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LOW TEMPERATURE HEAT CAPACITY OF LUTETIUM AND LUTETIUM HYDROGEN ALLOYS

David Keith Thome

M.S. Thesis Submitted to Iowa State University

Ames Laboratory, ERDA
Iowa State University
Ames, Iowa 50011

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Low temperature heat capacity of lutetium and lutetium hydrogen alloys

by

David Keith Thome

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ABSTRACT

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The heat capacity of high purity electrotransport refined lutetium was measured between 1 and 20 K. Results for θ_D were in excellent agreement with θ values determined from elastic constant measurements.

The heat capacity of a series of lutetium-hydrogen solid solution alloys was determined and results showed an increase in γ from 8.2 to about 11.3 mJ/g-atom-K^2 for hydrogen content increasing from zero to about one atomic percent. Above one percent hydrogen γ decreased with increasing hydrogen contents. The C/T data showed an increase with temperature decreasing below about 2.5 K for samples with 0.1 to 1.5 atomic percent hydrogen. This accounts for a large amount of scatter in θ_D versus hydrogen content in this range.

The heat capacity of a bulk sample of lutetium dihydride was measured between 1 and 20 K and showed a large increase in θ_D and a large decrease in γ compared to pure lutetium.

INTRODUCTION

The low temperature heat capacity of lutetium has been studied by several investigators[1-5] and many different values have been reported for the electronic specific heat constant, γ, and the Debye temperature, θ_D. These values are listed in Table 1. In this light an accurate determination of the heat capacity (1 to 20 K) of high purity lutetium was attempted on two different electrotransport purified samples. Electrotransport purification is currently the only way to reduce interstitial impurity contents to low levels in lutetium.[6]

The low temperature heat capacity of most metals can be expressed as:

$$C(\text{total}) = C_\ell + C_e \tag{1}$$

where C_ℓ is the lattice contribution to the heat capacity and C_e is the electronic contribution. The lattice contribution, according to the Debye model, (for $T < \theta_D/50$) can be written[7]:

$$C_\ell = (12/5)\pi^4 rR(T/\theta_D)^3 = \beta T^3 \tag{2}$$

where r is number of atoms per molecule, R is the gas constant, T is the absolute temperature, and θ_D is the Debye temperature. The important features are that the lattice heat capacity can be expressed with a single parameter, θ_D, and that a connection can be made between thermal and elastic properties of metals.

Table 1. Survey of published heat capacity results for lutetium

Investigator	γ(mJ/g-atom K)	θ_D (K)	Conditions
Wells, Lanchester Jones, Jordan (1976)[1]	6.8 ± 1	205 ± 3	1.5 to 16 K
Lounasmaa (1964)[3] and Culbert (1966)[4]	11.27	210	0.38 to 4 K 3 to 25 K
Jennings, Miller Spedding (1960)[2]	9.5	166	15 to 300 K

The electronic contribution, according to the free electron model, can be expressed as[7]:

$$C_{\ell} = \frac{2}{3}\pi^2 k^2 V\ n(\epsilon_F)T = \gamma T \qquad (3)$$

where k is Boltzmann's constant, V is the molar volume, $n(\epsilon_F)$ is the density of states at the Fermi surface, and γ is the electronic specific heat constant. The important feature in this case is that γ is directly proportional to the density of states at the Fermi surface.

The lutetium-hydrogen system is of interest because of (1) the large concentration of hydrogen per unit volume that can be stored in the metal at room temperature (almost twice that of hydrogen in the liquid phase) and (2) the large solid solution region extending from pure lutetium to approximately 21 atomic percent hydrogen at room temperature.[8] This is the second largest solid solubility range known for any pure metal, hydrogen dissolved in scandium being the largest.

The scandium-hydrogen system would be more difficult to study because use of electrotransport purified material would be necessary.[9] The reason is that scandium shows low temperature magnetic effects caused by traces of iron in solid solution which can only be removed by electrotransport purification. Many of the other rare earth metals, especially the heavy lanthanides, form extensive solid solutions with hydrogen[8], but due to their magnetic properties the low temperature heat capacities are difficult to analyze and thus the effects of hydrogen on γ and θ_D would be difficult if not impossible to determine. This makes lutetium most attractive for a study of this nature.

As well as having a large solid solution region, the lutetium-hydrogen system also has a cubic dihydride phase that exists from about 64.8 to 68.8 atomic percent hydrogen and a hexagonal trihydride phase above 73.6 atomic percent hydrogen.[10]

EXPERIMENTAL PROCEDURE

Lutetium Samples

Approximately 65 grams of high purity lutetium metal were obtained from the Rare Earth Preparation Group of the Ames Laboratory (USERDA), Iowa State University for this study. This material will be referred to as Lu-I. Lu-I was arc-melted into a rod 10 cm long and 0.5 cm^2 in cross-sectional area in a water cooled copper hearth arc-melter. Before melting the lutetium the system was evacuated to 1×10^{-3} Torr then backfilled with high purity argon. A piece of zirconium weighing approximately 35 grams was melted to getter the remaining oxygen from the argon gas. The rod was cut into pieces 0.75 cm long with a low speed diamond saw then electropolished. Electropolishing in this study is always done in a 6 percent perchloric acid in a methanol bath maintained at -70°C with a current density of about 0.2 $A \cdot cm^{-2}$. Samples were stored in helium until needed for hydriding or for calorimetry. The system used for hydriding will be discussed later in this section.

In order to obtain the best γ and θ_D values for lutetium a rod 16.5 cm long and 0.25 cm in diameter was prepared for purification by electrotransport as described below. Eleven grams of Lu-I were first arc-melted into a rod as described above. This rod was placed in a tantalum tube and swaged to reduce the cross sectional area by 30 percent. The tantalum was removed, the surface was filed with a new file, and the sample was then electropolished. After this it was placed in a tungsten lined tantalum crucible and heated to 800°C for one hour in a vacuum of 2×10^{-8} Torr for stress relief. It was cooled, removed from the vacuum furnace, placed in a new tantalum tube, and swaged again. This process was done five times until the desired dimensions were obtained. After the rod was formed, both ends were threaded with a new 3-48 N.F. die for a length of 0.5 cm. The threads were necessary to attach the sample to the holder used for electrotransport purification. The sample was electropolished just before loading into this system. The system was evacuated and outgassed at 380°C for one week before the electrotransport process was begun. The lutetium was electrotransported for 336 hours at 1065°C in a vacuum of 1.0×10^{-10} Torr. This sample will be called Lu-II. After this purification process the rod was cut into four pieces of equal length with a low speed diamond saw. The pieces were labeled A, B, C, and D as shown in Figure 1a. Only Section A was used for calorimetry as it is the most pure. It was cut as shown in Figure 1b in order to fit the sample holder of the calorimeter. Pieces b, c, and d were used. All pieces were electropolished immediately after cutting to passivate the surface.[11] The resistance ratio, $R_{298\,K}/R_{4.2\,K}$, of Lu-II was measured for Sections A, C, and D. The results are given in Table 2. Section B was not measured because it was desired to have a high purity single crystal for de Haas-von Alphen measurements and the sample holder in the resistivity apparatus might cause twinning in the material. Two measurements were made on each section, indicated by the section together with a (+) or (-). The (-)

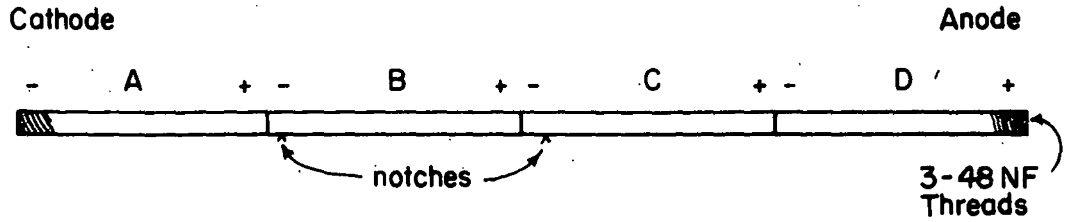

Figure 1a. The electrotransport purified lutetium rod (Lu-II) cut into sections. Sections B and C were marked with a notch to identify the end nearer the cathode

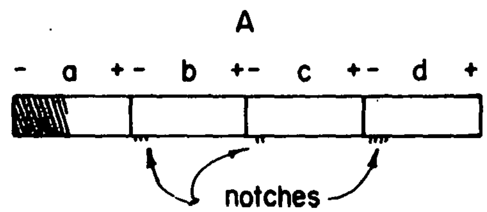

Figure 1b. The section of the electrotransport purified lutetium rod (Lu-II) cut for calorimetry. The cathode ends of b, c, and d were marked with notches for identification as shown

Table 2. Resistance ratio, $R_{298\,K}/R_{4.2\,K}$ for Lu-II

Section	$R_{298\,K}/R_{4.2\,K}$
A^-	152
A^+	103
B^-	not measured
B^+	not measured
C^-	89
C^+	88
D^-	82
D^+	55

signifies the end of the section nearer the cathode during the electrotransport process. The (+) signifies the end of each section that was nearer the anode.

A second piece of electrotransport purified lutetium was also obtained. This had been purified in 1967. This sample will be identified as Lu-III. The conditions for electrotransport of this sample were outgassing at 380°C for one week then electrotransport at 1100°C for 96 hours in a vacuum of 5×10^{-10} Torr. The highest resistance ratio (93) was found at the cathode end as in the case of Lu-II.

The chemical analyses for Lu-I, Lu-II, and Lu-III are given in Table 3. The oxygen, hydrogen, and nitrogen are from vacuum fusion analysis, the carbon and fluorine from chemical methods, and the other elements from mass spectrometry.

Table 3. Chemical Analysis of Lu-I, Lu-II, and Lu-III. Hydrogen, nitrogen, and oxygen are from vacuum fusion analysis; all other elements are from mass spectrometry. All are atomic ppm

Element	Lu-I	Lu-II	Lu-III[a]
H	1050	< 175	350
Li	< 0.007	< 0.001	-
Be	< 0.002	< 0.002	-
B	< 0.05	0.2	< 0.02
C	90	100	100
N	13	none detected	113
O	610	82	635
F	< 0.005	< 0.4	0.02
Ne	< 0.02	< 0.1	-
Na	0.9	0.1	0.9
Mg	< 0.3	< 0.1	0.7
Al	1	0.50	13
Si	< 3	0.50	40
P	0.1	0.1	0.2
S	0.4	2	0.5
Cl	0.6	3	-
Ar	< 0.2	< 2	-
K	1	< 0.02	0.9
Ca	0.40	< 0.4	3
Sc	1	0.10	2
Ti	1	2.6	3
V	0.04	< 0.01	1.5
Cr	0.3	0.2	2
Mn	< 0.09	< 0.02	1.5

[a]Mass spectrometric values reported are for the lutetium sample before electrotransport purification; the H, N, and O values were obtained after electrotransport purification in 1977.

Table 3 (continued)

Element	Lu-I	Lu-II	Lu-III
Fe	10	1	100
Co	< 0.04	< 0.04	1.3
Ni	1	< 0.2	20
Cu	5.0	< 0.03	20
Zn	0.04	< 0.02	0.8
Ga	< 0.04	< 0.02	-
Ge	< 0.06	< 0.1	-
As	< 0.02	< 0.02	-
Se	< 0.02	< 0.01	< 0.1
Br	0.03	0.02	< 0.1
Kr	< 0.3	< 0.06	-
Rb	< 0.1	< 0.1	-
Sr	< 0.6	< 0.05	-
Y	0.40	0.80	12
Zr	< 0.3	< 0.3	8
Nb	< 1	< 0.8	0.5
Mo	< 1	< 1	< 0.3
Ru	< 0.4	< 0.2	-
Rh	< 0.07	< 0.07	-
Pd	< 0.1	< 0.2	-
Ag	< 0.006	< 0.09	< 0.07
Cd	< 0.01	< 0.01	-
In	< 0.03	< 0.03	-
Sn	< 0.1	< 0.04	< 0.4
Sb	< 0.04	< 0.04	-
Te	< 0.01	< 0.01	-
I	< 0.03	< 0.04	-
Xe	< 0.4	< 0.4	-
Cs	< 0.004	< 0.003	-

Table 3 (continued)

Element	Lu-I	Lu-II	Lu-III
Ba	< 0.04	< 0.04	< 0.1
Hf	< 1	< 1	< 0.2
Ta	3.3	4.0	75
W	20	33	6.5
Re	< 0.5	< 2	< 0.2
Os	< 1	< 3	< 0.5
Ir	< 0.3	< 0.3	< 0.5
Pt	< 0.2	< 0.3	18
Au	< 0.07	< 0.07	< 0.2
Hg	< 0.009	1.2	< 0.6
Tl	< 0.05	< 0.05	< 0.2
Pb	0.50	< 0.2	3
Bi	< 0.04	< 0.04	< 0.2
Ra	< 0.2	< 0.2	-
Th	< 5	5.2	0.4
U	< 0.2	< 0.2	-
La	5.8	10	12
Ce	0.9	1.1	6
Pr	0.3	1.5	2
Nd	< 0.9	< 0.7	2.5
Sm	< 0.7	< 0.4	< 0.6
Eu	< 0.3	< 0.2	< 0.13
Gd	< 1	< 0.7	9
Tb	< 0.8	< 2	3.6
Dy	< 2	1	1
Ho	< 1	< 1	1
Er	< 2	< 1	9.5
Tb	< 1	< 0.3	< 0.06
Yb	< 3	< 1	< 0.4

The total maximum impurity content before electrotransport purification (Lu-I) was 1850 atomic parts per million (ppm). After electrotransport this value dropped to 447 atomic ppm (Lu-II) mainly due to a decrease in hydrogen and oxygen.

Hydriding Apparatus and Procedure

The system used to produce the lutetium hydride samples for calorimetry is a glass system with a liquid nitrogen cold-trapped diffusion pump capable of achieving vacuum of 1×10^{-7} Torr, a mercury manometer to measure the amount of hydrogen introduced to the sample chamber, and a quartz tube to withstand the temperatures required. The tank hydrogen was purified by reacting it with uranium turnings to form UH_3 which was then thermally decomposed to give hydrogen gas.

The lutetium samples were cut from the rod of Lu-I with a low speed diamond saw and weighed about four grams each. They were electropolished, washed with acetone, placed in a tantalum boat, and loaded into the quartz sample tube. The sample tube had a ground glass taper which was sealed to the system with Apiezon T grease. The system was then evacuated to about 2×10^{-7} Torr. When this vacuum was achieved, the sample was heated to 650°C in a split-tube resistance furnace. The desired amount of hydrogen was then added and was usually absorbed within one or two hours. The sample was held for 70 hours between 600°C and 650°C to ensure homogeneity. It was then furnace cooled, unloaded, and stored in helium gas until needed. Figure 2 is a diagram of the hydriding system.

