# Thermophysical properties of the lanthanide sesquisulfides. IV. Schottky contributions, magnetic, and electronic properties of $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub> and Lu<sub>2</sub>S<sub>3</sub>

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The heat capacities of  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub> and Lu<sub>2</sub>S<sub>3</sub> have been determined from 6 to 350 K and their thermodynamic properties evaluated. The resolution of the Schottky and magnetic properties by evaluation of the lattice heat capacity is shown to be in accord with spectroscopically determined energy levels. The lattice heat capacity of Yb<sub>2</sub>S<sub>3</sub> was determined by means of the Komada–Westrum phonon distribution model. Excess heat-capacity contributions were thus evaluated and analyzed as Schottky and magnetic heat capacities. A phase transition associated with magnetic ordering was detected in the heat capacity of Yb<sub>2</sub>S<sub>3</sub> near 7 K with an entropy content of 0.68*R*. The entropies at 298.15 K are 22.77*R* and 19.74*R* for Yb<sub>2</sub>S<sub>3</sub> and for Lu<sub>2</sub>S<sub>3</sub>.

# **I. INTRODUCTION**

The electronic and magnetic behavior of the  $\gamma$ -phase lanthanide sesquisulfides have been elucidated in the first three papers in this series<sup>1-3</sup> by separating the excess heat capacity from the lattice heat capacity by using both the volumetric priority<sup>4</sup> approach and the Komada–Westrum<sup>5</sup> approach. The analysis of the crystalline electric field splitting, the Raman and infrared spectra, and magnetic susceptibility are consistent with the resolved thermophysical values for the  $\gamma$ -phase sesquisulfides.

Lanthanide sesquisulfides including Ho, Er, Tm, Yb, and Lu adopt  $\delta$ - (or D- or Ho<sub>2</sub>S<sub>3</sub>)-type or the  $\epsilon$ - (or *E*- or rhombohedral Al<sub>2</sub>O<sub>3</sub>)-type structures. Other structure types which have been reported for these compounds<sup>6</sup> are not pertinent to this study. Lanthanide sesquichalcogenides (Ln<sub>2</sub>Ch<sub>3</sub>; Ln=lanthanide, Ch=S, Se, and Te)<sup>7</sup> and systems involving mixed chalcogenides (e.g., S with Se or Te)<sup>8</sup> are of interest particularly from the materials science point of view. Heat capacities of some Ln<sub>2</sub>Ch<sub>3</sub>, Ln<sub>3</sub>Ch<sub>4</sub> systems and mixed lanthanides with Ln<sub>2</sub>Ch<sub>3</sub> have also been explored.<sup>8-11</sup>

Yb<sub>2</sub>S<sub>3</sub> and Lu<sub>2</sub>S<sub>3</sub> crystallize into the  $\epsilon$ -phase structure. The structure was first observed by Flahaut *et al.*<sup>12</sup> and later confirmed by Range and Leeb.<sup>13</sup> In this structure, the cation is displaced along the ternary axes toward a trigonal face of the *S* octahedron in such a way that three *M*-*S* bonds are shorter than the other three.

Since  $Lu^{3+}$  has 14 electrons in its 4f orbital and a  ${}^{1}S_{0}$ ground state, Lu<sub>2</sub>S<sub>3</sub> exhibits only lattice heat-capacity contributions.  $Yb_2S_3$  with 13 4f electrons, however, does not have a closed shell and shows both magnetic and Schottky contributions. Moreover, the  ${}^{2}F_{7/2}$  ground-state manifold of the cation  $Yb^{3+}$  in the  $\epsilon$  phase is subjected to a crystalline electric field that has  $C_2$  point group symmetry. The manifold is split into four doubly degenerate electronic energy levels. The lattice heat capacity of Yb<sub>2</sub>S<sub>3</sub> cannot be determined experimentally in the subambient region and has to be evaluated by a parametric approximation based on the lattice heat capacity of Lu<sub>2</sub>S<sub>3</sub>. The method is essentially the same as that employed for the lattice heat capacities of  $\gamma$ -phase lanthanide sesquisulfides based on La<sub>2</sub>S<sub>3</sub> and  $Gd_2S_3$ .<sup>1-3</sup> The heat capacities of  $\epsilon$ -phase  $Yb_2S_3$  and  $Lu_2S_3$  have been reported between 1.2 and 20 K.<sup>9,10</sup>

This paper concerns the experimental thermodynamic properties of the two lanthanide sesquisulfides between 6 and 350 K and the resolution of the Schottky and magnetic contributions of the  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub> compound.

# II. EXPERIMENT

#### A. Sample provenance and characterization

The Yb<sub>2</sub>S<sub>3</sub> and Lu<sub>2</sub>S<sub>3</sub> samples were prepared at the Ames Laboratory by direct combination of the pure elements in a manner similar to that described by Gschneidner *et al.*<sup>10</sup> The lutetium and ytterbium metals used were prepared in the Ames Laboratory,<sup>14</sup> sublimed

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	Lattice parameters	; (Å)		rdi	_d			
Sesquisulfide	Present study	Ref. 16	(by analysis)	(cm <sup>3</sup> /mol)	$\rho^{-}$ (g/cm <sup>3</sup> )	<i>m</i> (g) <sup>c</sup>	M (g mol <sup>-1</sup> )	Color
N. C.	$a_0 = 6.7478 \pm 0.0003^{a}$	6.748	1 502 1 0 002	71.002	6 1401	42.60	442.26	Villan ald
10233	$c_0 = 18.1900 \pm 0.0008$	18.191	$1.302 \pm 0.003$	/1.993	0.1421	42.00	442.20	r ellow gold
T 6	$a_0 = 6.7220 \pm 0.0005^a$	6.722	1 400 1 0 005	71 215	COFFC	22 424	446 10	Carriel addite
Lu <sub>2</sub> S <sub>3</sub>	$c_0 = 18.154 \pm 0.001$	18.160	1.499±0.005	/1.315	0.2330	33.434	440.12	Greyish white

TABLE I. Lattice parameters and analyzed compositions of  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub> and Lu<sub>2</sub>S<sub>3</sub> (R=8.3144 J K<sup>-1</sup> mol<sup>-1</sup>).

<sup>a</sup>Hexagonal.

 ${}^{b}V = molar$  volume.

 $c_m = \text{sample mass.}$ 

 $^{d}\rho = x$ -ray density.

sulfur (99.999%) was obtained from ASARCO.<sup>15</sup> After completion of the reaction in the sealed fused silica ampoules, the Lu<sub>2</sub>S<sub>3</sub> was further purified by reaction with H<sub>2</sub>S. The ampoules were opened in a helium-filled glove box. The as-formed Lu<sub>2</sub>S<sub>3</sub> was ground to 200 mesh powder, cold pressed into pellets at  $2.1 \times 10^8$  Pa ( $3 \times 10^4$  lbs/ in<sup>2</sup>), and heated to 1275 °C for 50 h under a dynamic H<sub>2</sub>S atmosphere. A Debye–Scherrer x-ray diffraction pattern only gave lines of the  $\epsilon$  Lu<sub>2</sub>S<sub>3</sub> structure. All of the Lu<sub>2</sub>S<sub>3</sub> dissolved readily in a 1:1 HCl:H<sub>2</sub>O solution indicating that oxysulfide was not present.

In the preparation of Yb<sub>2</sub>S<sub>3</sub>, stoichiometric quantities of Yb metal and sulfur were sealed into two separate fused silica ampoules. The ampoules were heated slowly to 575 °C and maintained there until all free sulfur had reacted. The temperature was then slowly increased-over three days-to 850 °C, held there for ten days, and then raised to and held at 900 °C for two more days. Both ampoules contained hard chunks of yellow-gold colored  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub> at the end of this process. Heating Yb<sub>2</sub>S<sub>3</sub> under H<sub>2</sub>S was not required. Chemical analysis of a random sample gave  $YbS_{1.5\pm0.003}$ , indicating the intended composition of YbS<sub>1.500</sub> had been achieved within the accuracy of the analysis. A complete description of the chemical analysis method is given in the first paper of this series. An x-ray diffraction pattern gave only lines of  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub>. No acid insoluble residue remained after treatment with 1:1 HCl:H<sub>2</sub>O. Precision lattice parameters were determined for both  $\epsilon$ -Lu<sub>2</sub>S<sub>3</sub> and  $\epsilon$ -Yb<sub>2</sub>S<sub>3</sub> from Debye-Scherrer x-ray patterns taken at 295 K by measuring the theta values of the doublets in the back reflection and applying a Nelson-Riley extrapolation function to the data. Lattice parameters determined in this study are given in Table I along with literature values.<sup>16</sup>

#### **B.** Automated adiabatic calorimetry

Two gold-plated, oxygen-free, high-conductivity (OFHC) copper calorimeters (laboratory designation W-61 and W-AB) were employed in the two measurements. The  $Lu_2S_3$  sample was determined in the W-61 calorimeter, which is especially equipped with two pairs of

perforated, spring-loaded, copper sleeves soldered to the heater-thermometer well to hold the sample pellets. The heat capacity of the Yb<sub>2</sub>S<sub>3</sub> (Ref. 16) sample was determined in the W-AB calorimeter. After loading (and for  $Lu_2S_3$ , soldering the cover in place), the calorimeters were evacuated and approximately 2.0 kPa (at about 300 K) helium gas was added to facilitate rapid thermal equilibration (see also Table I). The data were taken in the Mark X calorimetric cryostat, an improved version of the Mark II cryostat described elsewhere, together with relevant operating techniques.<sup>17,18</sup> Data acquisition was computer assisted. The temperatures were measured with a Leeds and Northrup platinum resistance thermometer calibrated at the National Bureau of Standards (NBS). All other crucial measurements were similarly referenced to NBS calibrations.

# C. Optical spectroscopy

The material used to obtain the absorption spectrum of  $Yb_2S_3$  was prepared by the method of Henderson *et al.*<sup>19</sup> The samples contained less than 100 ppm atomic oxygen and displayed the Debye–Scherrer x-ray pattern for  $\epsilon$ -phase  $Yb_2S_3$ . Based on wet chemical analysis, the compounds can be represented as  $YbS_{1.5\pm0.003}$ . We had no success in growing  $YbS_{1.5}$  single crystals from the melt. Even with an appreciable sulfur vapor pressure within sealed capsules, it was not possible to keep some of the trivalent ytterbium from being reduced. The melted ingots were black with very small crystallites found scattered throughout the highly fractured material.

To obtain the absorption spectrum of Yb<sub>2</sub>S<sub>3</sub>, stoichiometric powder was mixed with an optically transparent inert gel to produce "mull" samples. The spectra were observed with a Cary Model 14R at 90 K and room temperatures. Hot bands of the  ${}^{2}F_{5/2}$  multiplet manifold observed at 1.0  $\mu$ m indicate that the ground state  ${}^{2}F_{7/2}$  has crystalfield electronic energy levels at 0, 155, 285, and 380 cm<sup>-1</sup>. Each level is twofold degenerate. Since there are more crystal-field parameters associated with  $C_{2}$  symmetry than experimental energy levels associated with the  ${}^{2}F_{7/2}$  and  ${}^{2}F_{5/2}$  multiplet manifolds, we were not able to obtain a

TABLE II. Experimental heat capacities of  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub> and Lu<sub>2</sub>S<sub>3</sub> (R=8.3144 J K<sup>-1</sup> mol<sup>-1</sup>).

TABLE II. (Continued.)

