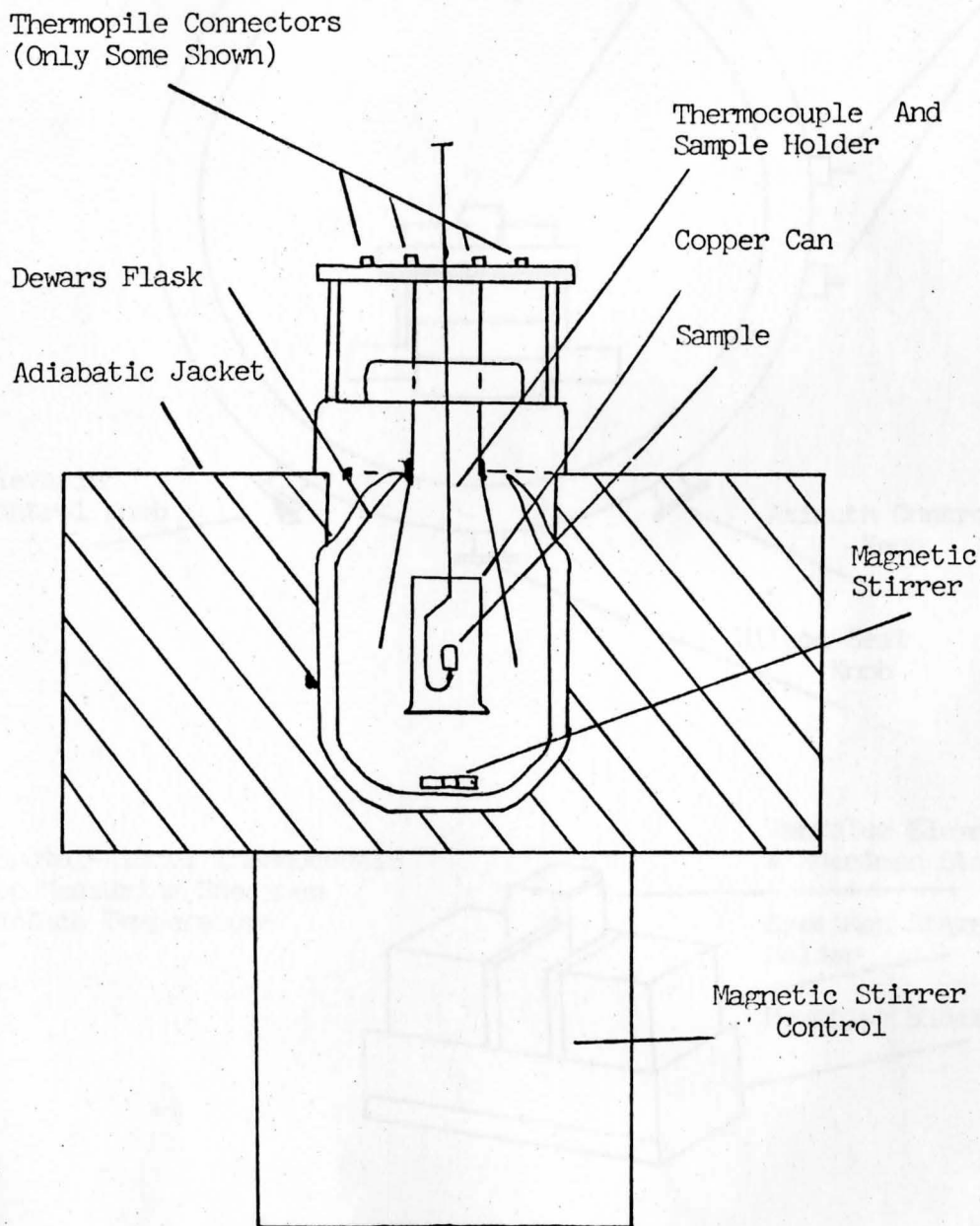


Figure 1. View of Modified Olsen Calorimeter.

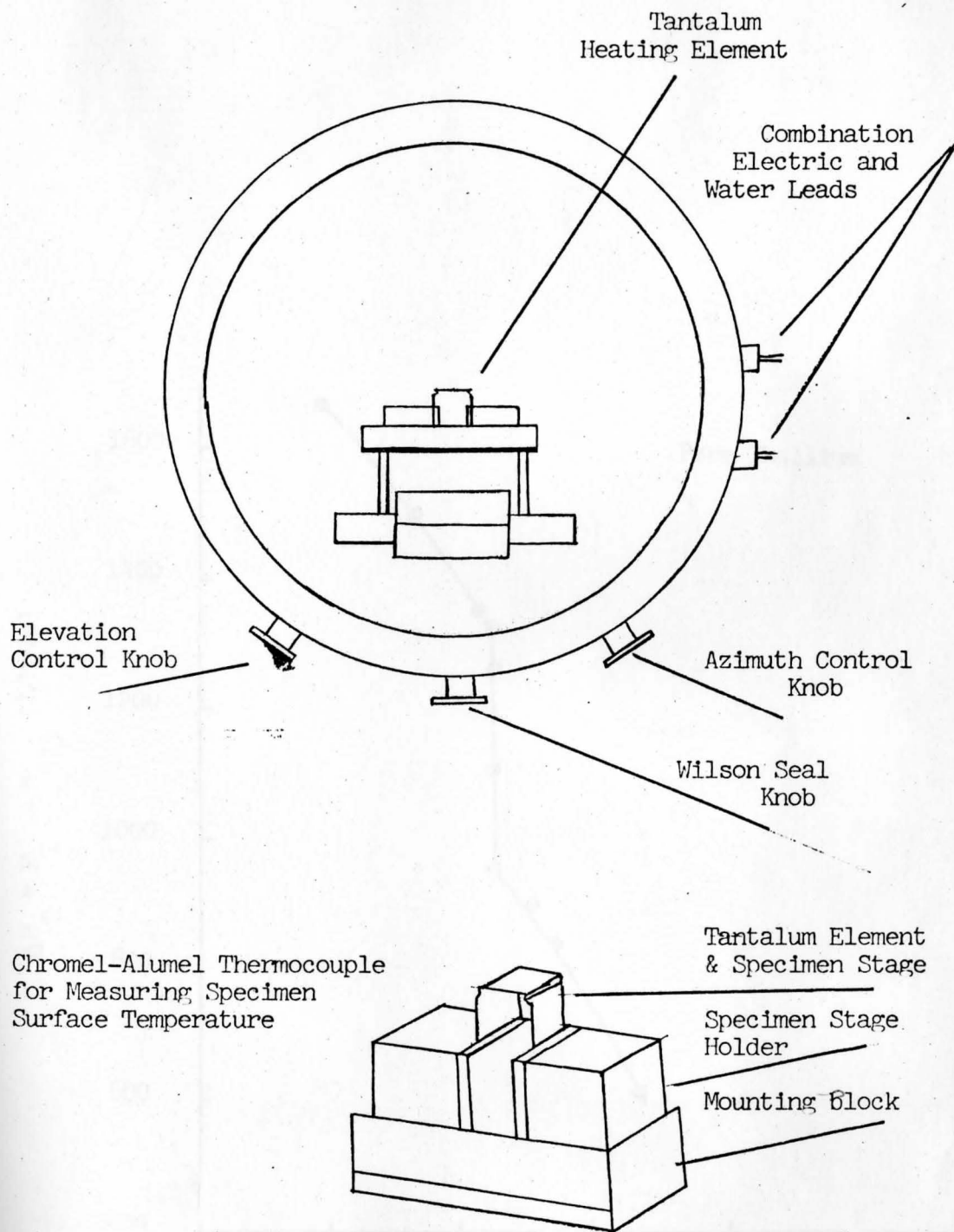


Figure 2. View of High Temperature X-Ray Camera And Specimen Mounting Arrangement.

