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**PROPERTIES OF THE RARE EARTH  
METALS AND COMPOUNDS**

*JOHN A. GIBSON  
GIFFORD S. HARVEY*

*BATTELLE MEMORIAL INSTITUTE*

TECHNICAL REPORT AFML-TR-65-430

JANUARY 1966

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**AIR FORCE MATERIALS LABORATORY  
RESEARCH AND TECHNOLOGY DIVISION  
AIR FORCE SYSTEMS COMMAND  
WRIGHT-PATTERSON AIR FORCE BASE, OHIO**

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## FOREWORD

This report was prepared by Battelle Memorial Institute under USAF Contract AF33(657)-8741 from March to December, 1965. The contract was initiated under Project No. 7381, "Materials Application", Task No. 738103, "Materials Information Processing and Retrieval". This contract was administered under the direction of Mr. George Young, Air Force Materials Laboratory, Research and Technology Division, Wright-Patterson AFB, Ohio.

The authors, John A. Gibson and Gifford S. Harvey, were principal investigators on the program. Assistance was provided by other members of the staff of Battelle Memorial Institute including Inez Wheldon and Henry Rawles of the Battelle library staff.


A survey of the literature has been made, and the best available data on the properties of yttrium and the 15 lanthanide rare-earth metals and compounds have been compiled.

This compilation of properties is presented in four sections. Section 1 contains the tabulated properties of the elements and compounds plus graphic representations of corrosion data. Section 2 contains phase diagrams. Section 3 lists the properties of the elements and their compounds by element, with reference to the source of information, and Section 4 is a list of references.

Unless otherwise indicated, the data represent the room-temperature values of a given property. Figures in parentheses following a property value indicate the temperature of measurement or the applicable temperature range. Property values in parentheses indicate estimated value.

Acknowledgment is given to the publishing houses and scientific societies that granted permission to reproduce the graphs and phase diagrams contained in this report: the American Physical Society, the National Association of Corrosion Engineers, the Metallurgical Society of the American Institute of Mining, Metallurgical & Petroleum Engineers, the American Ceramic Society, the American Chemical Society, U. S. Atomic Energy Commission, Elsevier Publishing Co. (Amsterdam), and Gordon and Breach, Science Publishers, Inc. (New York).

This report has been reviewed and approved.



D. A. SHINN  
Chief, Materials Information Branch  
Materials Applications Division  
AF Materials Laboratory

## ABSTRACT

The unclassified literature, both U. S. and foreign, relating to yttrium and the lanthanide rare-earth elements Numbers 57 through 71 has been reviewed. The best available data on properties have been compiled and are presented in tabular form by property and by element. Included are the physical, chemical, magnetic, electrical, mechanical, and nuclear properties of the elements and their compounds. Over 200 phase diagrams are presented. A supplemental list of publications containing data on optical properties has been included.

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Properties

PROPERTIES OF THE RARE EARTH ELEMENTS  
(Room Temperature)

Symbol	Atomic No.	Atomic Weight	Estimated Abundance, ppm	Density, g/cm <sup>3</sup>	Atomic Volume, cm <sup>3</sup> /mole	Melting Point, °C	Heat of Fusion, kcal/mole	Boiling Point, °C	
Y	39	88.92	28-70	4.472	19.886	1509	4.1	2927	YTTRIUM
La	57	138.92	5-18	6.162	22.50	920	2.75	3469	LANTHANUM
Ce	58	140.13	20-46	6.678	20.695	795	2.20	3468	CERIUM
Pr	59	140.92	3.5-5.5	6.769	20.778	935	1.650	3127	PRASEODYMIUM
Nd	60	144.27	12-24	7.016	20.60	1024	1.705	3027	NEODYMIUM
Pm	61	145	--	--	--	1080	3.00	(2727)	PROMETHIUM
Sm	62	150.35	4.5-7	7.536	19.0	1072	2.061	1804	SAMARIUM
Eu	63	152.0	0.14-1.1	5.245	28.91	826	2.0	1439	EUROPIUM
Gd	64	157.26	4.5-6.4	7.886	19.88	1312	2.1	3000	GADOLINIUM
Tb	65	158.93	0.7-1	8.253	19.245	1356	2.2	2800	TERBIUM
Dy	66	162.51	4.5-7.5	8.559	18.032	1407	3.8	2600	DYSPROSIUM
Ho	67	164.94	0.7-1.2	8.799	18.742	1461	4.1	2600	HOLMIUM
Er	68	167.27	2.5-6.5	9.062	18.473	1497	4.1	2900	ERBIUM
Tm	69	168.94	0.2-1	9.318	18.151	1545	4.3	1727	THULIUM
Yb	70	173.04	2.7-8	6.959	24.80	824	1.8	1427	YTTERBIUM
Lu	71	174.99	0.8-1.7	9.849	17.779	1652	4.5	3327	LUTETIUM

(Continued)

	Ref. State	Heat of Vaporization (25 C), kcal/mole	Specific Heat at 25 C, cal/(mole)(C)	Coefficient of Linear Thermal Expansion, $10^{-6}/C$	Thermal Conductivity, 28 C, cal/(sec)(cm)(C)	Crystal Structure <sup>(a)</sup>	Lattice Constants		Metallic Radius, A
							$a_0$ , A	$c_0$ , A	
YTTRIUM	93	6.01	6.01	10.8	0.035	Hcp	3.6474	5.7306	1.801
						Bcc	4.11	--	1.83
LANTHANUM	96	6.65	6.65	4.9	0.033	Hcp	3.770	12.159	1.877
						Fcc	5.304	--	1.875
CERIUM	95	6.44	6.44	8.5	0.026	Fcc	5.1612	--	1.825
						Bcc	4.11	--	1.83
PRASEODYMIUM	79	6.48	6.48	4.8	0.028	Hcp	3.6725	11.8354	1.828
						Bcc	4.13	--	1.84
NEODYMIUM	69	6.57	6.57	6.7	0.031	Hcp	3.6579	11.7992	1.821
						Bcc	4.13	--	1.84
PROMETHIUM	(60)	(6.50)	(6.50)	--	--	Fcc	--	--	(1.810)
SAMARIUM	46	6.76	6.76	--	--	Rhombohedral	8.066	$\alpha = 23^{\circ}13'$	1.802
						Bcc	4.07	--	1.81
EUROPIUM	42	6.4	6.4	32.0	--	Bcc	4.5820	--	2.042
GADOLINIUM	72	8.80	8.80	8.6	0.021	Hcp	3.6360	5.7826	1.802
						Bcc	4.06	--	--
TERBIUM	70	6.92	6.92	7.0	0.13	Hcp	3.6010	5.6936	1.782
DYSPROSIUM	67	6.3	6.3	8.6	0.024	Hcp	3.5903	5.6475	1.773
HOLMIUM	67	6.49	6.49	9.5	--	Hcp	3.5773	5.6158	1.766
ERBIUM	67	6.72	6.72	9.2	0.023	Hcp	3.5588	5.5874	1.757
THULIUM	59	6.45	6.45	11.6	--	Hcp	3.5375	5.5546	1.746
YTTERBIUM	38	(6.0)	(6.0)	25.0	--	Fcc	5.4862	--	1.940
						Bcc	4.45	--	1.93
LUTETIUM	90	(6.45)	(6.45)	12.5	--	Hcp	3.5031	5.5509	1.734

(a) Hcp, hexagonal close packed; Fcc, face-centered cubic; Bcc, body-centered cubic.