$T/K$ $C_{par}/R$ Series I           ephase spatialities (V)s, $M = 42.26 g mol-1+)$ 7.109         0.996           251.148         14.729         10.000         0.558           254.469         14.785         11.071         0.444           262.683         14.864         12.095         0.497           268.878         14.627         13.069         0.511           275.112         14.8461         14.023         0.354           287.532         13.064         13.981         0.063           297.769         15.138         17.080         0.742           299.989         15.228         18.174         0.635           316.452         13.335         7.573         0.635           317.11         13.49         8.221         0.506           333.4851         13.315         12.045         14.488         0.578           333.4851         13.315         12.045         14.488         0.578           333.4851         13.315         12.045         14.488         0.578           333.537         12.2445         18.122         0.802           333.545         13.317         13.348         0.3491			<i>T/</i> K		$C_{p,m}/R$	
c-plase ytterbium sequisuitish (Vb,S <sub>9</sub> , $M = 442.26 g mol^{-1})$ 7.100         0.956           Scris I         8.598         0.558           251.148         14.729         10.000         0.508           255.469         14.735         11.071         0.484           266.633         14.464         12.095         0.497           265.898         14.4021         0.554           281.318         15.204         14.461         0.603           295.759         15.158         17.080         0.742           290.905         15.225         18.17         0.875           312.412         15.265         Series V         13.141           314.636         15.309         0.633         0.633           31.411         15.339         8.453         0.633           31.412         15.349         8.539         0.645           31.071         15.349         8.539         0.645           31.071         15.349         8.539         0.645           31.071         15.349         8.539         0.645           31.071         15.340         8.539         0.645           31.071         15.340         8.21         0.506	T/K	$C_{p,m}/R$		Series IV		
Series I         7.109         0.996           251.148         14.729         10.000         0.538           226.469         14.785         11.071         0.484           226.683         14.864         12.055         0.497           226.689         14.927         13.060         0.511           227.512         14.981         14.023         0.662           227.52         13.044         15.981         0.662           227.52         13.045         15.981         0.700           229.989         13.238         16.174         0.663           237.52         13.153         5.169         0.673           318.465         13.509         6.733         0.663           313.671         15.349         8.521         0.566           313.671         15.349         8.821         0.561           313.775         12.445         1.8122         0.826           132.764         12.452         14.458         0.578           132.765         12.445         1.8122         0.826           133.775         12.445         1.8122         0.826           132.765         12.457         16.41         1.017      <	e-phase vtterbium ses	quisulfide (Yb <sub>2</sub> S <sub>3</sub> , $M = 442.26 \text{ g mol}^{-1}$ )		Sorres IV		
3.98 $0.538$ 251.48         14.729         10.000         .6.58           226.469         14.729         11.071         .0.484           226.839         14.927         13.069         .0.511           285.121         14.981         14.023         0.534           287.52         15.064         15.981         0.663           293.769         15.125         17.080         0.742           299.969         15.226         Series V         0.742           306.195         15.226         Series V         0.673           318.635         15.315         8.169         0.636           31.071         15.349         8.521         0.560           33.731         15.345         8.521         0.560           343.567         15.349         10.192         0.560           343.57         12.445         18.152         0.560           33.731         15.348         8.521         0.560           13.747         12.445         18.152         0.560           13.741         10.192         0.560         13.53         15.34         0.561           13.741         13.443         15.53         15.5		Series I	7.109		0.996	
221.43         14.729         10000         0.508           226.469         14.785         11.071         0.444           226.83         14.864         12.095         0.511           275.112         14.981         14.023         0.534           221.318         15.504         15.981         0.666           23.752         15.044         15.981         0.672           299.989         15.228         18.174         0.633           312.412         15.265         Series V         312.412           318.636         15.308         7.733         0.663           333.3457         15.348         8.519         0.664           337.313         15.448         8.819         0.578           322.455         15.315         8.169         0.502           5eries II         12.463         0.578         132.264           132.361         12.329         16.314         0.691           132.362         12.443         16.315         0.578           132.361         12.359         16.314         0.691           132.362         12.453         0.578         153           132.361         12.652         1.144 <td< td=""><td></td><td></td><td>8.598</td><td></td><td>0.558</td><td></td></td<>			8.598		0.558	
28.489         14.783         11.071         0.484           226.833         14.864         12.095         0.497           268.98         14.927         13.069         0.511           275.112         14.981         14.023         0.554           28.138         15.064         15.981         0.666           29.3769         15.158         17.080         0.742           29.989         15.223         18.174         0.827           306.195         15.365         Series V         0.673           318.656         15.308         7.573         0.663           31.671         15.39         8.169         0.666           33.3671         15.348         8.821         0.566           33.3671         12.455         14.453         0.378           132.764         12.045         14.345         0.378           132.765         14.453         0.378         0.344           13.2764         12.045         13.342         0.826           13.2765         14.453         0.378         0.342           13.3210         13.050         22.352         1.247           14.866         12.862         2.1124         1.10	251.148	14.729	10.000	-	0.508	
22.283         14.884         12.053         0.487           26.889         14.987         13.069         0.511           27.512         14.981         14.023         0.554           28.752         15.084         15.981         0.666           23.769         15.158         17.080         0.742           29.989         15.228         18.174         0.663           23.761         15.265         Series V           312.412         15.276         6.743         0.663           33.8636         15.309         7.733         0.663           33.7313         15.348         8.211         0.560           33.7313         15.349         10.192         0.362           13.2765         12.445         16.152         0.866           13.3735         12.445         16.152         0.866           13.2765         12.445         16.152         0.866           13.2765         12.445         16.152         0.866           14.275         12.445         16.152         0.866           14.275         12.445         16.152         0.866           14.275         12.445         16.152         0.866 <tr< td=""><td>256.469</td><td>14.785</td><td>11.071</td><td></td><td>0.484</td><td></td></tr<>	256.469	14.785	11.071		0.484	
268.898         14.927         13.069         0.311           275.112         14.921         14.0623         0.534           281.318         15.204         14.961         0.603           287.552         15.084         15.581         0.606           299.959         15.228         18.074         0.827           30.6195         15.265         Series V         V           318.636         15.308         7.733         0.653           318.636         15.339         8.139         0.645           33.1071         15.349         8.21         0.500           343.567         15.349         8.21         0.501           318.731         15.348         8.539         0.645           33.1071         15.349         8.21         0.501           343.567         15.445         0.578         0.501           129.513         12.045         14.458         0.578           132.764         12.239         16.514         0.691           142.978         12.667         13.609         13.371           153.210         13.050         22.552         1.247           144.996         1.6691         1.3.99         1.654	262.683	14.864	12.095		0.497	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	268.898	14.927	13.069		0.511	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	275.112	14.981	14.023		0.554	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	281.318	15.204*	14.961		0.603	
293.769         15.158         // ABD         0.42           293.989         15.228         18.74         0.827           316.615         15.265         Series V           312.412         15.276         6.73           316.636         15.308         6.743         0.653           331.631         15.339         8.169         0.636           331.011         15.339         8.201         0.669           343.567         15.349         8.21         0.560           343.567         15.349         8.21         0.500           25.73         12.445         14.458         0.578           132.764         12.299         16.314         0.691           137.875         12.445         18.152         0.826           144.998         12.637         19.641         0.959           144.906         13.800         22.552         1.247           153.240         13.197         23.990         1.399           163.477         13.48         25.443         1.563           164.661         13.456         31.877         2.311           175.66         13.609         28.382         1.904           175.94	287.552	15.084	15.981		0.666	
299,989         15,226         Series V           312,412         15,276         6,743         0,675           314,855         15,315         7,573         0,663           331,011         15,339         8,339         0,645           331,31         15,348         8,239         0,645           331,31         15,348         8,239         0,645           343,567         15,349         8,239         0,645           343,567         15,349         8,239         0,645           343,567         12,451         14,458         0,571           12,451         14,452         0,262           12,764         12,229         16,314         0,691           137,875         12,465         18,152         0,226           144,096         12,862         21,124         1,101           153,210         13,050         22,525         1,247           158,340         13,197         23,990         1,399           163,477         13,348         25,443         1,663           173,786         13,609         28,382         1,904           173,808         13,721         2,310         2,447*           199,535<	293.769	15.158	17.080		0.742	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	299.989	15.228	18.174	Contra M	0.827	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	306.195	15.265		Series v		
13.6.89         12-08         7,573         0.635           33.1071         15.315         8.169         0.636           33.1071         15.349         8.821         0.560           343.857         15.449         8.821         0.560           Series II         12.465         14.458         0.578           132.744         12.29         16.314         0.691           137.875         12.455         18.152         0.826           142.978         12.862         21.124         1.101           133.210         13.050         22.552         1.247           153.340         13.197         23.990         1.399           163.477         13.348         24.443         1.663           168.621         13.369         3.321         2.361           178.908         13.271         30.041         2.100           189.209         13.329         33.71         2.358           194.377         14.042         35.601         2.647*           199.345         14.116         37.498         3.223*           204.706         14.188         39.575         3.321           205.55         14.433         49.270	312.412	15.276	6.743		0.675	
324.833         1.5.133         1.5.133         1.5.139         1.6.69         0.636           337.313         1.5.348         8.821         0.560           343.567         1.5.349         10.192         0.902           Scries II         12.466         0.001           129.513         12.045         14.458         0.578           137.74         12.239         16.3144         0.691           137.875         12.445         18.152         0.826           148.066         12.637         19.641         0.939           148.066         12.647         12.445         1.011           153.10         13.050         22.552         1.247           158.340         13.197         23.990         1.399           163.477         13.348         25.443         1.563           178.908         13.721         30.041         2.100           184.061         13.866         31.877         2.311           189.209         13.329         3.721         2.558           199.455         14.116         37.498         3.223°           199.455         14.116         37.498         3.223°           20.4705         14.200	318.636	15.308	7.573		0.653	
33.10.11         15.348         8.5.39         0.645           343.57         15.349         10.192         0.500           Series II         12.468         0.501           129.513         12.045         14.458         0.578           132.764         12.239         16.314         0.691           137.775         12.445         18.152         0.826           142.978         12.637         19.641         0.959           146.096         12.862         21.124         1.101           153.210         13.050         22.552         1.247           158.340         13.197         23.990         1.399           163.477         13.348         25.443         1.563           168.621         13.475         26.907         1.711           173.756         13.609         28.82         1.904           178.908         13.721         30.041         2.100           189.200         13.939         33.721         2.558           194.377         14.042         3.5601         2.447*           199.545         14.116         37.698         3.223*           199.545         14.116         37.698         3.223*	324.855	15.315	8.169		0.636	
33.1.31         13.349         10.192         0.502           Stris II         12.466         0.501           129.513         12.045         14.458         0.578           132.764         12.232         16.314         0.091           137.875         12.445         18.152         0.826           142.978         12.637         19.641         0.399           148.096         12.862         21.124         1.101           153.210         13.050         22.552         1.247           183.340         13.197         23.990         1.399           163.477         13.348         25.443         1.563           166.621         13.475         26.097         1.731           173.756         13.609         28.382         1.904           178.908         13.721         2.518         1.904           189.209         13.929         33.721         2.558           194.437         14.042         35.601         2.647*           199.545         14.116         37.498         3.223*           200.4706         14.188         39.755         3.321           209.879         14.340         49.087         4.512     <	331.0/1	15.339	8.539		0.645	
343.50'         10.192         0.502           Striss II         12.468         0.501           129.513         12.045         14.453         0.578           132.764         12.239         16.514         0.091           137.875         12.445         18.152         0.826           142.978         12.667         19.641         0.599           148.096         12.862         21.124         1.101           133.210         13.050         22.552         1.247           158.340         13.197         23.990         1.399           163.477         13.348         25.443         1.563           178.508         13.721         30.041         2.100           178.908         13.721         30.041         2.001           189.209         13.529         33.721         2.558           194.377         14.042         35.601         2.647*           199.545         14.116         37.498         3.223*           204.706         14.188         39.575         3.321           205.799         14.240         44.311         3.873           205.555         14.496         49.087         4.512           <	337.313	15.348	8.821	·	0.560	·