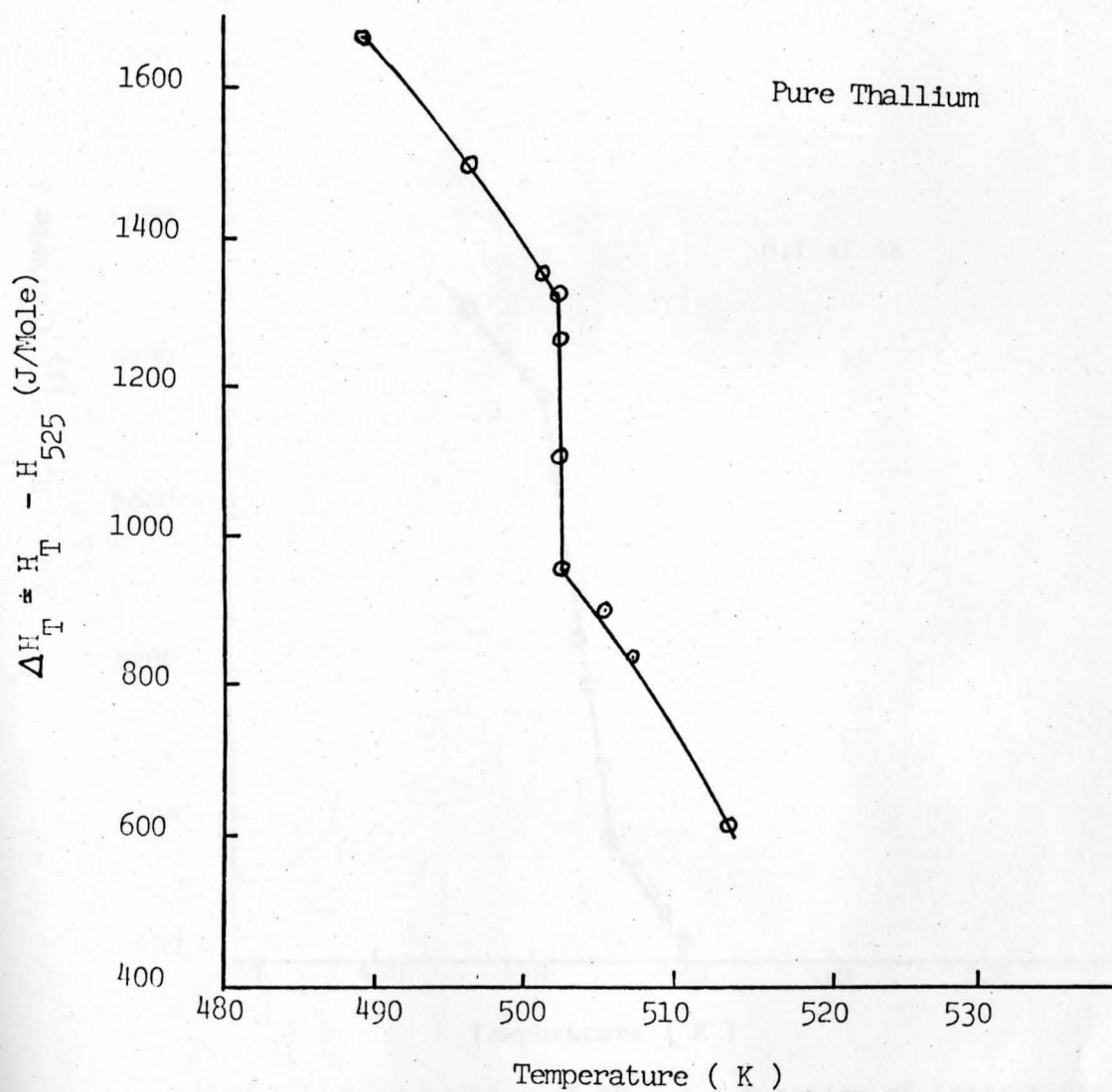


Figure 3. Variation of ΔH_T as a function of Temperature.