Structure Transition Temperature, C	Magnetic Susceptibility, $10^{-6}$ emu/mole	Magnetic Moment, Bohr magnetons	Curie Temperature, K	Néel Temperature, K	Debye Temperature, K	Thermal-Neutron Cross Section Barns/Atom $\text{cm}^2/\text{G}$		
1460	191	0.67	None	None	--	1.27	0.0094	YTTRIUM
310, 868	101	0.49	None	None	142	8.9	0.039	LANTHANUM
-150, -10, 730	2,430	2.51	--	--	147	0.70	0.0030	CERIUM
798	5,320	3.56	None	None	152	11.2	0.048	PRASEODYMIUM
868	5,650	3.3	--	7.6	157	46	0.19	NEODYMIUM
--	--	--	--	--	162	--	--	PROMETHIUM
917	1,275	1.74	--	15	166	5,500	22	SAMARIUM
--	33,100	7.12	108	91	70-120	4,600	18	EUROPIUM
1262	356,000	7.95	290	--	176	46,000	177	GADOLINIUM
1317	193,000	9.7	237	230	181	44	0.166	TERBIUM
--	99,800	10.64	85	178.5	186	1,100	4.1	DYSPROSIUM
--	70,200	10.89	<20	133	191	64	0.23	HOLMIUM
--	44,100	9.5	20	84	195	166	0.60	ERBIUM
--	26,200	7.62	22	60	200	118	0.42	THULIUM
798	71	0.41	None	None	118	36	0.125	YTTERBIUM
--	17.9	0.21	None	None	210	108	0.37	LUTETIUM

(Continued)

	Trivalent-Ion Radius, A	Stable Oxidation States (Positive)	Trivalent-Ion Oxidation Potential (Positive), volts	Young's Modulus, 10 <sup>11</sup> dynes/cm <sup>2</sup>	Shear Modulus, 10 <sup>11</sup> dynes/cm <sup>2</sup>	Poisson's Ratio	Sonic Compressibility, 10 <sup>6</sup> cm <sup>2</sup> /kg
YTRIUM	0.88	3	--	6.63	2.62	0.265	2.09
LANTHANUM	1.061	3	2.4	3.84	1.49	0.228	3.24
CERIUM	1.034	2,3,4	2.335	3.00	1.20	0.248	4.95
PRASEODYMIUM	1.013	3,4	2.2	3.52	1.35	0.305	3.28
NEODYMIUM	0.995	3	2.24	3.79	1.45	0.306	3.02
PROMETHIUM	0.979	3	--	--	--	--	3.06
SAMARIUM	0.964	2,3	2.2	3.41	1.26	0.352	2.56
EUROPIUM	0.950	2,3	2.2	--	--	--	--
GADOLINIUM	--	3	2.2	5.62	2.23	0.259	2.52
TERBIUM	0.923	3,4	2.2	5.75	2.28	0.261	2.45
DYSPROSIUM	0.908	3	2.2	6.31	2.54	0.243	2.39
HOLMIUM	0.894	3	2.1	6.71	2.67	0.266	2.14
ERBIUM	0.881	3	2.1	7.33	2.96	0.238	2.11
THULIUM	0.869	3	2.1	--	--	--	2.0
YTTERBIUM	0.858	2,3	2.1	1.78	0.70	0.284	7.12
LUTETIUM	0.848	3	2.1	--	--	--	2.3

<u>Tensile Strength, 1000 psi</u>	<u>Yield Strength, 1000 psi</u>	<u>Elongation, per cent</u>	<u>Izod Impact Strength, ft-lb</u>	<u>Resistivity, microhm-cm</u>	<u>Temperature Coefficient of Resistivity, 10<sup>-3</sup>/C</u>	
22.0	9.7	25	1.50	64.9	2.71	YTTRIUM
18.9	18.2	8	4.5	56.8	2.18	LANTHANUM
15.0	13.2	24	2.2	75.3	0.87	CERIUM
15.9	14.5	10	4.75	68.0	1.71	PRASEODYMIUM
24.7	23.9	11	8.3	64.3	1.64	NEODYMIUM
--	--	--	--	--	--	PROMETHIUM
18.0	16.2	3	0.53	88	1.48	SAMARIUM
--	--	--	--	81.3	4.80	EUROPIUM
27.6	25.1	8	1.3	104.5	1.76	GADOLINIUM
--	--	--	3.2	136	0.91	TERBIUM
35.7	32.6	6	1.6	56	1.19	DYSPROSIUM
37.5	32.1	5	7.0	87	1.71	HOLMIUM
42.4	38.7	4	1.2	107	2.01	ERBIUM
--	--	--	--	79	1.95	THULIUM
10.4	9.5	6	5.3	27	1.30	YTTERBIUM
--	--	--	--	79	1.40	LUTETIUM

(Corrosion and oxidation data are given on pages 6 and 7.)

CORROSION DATA AND OXIDATION RESISTANCE<sup>(109)</sup>CORROSION RATES OF RARE EARTHS AND YTTRIUM IN  
DISTILLED WATER AND ACIDS

Medium	Element Corroding at Indicated Corrosion Rates, mils/year						
	$1 - 9 \times 10^6$	$1 - 9 \times 10^4$	$1 - 9 \times 10^3$	$1 - 9 \times 10^2$	10-100	1-10	<1
Distilled Water 30C	Eu	--	--	--	--	La, Ce	Pr, Nd, Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, Y
100C	--	--	Ce	La, Pr, Nd	--	--	Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, Y
1N H <sub>3</sub> PO <sub>4</sub> 30C	Eu	--	--	--	La, Ce, Nd, Gd, Dy, Tm, Yb, Y	Pr, Ho, Er	Sm, Tb
Boiling	--	Ce	La, Pr	Nd	--	--	Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, Y
5N H <sub>3</sub> PO <sub>4</sub> 30C	Eu	--	Sm, Gd, Tb, Dy, Ho, Tm, Y	Pr, Nd, Er, Yb	La, Ce	--	--
1N CrO <sub>3</sub> , 30C	--	Eu	La, Tm	Tb, Nd, Ho, Er	Ce	Pr, Sm, Gd, Dy, Yb	Y
Boiling	La	Ho, Er	Ce, Pr, Tb	Nd, Sm, Tm, Yb	Gd, Dy, Y	--	--
1N H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> 30C	Eu	--	--	--	Ce, Nd	La, Er, Tm, Yb	Pr, Sm, Gd, Tb, Dy, Ho, Y
Boiling	--	--	La, Ce, Pr, Nd, Sm, Er, Y	Dy, Ho	--	Tb, Tm, Yb	Gd
1:1 H <sub>2</sub> -HNO <sub>3</sub> , 30C	--	Sm	Nd	La, Ce, Pr	Eu	Tb, Ho, Yb	Gd, Dy, Er, Tm, Y

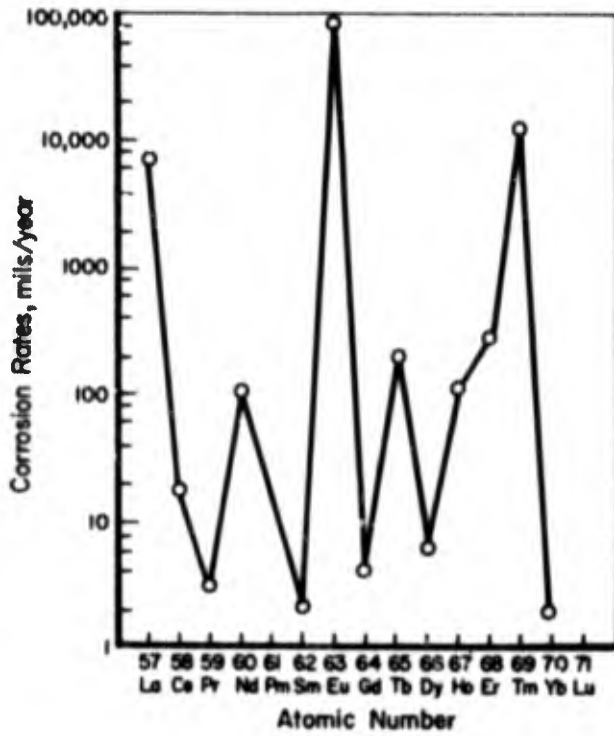
EXPLORATORY CORROSION TESTS OF GADOLINIUM,  
DYSPROSIUM, HOLMIUM, ERBIUM AND YTTRIUM  
AT 25 C