Series II         12.463         0.501           129.513         12.045         14.458         0.578           132.764         12.239         16.314         0.691           137.875         12.445         18.152         0.826           148.096         12.862         21.124         1.101           153.210         13.050         22.552         1.247           158.340         13.197         23.990         1.399           163.477         13.348         25.443         1.563           168.621         13.475         26.097         1.731           173.756         13.609         28.382         1.904           178.908         13.721         30.041         2.100           184.061         13.836         31.877         2.311           199.545         14.116         37.498         3.223*           204.706         14.188         39.575         3.321           205.9879         14.240         41.647*         4.863           202.077         14.337         44.311         3.873           202.077         14.385         51.794         4.863           203.555         14.496         49.087         4.539	343.567	15.349 Sucies II	10.192		0.502	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		Series II	12.468		0.501	
132,764       12,239       16,314       0.691         137,875       12,445       18,152       0.826         142,978       12,637       19,641       0.959         148,096       12,862       21,124       1.101         153,210       13,050       22,552       1.247         158,340       13,197       23,990       1.399         166,471       13,348       25,443       1.563         166,621       13,475       26,907       1.731         173,756       13,609       28,382       1.904         178,908       13,721       2.311       2.558         194,401       13,836       31,877       2.311         189,209       13,929       33,721       2.558         194,377       14,042       35,601       2.647*         199,545       14,116       37,498       3223*         204,706       14,188       39,575       3.321         209,879       14,240       41,349       3.609         215,042       14,307       44,311       3.873         202,077       14,355       51,794       4.863         215,042       14,307       45.512       5.597	129.513	12.045	14.458		0.578	
137.875       12.445       18.152       0.826         142.978       12.637       19.641       0.959         148.096       12.862       21.124       1.101         153.210       13.050       22.552       1.247         158.340       13.197       23.990       1.399         163.477       13.348       25.443       1.563         166.621       13.475       26.907       1.731         173.756       13.609       28.382       1.904         178.908       13.721       30.041       2.100         184.061       13.836       31.877       2.311         189.209       13.929       33.721       2.558         194.377       14.042       35.601       2.647*         199.545       14.116       37.498       3.223*         204.706       14.188       39.575       3.321         205.855       14.496       49.270       4.539         205.55       14.496       49.087       4.512         235.743       14.555       51.794       4.863         240.920       14.611       54.653       5.227         245.098       14.660       57.526       5.597	132.764	12.239	16.314		0.691	
142.07812.63719.6410.959148.09612.86221.1241.101153.21013.05022.5521.247153.34013.19723.9901.399163.47713.34825.4431.563168.62113.47526.9071.731173.75613.60928.3821.904178.90813.72130.0412.100184.06113.83631.8772.311189.20913.92933.7212.558204.70614.18839.5753.321208.87914.24041.9493.609215.04214.30744.3113.873223.38014.44349.2704.339230.55514.49649.0874.512235.74314.61156.655.997246.09814.61157.5265.997251.28014.71860.4215.9686.6500.30965.5566.7857.0591.92470.6617.1987.0591.92470.617.1987.13200.51888.6229.2101.13200.5679.0418.3928cries III84.8978.80513.3200.51888.6229.21014.4210.5679.2449.57015.2880.62097.0999.92316.3860.695100.61410.23317.4820.768106.13810.60018.5750.865110.66910.918 <t< td=""><td>137.875</td><td>12.445</td><td>18.152</td><td></td><td>0.826</td><td></td></t<>	137.875	12.445	18.152		0.826	
148.096       12.862       21.124       1.101         153.210       13.050       22.552       1.247         158.340       13.197       23.990       1.399         163.477       13.348       25.443       1.563         166.621       13.475       26.907       1.731         173.756       13.609       23.822       1.904         178.008       13.721       30.041       2.100         184.061       13.836       31.877       2.311         189.209       13.929       33.721       2.558         199.345       14.116       37.498       3.223*         204.706       14.188       39.575       3.321         209.706       14.188       39.575       3.321         209.706       14.483       49.270       4.539         215.042       14.307       44.311       3.873         225.380       14.443       49.270       4.539         235.743       14.455       51.794       4.663         240.920       14.611       54.653       5.227         246.098       14.660       57.526       5.597         251.280       14.718       60.453       5.227	142.978	12.637	19.641		0.959	
153.210       13.050       22.552       1.247         153.340       13.197       23.990       1.399         163.477       13.348       25.443       1.563         168.621       13.475       26.907       1.731         173.756       13.609       28.382       1.904         178.908       13.721       30.041       2.100         184.061       13.836       31.877       2.311         189.209       13.929       33.721       2.558         194.377       14.042       35.601       2.647*         199.545       14.116       37.498       3.223*         204.706       14.188       39.575       3.321         208.879       14.240       41.949       3.609         215.042       14.307       44.311       3.873         202.0207       14.385       46.670       4.187         225.380       14.443       49.270       4.539         235.743       14.555       51.794       4.863         246.098       14.611       54.653       5.227         246.098       14.660       57.526       5.597         251.280       14.718       60.421       5968 <td>148.096</td> <td>12.862</td> <td>21.124</td> <td></td> <td>1.101</td> <td></td>	148.096	12.862	21.124		1.101	
158.34013.19723.9901.399163.47713.34825.4431.563168.62113.47526.9071.731173.75613.60928.3821.904178.90813.72130.0412.100184.06113.83631.8772.311189.20913.92933.7212.558194.37714.04235.6012.647*199.54514.11637.4983.223*204.70614.18839.5753.321209.87914.24041.9493.609215.04214.30744.3113.873220.30714.38546.6704.187225.38014.44349.2704.539230.55514.49649.0874.512235.74314.55551.7944.863240.92014.61154.6535.22726.09814.66057.3265.997251.28014.71860.4215.9686.6500.30963.5666.3637.0591.92466.9586.7859.1010.55270.3617.19811.3200.48677.2397.97712.3390.51888.8629.21014.2710.56792.8489.57015.2880.62097.0999.92316.3860.695101.61410.25317.4820.768101.61410.25315.750.865101.61410.25315.750.865101.6141	153.210	13.050	22.552		1.247	
163.47713.34825.4431.563168.62113.47526.9071.731173.75613.60928.3821.904178.90813.72130.0412.100184.06113.33631.8772.311189.20913.92933.7212.558194.37714.04235.6012.647*199.54514.11637.4983.223*204.70614.18839.5753.321205.87914.24041.9493.609215.04214.30744.3113.873220.20714.38546.6704.187225.38014.44349.0874.551230.55514.49649.0874.551235.74314.55551.7944.863246.09814.66060.4215.9686.6500.30963.5666.6337.0591.92470.3617.1987.0591.92470.3617.1987.13297.9778eries III84.8978.80513.3200.5188.8.8629.21014.2110.56792.8489.57015.2880.62097.0999.92316.3860.695101.61410.25317.4820.768106.13810.60018.5750.865101.66910.91819.6710.962115.20911.245	158.340	13.197	23.990		1.399	
$168.621$ $13.475$ $26.907$ $1.731$ $173.756$ $13.609$ $28.382$ $1.904$ $178.908$ $13.721$ $30.041$ $2.100$ $184.061$ $13.836$ $31.877$ $2.311$ $189.209$ $13.929$ $33.721$ $2.558$ $194.377$ $14.042$ $35.601$ $2.647^{n}$ $199.545$ $14.116$ $37.498$ $3.223^{a}$ $204.706$ $14.188$ $39.575$ $3.321$ $209.879$ $14.240$ $41.949$ $3.609$ $215.042$ $14.307$ $44.311$ $3.873$ $220.207$ $14.385$ $46.670$ $4.187$ $225.380$ $14.443$ $49.270$ $4.539$ $230.555$ $14.496$ $49.087$ $4.512$ $230.555$ $14.496$ $49.087$ $4.512$ $246.098$ $14.660$ $57.526$ $5.597$ $251.280$ $14.718$ $60.421$ $5.968$ $6.650$ $0.309$ $63.566$ $6.363$ $7.059$ $1.924$ $66.958$ $6.785$ $9.101$ $0.552$ $70.361$ $7.198$ $11.320$ $0.486$ $77.793$ $7.327^{n}$ $12.339$ $0.501$ $77.239$ $7.977$ $13.320$ $0.518$ $88.862$ $9.210$ $14.4271$ $0.567$ $92.848$ $9.570$ $15.288$ $0.620$ $70.099$ $9.923$ $16.386$ $0.695$ $10.669$ $10.918$ $19.671$ $0.962$ $115.209$ $11.425$ $20.772$ $1.066$	163.477	13.348	25.443		1.563	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	168.621	13.475	26.907		1.731	
178.90813.72130.0412.100184.06113.83631.8772.311189.20913.92933.7212.558194.37714.04235.6012.647 <sup>a</sup> 199.54514.11637.4983.223 <sup>a</sup> 204.70614.18839.5753.321209.87914.24041.9493.609215.04214.30744.3113.873220.20714.38546.6704.187225.38014.44349.2704.539230.55514.49649.0874.512235.74314.55551.7944.863240.92014.61154.6535.227246.09814.66060.4215.96866.500.30963.5666.3637.0591.92470.3617.19811.3200.48677.7337.527 <sup>*</sup> 71.2390.50188.8629.21014.2710.56792.8489.57013.3200.51888.8629.21014.2710.56792.8489.57015.2880.62097.0999.92316.3860.695101.61410.23317.4820.768106.13810.60018.8750.865100.61310.60118.5750.865100.61410.23317.4820.768110.61410.23317.4820.768100.13810.60018.5750.865100.61310.60218.5750.865100.614<	173.756	13.609	28.382		1.904	
184.061       13.836       31.877       2.311         189.209       13.929       33.721       2.558         194.377       14.042       35.601       2.647 <sup>a</sup> 199.545       14.116       37.498       3.223 <sup>a</sup> 204.706       14.188       39.575       3.321         209.879       14.240       41.949       3.609         215.042       14.307       44.311       3.873         220.207       14.385       49.270       4.539         230.555       14.496       49.087       4.512         235.743       14.555       51.794       4.863         240.920       14.611       57.526       5.597         251.280       14.718       60.421       5.968         6.650       0.309       66.558       6.785         7.059       1.924       66.958       6.785         9.101       0.552       73.391       7.527 <sup>a</sup> 11.320       0.486       77.739       7.527 <sup>a</sup> 11.320       0.501       70.361       7.198         9.101       0.552       73.793       7.527 <sup>a</sup> 11.320       0.501       77.239       7.977	178.908	13.721	30.041		2.100	
189.20913.92933.7212.558194.37714.04235.6012.6474199.54514.11637.4983.223*204.70614.18839.5753.321209.87914.24041.9493.609215.04214.30744.3113.873220.20714.38546.6704.187225.38014.44349.2704.539230.55514.4969.0874.512235.74314.55551.7944.863240.92014.61154.6535.227246.09814.6606.5265.597251.22014.71860.4215.9686.6500.30963.5666.3637.0591.92470.3617.1989.1010.55277.2397.97712.3390.50177.2397.97712.3390.50180.9418.39284.8978.80513.3200.51888.8629.13.3200.51888.8629.21014.2710.56792.8489.57015.2880.62097.0999.92316.3860.695101.61410.25317.4820.768106.13810.60018.5750.865110.66910.91819.6710.962115.20911.24520.7721.066119.77011.527	184.061	13.836	31.877		2.311	
194.37714.04235.601 $2.647^{*}$ 199.54514.11637.498 $3.223^{*}$ 204.70614.18839.575 $3.321$ 209.87914.24041.949 $3.609$ 215.04214.30744.311 $3.873$ 220.20714.38546.6704.187225.38014.44349.2704.539230.55514.49649.0874.512235.74314.55551.7944.863240.92014.61157.5265.597251.28014.71860.4215.9686.6500.30966.9586.7857.0591.92470.3617.1989.1010.55270.3617.19811.3200.48673.7937.527*12.3390.50177.2397.977Series III80.9418.392513.3200.51888.8629.21014.2710.56792.8489.57015.2880.62097.0999.92316.3860.695101.61410.25317.4820.768106.13810.60018.5750.865101.66910.91819.6710.962115.20911.24520.7721.066119.77011.527	189.209	13.929	33.721		2.558	
199.54514.116 $37.498$ $3.223^{8}$ 204.70614.188 $39.575$ $3.321$ 209.87914.24041.949 $3.609$ 215.04214.30744.311 $3.873$ 220.20714.38546.670 $4.187$ 225.38014.44349.270 $4.539$ 230.55514.49649.087 $4.512$ 235.74314.555 $51.794$ $4.863$ 240.92014.611 $54.653$ $5.227$ 246.09814.600 $57.526$ $5.597$ 251.28014.718 $60.421$ $5.968$ 6.6500.309 $63.566$ $6.363$ 7.0591.924 $66.958$ $6.785$ 9.1010.552 $70.361$ $7.198$ 11.3200.486 $77.239$ $7.977$ Series III $84.897$ $8.805$ 13.3200.518 $88.862$ $9.210$ 14.2710.567 $92.848$ $9.570$ 15.2880.620 $97.099$ $9.923$ 16.3860.695101.61410.22317.4820.768106.613810.60018.5750.865100.613810.60018.5750.865100.66910.91819.6710.962115.20911.24520.7721.066119.77011.527	194.377	14.042	35.601		2.647 <sup>a</sup>	
204.70614.18839.575 $3.321$ $209.879$ 14.24041.949 $3.609$ $215.042$ 14.30744.311 $3.873$ $220.207$ 14.38546.6704.187 $225.380$ 14.44349.2704.539 $230.555$ 14.49649.0874.512 $235.743$ 14.55551.7944.863 $240.920$ 14.61154.6535.227 $246.098$ 14.66057.5265.597 $251.280$ 14.71860.4215.968 $6.650$ 0.30963.5666.363 $7.059$ 1.92466.9586.785 $9.101$ 0.55270.3617.198 $11.320$ 0.48677.2397.977 $12.339$ 0.51188.8629.210 $14.271$ 0.5679.8489.570 $15.288$ 0.62097.0999.923 $16.386$ 0.69510.61410.253 $17.482$ 0.768106.13810.600 $18.575$ 0.86510.66910.918 $19.671$ 0.962115.20911.245 $20.772$ 1.066119.77011.527	199.545	14.116	37.498	t	3.223ª	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	204.706	14.188	39.575		3.321	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	209.879	14.240	41.949		3.609	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	215.042	14.307	44.311		3.873	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	220.207	14.385	46.670		4.187	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	225.380	14.443	49.270		4.539	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	230.555	14.496	49.087		4.512	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	235.743	14.555	51.794		4.863	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	240.920	14.611	54.653		5.227	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	246.098	14.660	57.526		5.597	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	251.280	14.718	60.421		5.968	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	6.650	0.309	63.500		0.303	-
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	7.059	1.924	00.938		7,100	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	9.101	0.552	70.301		7.198	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	11.320	0.486	73.795		7.327	
Series III         80.941         8.392           13.320         0.518         84.897         8.805           14.271         0.567         92.848         9.570           15.288         0.620         97.099         9.923           16.386         0.695         101.614         10.253           17.482         0.768         106.138         10.600           18.575         0.865         110.669         10.918           19.671         0.962         115.209         11.245           20.772         1.066         119.770         11.527	12.339	0.501	77.239		1.977	
13.320         0.518         88.862         9.210           14.271         0.567         92.848         9.570           15.288         0.620         97.099         9.923           16.386         0.695         101.614         10.253           17.482         0.768         106.138         10.600           18.575         0.865         110.669         10.918           19.671         0.962         115.209         11.245           20.772         1.066         119.770         11.527		Series III	80.941		6.392 9.905	
13.320       0.318       88.802       9.210         14.271       0.567       92.848       9.570         15.288       0.620       97.099       9.923         16.386       0.695       101.614       10.253         17.482       0.768       106.138       10.600         18.575       0.865       110.669       10.918         19.671       0.962       115.209       11.245         20.772       1.066       119.770       11.527	12 220	0.518	04.077		0.003	
14.271         0.307         52.645         9.370           15.288         0.620         97.099         9.923           16.386         0.695         101.614         10.253           17.482         0.768         106.138         10.600           18.575         0.865         110.669         10.918           19.671         0.962         115.209         11.245           20.772         1.066         119.770         11.527	13.320	0.567	00.802 07 040		9.210	
15.266         0.020         97.059         9.923           16.386         0.695         101.614         10.253           17.482         0.768         106.138         10.600           18.575         0.865         110.669         10.918           19.671         0.962         115.209         11.245           20.772         1.066         119.770         11.527	14.4/1	0.007	72.848		9.370	
10.360         0.095         101.614         10.233           17.482         0.768         106.138         10.600           18.575         0.865         110.669         10.918           19.671         0.962         115.209         11.245           20.772         1.066         119.770         11.527	15.288	0.020	97.099		7.723	
17.482         0.768         106.138         10.600           18.575         0.865         110.669         10.918           19.671         0.962         115.209         11.245           20.772         1.066         119.770         11.527	10.380	0.073 0.7769	101.014		10.233	
18.575         0.665         110.669         10.918           19.671         0.962         115.209         11.245           20.772         1.066         119.770         11.527	17.482	0.865	110.138		10.000	
19.071         0.962         115.209         11.245           20.772         1.066         119.770         11.527	18.575	0.000	116,009		11.918	
20.772 1.000	19.071	0.902	110.209		11.240	
	20.772	1.000			11.327	