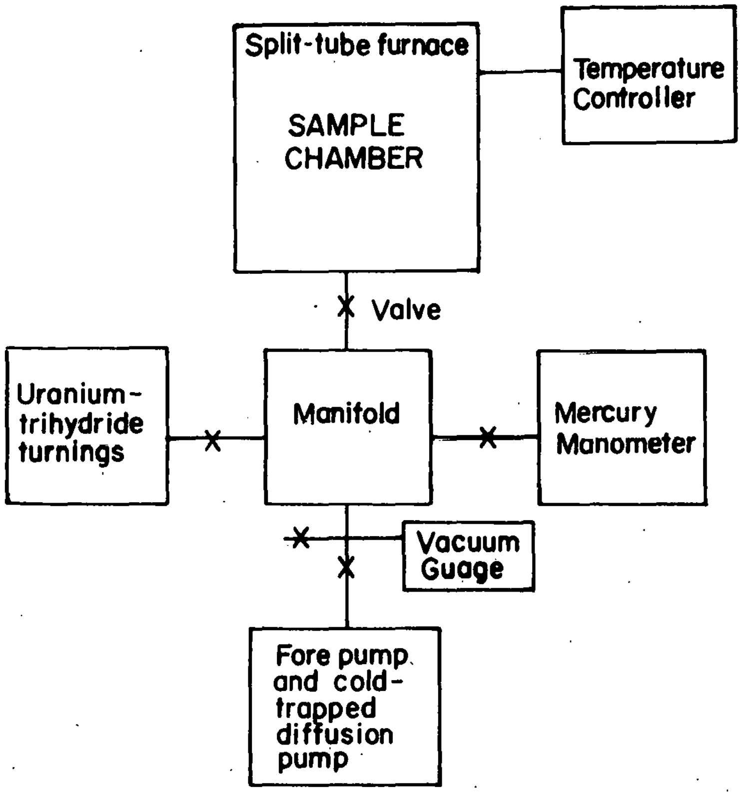

Figure 2. Simplified diagram of hydriding system

Calorimetry

Samples were prepared for calorimetry by electropolishing, rinsing with acetone, then drying in air. The samples were weighed with a Schaar double pan balance then 6.0± 0.1 mg of Apiezon N grease was added to form a bond between the sample and the sample holder of the calorimeter. The calorimeter is described briefly in Appendix A. After the sample was loaded, the vacuum can was soldered into place with Wood's metal and the system was checked for vacuum leaks. It was then placed in the cryostat and the sample chamber evacuated to less than 1×10^{-6} Torr. The outer nitrogen dewar was then filled and the system allowed to cool by radiation for at least 12 hours before liquid helium was transferred. Data points were taken from 4.2 to 20 K then the sample was cooled to 1 K by pumping on the liquid helium in the pumping pot. Data points were then taken from 1 K to 4.2 K. The heat capacity was determined by inputting heat pulses of 16 to 34 seconds duration at the desired heater current. The temperature was monitored on a strip chart recorder and was extrapolated to the center of the heat pulse. The duration of the heat pulse was measured with a Monsanto digital electronic timer. The entire electronic system for the calorimeter is described in Appendix A. All the measured values were coded, then analyzed by an IBM 360 computer. The heat capacity of the sample holder, C_{ad}, was determined separately, and was subtracted from the measured heat capacity by the equation,

$$C = \frac{\frac{\Delta Q}{\Delta T} - C_{ad}}{X} \qquad (4)$$

where ΔQ is the heat input, ΔT is the temperature change, and X is the number of gram-atoms of the alloy sample. The heat capacity of a piece of the 1965 Calorimetry Conference Standard Copper Sample was measured in this calorimeter and found to agree within two percent of the results of Osborne, Flotow, and Schreiner.[12] Results of the heat capacity measurements are tabulated in Appendix B. The data are fit to the equation:

$$C/T = \gamma + \beta T^2 \qquad (5)$$

between 1 to 5 K by a least squares treatment.

Vacuum Fusion and X-ray Analysis

The actual concentration of hydrogen in the samples containing less than 20 atomic percent hydrogen was determined by vacuum fusion analysis. Small samples are dropped into a molten platinum-tin bath containing carbon and the volume of the liberated gases H_2, N_2, and oxygen as CO is measured. The gases are then passed over hot CuO converting CO to CO_2 and H_2 to H_2O. The CO_2 is then condensed in a liquid nitrogen cold trap while the water is absorbed by $Mg(ClO_4)_2$ leaving only N_2 in the system. The N_2 is measured then the CO_2 is evaporated and the N_2

and CO_2 together are measured thus determining the amount of all three gases. All samples were measured in triplicate to assure accuracy and homogeneity.

Previous work by Beaudry and Spedding[8] has shown that the atomic volume of lutetium increases linearly with increasing hydrogen in solid solution. Lattice parameters for each of the lutetium hydride samples were measured after the heat capacity had been determined and were compared to Beaudry's results. X-ray "needles" were filed from material taken from the center of the sample. After filing to about 0.3 mm diameter

Table 4. Results of x-ray analysis

Sample	Atomic Percent Hydrogen [a]	Lattice Parameters [b] a_o	c_o	unit cell volume
Lu-II	< 0.018	-	-	-
Lu-III	0.035	-	-	-
Lu-IB	0.035	-	-	-
Lu-I	0.11	3.5051(4)	5.5491(5)	59.04(2)
2-20	0.22	3.5059(1)	5.5491(1)	59.07(0)
2-21	0.57	3.5060(2)	5.5507(2)	59.09(1)
2-19	1.4	3.5061(2)	5.5532(2)	59.12(1)
2-10	1.5	3.5071(2)	5.5544(2)	59.17(1)
1-84	3.1	3.5081(2)	5.5589(4)	59.25(1)
2-5	6.5	3.5114(2)	5.5685(4)	59.46(1)
1-98	12.4	3.5153(1)	5.5805(3)	59.72(1)
2-4	18.2	3.5209(2)	5.5940(2)	60.06(1)

[a] From vacuum fusion analysis.

[b] Figure in parentheses represents uncertainty in the last digit (1).

and 1 mm length, the needles were electropolished to 0.2 mm diameter to remove the cold worked surface. The needles were exposed to nickel filtered copper radiation for six to eight hours in a 114.6 mm Debye-Scherrer camera. The films were developed and read and this information was analyzed by an IBM 360 computer using a Nelson-Reilley extrapolation procedure to obtain reliable $\underline{a}_o$ and $\underline{c}_o$ lattice parameters. The results are given in Table 4 and are plotted along with Beaudry's data in Figure 3. Good agreement with Beaudry's results was found for all samples.

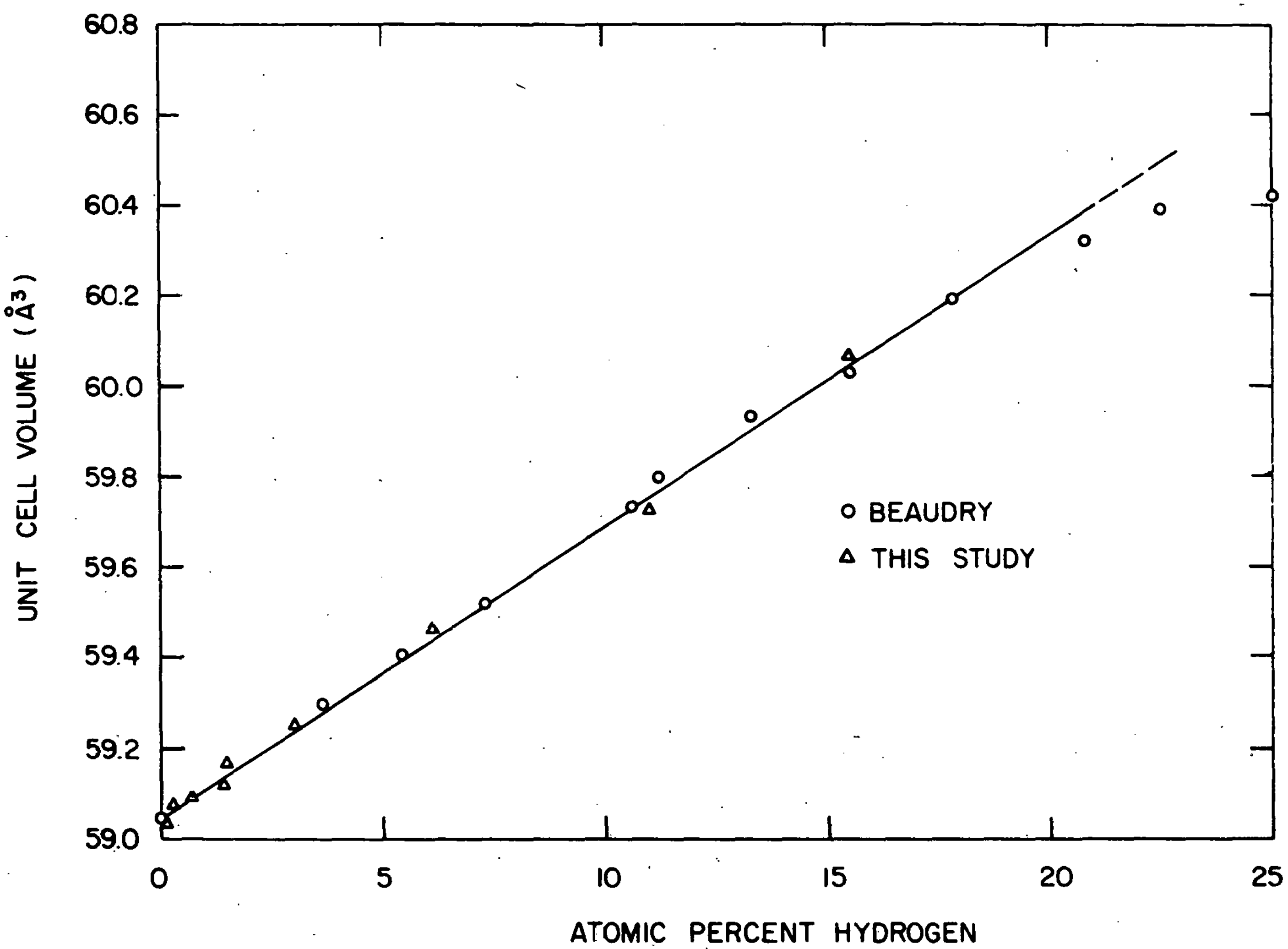

Figure 3. Atomic volume versus hydrogen content in lutetium.

RESULTS AND DISCUSSION

The heat capacity of the sample holder of the calorimeter was determined in a separate experiment and was checked using the 1965 Calorimetry Conference Standard Copper Sample. Figure 4 shows the measured heat capacity together with a plot of the copper reference equation of Osborne, Flotow, and Schreiner.[12] The measured data agree to within about two percent of the copper reference equation. The scatter in the data is due to the small size of the sample (about five grams).

The measured heat capacity of electrotransport purified lutetium, Lu-II, is shown in Figure 5 together with the line determined by the least squares fit of the data. This line is also plotted as a reference to pure lutetium for the lutetium hydrogen alloys in Figures 6 and 7. The γ and θ_D values determined from Lu-II and Lu-III agree well. The values of θ_D are also in good agreement with θ_D determined from elastic constant measurements on lutetium single crystals by Tonnies et al.[13] He reports a value of 184.5 K as compared to 183.2 K for Lu-II and 182.3 for Lu-III. The difference is probably less than the sum of errors in both experiments.

The heat capacity of the lutetium starting material for this study was measured (sample Lu-IA) and the data showed, in a C/T versus T^2 plot, a slight rise below about 2.5 K from the straight line established at higher temperature. See Figure 6. Since there is no evidence for this behavior in the electrotransport purified lutetium samples it was suspected that this anomaly might be due to hydrogen. Vacuum fusion analysis showed that there were about 1050 atomic parts per million (ppm)