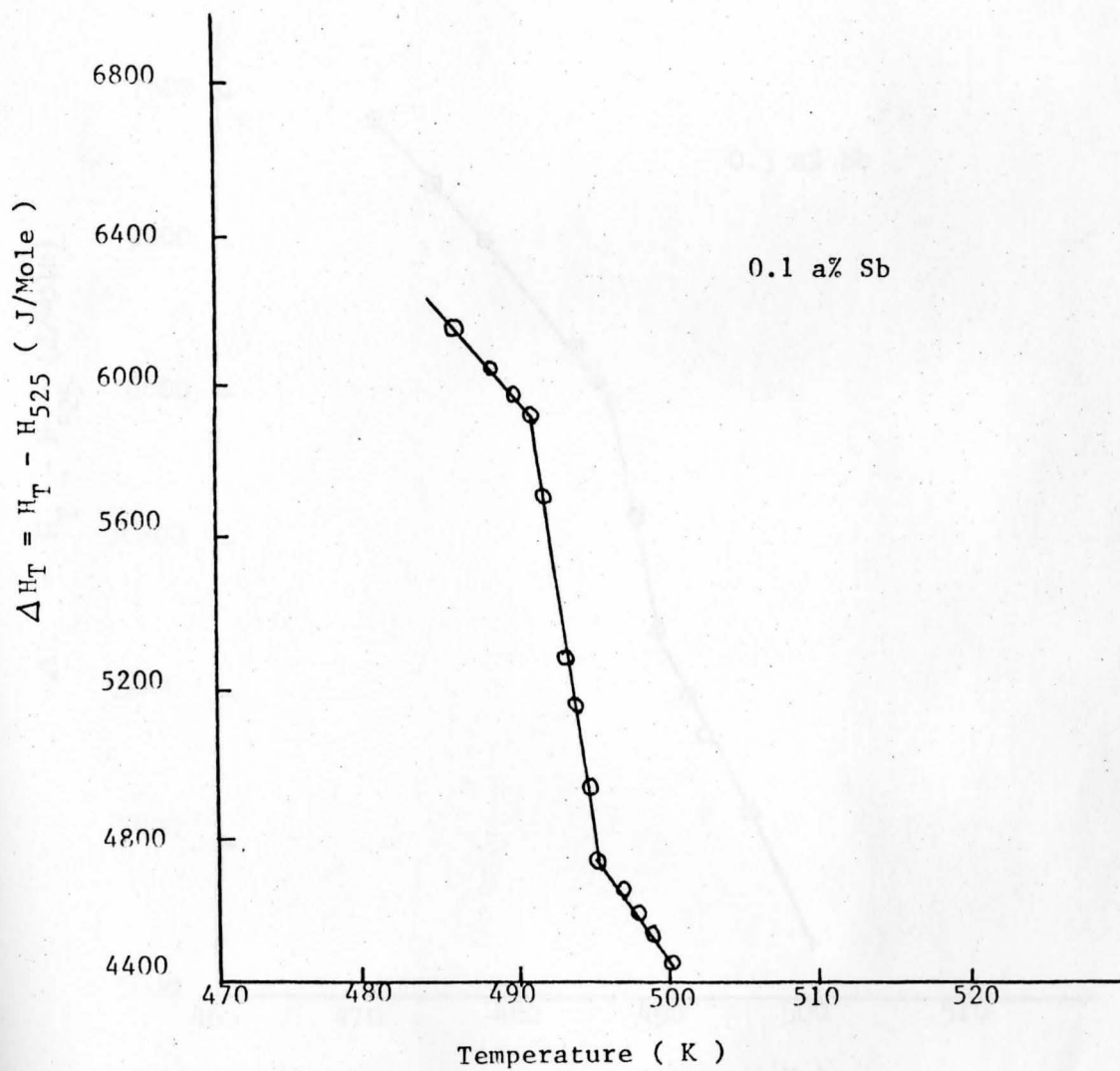


Figure 4. Variation of ΔH_T as a function of temperature.

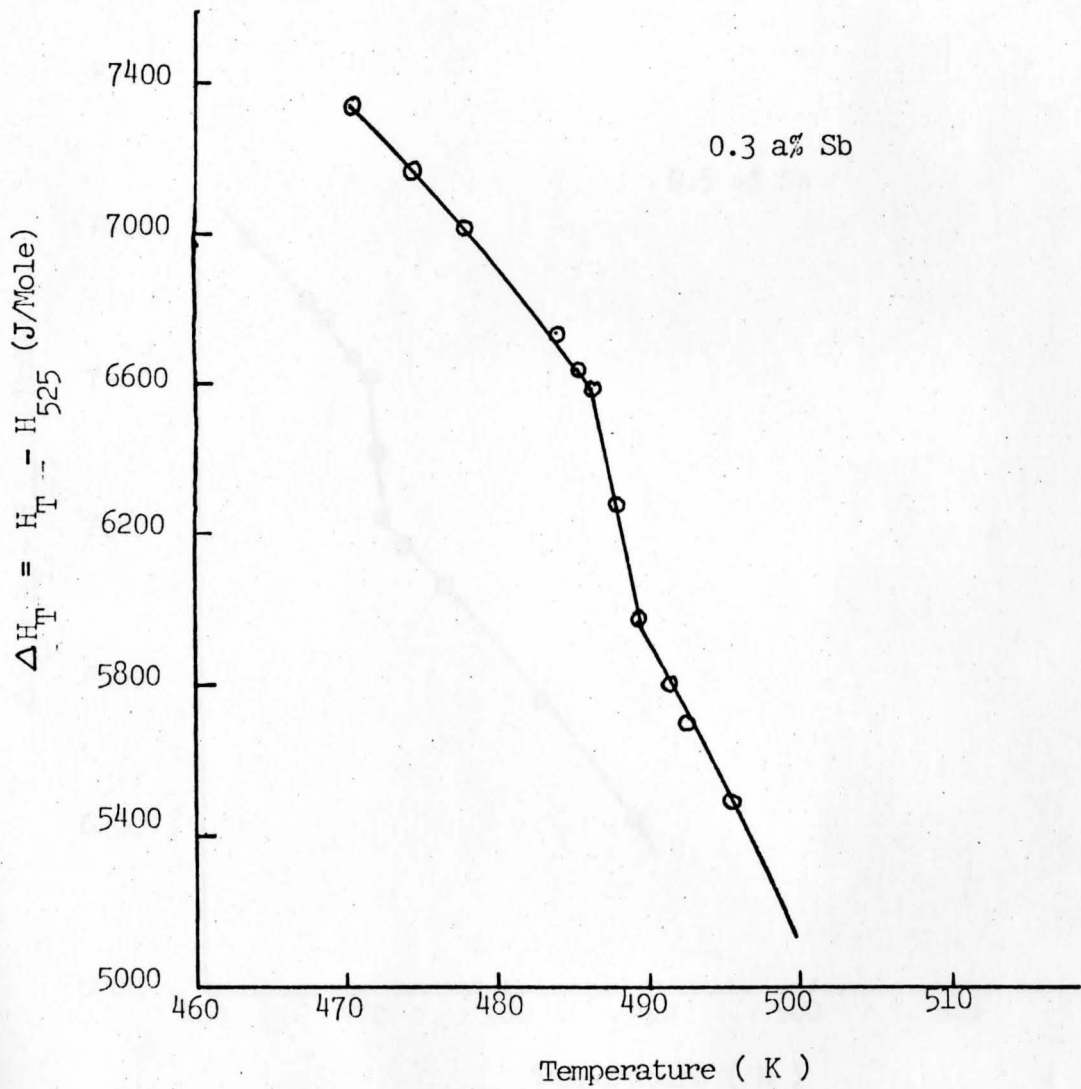


Figure 5. Variation of ΔH_T as a function of Temperature.