Medium	Corrosion Rate, mils/year
99% H <sub>2</sub> SO <sub>4</sub>	Dissolved <sup>(4)</sup>
37% HCl	Dissolved <sup>(4)</sup>
70% HNO <sub>3</sub>	Dissolved <sup>(4)</sup>
70% HClO <sub>4</sub>	Dissolved <sup>(4)</sup>
1N H <sub>2</sub> SO <sub>4</sub>	Over 10 <sup>6</sup>
1N HCl	Over 10 <sup>6</sup>
1N HNO <sub>3</sub>	$1 - 9 \times 10^6$
1N HClO <sub>4</sub>	$1 - 9 \times 10^6$
1N HCOOH	$1 - 9 \times 10^3$
0.1N H <sub>2</sub> SO <sub>4</sub>	$1 - 9 \times 10^4$
0.1N HCl	$1 - 9 \times 10^4$
1N KCl	$1 - 9 \times 10^4$
1N CuCl <sub>2</sub>	$1 - 9 \times 10^4$
3.5% Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	$1 - 9 \times 10^4$
99.9% CH <sub>3</sub> COOH	$1 - 9 \times 10^3$
85% H <sub>3</sub> PO <sub>4</sub>	$1 - 9 \times 10^3$
48% HF	1 - 10

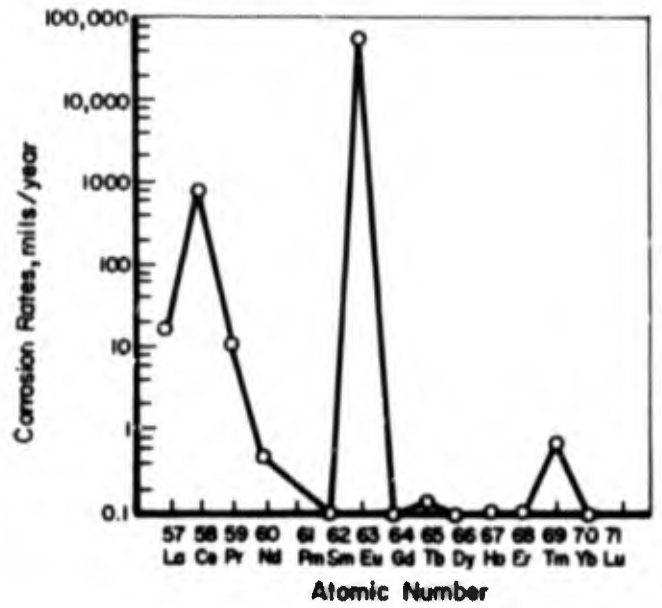
(4) Specimens had surface areas of approx. 2 sq cm and were completely dissolved within 10 minutes.

## OXIDATION OF RARE EARTHS AND YTTRIUM

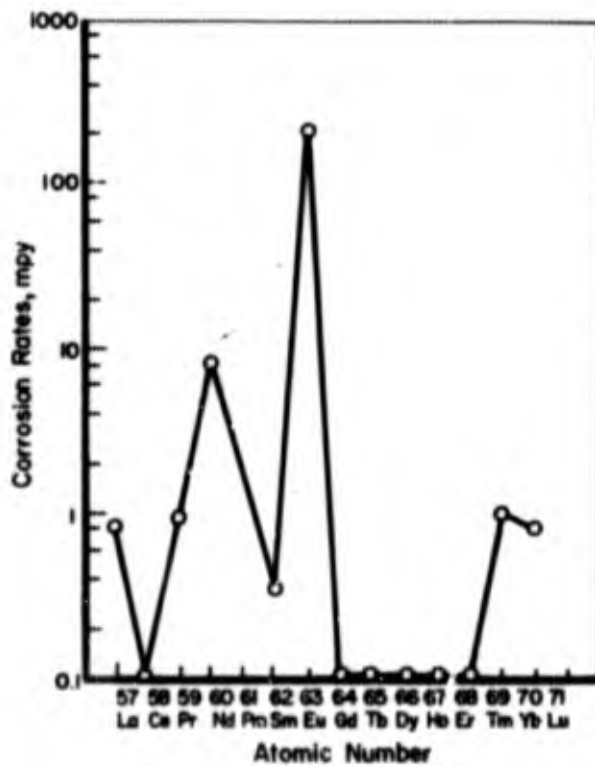
Metal	Weight Gain, milligrams per square decimeter per day				
	Air			Water-Saturated Air at 40C	
	25C	100C	200C	Air in Equilibrium with 30% H <sub>2</sub> O <sub>2</sub> at 40C	
La	2	48	<1	16	6
Ce	4	2000	670	37	25
Pr	<1	11	<1	13	25
Nd	0	3	<1	6	11
Sm	0	0	0	5	20
Eu	1550	230	540	3370	4540
Gd	0	0	0	<1	0
Tb	0	0	0	<1	2
Dy	0	0	0	<1	0
Ho	0	2	<1	<1	0
Er	0	0	0	<1	1
Tm	0	0	0	<1	<1
Y	0	0	0	<1	<1
Y	0	<1	0	0	0



CORROSION RATES OF RARE EARTHS IN 1-NORMAL CHROMIC ACID AT 30 C



CORROSION RATES OF RARE EARTHS IN 1-NORMAL SODIUM HYDROXIDE AT 30 C



CORROSION RATES OF RARE EARTHS IN 1-NORMAL SODIUM NITRITE AT 30 C

(Permission of National Association of Corrosion Engineers)

## PROPERTIES OF RARE EARTH COMPOUNDS

## ANTIMONIDES

Compound	Structure	Lattice Type	$a_0$ , Å	Melting Point, °C	Resistivity, microhm-cm	Magnetic Susceptibility, $10^{-6}$ emu/mole	Effective Magnetic Moment, Bohr magnetons
YSb	Cubic	NaCl	6.16	1925	65	--	--
LaSb	Cubic	NaCl	6.49	1540	120	--	--
CeSb	Cubic	NaCl	6.412	--	--	--	--
PrSb	Cubic	NaCl	6.366	--	--	--	3.63
NdSb	Cubic	NaCl	6.322	--	76	--	--
SmSb	Cubic	NaCl	6.271	--	--	1,000	--
GdSb	Cubic	NaCl	6.217	--	--	25,575	7.87
Gd <sub>4</sub> Sb <sub>3</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	9.224	--	220	--	--
TbSb	Cubic	NaCl	6.180	--	--	36,232	9.57
DySb	Cubic	NaCl	6.160	--	--	45,558	10.62
HoSb	Cubic	NaCl	6.130	--	--	44,743	10.35
ErSb	Cubic	NaCl	6.107	1900	47	36,232	9.36
TmSb	Cubic	NaCl	6.091	--	--	26,667	8.14
YbSb	Cubic	NaCl	6.079	--	--	5,450	3.74
LuSb	Cubic	NaCl	6.0555	--	--	--	--

## ARSENIDES

Compound	Structure	Lattice Type	$a_0$ , Å	Resistivity, microhm-cm	Magnetic Susceptibility, $10^{-6}$ emu/mole	Effective Magnetic Moment, Bohr magnetons
YAs	Cubic	NaCl	5.806	--	--	--
LaAs	Cubic	NaCl	6.137	--	--	--
CeAs	Cubic	NaCl	6.072	--	--	--
PrAs	Cubic	NaCl	6.009	--	--	3.80
NdAs	Cubic	NaCl	5.970	160	--	--
SmAs	Cubic	NaCl	5.921	160	1,000	--
GdAs	Cubic	NaCl	5.862	--	27,548	8.18
TbAs	Cubic	NaCl	5.827	--	39,033	9.65
DyAs	Cubic	NaCl	5.803	--	46,946	10.51
HoAs	Cubic	NaCl	5.771	--	46,080	10.47
ErAs	Cubic	NaCl	5.745	--	37,453	9.34
TmAs	Cubic	NaCl	5.721	--	24,390	7.77
YbAs	Cubic	NaCl	5.702	--	7,825	4.61