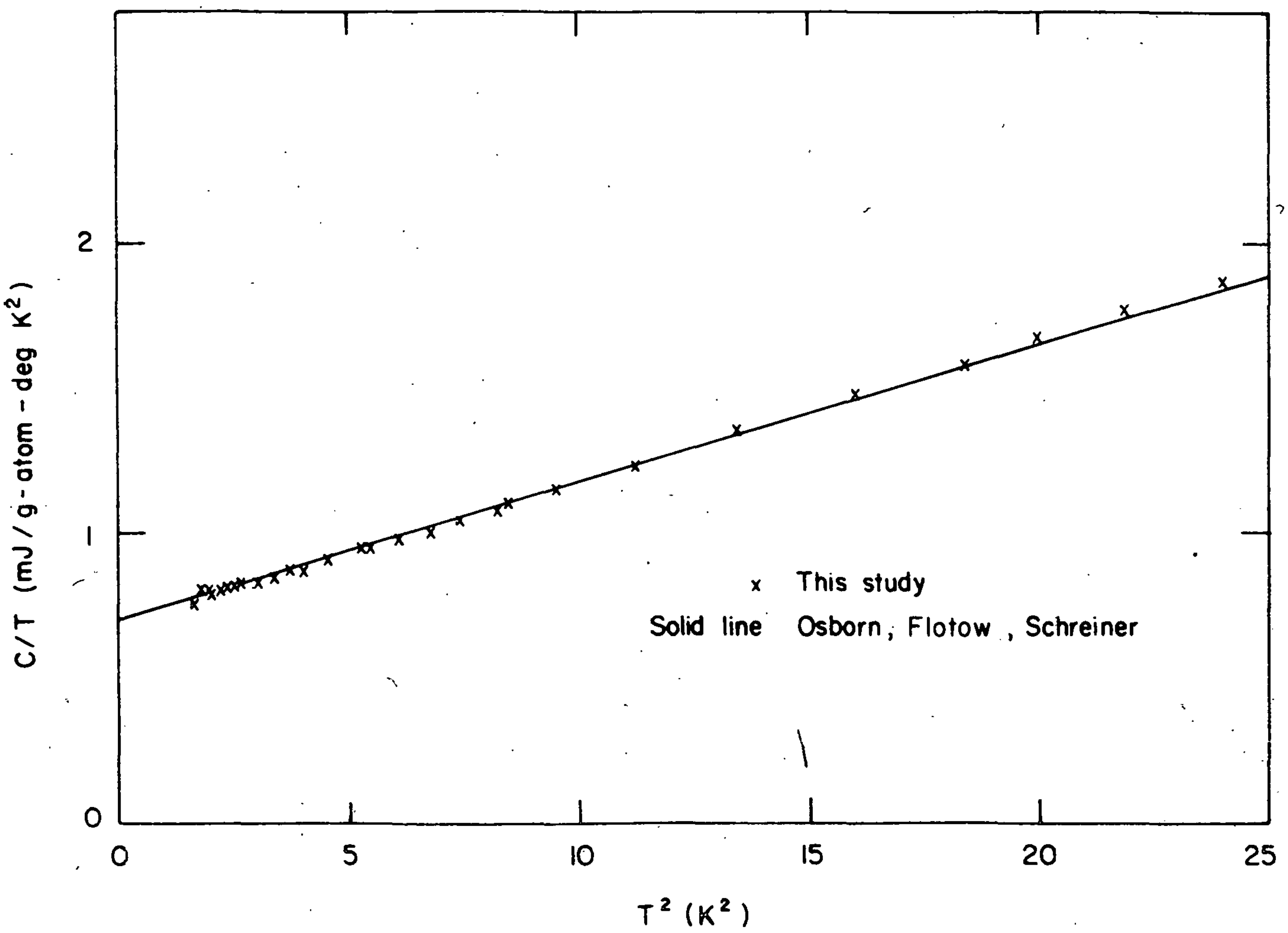

Figure 4. Heat capacity of the copper standard sample

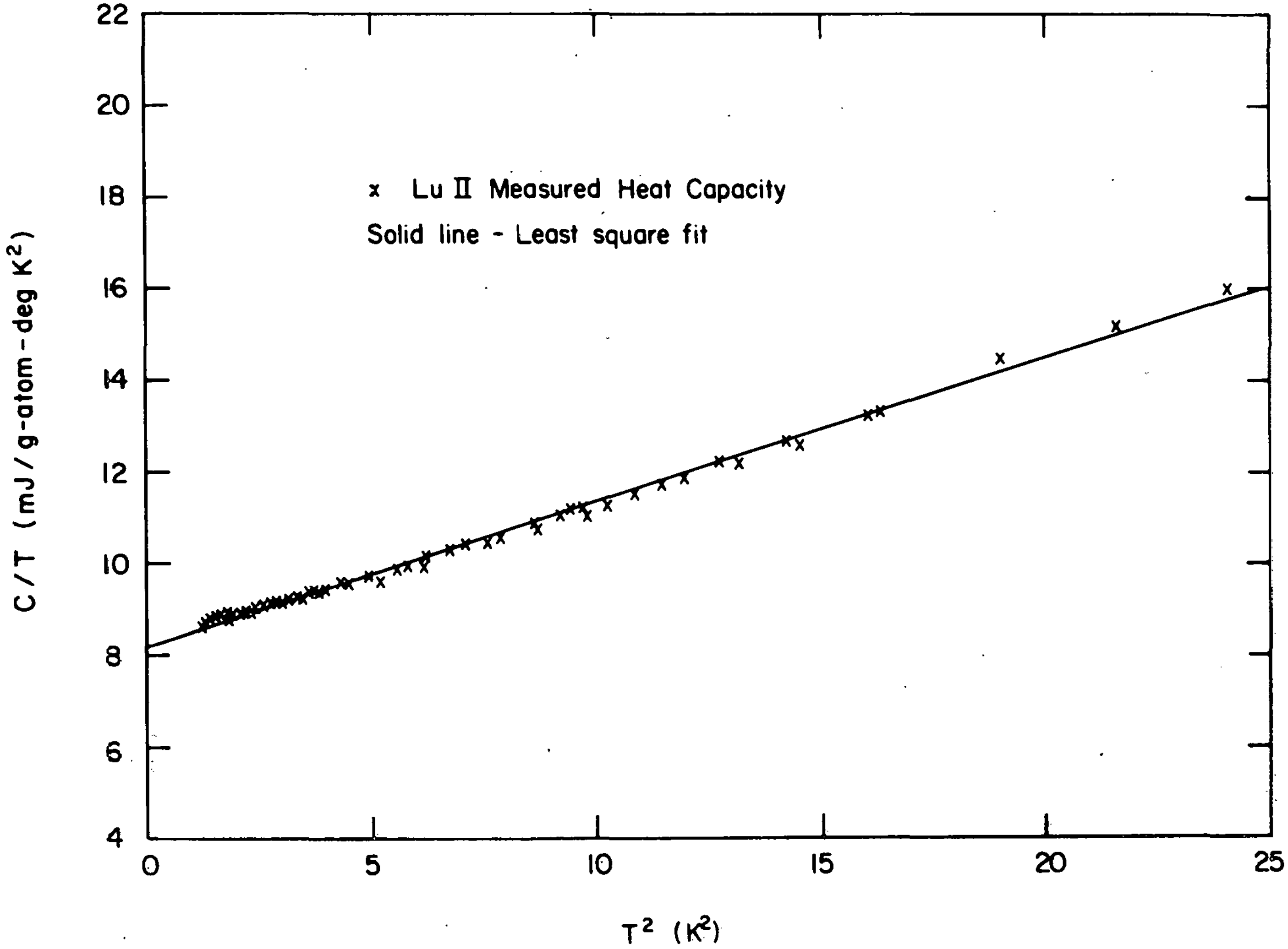

Figure 5. Heat capacity of electrotransport purified lutetium

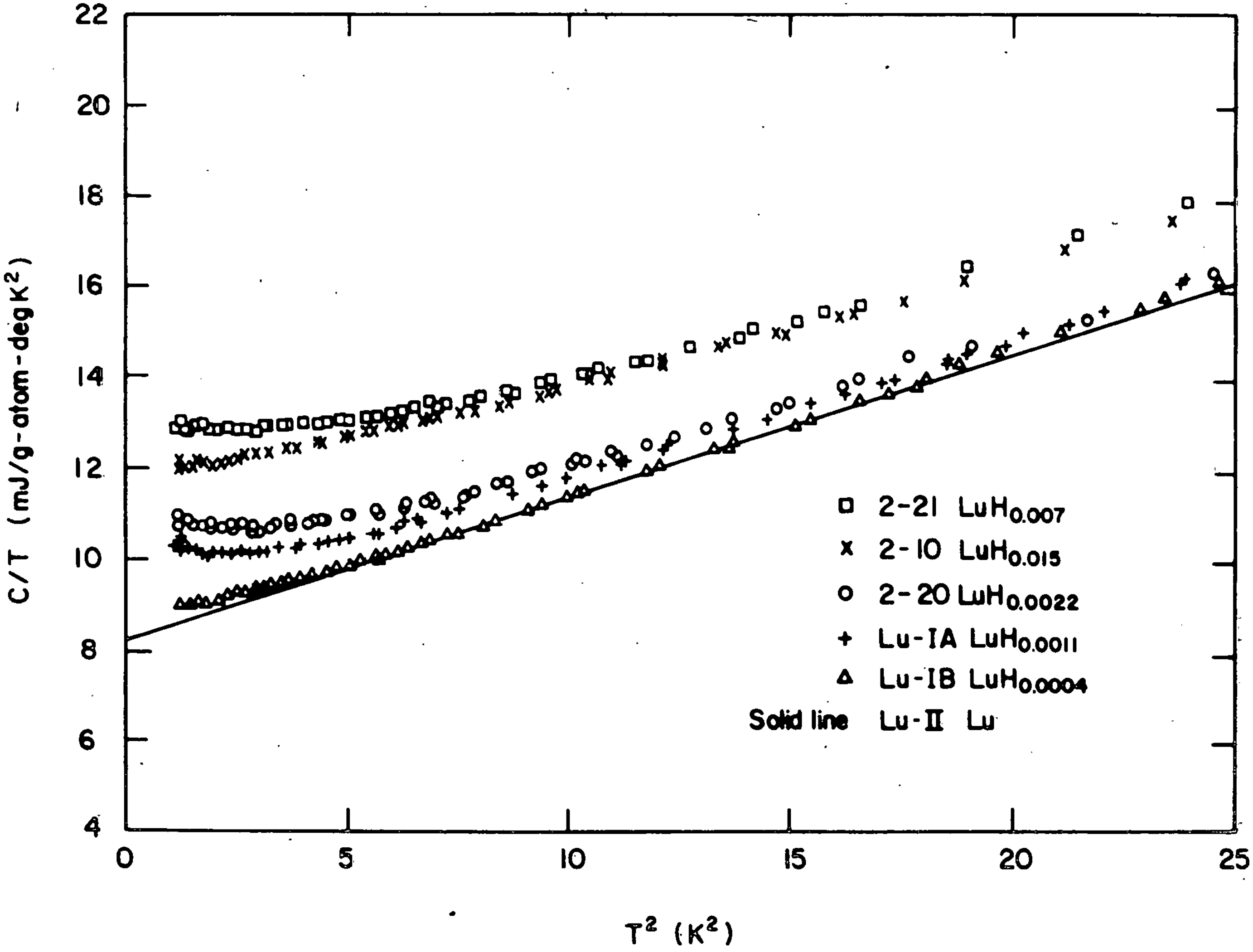

Figure 6. Heat capacity of lutetium-hydrogen alloys

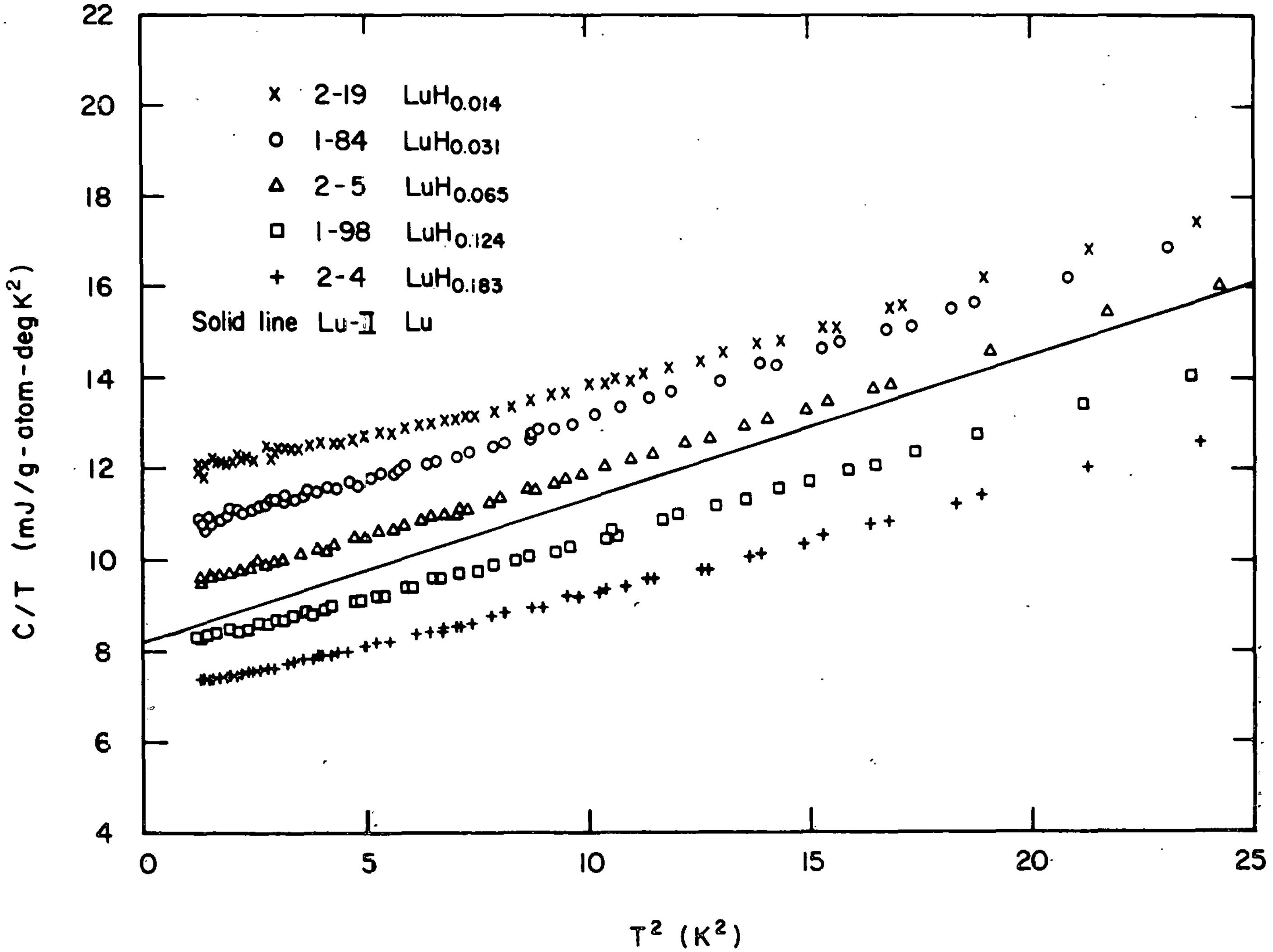

Figure 7. Heat capacity of lutetium-hydrogen alloys

of hydrogen in this material. A piece of Lu-I was then annealed at $1000^{\circ}C$ for six hours in a vacuum of 1×10^{-8} Torr to remove the hydrogen. The analysis for this sample, Lu-IB, showed about 350 atomic ppm of hydrogen and the heat capacity data were in much better agreement with Lu-II and Lu-III. The γ and θ_D values with their statistical error together with the analysis for hydrogen, nitrogen, and oxygen are listed in Table 5 for all samples measured. The heat capacity data for Lu-IA and Lu-IB are shown in Figure 6. The heat capacity of the starting material was remeasured (sample Lu-IC) and the results agreed with sample Lu-IA indicating that as little as 0.1 atomic percent hydrogen has an effect on the heat capacity of lutetium. It was found that other lutetium samples with concentrations between 0.1 and about 1.5 atomic percent hydrogen also showed a rise in C/T with decreasing temperature below about 2.5 K. The heat capacity data are shown in Figure 6 for these alloys. The increase in C/T with decreasing temperature is similar to that reported for the superconducting palladium-hydrogen system[14] except it appears that the peak in C/T versus T^2 for lutetium-hydrogen alloys would occur below 1 K which is below the limit of the calorimeter used in this study. The values for θ_D and γ for the low concentration lutetium hydrogen alloys (< 1.5 atomic percent hydrogen) were determined from data between the start of the increase in C/T versus T^2 and about 4.5 K. In some cases this meant only the points between 4 and 4.5 K which caused a large scatter in θ_D for these alloys as well as increased statistical error for γ. The θ_D versus hydrogen content values are

Table 5. θ_D, γ, and composition of lutetium hydrogen alloys

Sample	hydrogen[a]	nitrogen[a]	oxygen[a]	γ (mJ/g-atom K^2)	θ_D (K)
Lu-II	< 0.018	< 0.0013	0.008	8.194±0.016	183.2±0.3
Lu-III	0.035	0.0130	0.063	8.209±0.020	182.3±0.3
Lu-IB	0.035	0.0013	0.060	8.351±0.019	184.0±0.3
Lu-IA	0.105	0.0013	0.061	8.680±0.035	185.1±0.4
Lu-IC	0.105	0.0013	0.061	8.650±0.042	184.7±0.6
2-20	0.22	0.0013	0.064	9.234±0.044	190.5±0.7
2-21	0.57	0.0054	0.103	9.769±0.111	187.2±1.3
2-19	1.4	none	0.078	11.126±0.035	194.6±0.6
2-10	1.5	0.0008	0.074	10.707±0.088	189.3±1.0
1-84	3.0	0.0031	0.15	10.354±0.008	191.0±0.2
2-5	6.1	0.0021	0.14	9.102±0.005	190.8±0.1
1-98	11.0	0.0100	0.19	7.861±0.007	196.8±0.2
2-4	15.5	0.0150	0.20	6.964±0.005	204.9±0.2
2-8	67.0	-	-	0.724±0.002	361.4±0.3

[a]Atomic percent.

plotted in Figure 8 and with an expanded concentration scale in Figure 9. The γ versus hydrogen content values are plotted in Figure 10 with an expanded concentration scale in Figure 11. The γ values show an increase of about 40 percent with the hydrogen content increasing from zero to about 1.2 atomic percent and then a gradual decrease with further increase in hydrogen content. These results could give an indication of the band structure of lutetium however it is not possible to conclude this from heat capacity measurements alone.