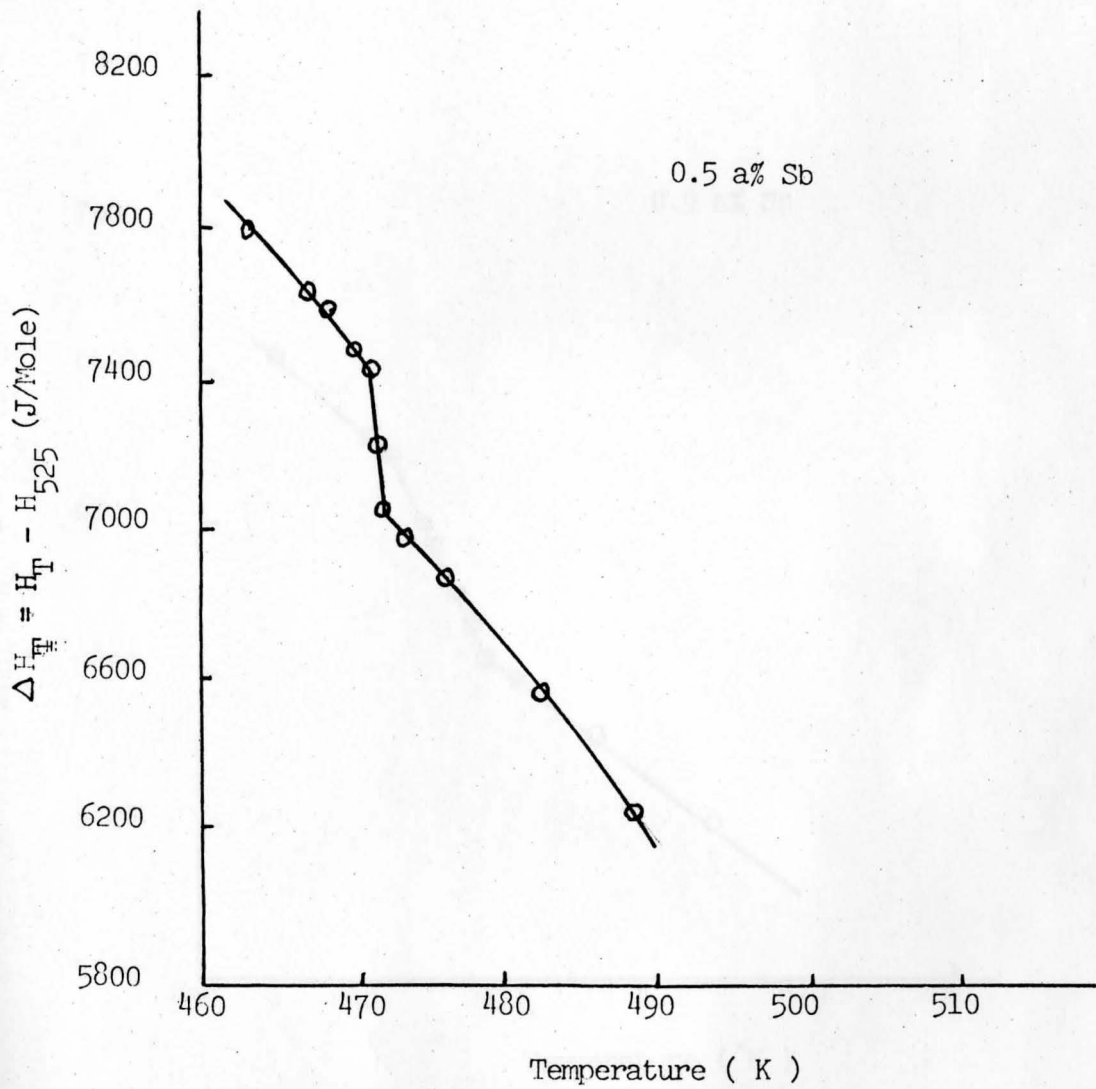


Figure 6. Variation of ΔH_T as a function of Temperature.

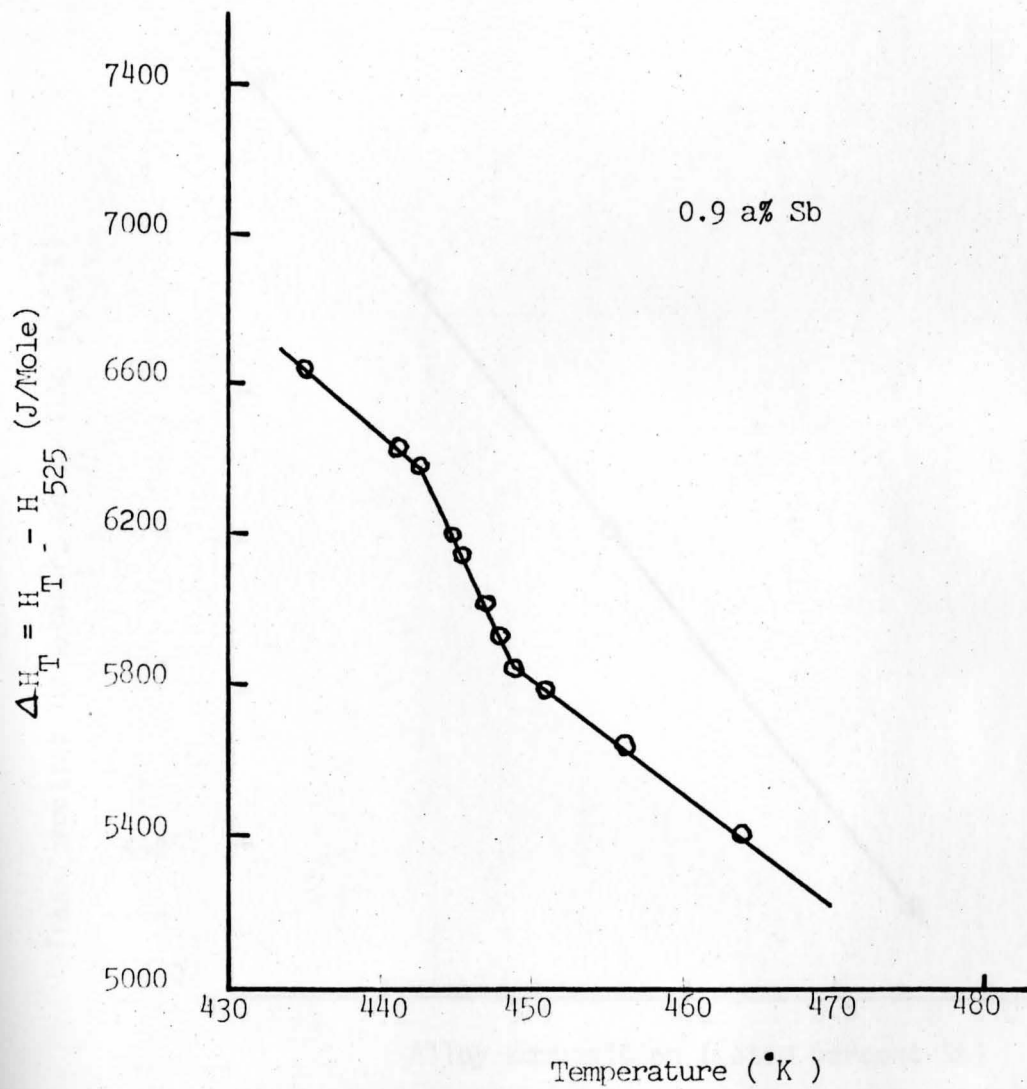


Figure 7. Variation of ΔH_T as a function of Temperature.