## Properties

## BERYLLIDES

Compound	$a_0, \text{A}$	Compound	$a_0, \text{A}$
YBe <sub>13</sub>	10.238	GdBe <sub>13</sub>	10.27
LaBe <sub>13</sub>	10.450	TbBe <sub>13</sub>	10.251
CeBe <sub>13</sub>	10.378	DyBe <sub>13</sub>	10.240
PrBe <sub>13</sub>	10.367	HoBe <sub>13</sub>	10.220
NdBe <sub>13</sub>	10.356	ErBe <sub>13</sub>	10.215
PmBe <sub>13</sub>	10.33	TmBe <sub>13</sub>	10.192
SmBe <sub>13</sub>	10.28	YbBe <sub>13</sub>	10.19
EuBe <sub>13</sub>	10.288	LuBe <sub>13</sub>	10.177

## BISMUTHIDES

Compound	Structure	Lattice Type	$a_0, \text{A}$	Resistivity, microhm-cm	Magnetic Susceptibility, $10^{-6}$ emu/mole	Effective Magnetic Moment, Bohr magnetons
YBi	Cubic	NaCl	6.23	196	--	--
LaBi	Cubic	NaCl	6.58	--	--	--
CeBi	Cubic	NaCl	6.500	--	--	--
PrBi	Cubic	NaCl	6.461	--	--	3.52
NdBi	Cubic	NaCl	6.424	--	--	--
SmBi	Cubic	NaCl	6.362	--	1,169	--
GdBi	Cubic	NaCl	6.316	--	24,038	8.20
Gd <sub>4</sub> Bi <sub>3</sub>	--	--	9.383	190	--	--
TbBi	Cubic	NaCl	6.280	--	36,086	9.64
DyBi	Cubic	NaCl	6.251	--	44,053	10.97
HoBi	Cubic	NaCl	6.228	--	44,543	10.32
ErBi	Cubic	NaCl	6.202	--	45,714	9.32
TmBi	Cubic	NaCl	6.192	--	25,000	7.63

## BORIDES

Compound	Structure	Lattice Constants, A		Density, g/cm <sup>3</sup>	Melting Point, C
		$a_0$	$c_0$		
<u>MB<sub>2</sub></u>					
YB <sub>2</sub>	Hexagonal	3.296	3.843	2.91	2100
GdB <sub>2</sub>	Hexagonal	3.31	3.94	--	--
TbB <sub>2</sub>	Hexagonal	3.28	3.86	--	--
DyB <sub>2</sub>	Hexagonal	3.285	3.835	--	--
HoB <sub>2</sub>	Hexagonal	3.17	3.81	--	--
ErB <sub>2</sub>	Hexagonal	3.28	3.79	--	--
LuB <sub>2</sub>	Hexagonal	3.246	3.704	9.76	--

## BORIDES (Continued)

Compound	Structure	Lattice Constants, A		Density, g/cm <sup>3</sup>
		a <sub>0</sub>	c <sub>0</sub>	
MB <sub>3</sub>				
YB <sub>3</sub>	Tetragonal	3.78	3.55	3.97
LaB <sub>3</sub>	Tetragonal	3.82	3.96	4.92
PrB <sub>3</sub>	Pseudocubic	3.81	--	5.20
GdB <sub>3</sub>	Tetragonal	3.79	3.63	6.03
YbB <sub>3</sub>	Tetragonal	3.77	3.562	6.74

Compound	Structure	Lattice Constants, A		Density, g/cm <sup>3</sup>	Melting Point, C	Color
		a <sub>0</sub>	c <sub>0</sub>			
MB <sub>4</sub>						
YB <sub>4</sub>	Tetragonal	7.111	4.017	4.36	2,800	--
LaB <sub>4</sub>	Tetragonal	7.30	4.17	5.44	--	--
CeB <sub>4</sub>	Tetragonal	7.205	4.090	5.74	--	Gray brown
PrB <sub>4</sub>	Tetragonal	7.20	4.11	5.74	--	Gray brown
NdB <sub>4</sub>	Tetragonal	7.212	4.1020	5.83	--	--
SmB <sub>4</sub>	Tetragonal	7.174	4.070	6.19	--	Gray brown
GdB <sub>4</sub>	Tetragonal	7.114	4.047	6.446	--	Gray brown
TbB <sub>4</sub>	Tetragonal	7.118	4.0286	6.579	--	Gray brown
DyB <sub>4</sub>	Tetragonal	7.101	4.0174	6.74	--	Gray brown
HoB <sub>4</sub>	Tetragonal	7.064	4.000	6.88	--	Gray brown
ErB <sub>4</sub>	Tetragonal	7.071	3.9972	7.261	--	Gray brown
TmB <sub>4</sub>	Tetragonal	7.06	3.99	7.09	--	Gray brown
YbB <sub>4</sub>	Tetragonal	7.01	4.00	7.31	--	Gray brown
LuB <sub>4</sub>	Tetragonal	6.997	3.938	7.52	--	Gray brown

Properties

BORIDES (Continued)

Compound	Structure	$a_0, \text{ \AA}$	Density, $\text{g/cm}^3$	Melting Point, C	Magnetic Susceptibility, $10^{-6} \text{ emu/mole}$	Effective Magnetic Moment, Bohr magnetons	Work Function, eV	Emissivity, $\lambda = 0.655$
<u>MB<sub>6</sub></u>								
YB <sub>6</sub>	Cubic	4.113	3.76	2,300	--	0.0	2.22	0.7
LaB <sub>6</sub>	Cubic	4.154	4.721	2,100	--	9.0	2.66	0.7
CeB <sub>6</sub>	Cubic	4.137	4.80	2,190	2,260	2.60	2.59	0.68
PrB <sub>6</sub>	Cubic	4.130	4.851	--	4,800	3.37	3.12	0.67
NdB <sub>6</sub>	Cubic	4.125	4.948	2,540	2,420	3.82	3.97	0.64
SmB <sub>6</sub>	Cubic	4.131	5.08	1,810	1,810	2.52	4.4	0.68
EuB <sub>6</sub>	Cubic	4.178	4.938	2,200	--	--	4.9	0.83
GdB <sub>6</sub>	Cubic	4.112	5.30	>2,100	21,000	7.68	2.05	0.65
TbB <sub>6</sub>	Cubic	4.1020	5.385	--	--	--	2.99	0.74
DyB <sub>6</sub>	Cubic	4.0976	5.49	--	--	--	3.53	0.7
HoB <sub>6</sub>	Cubic	4.096	5.53	--	--	--	3.42	0.7
ErB <sub>6</sub>	Cubic	4.110	5.58	--	--	--	3.37	0.7
TmB <sub>6</sub>	Cubic	4.11	5.59	--	--	--	3.34	--
YbB <sub>6</sub>	Cubic	4.144	5.556	--	8,740	4.58	3.13	0.7
LuB <sub>6</sub>	Cubic	4.11	5.74	--	--	--	3.0	0.7

Compound	Structure	$a_0, \text{ \AA}$	Density, $\text{g/cm}^3$
<u>MB<sub>12</sub></u>			
YB <sub>12</sub>	Cubic	7.500	3.44
TbB <sub>12</sub>	Cubic	7.504	--
DyB <sub>12</sub>	Cubic	7.501	4.60
HoB <sub>12</sub>	Cubic	7.492	4.655
ErB <sub>12</sub>	Cubic	7.484	4.705
TmB <sub>12</sub>	Cubic	7.476	4.756
YbB <sub>12</sub>	Cubic	7.476	--
LuB <sub>12</sub>	Cubic	7.464	4.868

Compound	Structure	Lattice Constants, $\text{ \AA}$		Melting Point, C
		$a_0$	$c_0$	
<u>MB<sub>70</sub></u>				
YB <sub>70</sub>	Tetragonal	11.75	12.62	(2,000)