# TABLE II. (Continued.)

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$77K$ $C_{\mu} R$ $7K$ $C_{\mu} R$ 124.348         11.754         28.33         13.29           123.350         12.39         27.42         13.11           133.15         12.290         27.640         13.11           133.16         12.450         28.357         13.370           e-phase lutetium receptionfide (Lu,S, $M=46.12$ g mol <sup>-1</sup> )         294.13         13.370           Series         0.033         304.49         14.027           5.44         0.033         304.69         14.027           5.45         0.0366         33.044         14.027           5.46         0.035         34.85         14.134           5.90         0.0666         33.044         14.134           5.90         0.0666         33.044         14.134           10.24         0.113         346.03         14.419           11.03         0.148         17.31         0.591           11.13         0.179         18.11         0.666           13.44         0.332         21.69         13.36           14.446         0.332         21.69         13.39           15.31         0.460         23.15         12				
124.348         11.754         268.33         13.750           133.515         12.280         274.62         13.813           133.515         12.280         274.60         13.813           133.116         12.450         28.57         13.810           Series I         293.31         14.005         28.55         13.924           5.04         0.033         300.49         14.027         14.072           5.04         0.035         300.47         14.612         14.072           5.04         0.035         30.459         14.232         14.232           5.05         0.046         30.049         14.027         14.072           5.04         0.033         300.477         14.672         14.232           10.24         0.113         30.81         14.392         14.232           10.64         0.128         346.03         14.419         11.39           11.59         0.173         13.11         0.666         13.31         0.411           11.54         0.226         12.69         1.131         0.316         14.322           11.53         0.424         22.69         1.143         13.371         13.31         0.326	T/K.	$C_{p,m}/R$	T/K	$C_{p,m}/R$
128.99       11.979       273.42       13.761         133.115       12.240       278.60       13.813         133.116       12.450       283.77       13.370         sephase luterium sequisulids (Lu <sub>2</sub> 5, $M=446.12$ g mol <sup>-1</sup> )       294.13       14005         Series       0.0045       300.499       14.027         8.46       0.0031       304.49       14.027         8.46       0.0056       320.00       14.186         9.35       0.0066       320.00       14.186         9.35       0.0011       335.61       14.291         10.24       0.113       335.61       14.391         11.05       0.148       36.03       14.991         11.05       0.148       17.31       0.666         12.11       0.199       18.94       0.782         13.34       0.262       20.73       0.933         13.44       0.262       20.73       0.933         13.43       0.340       14.691       1.145         13.31       0.404       23.75       1.263         13.43       0.300       21.69       1.145         13.44       0.262       20.73       0.933	124.348	11.754	268.23	13,729
133.15       12.240       278.00       18.83         138.16       12.440       288.05       13.970         series I       299.31       14.005         7.46       0.033       300.477       14.873         8.46       0.035       31.84.55       14.134         4.64       0.036       330.40       14.072         8.46       0.036       330.40       14.325         9.37       0.0051       330.40       14.321         9.35       0.0051       330.40       14.4321         10.64       0.128       340.63       14.419         11.59       0.173       17.31       0.991       18.11       0.666         12.67       0.228       18.94       0.746       13.35       0.331         13.35       0.300       20.59       13.35	128,939	11.979	273.42	13 761
138.116         12.450         23.77         13.870           sephase Intertion requisable (Las5, M=446.12 g ms] <sup>-1</sup> )         243.95         1394.1           Series I         293.11         14.005           7.46         0.031         304.49         14.027           8.46         0.045         314.85         14.134           8.46         0.066         33.04         .14.291           9.33         0.061         33.22         14.236           9.34         0.005         33.04.0         14.291           10.24         0.113         33.61         14.362           10.24         0.113         33.61         14.432           10.34         0.128         340.33         14.392           11.05         0.173         11.06         0.768           12.67         0.228         19.844         0.768           13.24         0.265         20.733         0.036           13.24         0.262         20.673         1.263           15.83         0.460         24.86         1.389           15.83         0.422         2.662         1.521           15.83         0.460         2.375         1.263           <	133 515	12 280	278.60	13.813
List of the legeneration sequipable (La,S <sub>2</sub> , M <sup>4</sup> +46,12 g mol <sup>-1</sup> )         284.15         13.370           Series I         293.1         14.005           7.46         0.033         309.97.7         14.607           8.04         0.045         314.85         14.134           8.46         0.035         320.04         14.85           9.33         0.066         325.22         14.26           9.39         0.066         335.41         14.362           10.24         0.013         336.41         14.362           10.24         0.013         335.61         14.362           10.24         0.173         17.31         0.591           11.59         0.173         17.31         0.581           12.67         0.228         18.94         0.748           13.34         0.460         21.67         1.325           13.85         0.300         21.67         1.326           13.85         0.302         21.69         1.364           15.13         0.464         24.65         1.329           15.33         0.464         24.65         1.329           15.43         0.404         21.07         1.55	138.116	12.280	283.77	13.813
e-phase lutetium sequentifies (La, §, M = 446.12 g mol <sup>-1</sup> )         241.1         1.5.35           Series I         304.40         14.027           8.04         0.045         309.67         14.037           8.04         0.045         309.67         14.037           8.04         0.066         352.24         14.36           8.00         0.066         355.21         14.36           9.79         0.095         353.61         14.329           9.79         0.095         353.61         14.36           10.64         0.128         340.83         14.492           11.05         0.173         18.11         0.666           12.47         0.228         19.81         0.676           12.67         0.228         19.81         0.636           13.35         0.300         21.69         1.135           13.43         0.404         23.75         1.265           13.83         0.400         24.86         1.329           14.43         0.322         2.602         1.321           13.13         0.440         2.375         1.265           13.24         0.252         2.602         1.521           2.55<	156.110	12.450	203.77	13.870
Series I         293,13         13,00           7.46         0.033         304,47         14,027           8.46         0.055         314,65         14,107           8.46         0.055         314,65         14,107           8.46         0.055         314,65         14,136           9.37         0.066         323,52         14,363           9.79         0.095         33,561         14,362           10.24         0.113         30,033         14,479           11.05         0.173         18,111         0.6666           12.11         0.199         18,044         0.768           12.67         0.228         19,844         0.676           13.35         0.300         21,69         1.136           13.44         0.352         22,69         1.145           13.53         0.404         23,75         1.263           13.53         0.425         23,31         1.687           13.53         0.426         2470         7.51         6.768           33.59         2.654         79,72         7.151         6.768           33.59         2.654         79,72         7.151         6.768 </td <td><math>\epsilon</math>-phase lutetium sesqui</td> <td>sulfide (Lu<sub>2</sub>S<sub>2</sub>, <math>M = 446.12 \text{ g mol}^{-1}</math>)</td> <td>208.95</td> <td>13.924</td>	$\epsilon$ -phase lutetium sesqui	sulfide (Lu <sub>2</sub> S <sub>2</sub> , $M = 446.12 \text{ g mol}^{-1}$ )	208.95	13.924
Lance         2931         14.00           7.46         0.033         304.67         14.072           8.04         0.045         300.66         14.072           8.46         0.055         314.66         14.136           8.30         0.066         335.22         14.136           9.35         0.081         335.61         14.237           10.24         0.113         30.33         14.632           10.64         0.128         36.03         16.4192           11.08         0.148         17.31         0.6591           12.11         0.199         18.14         0.646           12.67         0.228         19.81         0.333           13.83         0.400         24.66         1.339           13.83         0.400         24.75         1.263           13.83         0.400         24.75         1.263           13.83         0.400         24.75         1.263           13.83         0.400         24.75         1.263           13.83         0.400         24.75         1.263           13.83         0.400         24.75         1.263           13.83         0.400	· · · · · · · · · · · · · · · · · · ·	Series I	294.13	13.970
7.46       0.033 $304.429$ 14.4072         8.46       0.055 $314.435$ 14.143         8.40       0.066 $320.04$ 14.136         9.33       0.081 $325.22$ 14.236         9.79       0.095 $330.40$ 14.361         10.24       0.113 $335.61$ 14.862         10.24       0.113       335.61       14.462         11.08       0.148       340.03       14.429         11.09       18.94       0.026       0.228         12.11       0.173       18.94       0.646         12.12       0.173       10.31       0.035         13.24       0.265       20.73       0.033         13.24       0.265       20.73       0.035         13.24       0.252       26.60       1.145         15.13       0.404       23.75       1.265         15.83       0.460       24.86       1.389         16.55       0.522       26.02       1.521         29.85       1.958       7.99       2.72       7.151         37.79       2.454       79.72       7.151         37.89			299.31	14.005