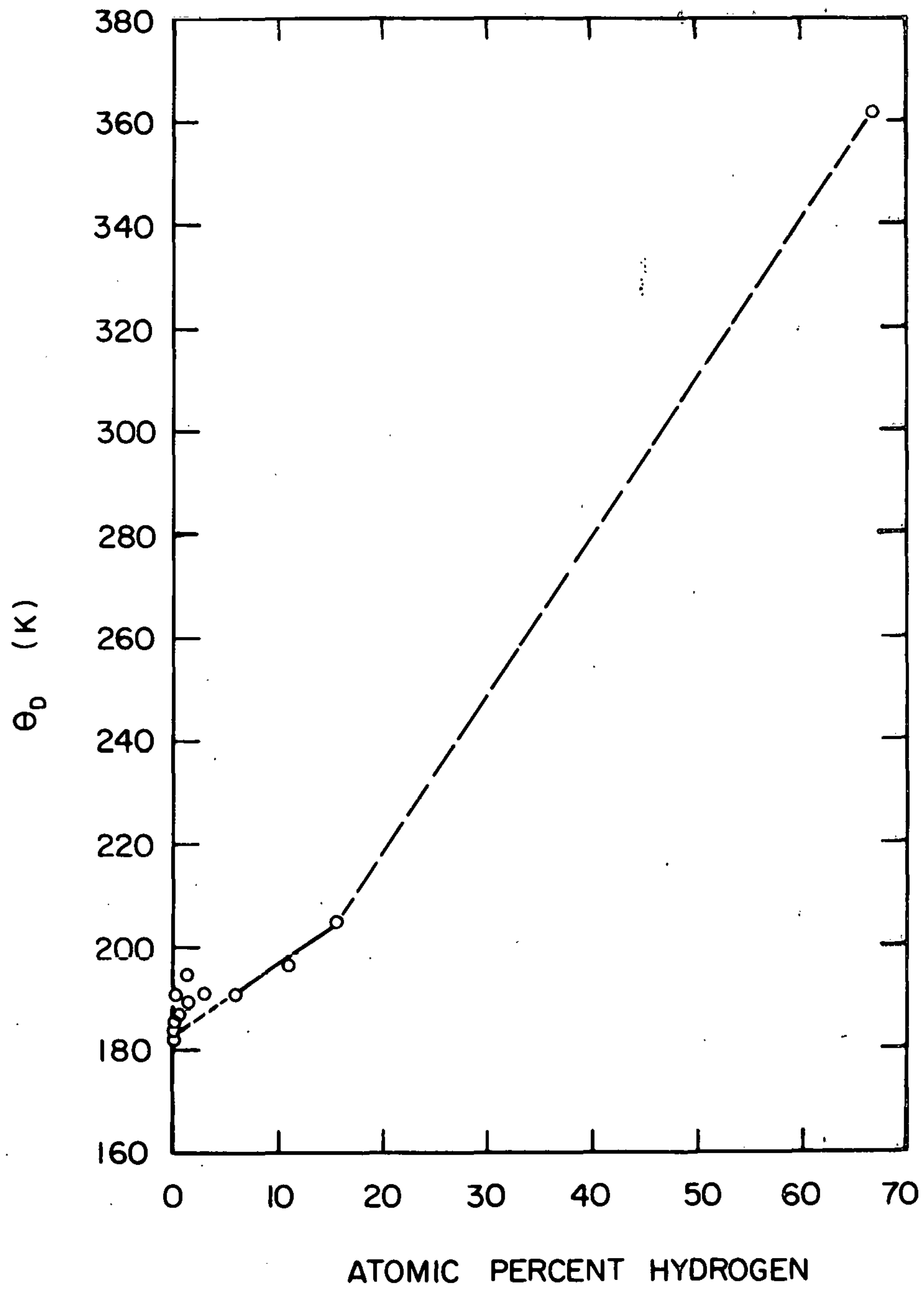

Figure 8. θ_D versus hydrogen content in lutetium

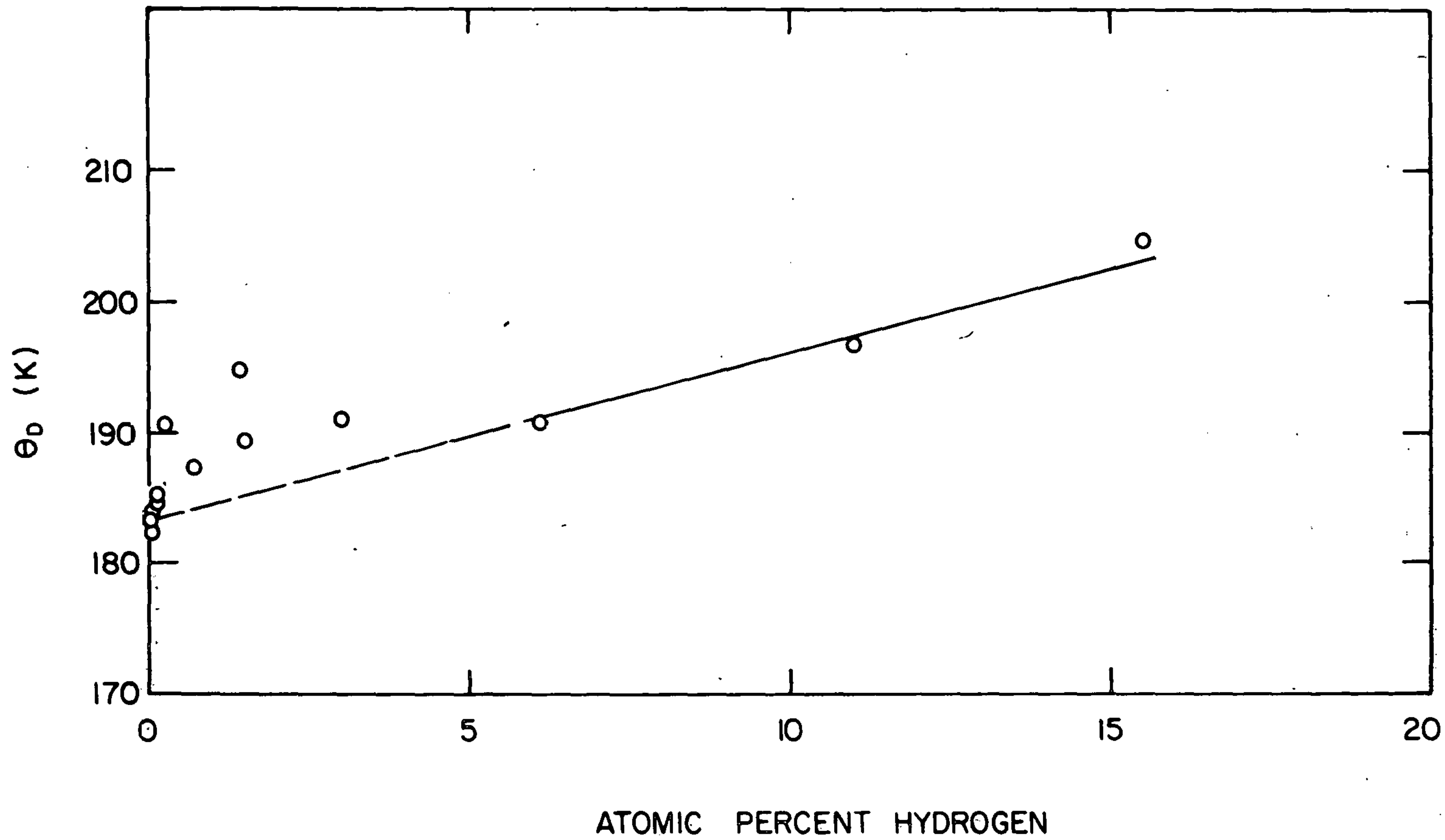

Figure 9. θ_D versus hydrogen content in lutetium

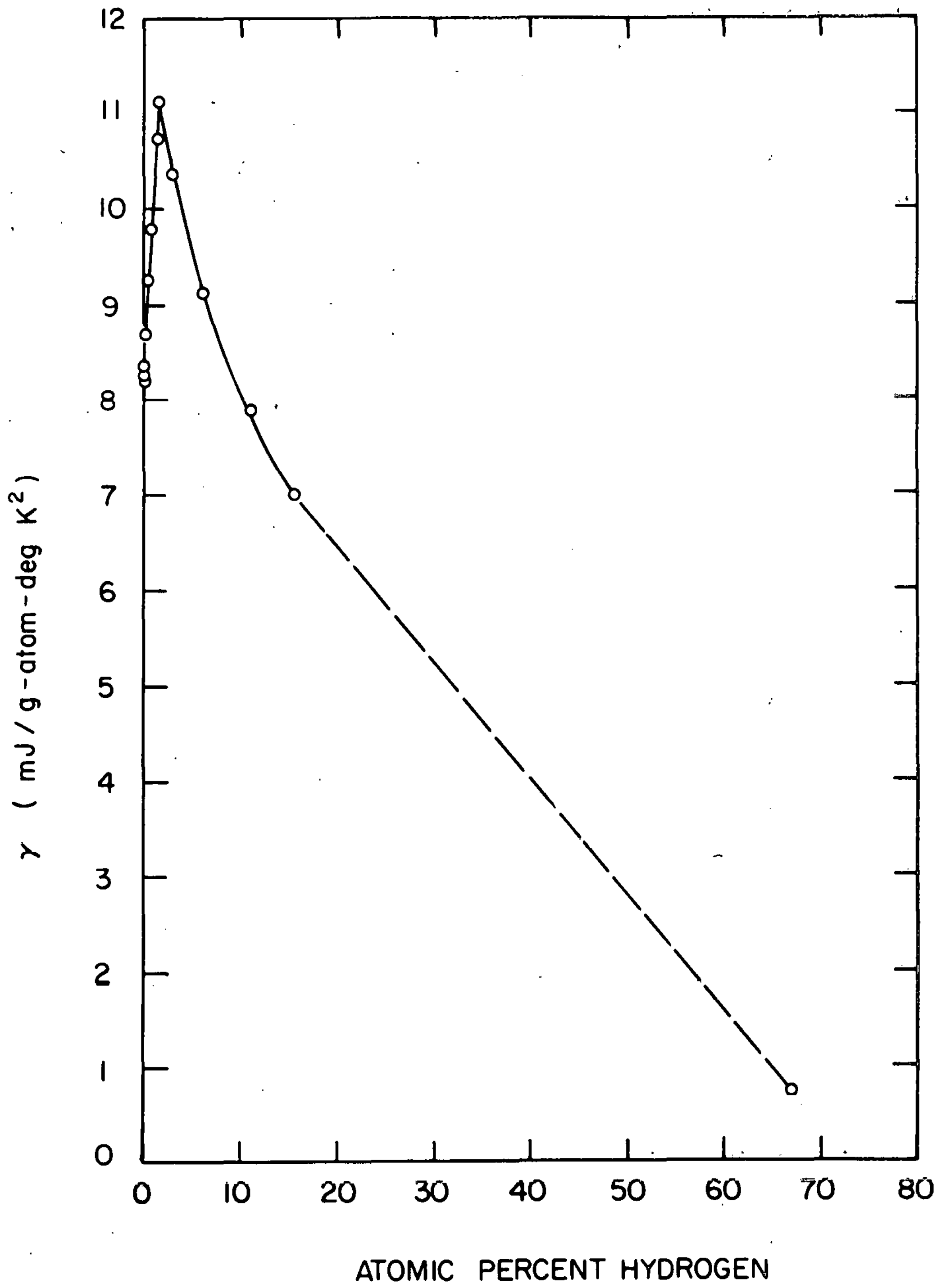

Figure 10. γ versus hydrogen content in lutetium

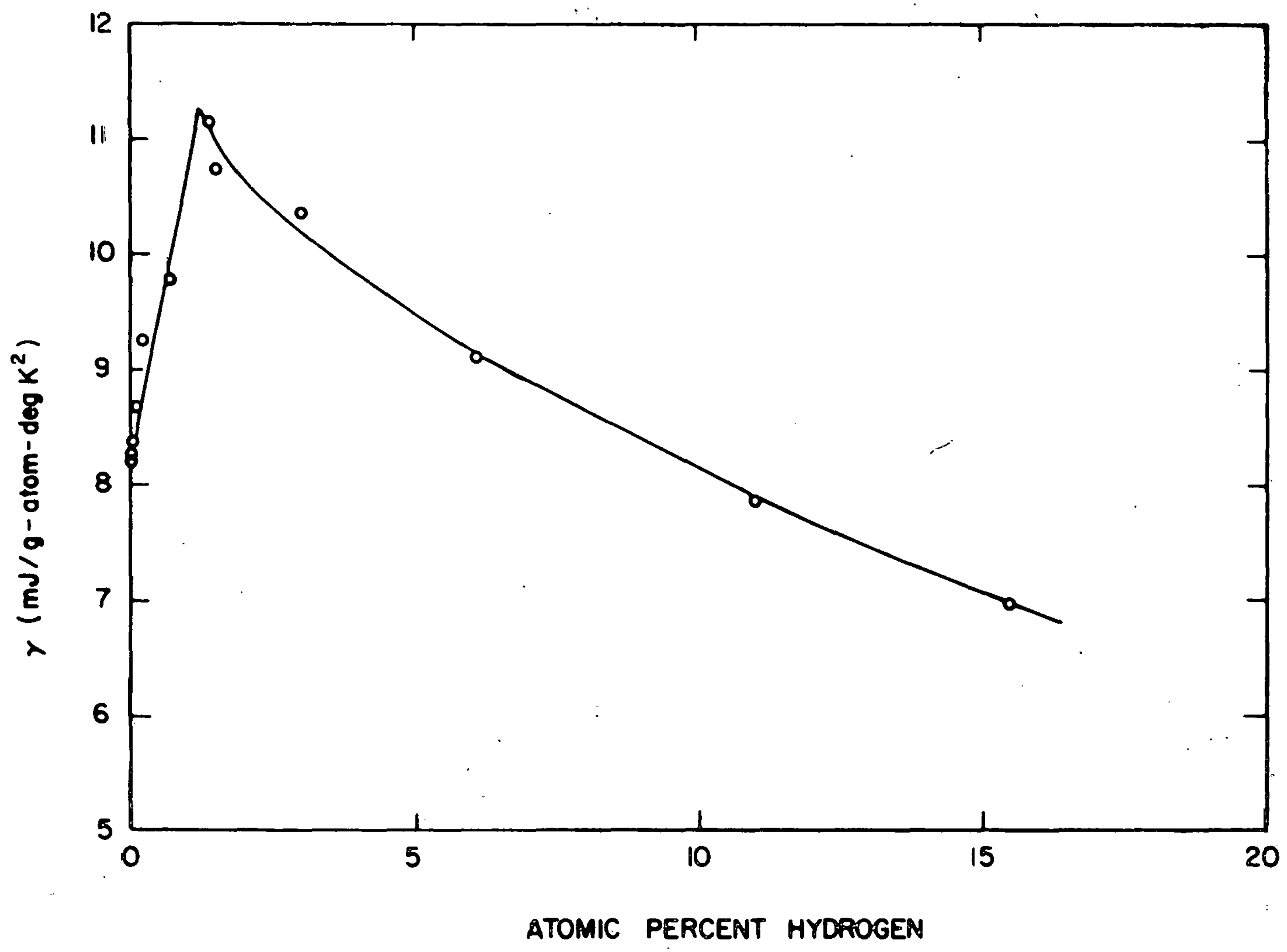

Figure 11. γ versus hydrogen content in lutetium

Sellers, Anderson, and Birnbaum have studied the effects of hydrogen and deuterium on the heat capacity of niobium between 0.06 and 2 K and find an isotope dependent anomaly.[15] They suggest that the anomaly is caused by lattice effects rather than electronic effects. They further suggest that the lattice effects are due to quantum mechanical tunneling of the hydrogen or deuterium interstitials. It may be possible that tunneling of hydrogen occurs in the lutetium-hydrogen system as well. It is difficult to compare the lutetium-hydrogen system to the niobium-hydrogen and deuterium systems for a number of reasons: (1) niobium is a superconductor in the temperature range studied and the heat capacity was measured in the superconducting state; (2) the niobium-hydrogen alloys were two-phase while evidence shows lutetium-hydrogen alloys up to 15.5 atomic percent hydrogen are single phase as is discussed later; (3) the calorimeter in this study could only attain a minimum temperature of 1.1 K so that any peak in heat capacity below this could not be characterized; and (4) the heat capacity of lutetium plus deuterium was not measured.

If tunneling does give rise to a linear term in the heat capacity of lutetium, then it is consistent with the peak in γ versus hydrogen content. As hydrogen is added to pure lutetium tunneling would occur increasing the heat capacity. As the hydrogen content increases neighboring sites for hydrogen become occupied and the probability for tunneling decreases because of the unavailability of unoccupied sites. This would be consistent with the decrease in γ with hydrogen increasing above about 1.2 atomic percent in lutetium. To confirm this, measurements of the effects of deuterium on lutetium need to be measured (preferably to below 1 K) to determine if the anomaly observed is isotope dependent. Magnetic susceptibility measurements could also shed light on the lutetium-hydrogen system by determining if the anomaly is due to magnetic effects, such as itinerant ferromagnetism, or superconductivity.

Daou et al.[16], in measuring resistivity of lutetium-hydrogen alloys found no evidence for precipitation of second phase from a solid solution of 12.8 atomic percent hydrogen on cooling to 4.2 K and gives several arguments against it. The fact that θ_D in this study does not extrapolate to values determined for lutetium dihydride (as shown in Figure 12) is strong evidence that lutetium with 15.5 atomic percent hydrogen is still a solid solution even at 1 K. A linear increase in θ_D with increasing hydrogen to the lutetium dihydride value would be expected from a two phase system. Observation of the 15.5 atomic percent hydrogen sample with an optical microscope while cooling to 77 K did not show any evidence of precipitation of second phase.

The heat capacity of the lutetium dihydride sample referred to above was measured and the results are shown in Figure 12. The γ and θ_D values for lanthanum dihydride[17] compare with those determined for lutetium dihydride. Bieganski et al. report their value for θ_D on a per mole basis which is incorrect; θ_D should be calculated on a per gram-atom basis. Their corrected values are 349 K for θ_D and 2.6 mJ/g-atom-K^2 for γ for lanthanum dihydride. These values compare with 361 K for θ_D and 0.72 mJ/g-atom-K^2 for γ for lutetium dihydride as is listed in Table 5.