## CARBIDES

Compound	Melting Point, C	Resistivity, microhm-cm
YC	1,950	$4.54 \times 10^4$

Compound	Structure	Lattice Type	Lattice Constants, Å		Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
			a <sub>0</sub>	c <sub>0</sub>					
<u>MC<sub>2</sub></u>									
YC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.664	6.169	4.528	2300	88.7	--	--
α-LaC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.92	6.56	5.35	--	68	--	--
β-LaC <sub>2</sub>	Cubic	FeS <sub>2</sub>	6.0	--	5.0	2438	--	--	--
CeC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.88	6.49	5.56	2540	58.8	1,640	2.19
PrC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.85	6.42	5.73	2585	25.7	4,500	(3.15)
NdC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.82	6.37	6.00	>2000	--	--	3.53
SmC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.76	6.29	6.50	>2200	--	~2,300	2.85
GdC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.718	6.275	6.939	>2200	--	--	7.92
TbC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.690	6.217	7.176	--	--	~2,850	9.57
DyC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.669	6.176	7.450	--	--	~38,500	10.53
HoC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.643	6.139	7.701	--	--	~43,500	10.57
ErC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.620	6.094	7.954	--	--	~33,300	8.75
TmC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.600	6.047	8.175	--	--	--	--
YbC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	2.673	6.109	8.097	--	--	~2,500	3.68
LuC <sub>2</sub>	Body-centered tetragonal	CaC <sub>2</sub>	3.563	5.964	8.728	--	--	--	--

Compound	Structure	Lattice Type	a <sub>0</sub> , Å	Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm
<u>M<sub>2</sub>C<sub>3</sub></u>						
Y <sub>2</sub> C <sub>3</sub>	--	--	--	--	1,800	350
La <sub>2</sub> C <sub>3</sub>	Bcc	Pu <sub>2</sub> C <sub>3</sub>	8.8185	8.079	2,000	144
Ce <sub>2</sub> C <sub>3</sub>	Bcc	Pu <sub>2</sub> C <sub>3</sub>	8.448	6.369	--	302
Pr <sub>2</sub> C <sub>3</sub>	Bcc	Pu <sub>2</sub> C <sub>3</sub>	8.7072	6.821	--	--
Nd <sub>2</sub> C <sub>3</sub>	Bcc	Pu <sub>2</sub> C <sub>3</sub>	8.5478	6.902	--	--
Sm <sub>2</sub> C <sub>3</sub>	Bcc	Pu <sub>2</sub> C <sub>3</sub>	8.6257	7.477	--	--
Gd <sub>2</sub> C <sub>3</sub>	Bcc	Pu <sub>2</sub> C <sub>3</sub>	8.3407	8.084	--	--
Tb <sub>2</sub> C <sub>3</sub>	Bcc	Pu <sub>2</sub> C <sub>3</sub>	8.2617	8.335	--	--

CARBIDES (Continued)

Component	Structure	Lattice Type	$a_0, \text{Å}$	Density, $\text{g/cm}^3$	Melting Point, C	Resistivity, microhm-cm
<u><math>M_2C_3</math> (Continued)</u>						
$Dy_2C_3$	Bcc	$Pu_2C_3$	8.198	--	--	--
$Ho_2C_3$	Bcc	$Pu_2C_3$	8.176	8.892	--	--
$Er_2C_3$	--	$Y_2C_3$	--	--	--	--
$Tm_2C_3$	--	$Y_2C_3$	--	--	--	--

Compound	Structure	Lattice Type	$a_0, \text{Å}$	Density, $\text{g/cm}^3$
<u><math>M_3C</math></u>				
$Y_3C$	Cubic	$Fe_4N$	5.102	5.41
$Sm_3C$	Cubic	$Fe_4N$	5.172	8.139
$Gd_3C$	Cubic	$Fe_4N$	5.126	8.701
$Tb_3C$	Cubic	$Fe_4N$	5.107	8.882
$Dy_3C$	Cubic	$Fe_4N$	5.079	9.211
$Ho_3C$	Cubic	$Fe_4N$	5.061	9.434
$Er_3C$	Cubic	$Fe_4N$	5.034	4.708
$Tm_3C$	Cubic	$Fe_4N$	5.016	9.901
$Yb_3C$	Cubic	$Fe_4N$	4.993	10.26
$Lu_3C$	Cubic	$Fe_4N$	4.965	10.54

GERMANIDES

Compound	Structure	Lattice Type	Lattice Constants, Å		
			$a_0$	$b_0$	$c_0$
<u>MGe</u>					
GdGe	Orthorhombic	CrB	4.175	3.960	10.61
DyGe	Orthorhombic	CrB	4.112	3.924	10.81

## GERMANIDES (Continued)

Compound	Structure	Lattice Type	Lattice Constants, Å			Density, g/cm <sup>3</sup>
			a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>	
<u>MGe<sub>2</sub></u>						
YGe <sub>2</sub>	Imperfect	--	3.96	--	4.14	--
α-LaGe <sub>2</sub>	--	α-ThSi <sub>2</sub>	4.321	--	14.209	--
β-LaGe <sub>2</sub>	--	α-GdSi <sub>2</sub>	4.41	4.30	14.190	7.059
α-CeGe <sub>2</sub>	--	α-ThSi <sub>2</sub>	4.27	--	14.08	--
β-CeGe <sub>2</sub>	--	α-GdSi <sub>2</sub>	4.36	4.26	14.07	--
PrGe <sub>2</sub>	--	α-ThSi <sub>2</sub>	4.26	--	13.98	--
NdGe <sub>2</sub>	--	α-ThSi <sub>2</sub>	4.230	--	13.920	--
SmGe <sub>2</sub>	--	α-ThSi <sub>2</sub>	4.193	--	13.835	--
EuGe <sub>2</sub>	--	AlB <sub>2</sub> defect	4.09	--	4.99	--
GdGe <sub>2</sub>	--	α-ThSi <sub>2</sub>	4.12	--	13.72	--

Compound	Lattice Type	Lattice Constants, Å	
		a <sub>0</sub>	c <sub>0</sub>
<u>M<sub>2</sub>Ge<sub>3</sub></u>			
Th <sub>2</sub> Ge <sub>3</sub>	AlB <sub>2</sub> defect	3.95	4.16
Dy <sub>2</sub> Ge <sub>3</sub>	AlB <sub>2</sub> defect	3.92	4.13
Ho <sub>2</sub> Ge <sub>3</sub>	AlB <sub>2</sub> defect	3.90	4.11
Er <sub>2</sub> Ge <sub>3</sub>	AlB <sub>2</sub> defect	3.89	4.09
Tm <sub>2</sub> Ge <sub>3</sub>	AlB <sub>2</sub> defect	3.88	4.07
Yb <sub>2</sub> Ge <sub>3</sub>	AlB <sub>2</sub> defect	3.96	4.18
Lu <sub>2</sub> Ge <sub>3</sub>	AlB <sub>2</sub> defect	3.83	4.05

Compound	Structure	Lattice Constants, Å		Density, g/cm <sup>3</sup>
		a <sub>0</sub>	c <sub>0</sub>	
<u>M<sub>5</sub>Ge<sub>3</sub></u>				
La <sub>5</sub> Ge <sub>3</sub>	Hcp	8.958	6.796	3.72
Ce <sub>5</sub> Ge <sub>3</sub>	Hcp	8.875	6.870	3.92