8.04         0.045         209.07         14.072           8.46         0.055         314.83         14.134           8.90         0.066         320.04         14.136           9.79         0.095         330.40         14.239           9.79         0.095         330.40         14.231           10.24         0.113         335.61         14.432           10.64         0.128         340.03         14.419           11.59         0.173         17.731         0.391           11.48         0.128         340.03         14.419           12.67         0.228         18.94         0.748           12.47         0.228         19.811         0.666           13.33         0.440         2.175         1.269           13.34         0.302         2.169         1.139           14.48         0.332         2.169         1.149           15.13         0.440         2.175         1.263           15.35         0.522         2.602         1.321           15.35         0.522         2.602         1.321           15.35         0.523         7.731         1.689           15.43	7.46	0.033	304.49	14.027
8.46     0.005     314.04     14.186       9.03     0.066     320.04     14.186       9.13     0.061     325.22     14.236       9.79     0.095     330.40     14.291       10.24     0.113     335.61     14.462       10.24     0.128     340.83     14.419       11.05     0.173     17.31     0.991       11.21     0.199     18.94     0.748       12.11     0.128     18.94     0.748       13.24     0.228     19.81     0.836       13.24     0.228     19.81     0.836       13.24     0.255     20.73     0.933       13.45     0.300     21.69     1.145       13.13     0.444     23.75     1.265       13.85     0.302     22.660     1.321       29.45     1.958     27.23     1.658       31.25     1.958     27.23     1.658       31.25     1.958     27.23     1.658       31.25     2.929     71.90     6.395       34.26     2.470     75.81     6.768       35.89     2.654     79.72     7.151       37.99     2.845     83.76     7.528       35.426     <	8.04	0.045	309.67	14.072
800         0.066         320.04         14.186           9.35         0.081         322.52         14.236           9.75         0.095         330.40         14.291           10.24         0.113         340.63         14.439           10.24         0.113         340.63         14.439           11.68         0.148         17.31         0.591           11.69         0.173         18.81         0.666           12.11         0.199         18.94         0.746           13.24         0.265         20.73         0.933           13.24         0.265         20.73         0.933           13.24         0.265         20.73         0.933           13.25         0.222         2.602         1.145           15.33         0.460         24.86         1.389           16.55         0.522         2.602         1.521           29.85         1.958         27.23         1.658           31.25         2.121         2.851         1.807           32.72         2.939         71.90         6.395           34.26         2.470         7.581         6.758           35.89	8.46	0.055	314.85	14.134
9.35         0.081         25.522         14.236           9.79         0.095         335.61         14.362           10.24         0.113         340.83         14.392           10.64         0.128         346.03         14.419           11.05         0.145         346.03         14.419           11.05         0.173         18.11         0.666           12.11         0.199         18.94         0.748           12.67         0.228         19.981         0.356           13.44         0.265         20.73         0.333           13.85         0.300         21.69         1.145           15.13         0.460         23.85         1.858           16.55         0.522         26.02         1.531           29.85         1.958         2.723         1.688           31.25         2.121         28.51         1.807           32.72         2.233         7.150         6.352           31.25         2.445         83.76         7.528           33.77         3.046         88.31         7.916           41.24         3.258         93.26         8.327           45.89	8.90	0.066		- 14.186
579         0.099         330.40         14.291           10.24         0.113         340.83         14.392           10.44         0.128         346.03         14.419           11.89         0.148         17.31         0.591           11.59         0.173         18.11         0.666           12.11         0.199         18.94         0.748           12.67         0.228         19.81         0.836           13.24         0.265         20.73         0.933           13.35         0.300         21.69         1.145           15.13         0.404         23.75         1.263           15.83         0.460         23.86         1.899           15.33         0.460         23.85         1.893           15.33         0.464         23.75         1.263           15.83         0.426         2.470         7.81         6.68           35.89         2.654         79.72         7.151         3.759           2.470         7.81         6.68         3.58         3.26         2.277           37.59         2.455         39.26         8.247         4.24         3.246         2.278 <td>9.35</td> <td>0.081</td> <td>325.22</td> <td>14.236</td>	9.35	0.081	325.22	14.236
10.24       0.113       335.61       14.892         10.64       0.128       346.03       14.419         11.08       0.148       17.31       0.591         11.59       0.173       18.11       0.666         12.67       0.228       19.81       0.856         13.24       0.265       20.73       0.933         13.85       0.300       21.69       1.145         14.44       0.352       22.69       1.145         15.13       0.460       22.75       1.263         14.44       0.352       26.62       1.521         15.83       0.460       22.75       1.261         15.83       0.460       22.73       1.687         20.85       1.525       2.121       2.811       1.807         21.72       2.933       71.90       6.395         31.25       2.121       2.851       1.807         22.79       2.845       3.76       7.528         35.89       2.654       79.72       7.151         37.79       2.845       3.76       7.528         39.37       3.046       83.31       7.916         41.24       3.258	9.55	0.005	330.40	14.291
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	2.72	0.093	335.61	14.362
10.04       0.148       14.49         11.09       0.173       18.11       0.666         12.11       0.199       18.94       0.73         12.67       0.228       19.81       0.836         13.35       0.300       21.69       1.135         13.44       0.352       22.69       1.145         15.13       0.404       23.75       1.263         15.83       0.400       24.86       1.389         16.55       0.522       26.02       1.511         15.83       0.400       24.86       1.389         16.55       0.522       26.02       1.521         2085       1.551       1.658       3.676       7.528         31.25       2.121       28.51       6.895       3.589       2.654       7.72       7.151         37.59       2.845       83.76       7.528       3.937       3.046       88.31       7.916         41.24       3.258       3.2.6       8.2.47       4.3.21       3.475       9.8.22       8.6.21         41.24       3.258       10.173       9.590       51.40       4.370       118.30       9.890         51.40       4.370<	10.24	0.113	340.83	14.392
11.08       0.148       17.31       0.591         12.11       0.199       18.04       0.748         12.11       0.199       18.04       0.748         13.24       0.265       20.73       0.933         13.85       0.300       21.69       1.145         15.13       0.404       23.75       1.263         15.83       0.460       24.66       1.389         16.55       0.522       26.02       1.521         29.85       1.988       27.23       1.638         31.25       2.121       28.51       1.807         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         35.89       2.654       79.72       7.151         37.59       2.845       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.621         42.31       3.475       98.22       8.621         45.28       3.710       103.19       9.195         46.89       3.885       108.20       9.278         46.89       3.885       108.20	10.64	0.128	346.03	14.419
11.59 $0.173$ 18.11 $0.666$ 12.67 $0.228$ 19.81 $0.748$ 13.24 $0.265$ $20.73$ $0.933$ 13.85 $0.300$ $21.69$ $1.036$ 14.48 $0.352$ $22.69$ $1.145$ 15.13 $0.404$ $23.75$ $1.263$ 15.83 $0.400$ $24.86$ $1.389$ 16.55 $0.522$ $26.02$ $1.521$ 29.85 $1.958$ $27.23$ $1.690$ 31.25 $2.121$ $28.51$ $1.807$ 32.72 $2.293$ $71.90$ $6.395$ 34.26 $2.470$ $75.81$ $6.768$ 35.89 $2.654$ $79.72$ $71.51$ 37.59 $2.845$ $83.76$ $7.528$ 39.37 $3.046$ $83.31$ $7.916$ 41.24 $3.285$ $08.20$ $9.273$ 46.89 $3.885$ $08.20$ $9.273$ 46.90 $1.383$ $20.60$ $1.325$ 53.88 $4.625$ $123.35$ <td>11.08</td> <td>0.148</td> <td>17.31</td> <td>0.591</td>	11.08	0.148	17.31	0.591
12.11       0.199       18.04       0.786         12.67       0.228       19.81       0.856         13.24       0.265       20.73       0.933         13.85       0.300       21.69       1.145         15.13       0.404       23.75       1.263         15.83       0.460       24.86       1.389         16.55       0.522       26.02       1.521         22.85       1.958       27.23       1.658         31.25       2.121       28.51       1.807         32.72       2.293       71.30       6.395         34.26       2.470       73.81       6.768         35.89       2.654       79.72       7.151         37.59       2.445       8.376       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.247         45.28       3.710       103.19       9.195         46.89       3.885       108.20       9.278         49.04       4.111       113.25       9.259         51.40       4.370       118.30       9.890         51.40       4.370       12.357	11.59	0.173	18 11	0.666
12.67       0.228       10.57       0.73       0.933         13.85       0.300       20.73       0.933         14.48       0.352       22.69       1.145         15.13       0.404       23.75       1.263         15.83       0.460       24.66       1.389         16.55       0.522       26.02       1.521         29.85       1.958       27.23       1.658         31.25       2.121       28.51       1.897         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         35.89       2.654       79.72       7.151         37.59       2.845       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.247         43.21       3.475       98.22       8.611         45.28       3.710       103.19       9.195         46.89       3.885       108.20       9.278         49.04       4.111       113.25       9.590         51.40       4.370       15.36       10.173         54.49       4.901	12.11	0.199	18 04	0.748
13.24       0.265       20.73       0.933         13.85       0.300       21.69       1.036         14.48       0.352       22.69       1.145         15.13       0.404       23.75       1.263         15.83       0.400       24.86       1.389         16.55       0.522       26.02       1.521         29.85       1.958       27.23       1.648         31.25       2.121       28.51       1.807         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         37.59       2.845       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.247         43.21       3.475       98.22       8.621         45.28       3.710       103.19       9.195         46.89       3.885       108.20       9.278         49.04       4.111       113.25       9.590         51.40       4.370       118.30       9.890         53.88       4.625       123.35       10.173         56.49       4.901       15.87 <td>12.67</td> <td>0.228</td> <td>10.91</td> <td>0.836</td>	12.67	0.228	10.91	0.836