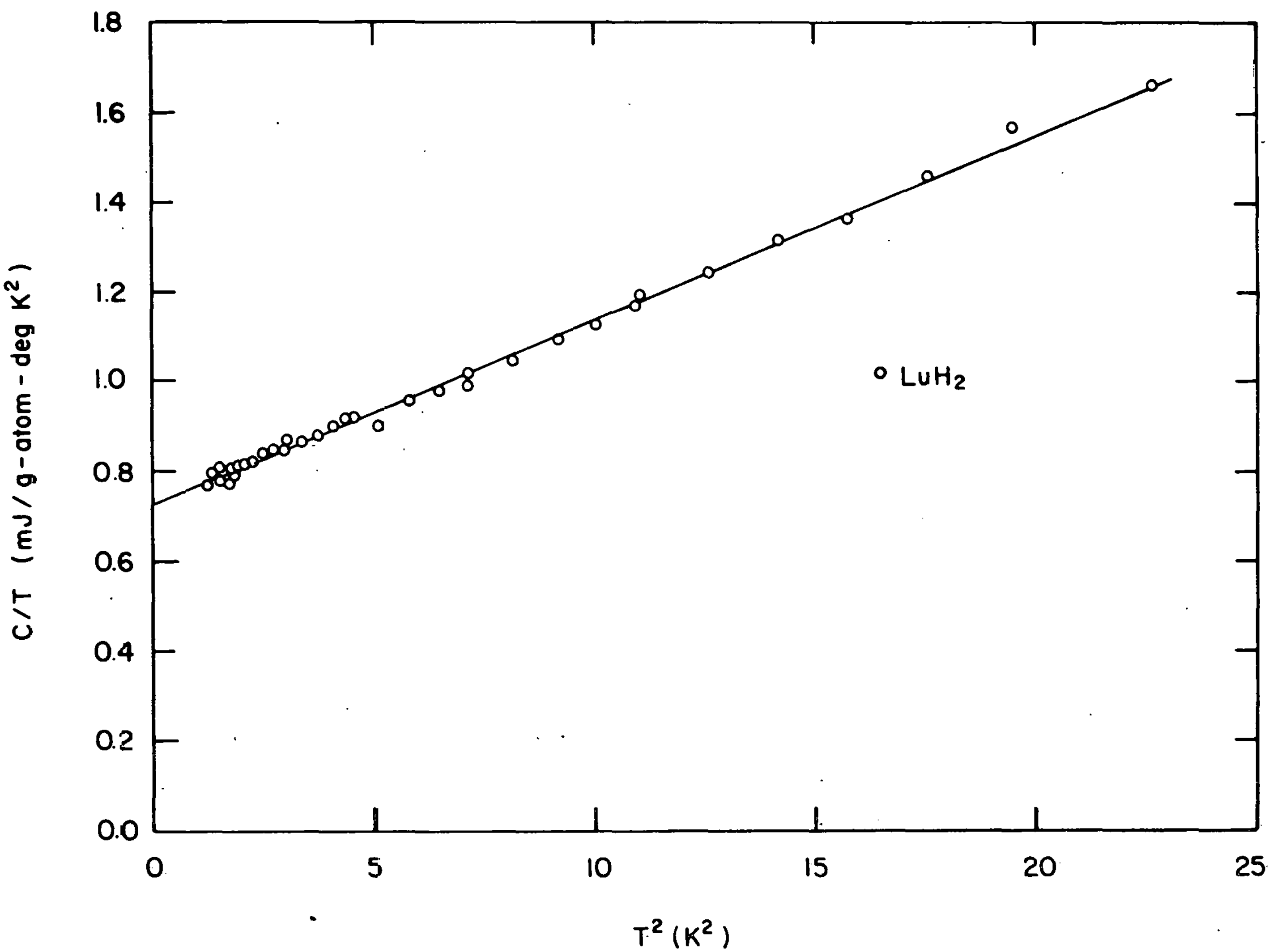

Figure 12. Measured heat capacity of lutetium dihydride

SUMMARY

The heat capacity of high purity electrotransport refined lutetium was measured between 1 and 20 K. Results for θ_D were in excellent agreement with θ values determined from elastic constant measurements.

The heat capacity of a series of lutetium-hydrogen solid solution alloys was determined and results showed an increase in γ from 8.2 to about 11.3 mJ/g-atom-K^2 for hydrogen content increasing from zero to about one atomic percent. Above one percent hydrogen γ decreased with increasing hydrogen contents. The C/T data showed an increase with temperature decreasing below about 2.5 K for samples with 0.1 to 1.5 atomic percent hydrogen. This accounts for a large amount of scatter in θ_D versus hydrogen content in this range.

The heat capacity of a bulk sample of lutetium dihydride was measured between 1 and 20 K and showed a large increase in θ_D and a large decrease in γ compared to pure lutetium.

REFERENCES

1. P. Wells, P. C. Lanchester, D. W. Jones, and R. G. Jordan, J. Phys. F, 6(1), 11 (1976).

2. L. D. Jennings, R. E. Miller, and F. H. Spedding, J. Chem. Phys., 33(6), 1849 (1960).

3. O. U. Lounasmaa, Phys. Rev., 133(1A), A219 (1964).

4. H. U. Culbert, Phys. Rev., 156(3), 701 (1967).

5. B. C. Gerstein, W. A. Taylor, W. D. Shickell, and F. H. Spedding, J. Chem. Phys., 51(7), 2924 (1969).

6. O. N. Carlson, F. A. Schmidt, and D. T. Peterson, J. Less-Common Metals, 39, 277 (1975).

7. E. S. R. Gopal, "Specific Heats at Low Temperatures," Plenum Press, New York, N.Y., 1966.

8. B. J. Beaudry and F. H. Spedding, Met. Trans., 6B, 419 (1975).

9. T.-W. E. Tsang, K. A. Gschneidner, Jr., and F. A. Schmidt, Solid State Commun., 20, 737 (1976).

10. A. Pebler and W. E. Wallace, J. Phys. Chem., 66, 148 (1962).

11. D. T. Peterson and E. N. Hopkins, AEC Report IS-1036, Iowa State University, October 1964.

12. D. W. Osborne, H. E. Flotow, and F. Schreiner, Rev. Sci. Inst., 38(2), 159 (1967).

13. J. J. Tonnies, K. A. Gschneidner, Jr., and F. H. Spedding, J. Appl. Phys., 42(9), 3275 (1971).

14. M. Zimmermann, G. Wolf, and K. Bohmhammel, Phys. Stat. Sol. (a), 31, 511 (1975).

15. G. J. Sellers, C. A. Anderson, and H. K. Birnbaum, Phys. Rev. B, 10(7), 2771 (1974).

16. J. N. Daou, A. Lucasson, and P. Lucasson, Solid State Commun., 19, 895 (1976).

17. Z. Bieganski, D. Gonzalez Alvarez, and F. W. Klaaijsen, Physica, 37, 153 (1967).

18. F. R. Kroeger and W. A. Rhinehart, Rev. Sci. Inst., 42(10), 1532 (1971).

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I am indebted to Rick Schmidt for the use of an electrotransport purified sample of lutetium, as well as for the electrotransport purification of a second lutetium sample; to Nile Beymer for much time and effort in vacuum fusion analysis of my samples; to Dr. Clayton A. Swenson's research group for the calibration of the germanium resistance thermometer in the calorimeter; to Edmund Tsang for the use of the calorimeter; to Bernard Beaudry for the use of his hydriding apparatus and help with hydriding procedure and x-ray analysis; and to Paul Palmer for the preparation of the lutetium used in this study.

I would also like to thank Jack Moorman for his expert technical assistance in this project.

APPENDIX A.

DESCRIPTION OF CALORIMETER AND ELECTRONIC SYSTEM

Calorimeter

The calorimeter used in this study is designed to measure small samples in the range of 1 K to 20 K. It operates on the heat pulse principle; a known amount of energy is applied to the sample and the temperature rise is measured. The ratio of the energy input to the change in temperature determines the heat capacity.

A diagram of the calorimeter is shown in Figure A1, and an enlarged view of the sample chamber shown in Figure A2 indicating the important features.

The sample holder was fabricated from 0.013 cm thick copper foil into the shape of a pan 1.6 cm in diameter with side walls 0.3 cm high. Six eyelets were silver soldered to the pan to support it in the calorimeter. A copper foil tab to hold a germanium resistance thermometer (GRT) and a copper wire thermal link to the helium pot were also silver soldered into place.

The GRT was a Cryocal, No. 3979, and was calibrated by Dr. C. A. Swenson's research group against two standard GRT's. The estimated accuracy is ±0.5 mK from 1 K to 5 K and ±3.0 mK above 5 K.

The heater is made of a length of 92 percent platinum, 8 percent tungsten wire wound noninductively around the side walls of the sample holder pan and secured with G.E. 7031 insulating varnish. This heater material was chosen for high strength and stability, low coefficient of resistance change with temperature and small heat capacity below 20 K.

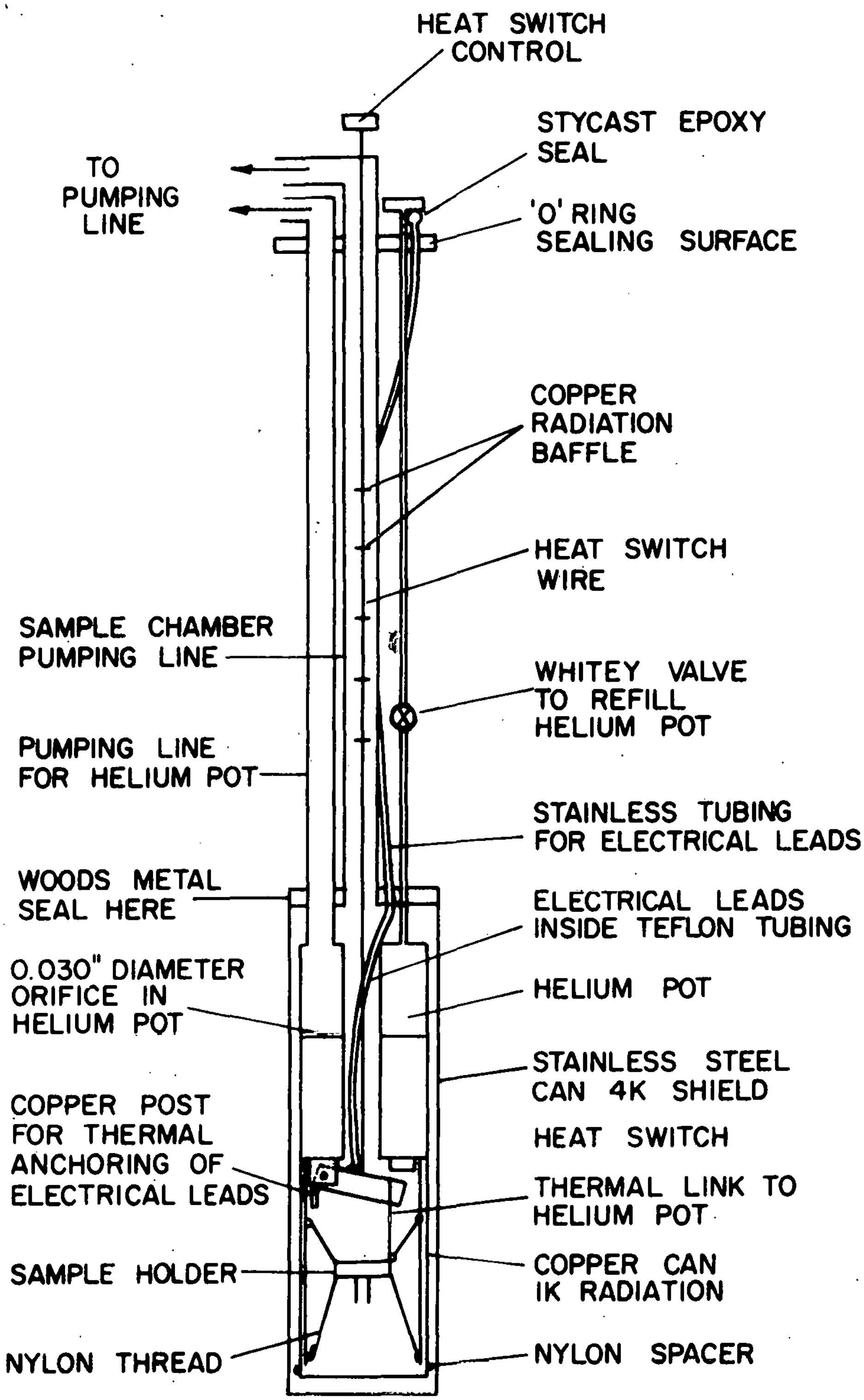

Figure A1. The low temperature calorimeter used in this study

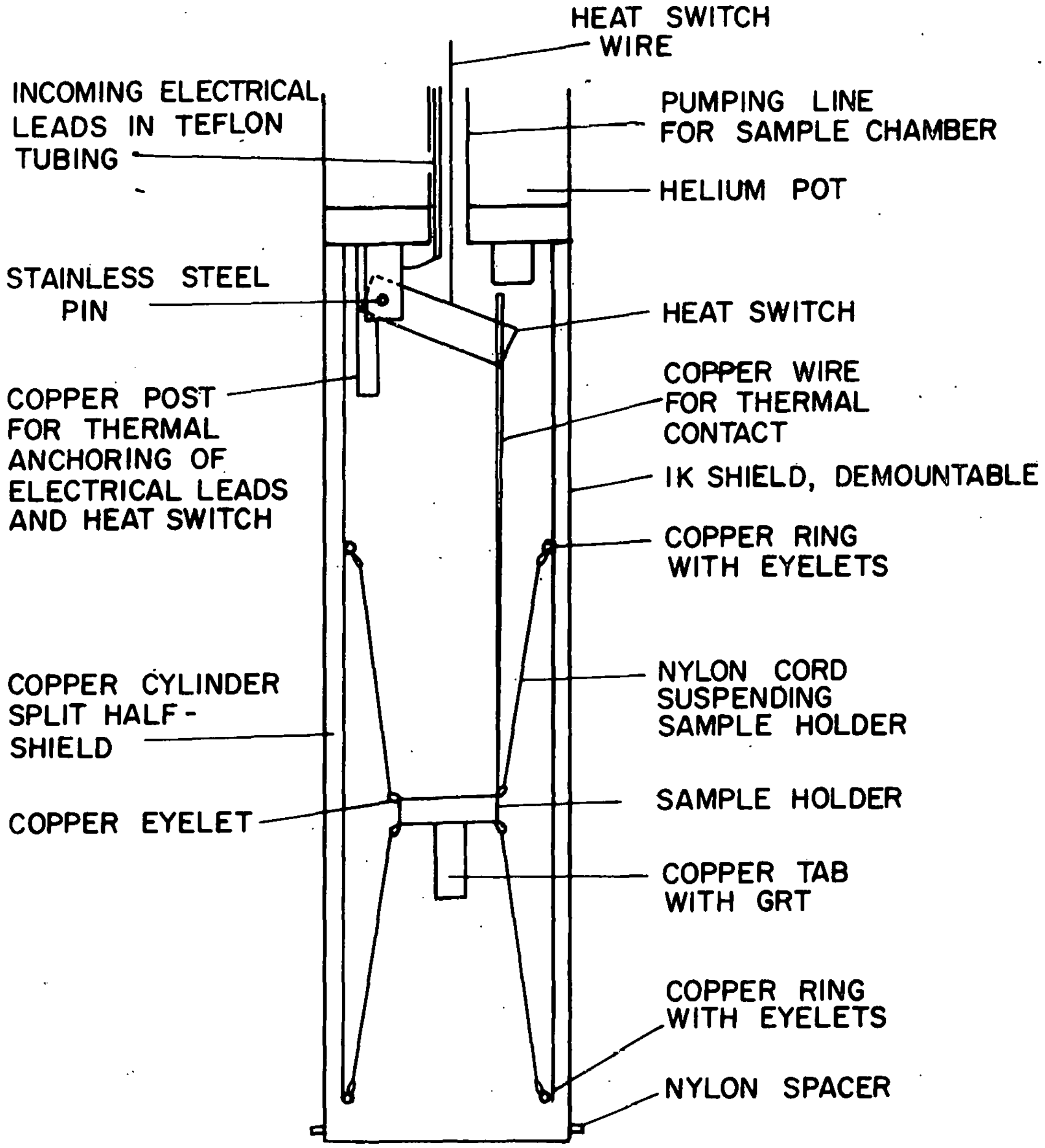

Figure A2. The sample chamber of the calorimeter

A copper half shield was mounted to the helium pot. This shield had two copper rings soldered to it with three eyelets on each ring to support the sample holder. The helium pot is a copper cylinder with a volume of about 100 cm^3. Half way between the top and bottom is a plate with an oriface 0.08 cm in diameter. The oriface is necessary to control the evaporation of liquid helium below the lambda point when it becomes a superfluid. The pot is isolated from the reservoir by stainless steel tubes. Liquid helium from the reservoir enters the pot through a small stainless steel tube. A valve can be opened to allow helium to enter the pot and closed to maintain a vacuum on the pot to cool to 1 K.

A copper tube mounts directly onto the helium pot to provide a 1 K radiation shield. Outside this shield is the sample chamber vacuum can which is maintained at 4.2 K in the helium reservoir. This can is sealed to the system with Wood's metal to provide a good vacuum.

Electronic System

The electronic system for the calorimeter is most easily described in sections below.

The germanium resistance thermometer current circuit

The current to the GRT is supplied by 20 mercury cells in series with a large adjustable resistance. Mercury cells were chosen since they provide a stable voltage at low current drain and are isolated from A·C line voltage. This helps to eliminate grounding loops or A·C line noise. By adjusting the series resistance, currents of 1, 2, 4, 6, 10, 20, or 50 microamperes can be supplied through shielded leads to the GRT.

The germanium resistance thermometer voltage circuit

The voltage drop across the GRT is measured with a Leeds and Northrup type K-5 potentiometer in series with a Keithley model 150B microvoltmeter. The potentiometer is used to "buck" most of the voltage signal of the GRT and the voltmeter measures the difference. The voltmeter provides an adjustable output to drive a Texas Instruments two pen strip chart recorder. The temperature drift is displayed and can be extrapolated to the midpoint of a heat pulse determined by the second pen of the recorder which indicates when the heater is on. The 100 or 30 microvolt full scale range is generally used below 4 K while the 10 microvolt full scale range is used above 4 K.