HALIDES

Compound	Structure	Lattice Constants, A			Melting Point, C	Boiling Point, C
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>		
<u>MBr<sub>3</sub></u>						
YBr <sub>3</sub>	Hexagonal	4.102	--	6.399	904	1,463
LaBr <sub>3</sub>	Hexagonal	--	--	--	788	1,580
CeBr <sub>3</sub>	Hexagonal	--	--	--	732	1,560
PrBr <sub>3</sub>	--	--	--	--	693	1,550
NdBr <sub>3</sub>	--	--	--	--	684	1,540
PmBr <sub>3</sub>	--	--	--	--	677	1,530
SmBr <sub>3</sub>	--	--	--	--	664	Decomposes
EuBr <sub>3</sub>	Orthorhombic	12.712	4.019	9.128	707	Decomposes
GdBr <sub>3</sub>	Hexagonal	4.172	--	6.441	785	1,490
TbBr <sub>3</sub>	Hexagonal	4.129	--	6.391	827	1,490
DyBr <sub>3</sub>	Hexagonal	4.114	--	6.400	881	1,480
HoBr <sub>3</sub>	Hexagonal	4.088	--	6.391	914	1,470
ErBr <sub>3</sub>	Hexagonal	4.070	--	6.388	950	1,460
TmBr <sub>3</sub>	Hexagonal	4.042	--	6.367	955	1,440
YbBr <sub>3</sub>	Hexagonal	4.032	--	6.382	940	Decomposes
LuBr <sub>3</sub>	Hexagonal	4.015	--	6.371	957	1,410

Compound	Structure	Lattice Constants, A			Melting Point, C	Boiling Point, C
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>		
<u>MCl<sub>2</sub></u>						
SmCl <sub>2</sub>	Orthorhombic	8.973	7.532	4.497	740	2,030
EuCl <sub>2</sub>	Orthorhombic	8.914	7.499	4.493	727	2,030
YbCl <sub>2</sub>	Orthorhombic	6.53	6.68	6.91	727	1,930

## HALIDES (Continued)

Compound	Structure	Lattice Constants, A			$\beta$ , degrees	Melting Point, C	Boiling Point, C
		$a_0$	$b_0$	$c_0$			
<u>MCl<sub>3</sub></u>							
YCl <sub>3</sub>	Monoclinic	11.94	--	--	111.0	700	1,507
LaCl <sub>3</sub>	Hexagonal	--	--	--	--	852	1,750
CeCl <sub>3</sub>	Hexagonal	7.450	--	4.315	--	802	1,730
PrCl <sub>3</sub>	Hexagonal	7.422	--	4.275	--	786	1,710
NdCl <sub>3</sub>	Hexagonal	--	--	--	--	759	1,690
PmCl <sub>3</sub>	Hexagonal	7.397	--	4.211	--	737	1,670
SmCl <sub>3</sub>	Hexagonal	7.378	--	4.171	--	678	Decomposes
EuCl <sub>3</sub>	Hexagonal	7.369	--	4.133	--	623	Decomposes
GdCl <sub>3</sub>	Hexagonal	7.363	--	4.105	--	602	1,580
TbCl <sub>3</sub>	Monoclinic	6.163	3.848	8.357	107.6	588	1,550
DyCl <sub>3</sub>	Monoclinic	6.91	11.97	6.40	111.2	654	1,530
HoCl <sub>3</sub>	Monoclinic	6.85	11.85	6.39	110.8	720	1,510
ErCl <sub>3</sub>	Monoclinic	6.80	11.79	6.39	110.7	776	1,500
TmCl <sub>3</sub>	Monoclinic	6.75	11.73	6.39	110.6	821	1,490
YbCl <sub>3</sub>	Monoclinic	6.73	11.65	6.38	110.4	854	Decomposes
LuCl <sub>3</sub>	Monoclinic	6.72	11.60	6.39	--	892	1,480

Compound	Structure	Lattice Constants, A			Density, g/cm <sup>3</sup>	Melting Point, C	Boiling Point, C
		$a_0$	$b_0$	$c_0$			
<u>MF<sub>3</sub> and MF<sub>4</sub></u>							
YF <sub>3</sub>	Orthorhombic	6.353	6.850	4.393	5.069	1,148	(2, 227)
YF <sub>3</sub>	Cubic	5.644	--	--	--	--	--
LaF <sub>3</sub>	Hcp	7.186	--	7.352	5.94	1,490	(2, 327)
CeF <sub>3</sub>	Hexagonal	7.114	--	7.273	5.99	1,437	(2, 327)
PrF <sub>3</sub>	Hexagonal	7.061	--	7.218	6.18	1,395	(2, 327)
NdF <sub>3</sub>	Hexagonal	7.030	--	7.200	6.37	1,374	(2, 327)
PmF <sub>3</sub>	Hexagonal	6.96	--	7.14	--	1,407	(2, 327)
SmF <sub>3</sub>	Orthorhombic	6.669	7.059	4.405	6.643	1,306	(2, 327)
SmF <sub>3</sub>	Hexagonal	6.956	--	7.120	6.925	--	--
EuF <sub>3</sub>	Orthorhombic	6.622	7.019	4.396	6.793	1,276	(2, 277)
EuF <sub>3</sub>	Hexagonal	6.916	--	7.091	7.088	--	--
GdF <sub>3</sub>	Orthorhombic	6.570	6.894	4.393	7.047	1,228	(2, 277)
TbF <sub>3</sub>	Orthorhombic	6.513	6.949	4.384	7.236	1,172	(2, 277)
TbF <sub>4</sub>	Monoclinic <sup>(s)</sup>	12.1	10.3	7.9	--	--	--
DyF <sub>3</sub>	Orthorhombic	6.460	6.906	4.376	7.456	1,154	2, 230
HoF <sub>3</sub>	Orthorhombic	6.404	6.875	4.379	7.644	1,143	2, 230
HoF <sub>3</sub>	Hexagonal	6.833	--	6.984	7.829	--	--
ErF <sub>3</sub>	Orthorhombic	6.354	6.846	4.380	7.814	1,140	2, 230
TmF <sub>3</sub>	Orthorhombic	6.283	6.811	4.408	7.971	--	--
TmF <sub>3</sub>	Hexagonal	6.763	--	6.927	8.220	1,158	2, 230
YbF <sub>3</sub>	Orthorhombic	6.216	6.786	4.434	8.168	1,157	2, 230
LuF <sub>3</sub>	Orthorhombic	6.151	6.758	4.467	8.332	1,182	2, 225

(s)  $\beta = 126$  deg.



HALIDES (Continued)

Compound	Structure	Lattice Constants, A			Melting Point, C	Boiling Point, C
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>		
<u>Ml<sub>3</sub></u>						
YI <sub>3</sub>	Hexagonal	4.340	--	6.960	1,000	1,307
LaI <sub>3</sub>	--	--	--	--	761	1,405
CeI <sub>3</sub>	Orthorhombic	14.0	4.4	10.1	752	1,400
PrI <sub>3</sub>	Orthorhombic	13.9	4.3	10.0	738	1,380
NdI <sub>3</sub>	Orthorhombic	13.988	4.316	9.977	787	1,370
PmI <sub>3</sub>	--	--	--	--	797	1,370
SmI <sub>3</sub>	Hexagonal	4.415	--	6.976	820	Decomposes
EuI <sub>3</sub>	--	--	--	--	(877)	Decomposes
GdI <sub>3</sub>	Hexagonal	4.383	--	6.968	926	1,340
TbI <sub>3</sub>	Hexagonal	4.357	--	6.954	(952)	(1,330)
DyI <sub>3</sub>	Hexagonal	4.335	--	6.958	955	1,320
HoI <sub>3</sub>	Hexagonal	4.319	--	6.946	1,010	1,300
ErI <sub>3</sub>	--	--	--	--	1,020	1,280
TmI <sub>3</sub>	Hexagonal	4.288	--	6.934	1,015	1,260
YbI <sub>3</sub>	Hexagonal	4.265	--	6.931	(1,027)	Decomposes
LuI <sub>3</sub>	Hexagonal	4.271	--	6.930	1,045	1,210

Compound	Structure	Lattice Constants, A	
		a <sub>0</sub>	c <sub>0</sub>
<u>MOBr</u>			
LaOBr	Tetragonal	4.149	7.359