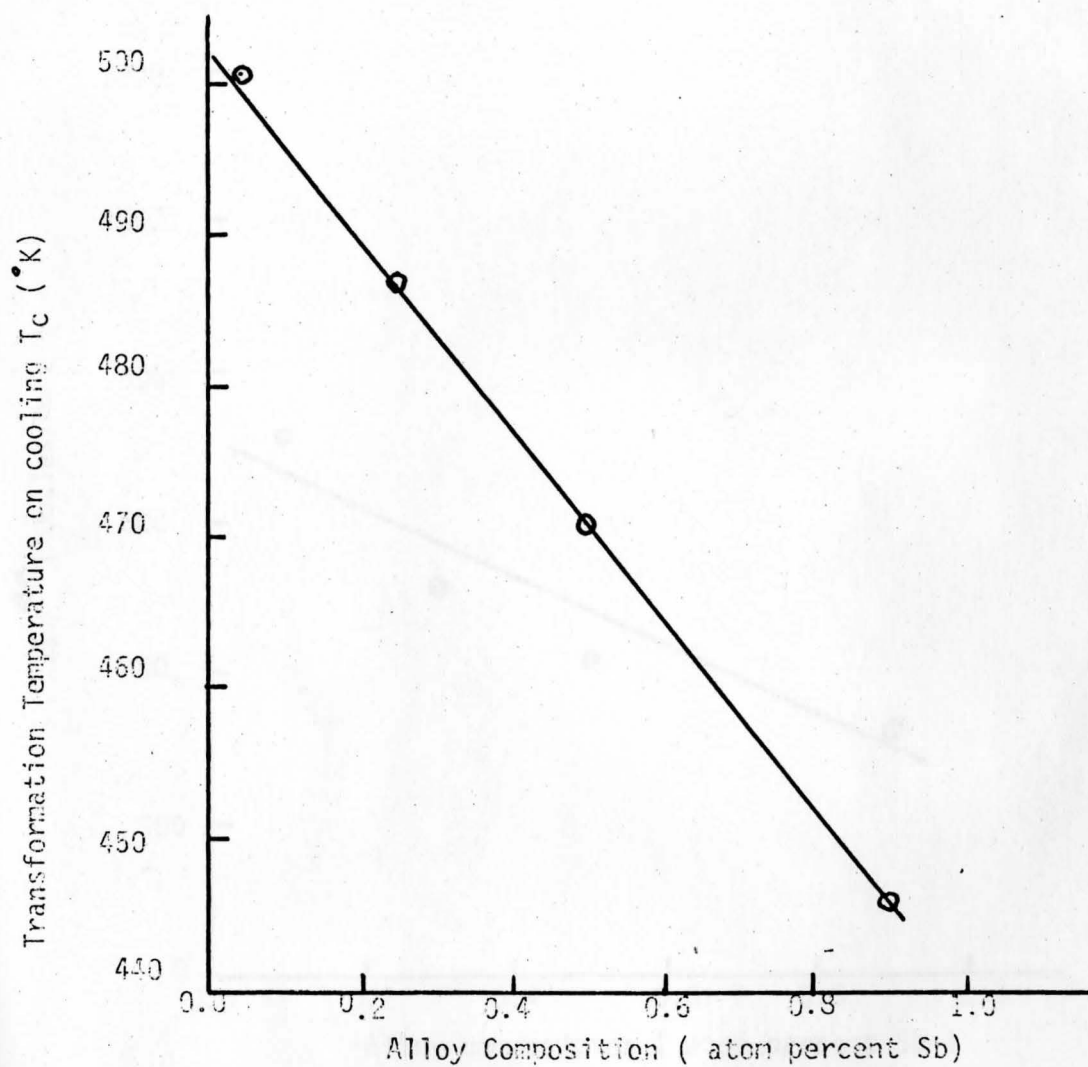


Figure 8. Variation of Transformation with alloy composition.