The potentiometer is used in a nonconventional way. Its power comes from a constant current supply[18] which was temperature compensated to drift less than 0.2 parts per million per degree centigrade. The potentiometer is standardized against a standard resistor rather than a standard voltage cell. Thermal emfs are taken into account. Although the accuracy of this method is not as good, the difference in voltage measured before and after the heat pulse is most important and this depends on the linearity and resolution of the potentiometer and not absolute value of the voltage measured. In any case, the voltage will be within about 0.02 percent of the true value. It should be mentioned that extrapolation of the temperature to the midpoint of the heat pulse probably produces the largest error. The GRT electrical circuit is shown in Figure A3.

The heater circuit

The heater current is provided by an adjustable constant current supply.[18] The value of the current is determined by reading the voltage across one of two standard resistors with a Leeds and Northrup type K-5 potentiometer with a Keithley model 153 microvoltmeter used as a null detector. This circuit is shown in Figure A4. The duration of the heat pulse is measured with a Monsanto digital timer. The current to the heater, the timer, and the marker pen of the strip chart recorder are all triggered with a relay. The contacts were measured to close within two milliseconds of each other. The relay is well shielded from the GRT because it is possible for the GRT to detect any radio frequency interference produced on opening and closing the contacts.

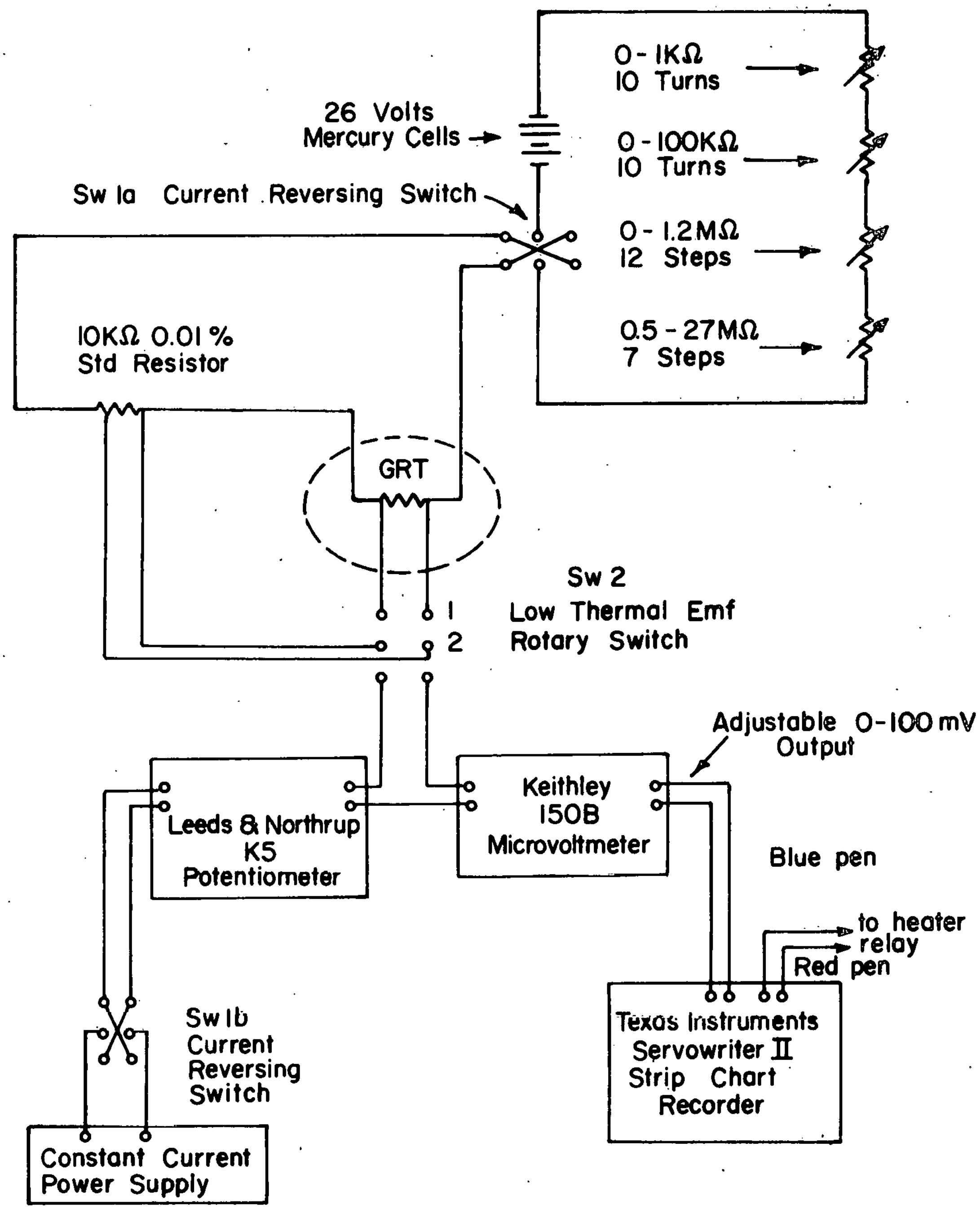

Figure A3. The GRT electrical circuit

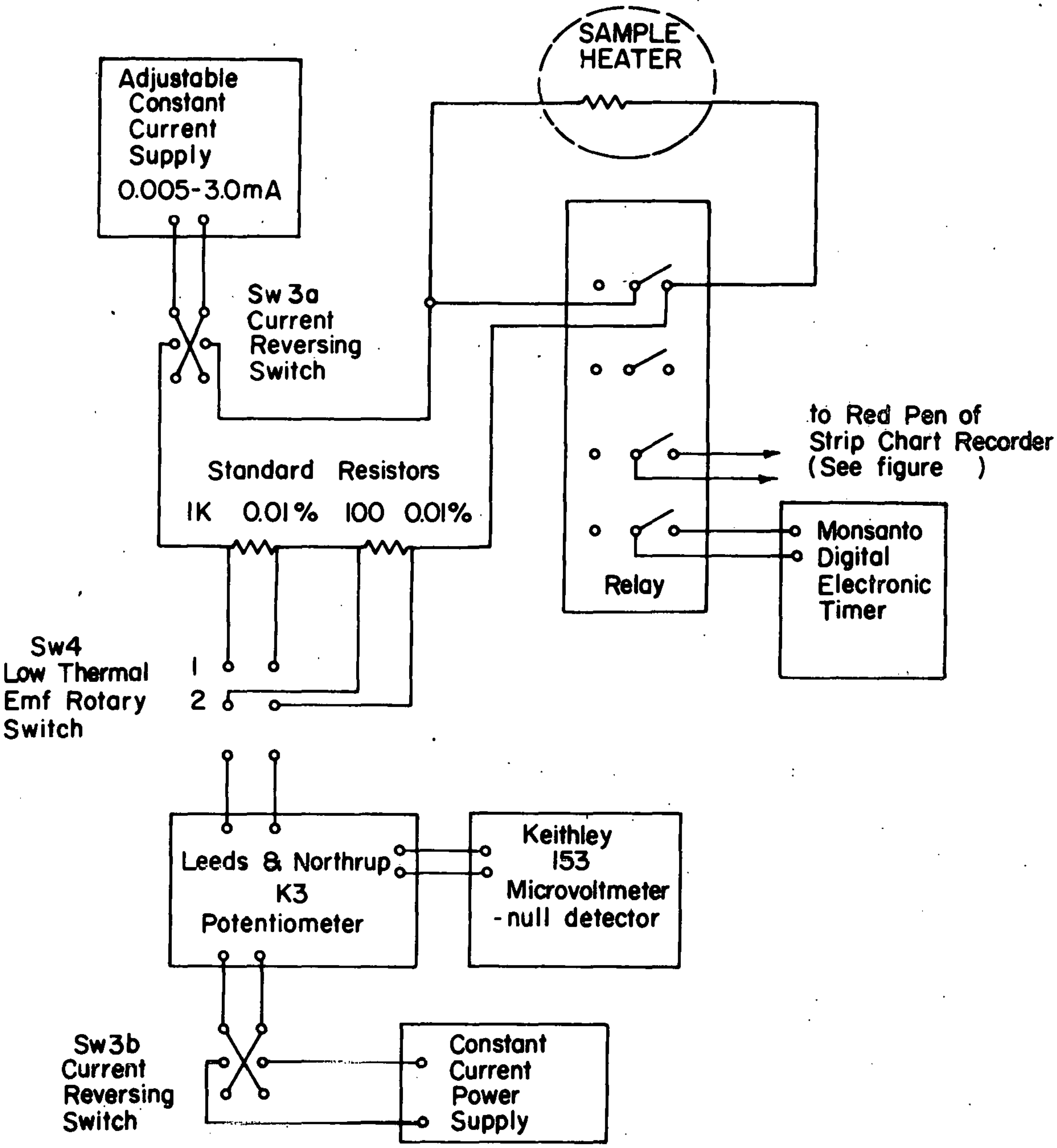

Figure A4. The heater electrical circuit

APPENDIX B.

MEASURED HEAT CAPACITY DATA

Measured Heat Capacity
Electrotransport Purified Lutetium Lu-II

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1002	9.4759	2.7950	29.4524
1.1140	9.6992	2.9377	31.7668
1.1521	10.1331	2.9413	31.6561
1.1813	10.3619	3.0379	33.6610
1.2133	10.7558	3.0658	34.2634
1.2449	10.9547	3.1113	34.8535
1.2699	11.2166	3.1306	34.6380
1.2946	11.3528	3.2080	36.0852
1.3086	11.6300	3.2998	37.9786
1.3412	11.9930	3.3799	39.5973
1.3467	11.8061	3.4570	40.9215
1.3980	12.4260	3.5703	43.6896
1.4005	12.4423	3.6321	44.3400
1.4491	12.9056	3.7764	47.9411
1.4576	12.8979	3.8091	47.8538
1.4973	13.2308	4.0052	52.9783
1.5017	13.3949	4.0393	53.6913
1.5171	13.5950	4.3619	63.1144
1.5535	13.8952	4.6466	70.3057
1.5613	14.0971	4.9036	78.5177
1.6115	14.6202	5.1358	85.7013
1.6529	15.0761	5.3684	93.5235
1.6943	15.4537	5.5392	99.9378
1.7380	15.9338	5.7845	110.6941
1.7766	16.2827	6.0217	121.9334
1.8161	16.8168	6.2511	132.8087
1.8487	16.9757	6.4805	146.3423
1.8617	17.2269	6.6187	152.3252
1.8931	17.7401	6.9337	171.5012
1.9345	18.1559	7.2735	193.4307
1.9605	18.3410	7.6360	222.3626
1.9809	18.6312	7.9895	250.6632
2.0761	19.8174	8.2432	272.1692
2.1195	20.2670	8.6407	313.7038
2.2193	21.5718	9.0587	360.2911
2.2698	21.9689	9.4895	415.8232
2.3642	23.3512	9.9166	476.4196
2.3952	23.7958	10.2184	522.6489
2.3968	23.7852	10.6709	606.2042
2.4868	25.2139	11.1132	686.4376
2.4877	24.7173	11.5495	767.8185
2.5907	26.6378	11.9984	878.4180
2.6572	27.6377	12.3589	965.6098
2.7639	28.8256	12.8456	1089.4806

Measured Heat Capacity
Electrotransport Purified Lutetium Lu-II
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
13.3472	1216.8488	16.3071	2209.5882
13.8601	1379.5632	17.0255	2483.5787
14.3704	1530.9248	17.7582	2781.2714
14.9103	1711.1504	18.3406	3050.7342
15.6564	1965.5492	19.1055	3378.5711

Measured Heat Capacity
Electrotransport Purified Lutetium Lu-III

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1085	7.3976	1.9477	18.3047
1.1953	10.3512	1.9633	18.4969
1.2043	10.6969	2.0197	18.6497
1.2333	10.7555	2.0552	19.6313
1.2604	11.1818	2.1504	20.7295
1.2782	11.2225	2.1820	21.2058
1.3031	11.6550	2.2383	21.8254
1.3154	11.7268	2.3158	22.8195
1.3188	11.7402	2.4348	24.3876
1.3715	12.4538	2.4468	24.3004
1.3760	12.4372	2.4941	25.1183
1.4309	12.8205	2.5205	26.1830
1.4329	13.1164	2.6094	26.8799
1.4330	12.9097	2.6041	26.9635
1.4858	13.1193	2.6460	27.5867
1.4971	13.4633	2.6959	27.7038
1.5051	13.6440	2.7441	28.7537
1.5497	14.7248	2.7936	29.3324
1.5707	14.2213	2.8187	30.0170
1.6069	14.8409	2.8877	30.9694
1.6340	14.8077	2.9540	32.0563
1.6622	15.2416	2.9911	32.6408
1.7001	15.6030	3.0505	33.6517
1.7097	15.5765	3.0639	34.2505
1.7289	15.9764	3.0741	34.2138
1.7547	16.1306	3.1454	35.4723
1.8124	16.6910	3.1584	35.7206
1.8462	17.0698	3.2269	36.8447
1.8939	17.7675	3.2399	37.3538
1.9381	18.2223	3.3378	55.6962

Measured Heat Capacity
Electrotransport Purified Lutetium Lu-III
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.5067	42.3757	8.9886	355.9257
3.5461	43.5320	9.3194	391.1468
3.8074	49.0397	9.3323	401.9046
3.8459	50.2536	9.6845	442.7364
4.0834	54.8166	9.7940	456.5090
4.1178	56.0110	9.9384	483.5313
4.2370	59.7831	10.1684	513.5643
4.3487	62.4770	10.3576	553.1702
4.5239	68.1006	10.5469	574.1437
4.6248	71.4257	10.7805	625.7976
4.7806	76.0923	10.9225	639.9161
4.8693	77.9267	11.2088	706.1090
4.9935	82.8055	11.3287	722.9549
5.0996	84.3419	11.6254	798.7890
5.1984	86.7892	11.7747	830.6457
5.3144	92.2274	11.9194	867.1964
5.3547	93.7047	12.1166	886.8952
5.4539	97.3005	12.3573	959.5770
5.6092	103.5144	12.6345	1020.1940
5.6914	107.6844	12.8312	1079.2488
5.8816	113.9250	13.1608	1158.6059
5.9434	119.6003	13.3248	1216.7911
6.1752	130.4948	13.6971	1317.8618
6.2141	132.4939	13.8289	1360.6552
6.4915	146.1845	14.1987	1476.6976
6.5270	149.5337	14.2364	1478.7927
6.7019	157.4147	14.6211	1606.5893
6.7610	162.6281	14.7394	1648.4248
7.0051	175.1446	15.0234	1713.7788
7.1123	183.4913	15.2526	1850.9116
7.3144	194.9061	15.7509	2007.0235
7.4410	206.2609	15.7828	2016.0227
7.6025	216.6403	16.4309	2259.3654
7.7681	230.9869	16.6136	2310.5378
7.9249	247.2211	16.9958	2501.9633
8.0930	260.2474	17.2966	2597.2951
8.1846	269.0172	17.7317	2798.5570
8.3154	282.2106	18.0047	2841.5835
8.5455	304.6897	19.2351	3443.9809
8.6571	314.5982	19.2351	3443.9809
8.9137	344.8518	19.9894	3772.1252

Measured Heat Capacity
Lutetium Starting Material Lu-IB
Annealed in High Vacuum to Remove Hydrogen

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0505	9.0631	2.5817	26.7023
1.0710	9.6160	2.6163	27.2636
1.1049	9.9960	2.6931	28.3111
1.1237	10.1405	2.7374	28.8426
1.1590	10.4130	2.8500	30.5457
1.1769	10.6548	2.8619	30.6943
1.2100	10.8950	2.8755	30.9231
1.2285	11.0393	2.8857	31.2519
1.2616	11.4365	3.0175	33.3870
1.2790	11.4892	3.0637	34.1007
1.2958	11.7494	3.1554	35.7694
1.3126	11.8237	3.2017	36.5739
1.3462	12.2075	3.2194	36.9464
1.3601	12.2468	3.3784	41.6728
1.3944	12.5219	3.4330	40.8790
1.4103	12.7655	3.4727	41.8308
1.4490	13.2219	3.6421	45.2197
1.4677	13.3603	3.6912	46.0586
1.5105	13.8708	3.7040	46.4822
1.5225	14.0318	3.8846	50.2348
1.5270	14.0017	3.9264	51.2876
1.5457	14.1077	4.0648	54.6921
1.5867	14.6782	4.1506	56.4449
1.6209	14.9472	4.2239	58.2255
1.6516	15.3353	4.2489	59.2496
1.6946	15.6581	4.3370	61.7720
1.7175	16.0072	4.4337	64.4631
1.7784	16.6724	4.5923	68.8294
1.8137	17.0638	4.6131	60.5558
1.8437	17.3018	4.7862	73.8840
1.8776	17.8183	4.8451	76.3241
1.9127	18.1966	4.9639	79.8659
1.9868	19.0740	5.0796	83.7594
2.0448	19.6997	5.0955	84.1803
2.1249	20.6745	5.2631	89.2872
2.1753	21.3459	5.3372	93.1484
2.2561	22.3137	5.4660	97.3166
2.2935	22.8397	5.5167	99.6631
2.3786	23.8864	5.6694	105.3249
2.3997	23.8218	5.7548	109.4985
2.4088	24.3092	5.8761	114.0858
2.4156	24.4010	5.9824	119.8639
2.4829	25.2917	6.0279	120.7354
2.5160	25.7447	6.2200	130.5434