13.85         0.300         21.69         1.036           14.48         0.352         22.69         1.145           15.13         0.400         24.86         1.389           15.55         0.522         26.02         1.521           29.85         1.958         27.23         1.658           31.25         2.121         28.51         1.807           32.72         2.293         71.90         6.395           34.26         2.470         75.81         6.768           35.89         2.654         79.72         7.151           37.59         2.845         83.76         7.528           39.37         3.046         88.31         7.916           41.24         3.258         93.26         8.247           43.21         3.475         98.22         8.621           45.28         3.710         103.19         9.195           46.89         3.885         106.20         9.278           45.43         4.625         123.35         10.173           56.49         4.901         195.87         12.646           59.23         5.180         206.14         12.865           65.12	13.24	0.265	20.72	0.030
14.48         0.352         21.69         1.145           15.13         0.404         23.75         1.263           15.83         0.460         24.86         1.389           16.55         0.522         26.02         1.51           29.85         1.958         27.23         1.689           31.25         2.121         28.51         1.807           32.72         2.293         71.90         6.395           34.36         2.470         75.81         6.768           35.89         2.654         79.72         7.151           37.59         2.845         83.76         7.528           39.37         3.046         88.31         7.916           41.24         3.258         93.26         8.247           43.21         3.475         98.22         8.621           44.89         3.885         108.20         9.278           49.04         4.111         113.25         9.590           51.40         4.301         195.87         12.646           52.23         5.183         20.100         12.765           63.11         6.087         216.48         13.049           13.50	13.85	0.300	20.73	0.933
15.13       0.404       22.69       1.143         15.13       0.404       23.75       1.263         15.83       0.400       24.86       1.389         16.55       0.522       26.02       1.521         29.85       1.958       27.23       1.658         31.25       2.121       28.51       1.807         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         35.89       2.654       79.72       7.151         37.59       2.845       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.247         43.21       3.475       98.22       8.61         43.31       3.475       98.22       8.621         45.88       3.710       103.19       9.195         46.89       3.885       106.20       9.278         40.04       4.111       113.23       9.500         51.40       4.370       118.30       9.890         53.88       4.625       123.35       10.173         56.49       4.901       195.87 <td>14 48</td> <td>0.352</td> <td>21.69</td> <td>1.036</td>	14 48	0.352	21.69	1.036
12.13       0.007       23,75       1,263         15.83       0.660       24.86       1.389         16.55       0.522       26.02       1.521         29.85       1.958       27.23       1.668         31.25       2.121       28.51       1.807         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         35.89       2.654       79.72       7.151         37.59       2.845       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.228       92.26       8.621         43.21       3.475       98.22       8.621         44.528       3.710       105.19       9.195         46.689       3.885       106.20       9.278         49.04       4.111       113.25       9.590         51.40       4.370       118.30       9.890         53.88       4.625       123.35       10.173         56.49       4.901       195.87       12.646         59.23       5.183       201.00       12.765         68.31       6.087       216	15 13	0.552	22.69	1.145
12.53       0.460       24.86       1.339         16.55       0.522       26.02       1.521         29.85       1.958       27.23       1.668         31.25       2.121       28.51       1.807         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         35.89       2.654       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.247         43.21       3.475       98.22       8.621         45.28       3.710       103.19       9.195         46.89       3.885       106.20       9.278         49.04       4.111       113.25       9.590         51.40       4.370       118.30       9.890         53.88       4.625       123.35       10.173         56.49       4.001       195.87       12.646         59.23       5.183       201.00       12.765         65.12       5.798       21.131       12.993         13.30       10.689       226.82       13.216         133.50       10.689 <td< td=""><td>15.15</td><td>0.404</td><td>23.75</td><td>1.263</td></td<>	15.15	0.404	23.75	1.263
16.33       0.522       26.00       1.521         29.85       1.958       27.23       1.658         31.25       2.121       28.51       1.807         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         35.89       2.654       79.72       7.151         37.59       2.845       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.247         43.21       3.475       98.22       8.621         45.28       3.710       103.19       9.195         46.89       3.885       106.80       9.278         49.04       4.111       113.25       9.590         51.40       4.370       118.30       9.800         53.38       4.665       12.335       10.173         56.49       4.901       195.87       12.646         59.23       5.183       201.00       12.765         62.10       5.502       206.14       12.865         63.31       6.087       216.48       13.049         128.42       10.444 <td< td=""><td>15.83</td><td>0.400</td><td>24.86</td><td>1.389</td></td<>	15.83	0.400	24.86	1.389
29.85       1.958       27.23       1.658         31.25       2.121       28.51       1.807         32.72       2.293       71.90       6.395         34.26       2.470       75.81       6.768         35.89       2.654       9.772       7.151         37.59       2.845       83.76       7.528         39.37       3.046       88.31       7.916         41.24       3.258       93.26       8.247         43.21       3.475       9.82.2       8.621         45.28       3.710       103.19       9.195         46.89       3.885       108.20       9.278         9.46.89       3.885       108.20       9.278         9.46.90       4.813       10.173       13.55         51.40       4.370       118.30       9.890         53.88       4.625       123.35       10.173         56.49       4.901       195.87       12.646         59.23       5.183       20.100       12.765         65.12       5.798       211.31       12.953         65.31       6.067       216.48       13.049         133.50       10.648	16.55	0.522	26.02	1.521
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	29.85	1.958	27.23	1.658
32.72 $2.293$ 71.90 $6.395$ $34.26$ $2.470$ $75.81$ $6.768$ $35.89$ $2.654$ $97.72$ $7.151$ $37.59$ $2.845$ $83.76$ $7.528$ $93.37$ $3.0466$ $88.31$ $7.916$ $41.24$ $3.258$ $93.26$ $8.247$ $45.28$ $3.710$ $03.19$ $9.195$ $46.89$ $3.855$ $108.20$ $9.278$ $49.04$ $4.111$ $113.25$ $9.590$ $51.40$ $4.370$ $118.30$ $9.890$ $51.40$ $4.370$ $118.30$ $9.890$ $53.88$ $4.625$ $123.35$ $10.173$ $56.49$ $4.901$ $195.87$ $12.646$ $59.23$ $5.183$ $201.00$ $12.765$ $65.11$ $5.502$ $226.82$ $13.130$ $128.42$ $10.444$ $221.65$ $13.130$ $133.50$ $10.689$ $226.82$ $13.216$ $133.50$ $10.916$ $232.00$ $13.298$	31.25	2.121	28.51	1.807
34.26 $2.470$ $75.81$ $6.768$ $35.89$ $2.684$ $79.72$ $7.151$ $37.59$ $2.845$ $83.76$ $7.528$ $39.37$ $3.046$ $88.31$ $7.916$ $41.24$ $3.258$ $93.26$ $8.347$ $43.21$ $3.475$ $98.22$ $8.621$ $45.28$ $3.710$ $103.19$ $9.195$ $46.89$ $3.885$ $108.20$ $9.278$ $49.04$ $4.111$ $113.25$ $9.590$ $51.40$ $4.370$ $118.30$ $9.890$ $53.88$ $4.625$ $123.35$ $10.173$ $56.49$ $4.901$ $95.87$ $12.646$ $59.23$ $5.183$ $201.00$ $12.765$ $65.12$ $5.798$ $211.31$ $12.963$ $68.31$ $6.087$ $216.48$ $13.049$ $128.42$ $10.444$ $221.65$ $13.310$ $133.50$ $10.689$ $226.82$ $13.216$ $133.50$ $10.812$ $274.234$ $13.496$	32.72	2.293	71.90	6.395
35.89 $2.654$ $79.72$ $7,151$ $37.59$ $2.845$ $83.76$ $7.528$ $39.37$ $3.046$ $88.31$ $7.916$ $41.24$ $3.258$ $93.26$ $8.247$ $43.21$ $3.475$ $98.22$ $8.621$ $45.28$ $3.710$ $103.19$ $9.195$ $46.89$ $3.885$ $108.20$ $9.278$ $49.04$ $4.111$ $113.25$ $9.590$ $51.40$ $4.370$ $118.30$ $9.890$ $53.88$ $4.625$ $123.35$ $10.173$ $56.49$ $4.901$ $195.87$ $12.646$ $59.23$ $5.183$ $200.100$ $12.765$ $62.10$ $5.502$ $206.14$ $12.865$ $65.12$ $5.798$ $211.31$ $12.953$ $68.31$ $6.087$ $216.48$ $13.049$ $128.42$ $10.444$ $221.65$ $13.130$ $133.50$ $10.689$ $226.82$ $13.216$ $133.50$ $10.689$ $226.82$ $13.216$ $133.50$ $10.689$ $226.82$ $13.216$ $133.52$ $11.327$ $247.52$ $13.496$ $159.04$ $11.670$ $252.69$ $13.551$ $164.17$ $11.864$ $23.43$ $13.961$ $179.59$ $12.285$ $298.61$ $13.982$ $184.79$ $12.38$ $303.79$ $14.031$ $19.57$ $12.454$ $304.55$ $14.217$ $184.74$ $12.865$ $32.757$ $14.4273$ $185.57$ $12.454$ $34.92$ $14.33$ <	34.26	2.470	75.81	6.768
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	35.89	2.654	79.72	7.151
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	37.59	2.845	83.76	7.528
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	39.37	3.046	88.31	7.916
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	41.24	3.258	93.26	8.247
45.28       3.710       103.19       9.195         46.89       3.885       108.20       9.278         49.04       4.111       113.25       9.590         51.40       4.370       118.30       9.890         53.88       4.625       123.35       10.173         56.49       4.901       195.87       12.646         59.23       5.183       201.00       12.765         62.10       5.502       206.14       12.865         65.12       5.798       211.31       12.953         68.31       6.087       216.48       13.049         128.42       10.444       221.65       13.130         133.50       10.689       226.82       13.216         133.50       10.689       232.00       13.298         143.69       11.132       237.17       13.361         148.79       11.327       242.34       13.446         159.04       11.670       232.69       13.551         164.17       11.864       Series III       13.961         159.04       12.122       293.43       13.961         179.59       12.285       298.61       13.982         1	43.21	3.475	98.22	8 621