Compound	Structure	Lattice Constants, A		Heat of Formation, kcal/mole
		a <sub>0</sub>	c <sub>0</sub>	
<u>MOCI</u>				
YOCl	Tetragonal	3.903	6.597	--
LaOCl	Tetragonal	4.149	7.359	242.6
CeOCl	Tetragonal	4.080	6.831	--
PrOCl	Tetragonal	4.051	6.810	242.8
NdOCl	Tetragonal	4.018	6.782	237.1
SmOCl	Tetragonal	3.982	6.721	(238)
EuOCl	Tetragonal	3.965	6.695	--
GdOCl	Tetragonal	3.950	6.672	234.8
TbOCl	Tetragonal	3.927	6.645	--
DyOCl	Tetragonal	3.911	6.620	--
HoOCl	Tetragonal	3.893	6.602	--
ErOCl	Tetragonal	3.88	6.58	--

## HALIDES (Continued)

Compound	Structure	Lattice Constants, A		$\beta$ , degrees	Density, g/cm <sup>3</sup>
		$a_0$	$c_0$		
<u>MOF</u>					
YOF	--	--	--	--	5.13
LaOF	Cubic	7.132	--	--	6.00
CeOF	Fcc	5.703	--	--	--
PrOF	Rhombohedral	7.016	--	33.03	6.39
NdOF	Rhombohedral	6.953	--	33.04	6.65
$\alpha$ -PmOF	Fcc	5.56	--	--	--
$\beta$ -PmOF	Tetragonal	3.95	5.58	--	--
SmOF	Rhombohedral	6.857	--	33.07	7.19
EuOF	Rhombohedral	6.827	--	33.05	--
GdOF	Rhombohedral	6.800	--	33.05	7.51
TbOF	Rhombohedral	6.758	--	33.02	--
DyOF	Rhombohedral	--	--	--	--

Compound	Structure	Lattice Type	Lattice Constants, A	
			$a_0$	$c_0$
<u>MOI</u>				
LaOI	Tetragonal	PbFCI	4.144	9.126
SmOI	Tetragonal	PbFCI	4.008	9.192
TmOI	Tetragonal	PbFCI	3.887	9.166
YbOI	Tetragonal	PbFCI	3.870	9.161

## HYDRIDES

Compound	Structure	Lattice Constants, A			Density, g/cm <sup>3</sup>	Heat of Formation, kcal/mole H <sub>2</sub>	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
		$a_0$	$b_0$	$c_0$				
<u>MH<sub>2</sub>-MD<sub>2</sub></u>								
YH <sub>2</sub>	--	5.205	--	--	--	--	--	--
LaH <sub>2</sub>	--	5.667	--	--	5.14	49.7	--	--
CeH <sub>2</sub>	Fluorite	5.561	--	--	5.43	33.9	--	--
PrH <sub>2</sub>	Fluorite	5.517	--	--	5.65	47.8	--	--
NdH <sub>2</sub>	Fluorite	5.464	--	--	5.94	44.8	--	--
SmH <sub>2</sub>	Fluorite	5.374	--	--	6.52	--	--	--
EuD <sub>2</sub>	Orthorhombic	6.21	3.77	7.16	--	--	--	--
GdH <sub>2</sub>	Fluorite	5.303	--	--	7.08	46.9	--	--
TbH <sub>2</sub>	Cubic	5.246	--	--	--	--	--	--
DyH <sub>2</sub>	Cubic	5.201	--	--	--	--	46,700	10.8
HoH <sub>2</sub>	Cubic	5.165	--	--	--	--	--	--
ErH <sub>2</sub>	Cubic	5.123	--	--	--	--	36,200	9.75
TmH <sub>2</sub>	Cubic	5.090	--	--	--	--	21,870	7.60
YbH <sub>2</sub>	Orthorhombic	--	--	--	--	--	--	--
YbD <sub>2</sub>	Orthorhombic	5.871	3.561	6.763	--	--	--	--
LuH <sub>2</sub>	Cubic	5.033	--	--	--	--	--	--

HYDRIDES (Continued)

Compound	Structure	Lattice Constants, Å			Density, g/cm <sup>3</sup>	Heat of Formation, kcal/mole H <sub>2</sub>	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>				
MH <sub>3</sub> -MD <sub>3</sub>								
YH <sub>3</sub>	Hcp	3.672	--	6.625	--	--	--	--
YD <sub>3</sub>	Hcp	3.659	--	6.586	--	--	--	--
LaH <sub>3</sub>	Amorphous	--	--	--	5.26	40.09	--	--
CeH <sub>3</sub>	Fluorite	--	--	--	5.55	42.26	--	--
PrH <sub>3</sub>	Fluorite	--	--	--	5.56	39.52	--	--
NdH <sub>3</sub>	Fluorite	--	--	--	--	--	--	--
SmH <sub>3</sub>	Hexagonal	3.782	--	6.779	--	--	--	--
GdH <sub>3</sub>	Hexagonal	3.73	--	6.71	--	--	--	--
TbH <sub>3</sub>	Hexagonal	3.700	--	6.658	--	--	--	--
DyH <sub>3</sub>	Hexagonal	3.671	--	6.615	--	--	38,900	9.5
HoH <sub>3</sub>	Hexagonal	3.642	--	6.560	--	--	--	--
ErH <sub>3</sub>	Hexagonal	3.621	--	6.526	--	--	34,900	9.54
TmH <sub>3</sub>	Hexagonal	3.599	--	6.489	--	--	21,140	7.47
LuH <sub>3</sub>	Hexagonal	3.558	--	6.443	--	--	--	--

NITRIDES

Compound	Structure	Lattice Type	a <sub>0</sub> , Å	Density, g/cm <sup>3</sup>	Heat of Formation, kcal/ mole	Resistivity, microhm- cm	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
LaN	Fcc	NaCl	5.286	6.73	72	100	--	--
CeN	Fcc	NaCl	5.02	7.89	78	--	433	--
PrN	Fcc	NaCl	5.16	7.467	--	110	4,460	3.66
NdN	Fcc	NaCl	5.151	7.691	--	75	5,850	3.71
SmN	Fcc	NaCl	5.046	8.495	--	--	1,125	--
EuN	Fcc	NaCl	5.014	8.767	--	--	--	--
GdN	Fcc	NaCl	4.999	9.105	--	--	35,600	8.2
TbN	Fcc	NaCl	4.933	9.567	--	--	42,900	8.8
DyN	Fcc	NaCl	4.905	9.507	--	100	48,900	10.6
HoN	Fcc	NaCl	4.87	10.26	--	110	47,800	10.3
ErN	Fcc	NaCl	4.831	10.26	--	79	36,300	9.2
TmN	Fcc	NaCl	4.809	10.84	--	--	23,600	7.5
YbN	Fcc	NaCl	4.78	11.33	--	--	7,250	4.8
LuN	Fcc	NaCl	4.766	11.59	--	--	--	--

## OXIDES

Compound	Structure	Lattice Type	$a_0$ , Å	Density, g/cm <sup>3</sup>	Heat of Formation, kcal/mole metal
<u>MO</u>					
SmO	Fcc	NaCl	4.988	--	159
EuO	Fcc	--	3.142	8.16	145.2
YbO	--	--	--	--	159

Compound	Struct.	$a_0$ , Å	Density, g/cm <sup>3</sup>	Melting Point, °C	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole
<u>MO<sub>2</sub></u>					
CeO <sub>2</sub>	Fcc	3.41	7.2	1,950	--
PrO <sub>2</sub>	--	--	--	--	1,910