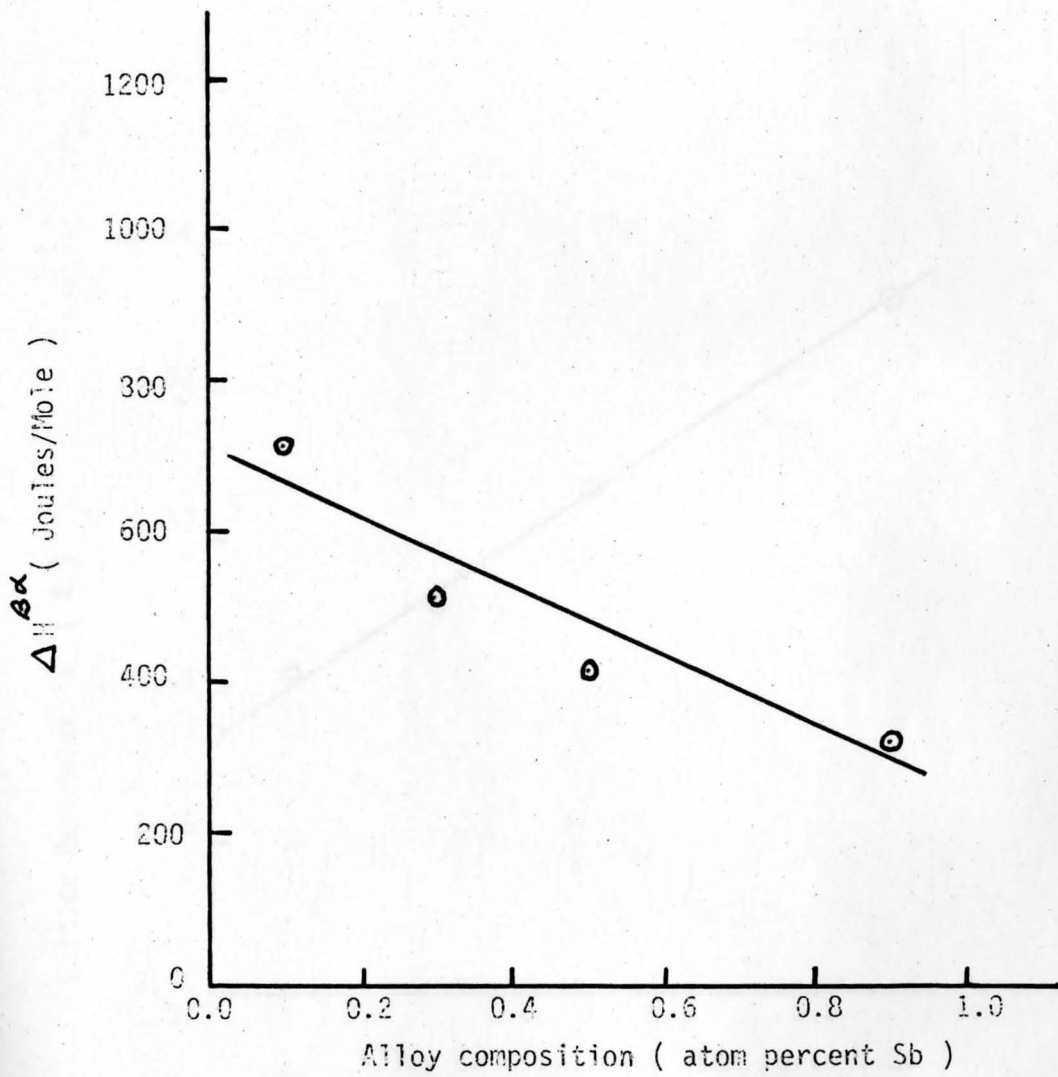


Figure 9. Enthalpy of transformation vs. alloy composition

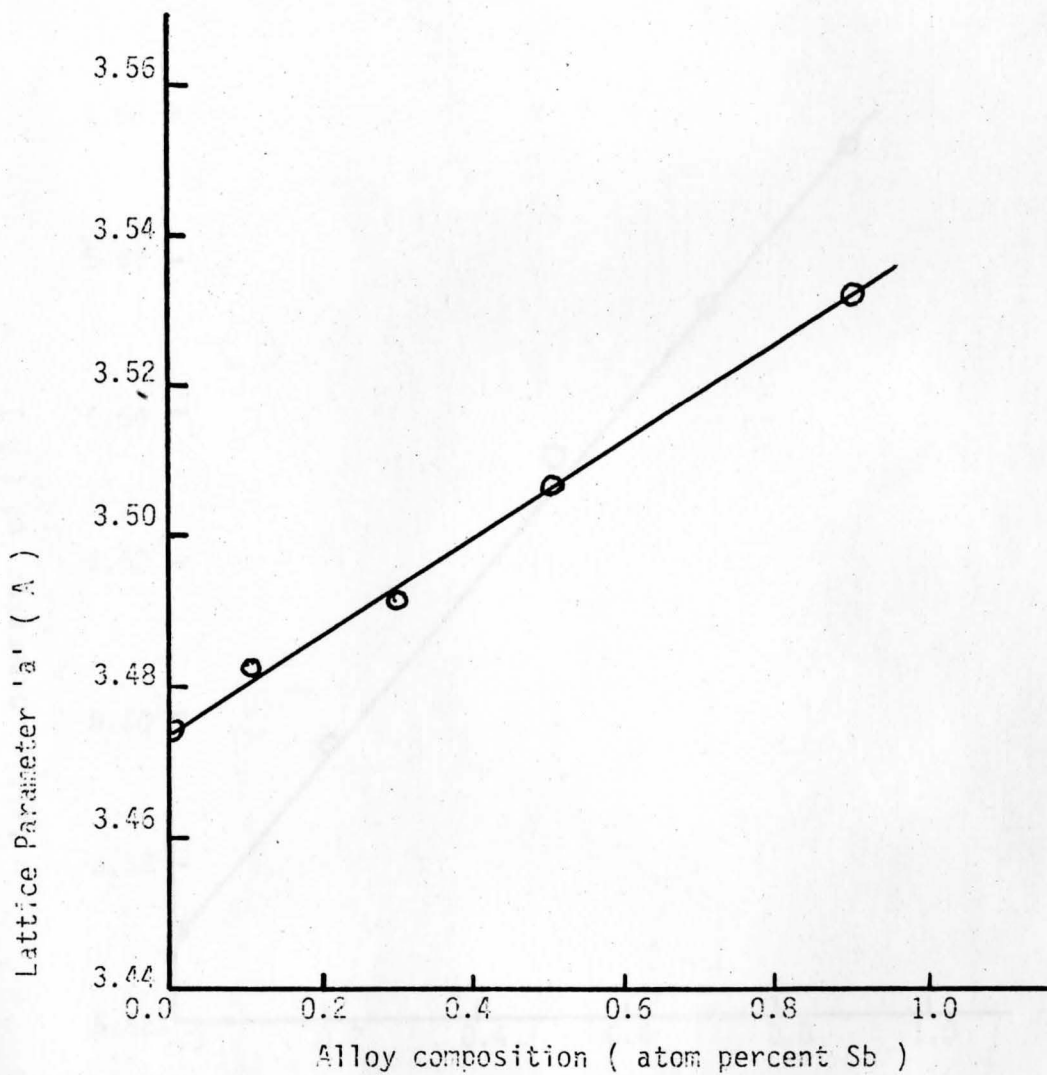


Figure 10. Variation of Lattice Parameter 'a' with alloy composition for α -phase.

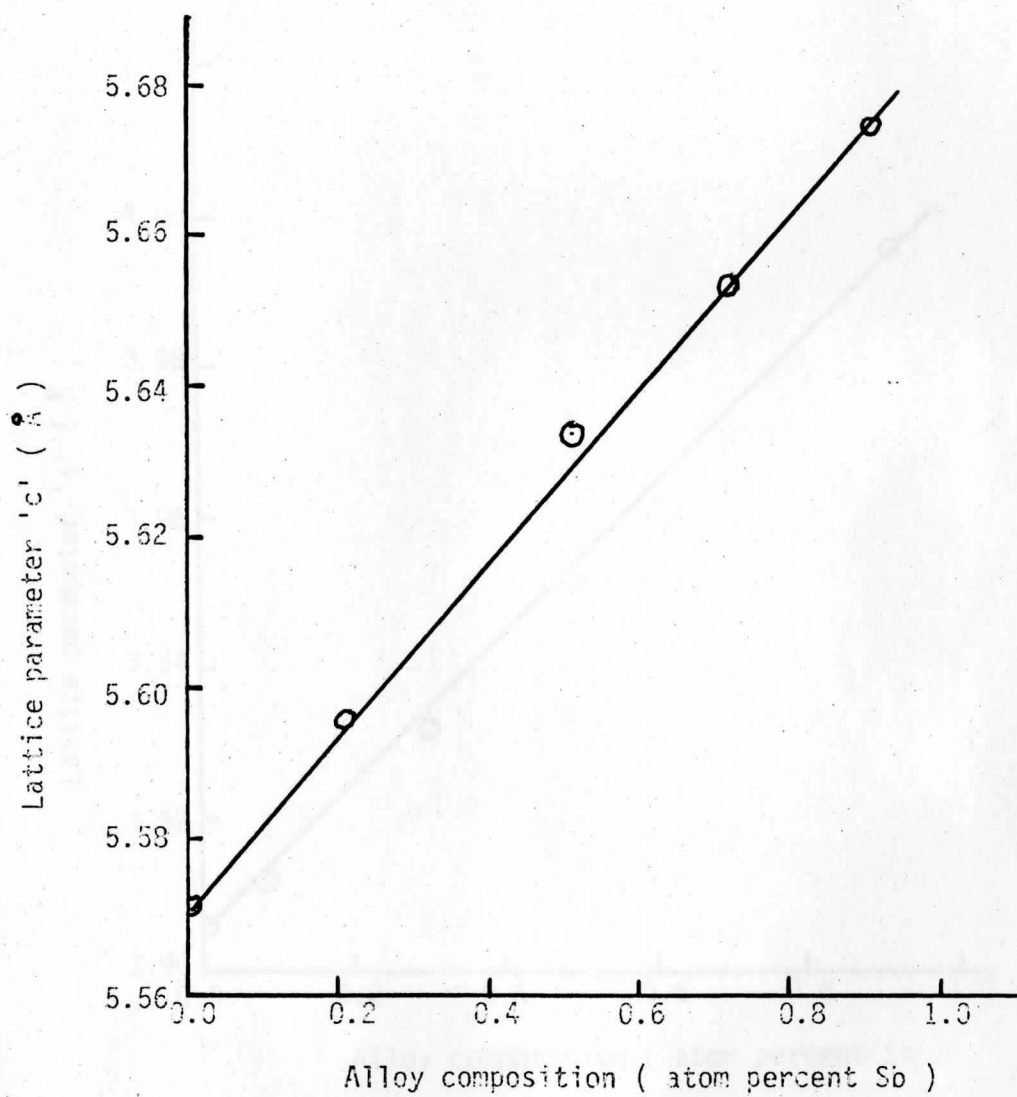


Figure 11. Variation of lattice parameter 'c' with alloy composition for α -phase.