Measured Heat Capacity
Lutetium Starting Material Lu-IB
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
6.2566	131.4415	11.2127	699.9024
6.4971	144.8538	11.4928	759.4155
6.5353	146.8586	11.5348	763.4597
6.7089	157.4330	11.8926	843.6417
6.8332	163.6131	12.0514	876.4965
7.0060	175.0904	12.3152	937.7007
7.1353	182.8090	12.5495	1003.1395
7.3010	195.9489	12.7391	1044.5113
7.3022	191.0609	13.1168	1145.6179
7.5410	211.2378	13.1604	1159.2817
7.5896	215.8600	13.5044	1263.3887
7.8114	232.2938	13.6862	1308.6165
7.8714	239.0965	13.9428	1387.8648
8.0725	256.3312	14.3369	1492.0721
8.1284	260.5662	14.4380	1532.3568
8.4220	289.1648	14.9840	1716.7614
8.4665	294.2588	14.9889	1725.7706
8.7748	325.3528	15.5613	1926.7307
8.7883	327.4636	15.6387	1959.3108
9.1603	371.5006	16.0551	2101.7685
9.2163	376.8634	16.2844	2188.0255
9.5326	420.7375	16.6615	2339.8897
9.6595	435.5667	16.8397	2395.0597
9.7479	452.1601	17.2641	2581.1618
10.0996	500.0269	17.4518	2656.7325
10.1356	508.1984	17.8923	2842.5141
10.5160	571.1835	18.0613	2894.7508
10.5887	580.6920	18.5861	3142.6422
10.8687	634.7414	18.7358	3174.0549
11.0188	658.5830	19.5009	3561.9654

Measured Heat Capacity
Lutetium Starting Material Lu-IA

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0614	10.9127	1.1744	11.9663
1.0950	11.2562	1.2144	12.4443
1.0997	11.2274	1.2156	12.4857
1.1332	11.7131	1.2517	12.8137
1.1371	11.9152	1.2948	13.1433

Measured Heat Capacity
Lutetium Starting Material Lu-IA
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.3262	13.3754	3.4836	43.2095
1.3386	13.4936	3.4925	43.5677
1.3819	14.0373	3.6975	47.4791
1.3947	14.1472	3.7974	49.6563
1.4256	14.4059	3.9282	52.6912
1.4628	14.8276	4.0288	54.8980
1.4736	14.8895	4.1326	57.2944
1.4926	15.1185	4.1624	57.9918
1.5322	15.5669	4.1626	57.9867
1.5495	15.6625	4.3063	61.6154
1.6089	16.3371	4.3109	62.1077
1.6121	16.3580	4.3587	63.1538
1.6475	16.7236	4.4586	65.4256
1.6705	16.9518	4.4570	65.3944
1.6866	17.0297	4.5014	67.4070
1.7480	17.8139	4.6088	69.6967
1.7782	18.0954	4.6937	72.5118
1.8556	19.0567	4.8759	78.3333
1.8837	19.9082	4.8832	78.8187
1.9663	20.2327	5.0269	82.7686
1.9938	20.6004	5.0731	84.4688
2.0853	21.6154	5.1821	87.6067
2.0987	21.7463	5.2120	88.7395
2.1320	22.1859	5.3540	94.0131
2.1995	22.9795	5.4098	95.9667
2.2390	23.4398	5.4876	98.9879
2.2524	23.6406	5.6059	104.0069
2.3660	24.9579	5.6791	106.4766
2.3687	25.0019	5.7900	111.6316
2.4725	26.4863	5.8712	114.5807
2.4791	26.5369	5.9678	119.6224
2.5743	27.9377	6.0682	123.7243
2.5801	28.1481	6.0823	124.5201
2.5825	27.9099	6.2656	133.3352
2.7007	29.7628	6.2933	134.5784
2.7456	30.5015	6.4353	142.5782
2.7743	37.9122	6.5110	146.1939
2.9161	34.5050	6.6366	153.7867
2.9518	33.6956	6.7846	161.6997
3.0597	35.4790	6.8505	166.0191
3.1564	37.1421	6.9914	174.8447
3.2794	39.5135	7.0711	180.4936
3.3463	40.2957	7.2331	190.4621
3.3575	40.7435	7.3455	197.9740

Measured Heat Capacity
Lutetium Starting Material Lu-IA
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
7.4842	207.4192	11.7969	819.4511
7.6371	220.5103	11.8457	829.0468
7.7386	226.7782	12.1856	909.9584
7.8068	234.7255	12.2778	928.2906
7.9807	245.8699	12.5959	1005.3076
8.0699	255.3348	12.7143	1036.5043
8.1456	263.1248	13.0124	1120.5435
8.3578	283.0139	13.0858	1137.6473
8.3779	284.6780	13.4591	1237.5927
8.6158	308.9873	13.5695	1269.1684
8.6703	314.2122	13.8706	1358.9108
8.8666	336.0783	14.1242	1435.9653
9.0409	381.1837	14.4054	1527.9997
9.1071	365.2783	14.6922	1616.8371
9.2383	378.0958	14.9937	1721.0984
9.3096	390.1960	15.2765	1826.8735
9.5041	415.5198	15.6077	1933.3717
9.6728	437.2132	15.7774	1993.2396
9.7694	450.8247	16.2814	2183.0034
10.0274	489.4220	16.4061	2232.3780
10.0321	488.2359	17.0112	2468.7946
10.2930	532.0964	17.0431	2477.9542
10.3907	547.0232	17.6864	2745.2884
10.4746	562.5864	17.7182	2746.9543
10.7397	607.2995	18.2866	2987.6072
10.7412	609.5718	18.4075	3052.5756
11.0189	659.0590	18.8824	3273.2062
11.0314	661.7195	19.1829	3401.3260
11.3016	716.8668	19.5108	3548.0618
11.4313	740.4925	20.0330	3770.2022
11.5870	778.2833		

Measured Heat Capacity
Lutetium Starting Material Lu-IC

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0912	10.3389	1.2227	11.0049
1.1044	10.8006	1.2384	12.4648
1.1570	10.8525	1.2832	12.2524
1.1741	11.8624	1.3004	13.1003

Measured Heat Capacity
Lutetium Starting Material Lu-IC
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.3413	12.9611	3.5377	44.1834
1.3644	13.8466	3.6135	45.7231
1.3782	13.4290	3.7106	47.7738
1.4307	14.4454	3.8030	49.6577
1.4463	14.4524	3.8950	51.4505
1.4727	14.9407	3.9960	53.9687
1.5160	15.2438	4.0790	55.8930
1.5478	15.6786	4.1791	58.3836
1.5773	15.9031	4.3496	62.8676
1.6274	16.4972	4.6264	70.7687
1.6468	16.6022	4.8987	79.0503
1.6743	16.9545	5.1671	87.5900
1.7073	17.2936	5.4224	97.4349
1.7372	17.5932	5.6144	104.6609
1.7562	17.7934	5.8704	114.8795
1.8141	18.4162	6.1489	127.8593
1.8477	18.9156	6.4584	144.1767
1.9122	19.6945	6.7743	162.4254
1.9641	20.2001	7.0292	174.7694
2.0410	21.1571	7.3575	197.8804
2.0885	21.6388	7.6740	222.3168
2.1377	22.3199	7.9872	251.8607
2.1692	22.6925	8.3028	278.9954
2.2043	23.0804	8.5829	304.2144
2.2753	24.0170	8.9669	346.2497
2.3396	24.8286	9.3572	395.1786
2.4052	25.7977	9.7479	447.3551
2.4798	26.6125	10.1441	508.1296
2.5308	27.3959	10.2794	530.9400
2.5689	28.0966	10.6880	602.4898
2.5914	28.2919	11.0752	669.9838
2.6463	29.0658	11.4543	748.9943
2.7108	29.9998	11.8474	831.8530
2.7153	29.9994	12.1730	904.0403
2.7372	30.3624	12.6151	1011.6189
2.8754	32.3676	13.0593	1126.3221
2.8964	32.8564	13.5003	1259.7123
3.0286	34.8620	13.9895	1393.7903
3.0394	35.0201	14.4524	1539.2630
3.1970	37.7894	15.0909	1747.4623
3.2135	38.2050	15.7505	1994.7634
3.3557	40.5983	16.3623	2217.9393
3.3750	41.3330	17.0487	2482.0385
3.4230	41.9163	17.6609	2717.0718

Measured Heat Capacity
Lutetium + 0.22 Atomic Percent Hydrogen
Sample 2-20

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0964	12.0087	2.9367	34.2985
1.1015	11.8769	3.0332	36.1068
1.1635	12.6692	3.0602	36.5145
1.1680	12.7146	3.1737	38.3507
1.2287	13.3263	3.1912	38.8515
1.2301	13.2808	3.2227	39.0831
1.2875	13.7381	3.3145	40.8662
1.2934	13.8941	3.3268	40.7490
1.3422	14.3554	3.4276	42.8297
1.3586	14.6533	3.5207	44.5834
1.3744	14.8619	3.6193	46.6709
1.4061	15.0868	3.6950	48.1959
1.4300	15.4794	3.8305	51.0003
1.4811	15.7998	3.8706	51.8833
1.4909	15.8488	4.0202	55.2022
1.5551	16.7090	4.0675	56.5852
1.5596	16.6653	4.2060	60.6367
1.6200	17.4824	4.3667	64.0260
1.6334	17.4520	4.6556	70.8603
1.6436	17.5206	4.9499	80.4300
1.7084	18.0978	5.2340	90.1916
1.7110	18.3142	5.4937	99.9790
1.7242	18.3165	5.6935	107.1439
1.8136	19.4015	5.9264	117.0916
1.8187	19.6117	6.1543	128.3171
1.9319	20.9351	6.4038	139.7203
1.9445	20.8737	6.7369	160.5835
2.0496	22.1371	6.9758	173.8628
2.0695	22.3802	7.2445	189.0724
2.1058	22.8031	7.5443	209.7884
2.1076	22.8493	7.8568	235.1154
2.2468	24.6084	8.1660	264.1828
2.2617	24.6907	8.3930	284.4982
2.3805	26.2949	8.7833	324.7168
2.3909	26.2775	9.1641	369.9371
2.5161	28.2272	9.5475	420.1764
2.5164	27.9328	9.9352	474.3863
2.6188	29.6207	10.2054	514.1752
2.6273	29.7119	10.6095	583.4749
2.6411	29.7072	11.0386	662.6411
2.7634	31.4369	11.4717	744.9990
2.7729	31.7451	11.8883	835.9614
2.8067	32.1216	12.2351	914.1579
2.8972	33.6632	12.6911	1022.2498

Measured Heat Capacity
Lutetium + 0.22 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
13.1401	1143.9450	16.4604	2243.9163
13.5736	1309.8432	17.1242	2510.8991
14.0918	1419.9196	17.7770	2766.9189
14.6930	1607.5669	18.3835	3031.6097
15.1683	1771.5749	18.9942	3349.0067
15.8179	2010.0936		

Measured Heat Capacity
Lutetium + 0.70 Atomic Percent Hydrogen
Sample 2-21

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0794	12.8265	2.1382	25.6710
1.0869	12.8860	2.2140	26.7234
1.1340	13.6106	2.2538	27.2392
1.1487	13.5574	2.2562	27.1769
1.1889	14.1300	2.3379	28.3065
1.2115	14.2355	2.3873	28.9218
1.2418	14.7259	2.4493	29.8133
1.2724	14.9870	2.5085	30.7696
1.2942	15.3758	2.5529	31.4177
1.3265	15.8584	2.5656	31.6005
1.3330	15.8907	2.6266	32.7244
1.3838	16.4187	2.6539	32.7895
1.3863	16.5152	2.6933	33.4418
1.4515	17.2070	2.7878	34.7673
1.4548	17.1900	2.8321	35.5333
1.5226	18.0422	2.9336	37.2765
1.5259	18.0973	2.9647	37.5727
1.5977	18.9412	3.0653	39.4333
1.5983	18.9517	3.1008	40.0469
1.6347	19.3591	3.2103	42.0060
1.6679	19.7291	3.2289	42.2455
1.6856	19.8679	3.2289	42.2190
1.7153	20.3066	3.2664	42.9064
1.7825	21.2801	3.3918	45.2314
1.8075	21.6003	3.4235	45.7796
1.8964	22.6740	3.5642	48.7208
1.9142	22.8994	3.5758	48.8509
2.0141	24.1386	3.7221	51.6860
2.0239	24.2731	3.7635	52.9288
2.0906	25.0652	3.8870	55.2211

Measured Heat Capacity
Lutetium + 0.70 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.9648	57.1980	9.7646	451.6155
4.0685	59.1737	10.1515	511.7022
4.3579	67.2187	10.4461	553.1026
4.6331	74.8358	10.8326	625.6755
4.8948	82.5808	11.2248	698.4560
5.1577	90.7525	11.6528	787.8069
5.4189	100.2875	12.0933	881.8433
5.6274	107.7838	12.4759	970.2828
5.8807	117.9019	12.9406	1090.1020
6.1585	130.6982	13.4019	1214.5812
6.4629	145.9055	14.0336	1399.6217
6.7732	163.5820	14.7237	1615.3874
7.0359	178.4499	15.2327	1796.6266
7.3638	200.5693	15.8501	2021.4081
7.6815	225.3473	16.4837	2224.8685
7.9951	251.0589	17.1127	2500.0995
8.3230	281.9474	17.7497	2760.7737
8.5764	303.0375	18.2832	2978.0827
8.9707	347.5881	18.9000	3259.0331
9.3660	396.9730	19.5911	3586.2214

Measured Heat Capacity
Lutetium + 1.40 Atomic Percent Hydrogen
Sample 2-19

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0901	13.0084	1.5819	19.2799
1.0952	13.2364	1.5895	19.8874
1.1573	13.9933	1.6557	20.4992
1.1686	13.8087	1.6618	20.6434
1.2229	14.9497	1.6993	20.8313
1.2410	15.0584	1.7297	21.3150
1.2840	15.5820	1.7522	21.7450
1.3065	15.8524	1.7849	22.2247
1.3431	16.2923	1.8408	22.8528
1.3712	16.5683	1.8880	23.3918
1.4069	17.0437	1.9516	24.3878
1.4214	17.3464	2.0054	25.1793
1.4517	17.8274	2.0702	26.0189
1.5020	18.3488	2.1056	26.3957
1.5224	18.6523	2.1221	27.2931

Measured Heat Capacity
Lutetium + 1.40 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
2.1790	27.6151	5.1221	92.5472
2.2450	28.4890	5.3774	101.9297
2.3114	29.4790	5.5775	109.2842
2.3764	30.4032	5.8323	119.8906
2.4329	31.3443	6.0787	131.0581
2.5006	32.3635	6.3498	144.1998
2.5515	33.1957	6.6491	160.3564
2.6185	34.2400	6.9129	176.5260
2.6643	34.8530	7.2426	196.6371
2.7008	35.4969	7.5521	218.9469
2.7305	35.8056	7.8586	244.0598
2.7345	35.9178	8.1743	267.2525
2.8218	37.3953	8.4148	290.5503
2.8865	38.5910	8.8027	329.8656
2.9520	39.8412	9.2074	380.0460
3.0346	41.3784	9.6027	428.5819
3.0860	42.0639	10.0110	487.2090
3.1754	43.9198	10.3329	536.0606
3.2273	44.7966	10.7429	608.2274
3.2664	45.6476	11.1444	679.5135
3.3121	46.1673	11.5531	764.2057
3.3588	47.4106	11.9845	854.7769
3.4383	48.9700	12.3638	936.2816
3.5389	50.9137	12.8342	1051.5264
3.6070	52.5617	13.3141	1187.4770
3.7206	54.8349	13.7930	1316.8758
3.7842	56.0966	14.8822	1649.9356
3.9193	59.2722	15.5297	1894.7723
3.9530	59.8771	16.1543	2112.8963
4.1073	63.8360	16.8381	2363.0769
4.1354	64.4634	17.5231	2639.3879
4.3532	70.5205	18.1423	2897.1545
4.6187	77.7195	18.7795	3186.0599
4.8698	84.8682	19.4100	3431.1448