46.89         3.885         108.20         9.278           49.04         4.111         113.25         9.590           51.40         4.370         118.30         9.890           53.88         4.625         123.35         10.173           56.49         4.901         195.87         12.646           59.23         5.183         201.00         12.765           62.10         5.502         206.14         12.865           65.12         5.798         211.31         12.953           68.31         6.087         216.48         13.049           128.42         10.444         221.65         13.130           133.50         10.689         226.82         13.216           138.59         10.916         232.00         13.298           143.69         11.132         237.17         13.361           159.04         11.670         252.69         13.51           164.17         11.864         Series III         19.96           179.59         12.285         298.61         13.982           184.74         12.388         303.79         14.031           199.59         12.285         298.61         13.982	45.28	3.710	103.19	9.195
49.04 $4.111$ $113.25$ $9.590$ $51.40$ $4.370$ $118.30$ $9.890$ $53.88$ $4.625$ $123.35$ $10.173$ $56.49$ $4.901$ $195.87$ $12.646$ $59.23$ $5.183$ $201.00$ $12.765$ $62.10$ $5.502$ $206.14$ $12.865$ $65.12$ $5.798$ $211.31$ $12.953$ $68.31$ $6.087$ $216.48$ $13.049$ $128.42$ $10.444$ $221.65$ $13.130$ $133.50$ $10.689$ $226.82$ $13.216$ $138.59$ $10.916$ $232.00$ $13.298$ $143.69$ $11.132$ $237.17$ $13.361$ $148.79$ $11.327$ $242.34$ $13.496$ $159.04$ $11.670$ $252.69$ $13.551$ $164.17$ $11.864$ Series III $169.30$ $12.019$ $293.43$ $13.961$ $179.59$ $12.285$ $298.61$ $13.982$ $184.74$ $12.388$ $30.79$ $14.031$ $179.59$ $12.285$ $298.61$ $13.982$ $184.74$ $12.388$ $30.79$ $14.031$ $179.58$ $12.196$ $319.35$ $14.182$ $175.28$ $12.156$ $324.55$ $14.217$ $185.57$ $12.454$ $334.92$ $14.33$ $190.72$ $12.542$ $30.11$ $14.35$ $190.72$ $12.542$ $30.11$ $14.35$	46.89	3.885	108.20	9 278
10.011.111.2.22.0.051.404.370118.309.89053.884.625123.3510.17356.494.901195.8712.64659.235.183201.0012.76562.105.502206.1412.86565.125.798211.3112.95368.316.087216.4813.049128.4210.444221.6513.130133.5010.689226.8213.216138.5910.916232.0013.298143.6911.132237.1713.361148.7911.327242.3413.446153.9211.500247.5213.496159.0411.670252.6913.551164.1711.864Series III179.5912.285298.6113.982184.7412.388303.7914.031179.5912.285298.6113.982184.7412.388303.7914.031170.3311.986319.35514.182175.2812.156324.5514.217186.4212.314329.7414.273185.5712.45433.49214.33190.7212.542340.1114.35190.7212.542340.1114.35	49 04	4 111	113.25	9.590
31.40 $1.73$ $116.30$ $2.930$ $53.88$ $4.625$ $123.35$ $10.173$ $56.49$ $4.901$ $195.87$ $12.646$ $59.23$ $5.183$ $201.00$ $12.765$ $62.10$ $5.502$ $206.14$ $12.865$ $65.12$ $5.798$ $211.31$ $12.953$ $68.31$ $6.087$ $216.48$ $13.049$ $128.42$ $10.444$ $221.65$ $13.130$ $133.50$ $10.689$ $226.82$ $13.216$ $138.59$ $10.916$ $232.00$ $13.298$ $143.69$ $11.132$ $237.17$ $13.361$ $148.79$ $11.327$ $242.34$ $13.446$ $153.92$ $11.500$ $247.52$ $13.496$ $159.04$ $11.670$ $252.69$ $13.551$ $164.17$ $11.864$ Series III $169.30$ $12.019$ $298.61$ $13.982$ $184.74$ $12.285$ $298.61$ $13.982$ $184.74$ $12.388$ $303.79$ $14.031$ $179.59$ $12.285$ $298.61$ $13.982$ $184.74$ $12.386$ $308.98$ $14.070$ $314.17$ $14.124$ $17.33$ $11.986$ $319.35$ $14.31$ $12.456$ $324.55$ $14.217$ $180.42$ $12.314$ $329.74$ $14.273$ $185.57$ $12.454$ $334.92$ $14.33$ $190.72$ $12.542$ $340.11$ $14.35$	51.40	4.270	118.20	0,800
35.86 $4.023$ $123.33$ $101173$ $56.49$ $4.901$ $195.87$ $12.646$ $59.23$ $5.183$ $201.00$ $12.765$ $62.10$ $5.502$ $206.14$ $12.865$ $65.12$ $5.798$ $211.31$ $12.953$ $68.31$ $6.087$ $216.48$ $13.049$ $128.42$ $10.444$ $221.65$ $13.130$ $133.50$ $10.689$ $226.82$ $13.216$ $138.59$ $10.916$ $232.00$ $13.298$ $143.69$ $11.132$ $237.17$ $13.361$ $148.79$ $11.327$ $242.34$ $13.446$ $153.92$ $11.500$ $247.52$ $13.496$ $159.04$ $11.670$ $252.69$ $13.551$ $164.17$ $11.864$ Series III $169.30$ $12.019$ $12.019$ $174.45$ $12.122$ $293.43$ $13.961$ $179.59$ $12.285$ $298.61$ $13.982$ $18.74$ $12.388$ $303.79$ $14.031$ $308.98$ $14.070$ $314.17$ $14.124$ $170.33$ $11.986$ $319.35$ $14.182$ $175.28$ $12.156$ $324.55$ $14.217$ $180.42$ $12.314$ $329.74$ $14.273$ $185.57$ $12.454$ $334.92$ $14.33$ $190.72$ $12.542$ $340.11$ $14.35$ $190.72$ $12.542$ $340.11$ $14.35$	52.90	4.570	122.25	10 173
30.49 $4.901$ $193.57$ $12.040$ $59.23$ $5.183$ $201.00$ $12.765$ $62.10$ $5.502$ $206.14$ $12.865$ $65.12$ $5.798$ $211.31$ $12.953$ $68.31$ $6.087$ $216.48$ $13.049$ $128.42$ $10.444$ $221.65$ $13.130$ $133.50$ $10.689$ $226.82$ $13.216$ $138.59$ $10.916$ $232.00$ $13.298$ $143.69$ $11.132$ $237.17$ $13.361$ $148.79$ $11.327$ $242.34$ $13.446$ $153.92$ $11.500$ $252.69$ $13.551$ $164.17$ $11.864$ Series III $169.30$ $12.019$ $12.285$ $298.61$ $179.59$ $12.285$ $298.61$ $13.982$ $184.74$ $12.388$ $303.79$ $14.031$ $179.59$ $12.285$ $298.61$ $13.982$ $184.74$ $12.388$ $303.79$ $14.031$ $184.74$ $12.388$ $303.79$ $14.031$ $184.74$ $12.314$ $329.74$ $14.273$ $185.57$ $12.454$ $334.92$ $14.33$ $190.72$ $12.454$ $34.92$ $14.33$ $190.72$ $12.542$ $340.11$ $14.35$	55.40	4.023	105.97	10.175
39,23 $5,183$ $201,00$ $12,765$ $62,10$ $5,502$ $206,14$ $12,865$ $65,12$ $5,798$ $211,31$ $12,953$ $68,31$ $6087$ $216,48$ $13,049$ $128,42$ $10,444$ $221,65$ $13,130$ $133,50$ $10,689$ $226,82$ $13,216$ $138,59$ $10,916$ $232,00$ $13,298$ $143,69$ $11,132$ $237,17$ $13,361$ $148,79$ $11,327$ $242,34$ $13,446$ $153,92$ $11,500$ $227,52$ $13,496$ $159,04$ $11,670$ $252,69$ $13,551$ $164,17$ $11,864$ Series III $169,30$ $12,019$ $293,43$ $13,961$ $179,59$ $12,285$ $298,61$ $13,982$ $184,74$ $12,388$ $303,79$ $14,031$ $170,33$ $11,986$ $319,35$ $14,182$ $175,28$ $12,156$ $324,55$ $14,217$ $180,42$ $12,314$ $329,74$ $14,273$ $185,57$ $12,454$ $334,92$ $14,33$ $190,72$ $12,542$ $340,11$ $14,35$ $257,87$ $13,577$ $345,29$ $14,425$	56.49	4.901	195.87	12.040
62.105.502206.1412.86565.125.798211.3112.95368.316.087216.4813.049128.4210.444221.6513.130133.5010.689226.8213.216138.5910.916232.0013.298143.6911.132237.1713.361148.7911.327242.3413.446153.9211.500247.5213.496159.0411.670252.6913.551164.1711.864Series III169.3012.0197174.4512.122293.4313.961179.5912.285298.6113.982184.7412.388303.7914.031179.5512.28514.1714.124170.3311.986319.3514.182175.2812.156324.5514.217180.4212.314329.7414.273185.5712.454334.9214.33190.7212.542340.1114.35257.8713.577345.2914.425	59.23	5.183	201.00	12.765
65.12 $5.798$ $211.31$ $12.953$ $68.31$ $6.087$ $216.48$ $13.049$ $128.42$ $10.444$ $221.65$ $13.130$ $133.50$ $10.689$ $226.82$ $13.216$ $138.59$ $10.916$ $232.00$ $13.298$ $143.69$ $11.132$ $237.17$ $13.361$ $148.79$ $11.327$ $242.34$ $13.446$ $153.92$ $11.500$ $247.52$ $13.496$ $159.04$ $11.670$ $252.69$ $13.551$ $164.17$ $11.864$ Series III $169.30$ $12.019$ $12.285$ $179.59$ $12.285$ $298.61$ $179.59$ $12.285$ $298.61$ $179.59$ $12.285$ $298.61$ $179.59$ $12.285$ $303.79$ $184.74$ $12.388$ $303.79$ $164.17$ $11.986$ $319.35$ $184.74$ $12.388$ $303.79$ $184.74$ $12.388$ $303.79$ $184.74$ $12.388$ $303.79$ $184.74$ $12.388$ $303.79$ $184.74$ $12.384$ $319.35$ $184.74$ $12.384$ $319.35$ $185.57$ $12.56$ $324.55$ $14.182$ $175.28$ $12.126$ $319.35$ $14.182$ $175.28$ $12.542$ $340.11$ $14.33$ $190.72$ $12.542$ $345.29$ $14.425$	62.10	5.502	206.14	12.865
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	65.12	5.798	211.31	, 12.953
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	68.31	6.087	216.48	13.049
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	128.42	10.444	221.65	13.130
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	133.50	10.689	226.82	13.216
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	138.59	10.916	232.00	13.298
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	143.69	11.132	237.17	13.361
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	148.79	11.327	242.34	13.446
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	153.92	11.500	247.52	13.496
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	159.04	11.670	252.69	13.551
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	164.17	11 864	Series III	r
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	169.30	12 010	Series III	L
174.45       12.122       298.61       13.982         179.59       12.285       298.61       13.982         184.74       12.388       303.79       14.031         Series II       308.98       14.070         314.17       14.124         170.33       11.986       319.35       14.182         175.28       12.156       324.55       14.217         180.42       12.314       329.74       14.273         185.57       12.454       334.92       14.33         190.72       12.542       340.11       14.35         257.87       13.577       345.29       14.425	174.45	12.019	293.43	13.961
179.39     12.283     20.01     10.02       184.74     12.388     303.79     14.031       Series II       314.17     14.124       170.33     11.986     319.35     14.182       175.28     12.156     324.55     14.217       180.42     12.314     329.74     14.273       185.57     12.454     334.92     14.33       190.72     12.542     340.11     14.35       257.87     13.577     345.29     14.425	174.45	12.122	298.61	13.982
184.74         12.388         308.98         14.070           Series II         308.98         14.170           170.33         11.986         319.35         14.182           175.28         12.156         324.55         14.217           180.42         12.314         329.74         14.273           185.57         12.454         334.92         14.33           190.72         12.542         340.11         14.35           257.87         13.577         345.29         14.425	1/9.39	12.285	303.79	14.031
Series II         303.76         14.070           314.17         14.124           170.33         11.986         319.35         14.182           175.28         12.156         324.55         14.217           180.42         12.314         329.74         14.273           185.57         12.454         334.92         14.33           190.72         12.542         340.11         14.35           257.87         13.577         345.29         14.425	184.74	12.388	308 08	14 070
170.3311.986319.3514.124170.3311.986319.3514.182175.2812.156324.5514.217180.4212.314329.7414.273185.5712.454334.9214.33190.7212.542340.1114.35257.8713.577345.2914.425	:	Series II	214 17	14 104
170.5511.980519.5514.182175.2812.156324.5514.217180.4212.314329.7414.273185.5712.454334.9214.33190.7212.542340.1114.35257.8713.577345.2914.425	170.22	11.002	314.17 210.25	14.124
173.2612.150324.5514.217180.4212.314329.7414.273185.5712.454334.9214.33190.7212.542340.1114.35257.8713.577345.2914.425	170.33	11.760	317.33 204 FF	14.182
180.4212.314329.7414.273185.5712.454334.9214.33190.7212.542340.1114.35257.8713.577345.2914.425	1/5.28	12.156	324.33	14.21/
185.5712.454334.9214.33190.7212.542340.1114.35257.8713.577345.2914.425	180.42	12.314	329.74	14.2/3
190.7212.542340.1114.35257.8713.577345.2914.425	185.57	12.454	334.92	14.33
257.87 13.577 345.29 14.425	190.72	12.542	340.11	14.35
	257.87	13.577	345.29	14.425
263.05 13.658	263.05	13.658	aNot included in volves on which	thad ourse (Fig 1) is trand