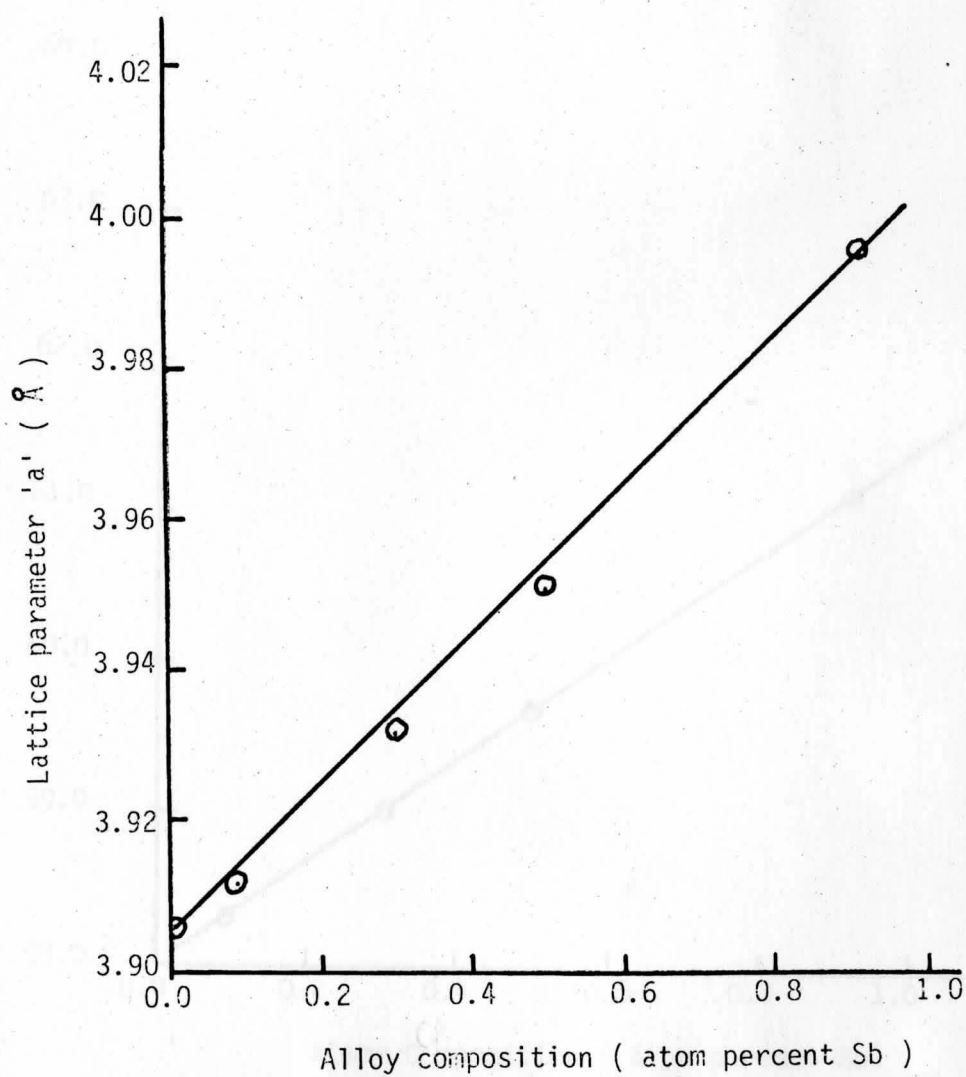


Figure 12. Variation of lattice parameter 'a' with alloy composition for high temperature β -phase.

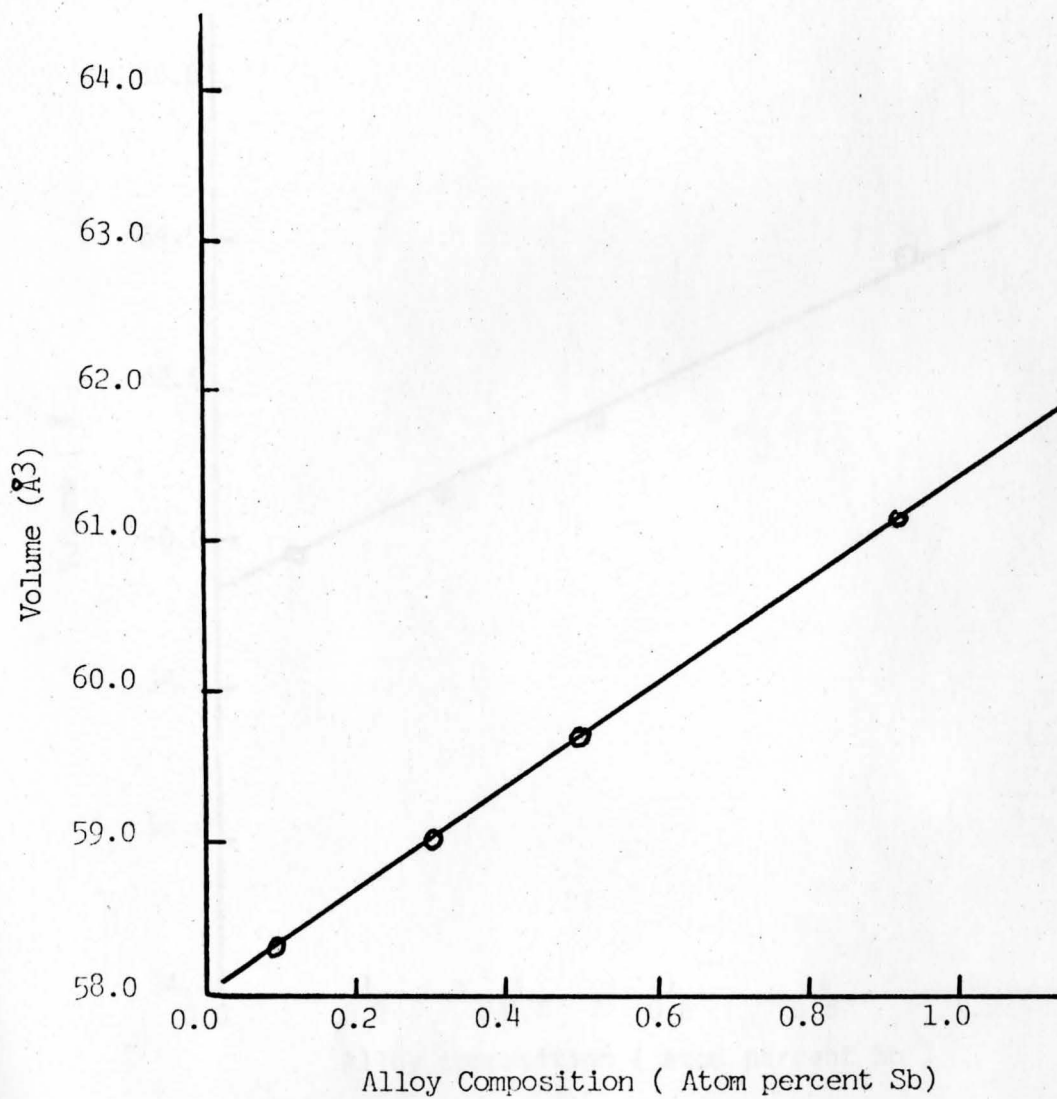


Figure 13. Variation of Unit Cell Volume with Alloy Composition for HCP - phase.