Measured Heat Capacity
Lutetium + 1.50 Atomic Percent Hydrogen
Sample 2-10

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0961	13.1298	2.9487	39.7872
1.1154	13.5525	3.0553	41.4720
1.1392	13.6673	3.0925	42.2686
1.1673	14.1042	3.1247	42.9193
1.1816	14.1951	3.2423	45.2315
1.2191	14.7140	3.3028	46.3131
1.2276	14.7326	3.3079	46.4737
1.2689	15.4715	3.4827	49.9666
1.2806	15.4489	3.4832	49.7837
1.3198	16.0294	3.6571	53.7909
1.3260	16.0357	3.6733	54.1512
1.3574	16.4358	3.8302	57.5661
1.3917	16.8046	3.8588	57.7791
1.4574	17.6192	4.0127	61.6120
1.4878	17.9936	4.0516	62.3153
1.5262	18.5323	4.1853	65.6206
1.5523	19.0181	4.3478	70.2446
1.5935	19.3793	4.6015	77.2047
1.6190	19.7718	4.8566	84.7572
1.6191	19.9159	5.1098	92.8905
1.6417	20.1924	5.3587	101.5633
1.7031	20.9159	5.5269	107.9654
1.7146	21.0804	5.7745	117.8465
1.8060	22.3207	6.0413	129.4854
1.8067	22.3933	6.3495	144.3879
1.9112	23.7985	6.6649	160.5496
1.9115	23.8128	6.9221	176.6505
1.9647	24.5207	7.2442	195.4909
1.9712	24.5508	7.5631	218.7160
2.0978	26.4194	7.8691	243.0012
2.1063	26.4926	8.1995	271.8059
2.2238	28.2236	8.4643	295.9962
2.2465	28.5461	8.8590	336.9183
2.3368	29.9552	9.2562	384.0213
2.3661	30.3231	9.6468	436.2392
2.4451	31.6012	10.0285	492.9541
2.4795	32.0645	10.2925	529.2455
2.4888	32.3120	10.6889	592.2818
2.6044	33.9939	11.0923	668.1601
2.6190	34.3063	11.5214	749.6642
2.6564	34.8408	11.9587	847.6547
2.7621	36.6439	12.3196	927.1016
2.8076	37.2790	12.7781	1036.6839
2.9081	38.9773	13.2478	1228.4814

Measured Heat Capacity
Lutetium + 1.50 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
13.7483	1303.4317	16.7864	2333.8818
14.3273	1478.1382	17.4315	2587.8052
14.8535	1639.5836	17.9711	2813.7917
15.5045	1858.9052	18.5886	3062.3888
16.1404	2088.0066	19.2869	3384.0960

Measured Heat Capacity
Lutetium + 3.10 Atomic Percent Hydrogen
Sample 1-84

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1188	12.1453	1.9645	22.4930
1.1666	12.5579	1.9681	22.5549
1.1787	12.5087	2.0382	23.5196
1.2148	13.2229	2.0819	24.0867
1.2244	13.2118	2.1513	25.0252
1.2663	13.7220	2.1936	25.4211
1.2744	13.7977	2.2663	26.6856
1.3151	14.4263	2.3066	27.3285
1.3236	14.3371	2.3587	28.0413
1.3517	14.6043	2.3815	28.3100
1.3696	14.9898	2.4057	28.7128
1.3967	15.4960	2.4258	29.1935
1.4047	16.5812	2.5378	30.6961
1.4423	15.2952	2.5647	31.1453
1.4549	16.0721	2.6679	32.7632
1.4937	16.3573	2.7107	33.5026
1.5066	16.5488	2.8070	34.9936
1.5445	17.0892	2.8485	35.8064
1.5631	17.3119	2.9509	37.6427
1.5733	17.4235	2.9519	37.2524
1.6238	18.0466	2.9823	38.2663
1.6319	18.0523	3.0477	39.2734
1.6608	18.5057	3.1133	40.4206
1.6969	19.0544	3.1941	42.0941
1.7219	19.4279	3.2781	43.6789
1.7748	20.0243	3.3748	45.6514
1.7817	20.1776	3.4463	47.1338
1.8419	20.7774	3.5769	49.7670
1.8962	21.5446	3.6070	50.3262
1.9235	22.0157	3.7289	53.2431

Measured Heat Capacity
Lutetium + 3.10 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.7728	53.8780	8.7310	316.5806
3.9140	57.2698	9.1164	358.1778
3.9581	58.5165	9.4946	403.4283
4.0932	61.5051	9.8035	446.0583
4.1607	62.9145	10.2069	502.9326
4.2669	65.7737	10.5974	565.4762
4.3273	67.6257	10.9690	628.5894
4.5646	74.0068	11.4918	731.6470
4.8058	80.9133	11.9188	814.8343
5.0428	88.2840	12.2653	891.9608
5.2845	96.6469	12.6557	984.9854
5.4602	102.7618	13.0382	1074.0033
5.7064	112.3801	13.4048	1169.0022
5.9417	122.6702	13.7193	1265.6868
6.1900	133.7794	14.2430	1417.5101
6.4628	147.8411	14.8363	1598.7787
6.6770	159.5502	15.3769	1778.3280
6.9740	176.4519	15.9435	1962.5976
7.2687	195.2421	16.3312	2104.4215
7.5612	216.1570	16.9172	2326.2456
7.8531	238.5679	17.5111	2549.6477
8.0727	255.1801	18.0966	2794.2793
8.3626	281.8929	18.7178	3057.4564

Measured Heat Capacity
Lutetium + 6.10 Atomic Percent Hydrogen
Sample 2-5

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1057	10.4384	1.4589	14.1784
1.1156	10.6088	1.4818	14.4057
1.1688	11.0526	1.5325	14.9992
1.1850	11.3866	1.5578	15.2454
1.2294	11.7434	1.6022	15.9118
1.2400	11.9062	1.6358	16.0752
1.2874	12.3436	1.6729	16.5914
1.2970	12.4425	1.6779	16.5502
1.3456	12.9562	1.7118	16.9464
1.3637	13.1494	1.7522	17.4943
1.3877	13.3725	1.7716	17.6750
1.4062	13.6044	1.8689	18.8619

Measured Heat Capacity
Lutetium + 6.10 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.8790	18.9395	4.6605	71.8981
1.9619	19.9816	4.9249	78.8882
1.9878	20.3083	5.1588	85.7513
2.0401	20.9155	5.4070	94.8605
2.0469	20.8686	5.6067	102.1120
2.0641	21.2421	5.8456	111.2062
2.1747	22.6684	6.1236	122.7489
2.2286	23.3079	6.4340	137.3802
2.3028	24.3362	6.7441	153.3105
2.3683	25.2249	6.9720	166.7091
2.4279	26.0469	7.2788	184.8560
2.4997	27.0354	7.5959	206.0940
2.5459	27.7698	7.9116	230.2106
2.6061	28.5331	8.2233	253.5092
2.6605	29.4704	8.4672	271.0243
2.6683	29.6357	8.8305	311.1184
2.6985	29.8909	9.2369	353.7633
2.7007	29.7914	9.6406	402.3085
2.7924	31.3799	10.0434	453.6578
2.8314	32.0410	10.3444	498.2740
2.9406	33.8778	10.7365	558.8818
2.9656	34.1834	11.1401	626.2098
3.0364	35.3652	11.5717	705.3067
3.0811	36.1977	12.0161	794.2266
3.1393	37.1945	12.3574	866.7663
3.2189	38.6583	12.8203	969.1008
3.3170	40.4473	13.2855	1086.5594
3.3879	41.6589	13.7553	1207.7122
3.4935	43.7592	14.2967	1357.3146
3.5718	45.2654	14.8677	1526.5920
3.6766	47.4713	15.5078	1737.4413
3.7492	49.0491	16.1563	1955.8671
3.8687	51.4723	16.8073	2181.7168
3.9248	52.7785	17.4529	2419.6495
4.0542	55.6092	17.9559	2628.9615
4.1054	56.6494	18.5408	2837.7215
4.3707	63.7208	19.1761	3116.7235

Measured Heat Capacity
Lutetium + 11.0 Atomic Percent Hydrogen
Sample 1-98

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0920	9.0732	2.8883	28.7509
1.1068	9.0867	2.9448	29.6955
1.1546	9.5620	3.0424	30.9343
1.2109	10.0676	3.0840	31.5474
1.2271	10.2415	3.0868	31.6316
1.2624	10.4927	3.2263	33.7925
1.2862	10.7936	3.2495	34.2853
1.2984	10.7716	3.2616	34.2369
1.3446	11.2197	3.4161	37.0852
1.3487	11.2466	3.4640	37.8920
1.3854	11.6494	3.5898	40.0684
1.3999	11.7793	3.6770	41.5896
1.4543	12.2752	3.7816	43.6243
1.4569	12.2317	3.8689	45.2516
1.5154	12.7921	3.9810	47.4435
1.5322	12.8870	4.0530	48.8683
1.5359	13.0313	4.1723	51.5041
1.6023	13.6414	4.3338	55.3776
1.6025	13.6780	4.5972	61.6646
1.6689	14.2488	4.8584	68.2285
1.6765	14.2835	5.1164	75.2711
1.6975	14.3833	5.3610	82.4852
1.7236	14.8873	5.5574	88.9925
1.7831	15.4847	5.8038	97.7215
1.7903	15.4866	6.0719	107.6597
1.8231	15.9119	6.3779	120.4091
1.9026	16.7494	6.6918	134.5856
1.9352	16.9889	6.9504	147.6813
2.0173	17.9610	7.2731	174.7562
2.0527	18.3583	7.5995	183.9374
2.0668	18.5207	7.9121	205.0584
2.1823	19.7764	8.2408	230.0620
2.1961	19.9352	8.5061	249.8019
2.2928	21.0679	8.8911	283.5202
2.3238	21.3752	9.2829	323.2748
2.3311	21.4397	9.6775	364.4295
2.4452	22.8701	10.0681	412.3233
2.4498	22.9641	10.7575	506.6493
2.5549	24.3699	11.1621	568.9113
2.5848	24.7527	11.5653	632.8378
2.6539	25.6435	11.9937	713.8796
2.6645	25.7438	12.3544	780.7615
2.7376	26.5777	12.8146	871.1417
2.7996	27.5976	13.2754	977.3115

Measured Heat Capacity
Lutetium + 11.0 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
13.7786	1095.2243	16.8697	2001.5180
14.3530	1245.9496	17.5115	2215.6814
14.9251	1395.9238	18.0998	2447.1949
15.5904	1598.5585	18.6673	2628.7144
16.2293	1796.0810	19.2897	2888.8237

Measured Heat Capacity
Lutetium + 15.5 Atomic Percent Hydrogen
Sample 2-4

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0880	7.9696	2.1458	17.1293
1.1023	8.1038	2.2289	17.9941
1.1542	8.4669	2.2847	18.6255
1.1735	8.6281	2.3558	19.2975
1.2186	8.9135	2.4114	18.7039
1.2347	9.0712	2.4736	20.6203
1.2786	9.3979	2.5351	21.3169
1.2962	9.5568	2.5884	21.9813
1.3389	9.8756	2.5889	21.9080
1.3599	10.0682	2.6518	22.6507
1.3837	10.2722	2.6633	22.7221
1.4060	10.4427	2.7085	23.2271
1.4562	10.8505	2.8044	24.5035
1.4848	11.1052	2.8415	24.9348
1.5302	11.4665	2.9535	26.3445
1.5556	11.6928	2.9890	26.8344
1.6021	12.0661	3.0866	28.2132
1.6233	12.2444	3.1331	28.7399
1.6725	12.6734	3.2022	29.6771
1.6903	12.8401	3.2197	30.0156
1.6897	12.8500	3.2889	30.9887
1.7151	13.0364	3.3712	32.3562
1.7955	13.8136	3.3780	32.3193
1.8292	14.1365	3.5420	34.6569
1.9026	14.8292	3.5552	34.8343
1.9474	15.1897	3.6923	37.1713
1.9951	15.7067	3.7213	37.6474
2.0070	15.8121	3.8541	39.9841
2.0528	16.2165	3.9164	41.2045
2.0960	16.6271	4.0458	43.4865

Measured Heat Capacity
Lutetium + 15.5 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
4.0965	44.2958	9.7330	333.9086
4.2805	47.8522	10.1283	375.4281
4.3446	49.6138	10.4365	413.6743
4.6108	55.3756	10.8880	473.6622
4.8751	61.2794	11.3391	539.8764
5.1363	67.8177	11.7544	604.0990
5.3876	74.6162	12.1782	675.6639
5.5918	80.3315	12.5240	735.6055
5.8479	88.7944	12.9790	829.2976
6.1208	98.2335	13.4322	923.4213
6.4297	109.7796	13.9275	1038.7161
6.7508	123.0025	14.4889	1163.0554
6.9958	134.0584	15.0184	958.8996
7.3216	150.1526	15.6328	1468.5807
7.6433	167.7903	16.2517	1651.2611
7.9604	187.2083	16.8765	1847.1373
8.2847	208.5816	17.5171	2051.7251
8.5501	228.0126	18.1063	2247.7220
8.9412	259.2574	18.7210	2464.4783
9.3405	295.0273	19.4160	2701.0014

Measured Heat Capacity
Lutetium + 67.0 Atomic Percent Hydrogen
Sample 2-8

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1153	0.8531	1.8455	1.5954
1.1480	0.9093	1.9403	1.7003
1.1827	1.0171	2.0273	1.8191
1.2290	0.9875	2.0936	1.9154
1.2508	0.9678	2.1295	1.9464
1.3066	1.0052	2.2655	2.0387
1.3518	1.0936	2.4163	2.3196
1.3645	1.0790	2.5513	2.4974
1.4175	1.1484	2.6750	2.7222
1.4330	1.1660	2.6778	2.6469
1.5026	1.2237	2.8622	2.9847
1.5790	1.3201	3.0316	3.3132
1.6669	1.4128	3.1681	3.5669
1.7372	1.4708	3.3074	3.8680
1.7533	1.5168	3.3243	3.9602

Measured Heat Capacity
Lutetium + 67.0 Atomic Percent Hydrogen
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.5505	4.4045	8.5907	33.7956
3.7680	4.9396	8.9015	37.1845
3.9702	5.4081	9.2268	41.1454
4.1940	6.1047	9.5878	47.3592
4.4137	6.8964	9.9862	52.6945
4.7564	7.8813	10.2607	56.9830
5.0596	8.9315	10.6836	65.7188
5.3351	10.0151	11.1038	72.3978
5.5793	11.2213	11.5269	80.5181
5.7435	11.8951	11.9306	85.5072
6.0090	13.2977	12.3090	94.2698
6.2652	14.7388	12.7821	114.5602
6.5128	16.2775	13.2338	128.0562
6.7893	17.8551	13.6713	146.0138
7.0401	19.9706	14.1705	162.6746
7.3709	21.8818	14.7449	193.8809
7.7064	24.8228	16.0081	246.0936
8.0444	27.6178	16.8010	294.2017
8.3797	31.3384	17.6074	336.3975

Measured Heat Capacity
Calorimetry Conference Standard Copper Sample

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.2910	0.9719	2.4671	2.4034
1.3352	1.0696	2.6041	2.6113
1.3761	1.1031	2.7199	2.8392
1.3943	1.1070	2.8734	3.0923
1.4849	1.1868	2.9047	3.1869
1.5266	1.2463	3.0831	3.5430
1.5633	1.2795	3.3443	4.1232
1.6126	1.3257	3.6597	4.9286
1.7201	1.4206	4.0004	5.8828
1.8219	1.5331	4.2905	6.7860
1.9132	1.6617	4.4738	7.5054
1.9931	1.7237	4.6764	8.2743
2.1226	1.9217	4.8947	9.1481
2.2905	2.1559	5.0974	9.9359
2.3118	2.1789		