<sup>a</sup>Not included in values on which smoothed curve (Fig 1) is based.



FIG. 1. Cp  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub>- $\bigcirc$ -and  $\epsilon$ -phase Lu<sub>2</sub>S<sub>3</sub>- $\boxdot$ -. The data of Gschneidner *et al.* (Ref. 10) are shown as ---.

unique theoretical crystal-field splitting using the latticesum method described in Ref. 2.

## **III. RESULTS AND DISCUSSION**

The experimental heat-capacity data for  $Yb_2S_3$  and  $Lu_2S_3$  are presented in Table II and plotted in Fig. 1. Smoothed heat capacities and thermodynamic functions at selected temperatures are presented in Table III. The standard deviation in these measurements is less than  $\pm 0.1\%$ above 20 K. Between 6 and 20 K, the deviations decrease gradually from about  $\pm 4\%$  to  $\pm 0.1\%$  at 20 K.

The Komada–Westrum characteristic temperature  $(\Theta_{KW})$  was calculated for  $\epsilon$ -phase Lu<sub>2</sub>S<sub>3</sub> on the assumption that no excess contributions are present in the experimental data.<sup>5</sup> The lattice heat-capacity contribution of  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub> was then calculated with the LEM-3 computer program using input coefficients calculated in the same manner as those for  $\gamma$ -phase compounds, but extrapolating from Lu<sub>2</sub>S<sub>3</sub> as a reference point.<sup>2,3,5</sup> Since only one reference point was available in the  $\epsilon$  phase, it was assumed that the coefficients vary similarly to those in the  $\gamma$ -phase lanthanide sesquisulfides, i.e., that the same dependence on atomic number used for the coefficients in the  $\gamma$ -phase.

The variation in  $\Theta_{KW}$  for Lu<sub>2</sub>S<sub>3</sub> (82.3 K) is shown in Fig. 2. The value calculated for Yb<sub>2</sub>S<sub>3</sub>,  $\Theta_{KW}$ =89.1 K has been used to obtain the excess heat-capacity contributions to Yb<sub>2</sub>S<sub>3</sub> which are shown in Fig. 3 together with the Schottky contribution based on the analysis of the optical

TABLE III. Smoothed heat capacities and derived thermodynamic properties ( $R=8.3144 \text{ J K}^{-1} \text{ mol}^{-1}$ ).

	$C_{p,m}$	$S_m^0 - S_m^0(0 \text{ K})$	$H_m^0 - H_m^0(0 \text{ K})$	$\Phi_m^0$
<i>Т/</i> К	R	R	R · K	R
€-ph	ase ytterbiu	m sesquisulfide Yb	$_{2}S_{3}, M = 442.26 \text{ g m}_{2}$	ol <sup>-1</sup>
0.0	0.0	0.0	0.0	0.0
5.0	0.094	0.022	0.110	0.0
10.0	0.004	0.546	4 74	0.072
15.0	0.495	0.540	7 34	0.266
13.0	0.009	0.733	11.35	0.200
20.0	1.510	0.977	11.23	0.414
25.0	1.512	1.2320	17.47	0.554
30.0	2.096	1.580	29.20	0.005
35.0	2.715	1.949	38.49	0.849
40.0	3.352	2.353	53.65	1.012
45.0	3.989	2.784	72.00	1.184
50.0	4.625	3.238	93.54	1.367
60.0	5.920	4.195	146.27	1.757
70.0	7.155	5.201	211.66	2.177
80.0	8.294	6.232	289.01	2.619
90.0	9.293	7.268	377.07	3.078
100.0	10.153	8.293	474.41	3.549
110.0	10.890	9.296	579.7	4.026
120.0	11.523	10.271	691.8	4.506
130.0	12.068	11.216	809.9	4.986
140.0	12.534	12.128	932.9	5.464
150.0	12.927	13.006	1060.3	5.937
160.0	13.255	13.851	1191.2	6.406
170.0	13.526	14.663	1325.2	6.868
180.0	13 753	15 443	1461.6	7.323
100.0	13 943	16 20	1600.1	7 778
200.0	14 107	16.92	1740.4	8 218
200.0	14.251	17.61	1882.2	8 647
210.0	14.201	19.07	2025 4	0.047
220.0	14.380	10.27	2023.4	9.004
230.0	14.490	10.92	2109.0	9.400
240.0	14.605	19.53	2515.5	9.885
250.0	14.711	20.13	2461.9	10.282
260.0	14.818	20.71	2609.5	10.673
270.0	14.926	21.27	2758.0	11.054
280.0	15.03	21.82	2908.0	11.434
290.0	15.13	22.35	3058.8	11.802
298.15	15.20	22.77	3182.5	12.096
300.0	15.22	22.86	3210.6	12.158
325.0	15.32	24.08	3592.6	13.026
350.0	15.37	25.22	3976.2	13.859
<i>€</i> -p	hase lutetiu	m sesquisulfide Lu	$_{2}S_{3}, M = 446.12 \text{ g mo}$	ol-'
0.0	0.0	0.0	0.0	0.0
10.0	0.103	0.033	0.250	0.008
15.0	0.392	0.123	1.399	0.029
20.0	0.857	0.296	4.468	0.073
25.0	1.404	0.545	10.100	0.141
30.0	1.978	0.852	18.551	0.233
40.0	3.115	1.578	44.060	0.476
50.0	4.209	2.390	80.67	0.777
60.0	5.270	3.252	128.11	1.117
70.0	6.259	4.140	185.82	1.485
80.0	7.165	5.036	253.01	1.873
90.0	7.985	5.928	328.83	2.274
100.0	8.724	6.808	412.44	2.683
120.0	9 981	8.514	600.0	3.514
140.0	10.973	10.130	809.9	4.345
160.0	11 733	11 647	1037 3	5,164
180.0	17 202	13.064	1278 0	5 964
200.0	12.303	11.004	1578 6	6 7/1
200.0	12./38	14.303	1726.0	7 402
220.0	13.091	15.01	1/80.9	1.492
240.0	13.392	10.77	2051.8	0.21/
260.0	13.645	17.85	2322.3	8.917
280.0	13.841	18.87	2597.3	9.592
298.15	13.987	19.74	2849.7	10.183
300.0	14.001	19.83	2875.6	10.243
320.0	14.162	20.74	3157.2	10.870
350.0	14,507	22.02	3587.0	11.772



FIG. 2.  $\Theta_{KW}$  for  $\epsilon$ -phase Lu<sub>2</sub>S<sub>3</sub>.

spectra. The agreement shown in Table IV between the calorimetrically determined and the spectroscopically ascertained electronic heat capacity is good. Although an independent evaluation of the lattice contribution might also have been made by the volumetric priority method.<sup>1</sup> the preceding paper in this series<sup>3</sup> has demonstrated convincingly that-despite differences in approach-the agreement is excellent.

In the vicinity of 7 K, a magnetic transition is found. Resolution of the transition indicated a  $\Delta_{trs}S^0$  about 0.68*R*. This value agrees very well with the entropy for the magnetic ordering of Yb<sup>3+</sup> with effective spin S=1/2 in a crystal-field split ground state that is doubly degenerate.



FIG. 3. Excess heat capacities of e-phase Yb2S3. Calorimetric-, spectroscopic---, and magnetic- · -contributions.

TABLE IV. Schottky levels, ground state manifold, for  $\epsilon$ -phase Yb<sub>2</sub>S<sub>3</sub>.

Compound (term $\theta_{KW}$ )	Method of determination	Energy (cm <sup><math>-1</math></sup> ) and degeneracy ( <i>n</i> )
$\frac{\epsilon - Yb_2S_3}{Yb^{3+}(^2F_{7/2})}$	Optical spectra Excess $C_p$ (KW)	0(2), 155(2), 285(2), 380(2) 0(2), 155(2), 285(2), 380(2)
$\theta_{\rm KW} = 89.12$		
$\epsilon$ -Lu <sub>2</sub> S <sub>3</sub> , Lu <sup>3+</sup>	$({}^{1}S_{0}), \ \theta_{\mathrm{KW}} = 82.3$	

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- <sup>1</sup>E. F. Westrum, Jr., R. Burriel, J. B. Gruber, P. E. Palmer, B. J. Beaudry, and W. A. Plautz, J. Chem. Phys. 91, 4838 (1989).
- <sup>2</sup>J. B. Gruber, R. Burriel, E. F. Westrum, Jr., W. Plautz, G. Metz, Xiao-Xia Ma, B. J. Beaudry, and P. E. Palmer, J. Chem. Phys. 95, 1964 (1991).
- <sup>3</sup>R. Shaviv, E. F. Westrum, Jr., J. B. Gruber, B. J. Beaudry, and P. E. Palmer, J. Chem. Phys. 96, 6149 (1992).
- <sup>4</sup>E. F. Westrum, Jr., Pure Appl. Chem. 55, 539 (1983).
- <sup>5</sup>N. Komada, Ph.D. thesis, University of Michigan, Ann Arbor, MI, 1985.
- <sup>6</sup>J. Flahaut, in Handbook on the Physics and Chemistry of Rare Earths, edited by K. A. Gschneidner, Jr. and L. Eyring (North Holland, Amsterdam, 1978), Vol. 4, p. 429.
- <sup>7</sup>V. V. Tikhonov and I. A. Smirnov, Sov. Phys. Solid State 13, 2296 (1971).
- <sup>8</sup>E. Bucher, K. Andrés, F. J. Di Salvo, J. P. Maita, A. C. Gossard, A. S. Cooper, and G. W. Hull, Jr., Phys. Rev. B 11, 500 (1975).
- <sup>9</sup>S. M. A. Taher, J. C. Ho, J. B. Gruber, B. J. Beaudry, and K. A. Gschneidner, Jr., The Rare Earths in Modern Science and Technology (Plenum, New York, 1980), Vol. 2, p. 423.
- <sup>10</sup>K. A. Gschneidner, Jr., B. J. Beaudry, T. Takeshita, S. S. Eucker, S. M. A. Taher, J. C. Ho, and J. Gruber, Phys. Rev. B 24, 7187 (1981).
- <sup>11</sup>J. C. Ho, S. M. A. Taher, G. B. King, J. B. Gruber, B. J. Beaudry, and K. A. Gschneidner, Jr., J. Phys. 39, C6 (1978).
- <sup>12</sup>J. Flahaut, L. Domange, M. Guittard, and M. P. Pardo, Bull. Soc. Chim. France 7, 326 (1965).
- <sup>13</sup>K. J. Range and R. Leeb, Z. Naturforsch. Teil B 30, 637 (1975).
- <sup>14</sup>B. J. Beaudry and K. A. Gschneidner, Jr., in Handbook on the Physics and Chemistry of Rare Earths, edited by K. A. Gschneidner, Jr. and L. Eyring (North Holland, Amsterdam, 1978), Vol. 1, p. 173.
- <sup>15</sup>American Smelting and Refining Co., Denver, CO.
- <sup>16</sup>A. W. Sleight and C. T. Prewitt, Inorg. Chem. 7, 2282 (1968).
   <sup>17</sup>E. D. West and E. F. Westrum, Jr., in *Experimental Thermodynamics*, edited by J. P. McCullough and D. W. Scott (Butterworths, London, 1968), Vol. 1, p. 333.
- <sup>18</sup>E. F. Westrum, Jr., in Thermochemistry and its Applications to Chemical and Biochemical Systems, edited by M. A. V. Ribeiro da Silva (Reidel, Dordrecht, 1984), p. 754.
- <sup>19</sup>J. R. Henderson, M. Muramoto, E. Loh, and J. B. Gruber, J. Chem. Phys. 47, 3347 (1967).