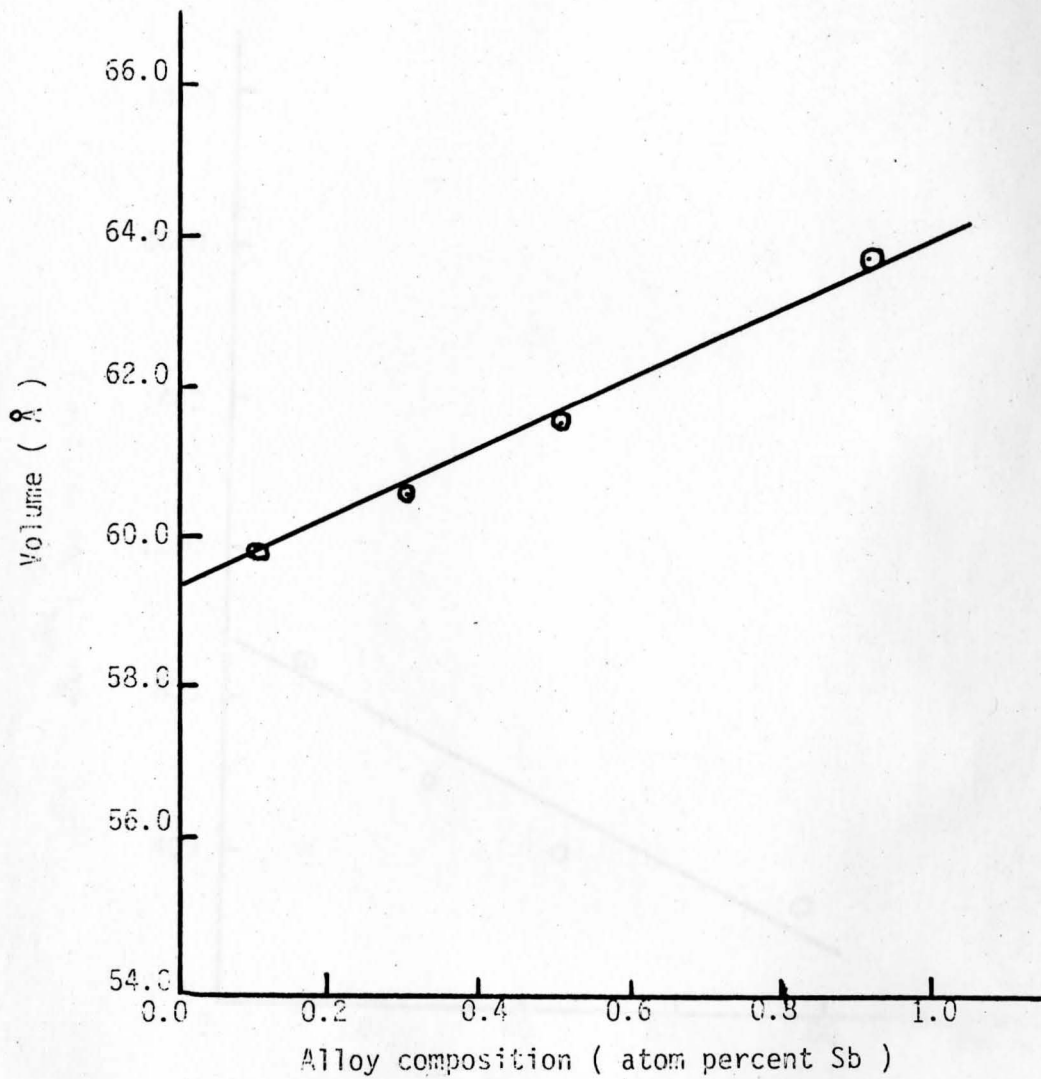


Figure 14. Variation of unit cell volume for high temperature β -phase.

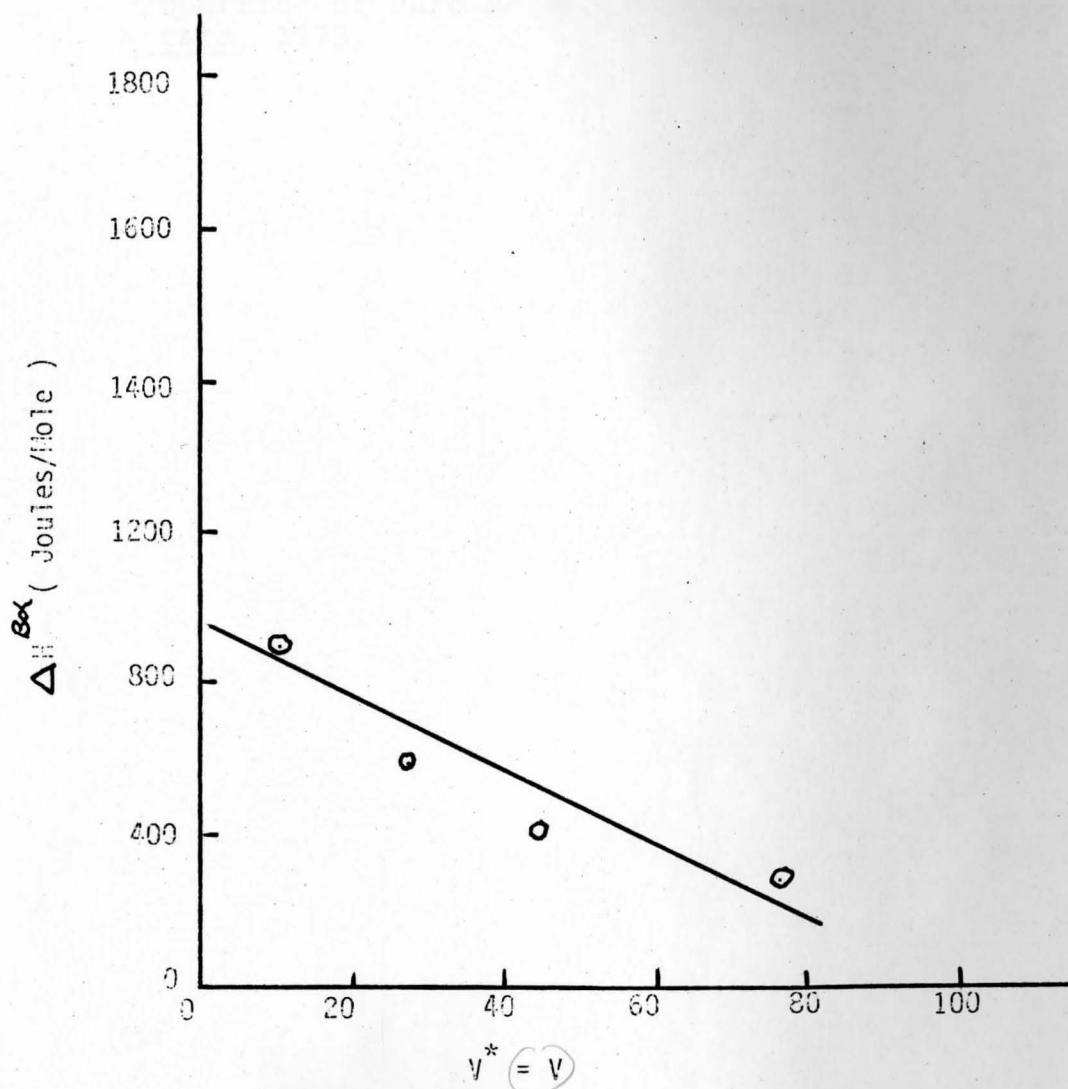


Figure 15. Variation of enthalpy of transformation with V^* (normalised volume change).

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