Compound	Structure	Lattice Constants, Å			$\beta$ , degrees	Density, g/cm <sup>3</sup>	Melting Point, °C	Heat of Formation, kcal/mole of metal	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
		$a_0$	$b_0$	$c_0$						
<u>M<sub>2</sub>O<sub>3</sub></u>										
Y <sub>2</sub> O <sub>3</sub>	Bcc	10.60	--	--	--	5.03	2,410	227.73	--	--
La <sub>2</sub> O <sub>3</sub>	Hcp	3.94	--	6.16	--	6.51	2,300	214.29	--	0.0
Ce <sub>2</sub> O <sub>3</sub>	Hcp	3.880	--	6.057	--	--	-1,690	217.46	--	2.6
Pr <sub>2</sub> O <sub>3</sub>	Cubic	10.9	--	--	--	7.0	2,200	218.4	4,410	3.6
Pr <sub>2</sub> O <sub>3</sub>	Hexagonal	--	--	--	--	--	--	217.9	--	--
Nd <sub>2</sub> O <sub>3</sub>	Hexagonal	3.831	--	5.999	--	7.24	2,270	216.06	--	3.7
Pm <sub>2</sub> O <sub>3</sub> (A)	Hexagonal	3.806	--	5.954	--	--	--	(216.5)	--	2.8
(B)	Monoclinic	14.15	3.69	8.78	98.5	--	--	--	--	--
(C)	Cubic	10.99	--	--	--	--	--	--	--	--
$\alpha$ -Sm <sub>2</sub> O <sub>3</sub>	Monoclinic	--	--	--	--	7.43	--	--	--	--
$\beta$ -Sm <sub>2</sub> O <sub>3</sub>	Cubic	10.90	--	--	--	7.62	2,350	--	--	1.6
$\alpha$ -Eu <sub>2</sub> O <sub>3</sub>	Bcc	10.689	--	--	--	7.28	--	194.8	--	--
$\beta$ -Eu <sub>2</sub> O <sub>3</sub>	Monoclinic	14.082	3.640	8.788	100	7.99	2,050	195.5	--	3.4
$\alpha$ -Gd <sub>2</sub> O <sub>3</sub>	Cubic	10.79	--	--	--	7.41	--	216.97	--	--
$\beta$ -Gd <sub>2</sub> O <sub>3</sub>	Monoclinic	--	--	--	--	--	2,350	--	--	7.9
Tb <sub>2</sub> O <sub>3</sub>	Bcc	10.69	--	--	--	7.81	2,390	218.4	35,800	9.7
Dy <sub>2</sub> O <sub>3</sub>	Bcc	10.63	--	--	--	7.81	2,340	222.92	--	10.6
Ho <sub>2</sub> O <sub>3</sub>	Bcc	10.58	--	--	--	8.36	--	224.78	--	10.6
Er <sub>2</sub> O <sub>3</sub>	Bcc	10.51	--	--	--	8.640	--	226.80	--	9.6
Tm <sub>2</sub> O <sub>3</sub>	Bcc	10.52	--	--	--	8.6	--	225.7	--	7.6
Yb <sub>2</sub> O <sub>3</sub>	Bcc	10.41	--	--	--	9.2	2,350	216.84	--	4.5
Lu <sub>2</sub> O <sub>3</sub>	Bcc	10.38	--	--	--	--	--	224.5	--	0.0

OXIDES (Continued)

Compound	Structure	Lattice Constants, Å			Density, g/cm <sup>3</sup>	Heat of Formation, kcal/mole of metal	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>			
<u>Other Oxides</u>							
Pr <sub>6</sub> O <sub>11</sub>	Cubic	5.4695	--	--	--	--	2,540
Eu <sub>2</sub> O <sub>3</sub>	Orthorhombic	10.085	12.054	3.502	8.07	--	--
Oxide I (Eu <sub>10</sub> O <sub>21</sub> )	Orthorhombic	9.75	49.5	5.63	6.74	--	--
Tb <sub>4</sub> O <sub>7</sub>	Cubic	10.70	--	--	--	224.8	30,100

PHOSPHIDES

Compound	Structure	Lattice Type	a <sub>0</sub> , Å	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
Y <sub>2</sub> P <sub>3</sub>	Fcc	NaCl	5.682	--	--
LaP	Fcc	NaCl	6.016	--	--
CeP	Fcc	NaCl	5.909	--	--
PrP	Fcc	NaCl	5.872	--	3.77
NdP	Fcc	NaCl	5.838	--	--
SmP	Fcc	NaCl	5.760	1,112	--
GdP	Fcc	NaCl	5.723	28,450	7.95
TbP	Fcc	NaCl	5.686	39,526	9.55
DyP	Fcc	NaCl	5.654	46,729	10.34
HoP	Fcc	NaCl	5.626	46,083	10.34
ErP	Fcc	NaCl	5.606	37,523	9.32
TmP	Fcc	NaCl	5.573	25,316	7.93
YbP	Fcc	NaCl	5.554	1,813	4.5

## SELENIDES

Compound	Structure	Lattice Type	Lattice Constant, $a_0$ , Å	Density, $g/cm^3$	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, $10^{-6}$ emu/mole	Effective Magnetic Moment, Bohr magnetons
TlSe	Fcc	NaCl	5.703	--	--	--	--	--
LaSe	Fcc	NaCl	6.048	6.34	--	--	--	--
CeSe	Fcc	NaCl	5.992	6.55	1820	50	7.08	0.46
PrSe	Fcc	NaCl	5.940	6.80	--	100	2,186	2.3
NdSe	Fcc	NaCl	5.879	6.93	--	--	4,611	3.3
SmSe	Fcc	NaCl	6.159	6.42	2100	50	4,780	3.4
EuSe	Fcc	NaCl	6.178	6.42	2286	$1.38 \times 10^9$	4,440	3.3
GdSe	Fcc	NaCl	5.758	8.2	1865	--	--	7.65
TbSe	Fcc	NaCl	5.740	--	--	72	22,090	8.20
DySe	Fcc	NaCl	5.711	--	--	--	33,755	9.82
HoSe	Fcc	NaCl	5.680	--	--	--	40,984	10.37
ErSe	Fcc	NaCl	5.662	--	(1800)	--	43,478	10.62
TmSe	Fcc	NaCl	5.640	--	--	170	35,635	9.56
YbSe	Fcc	NaCl	5.594	--	1945	--	18,180	6.89
						$1.0 \times 10^8$	--	0.84

Compound	Structure	Lattice Constants, Å			Density, $g/cm^3$	Resistivity, microhm-cm	Magnetic Susceptibility, $10^{-6}$ emu/mole	Effective Magnetic Moment, Bohr magnetons
		$a_0$	$b_0$	$c_0$				
MSe <sub>2</sub>								
LaSe <sub>2</sub>	Tetragonal	8.47	--	8.53	6.33	$1.46 \times 10^4$	32	0
CeSe <sub>2</sub>	Tetragonal	8.43	--	8.49	6.45	$2.92 \times 10^4$	--	2.2
PrSe <sub>2</sub>	Tetragonal	8.37	--	8.44	6.68	--	4,630	3.3
NdSe <sub>2</sub>	Tetragonal	8.33	--	8.41	6.83	--	4,763	3.4
SmSe <sub>2</sub>	Tetragonal	8.16	--	8.36	6.94	--	1,200	1.6
GdSe <sub>2</sub>	Orthorhombic	7.27	4.03	8.30	--	--	--	--

Compound	Structure	Lattice Type	Lattice Constants, Å			Density, $g/cm^3$	Resistivity, microhm-cm	Magnetic Susceptibility, $10^{-6}$ emu/mole	Effective Magnetic Moment, Bohr magnetons
			$a_0$	$b_0$	$c_0$				
M <sub>2</sub> Se <sub>3</sub>									
Y <sub>2</sub> Se <sub>3</sub>	Fcc	NaCl	5.75	--	--	4.81	--	--	
La <sub>2</sub> Se <sub>3</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	9.037	--	--	6.15	$2.4 \times 10^4$	69.77	
Ce <sub>2</sub> Se <sub>3</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.960	--	--	6.33	$3.3 \times 10^3$	2,068	
Pr <sub>2</sub> Se <sub>3</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.909	--	--	--	--	4,465	
Nd <sub>2</sub> Se <sub>3</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.841	--	--	6.69	--	4,685	

SELENIDES (Continued)

Compound	Structure	Lattice Type	Lattice Constants, Å			Density, g/cm <sup>3</sup>	Resistivity, microhm-cm	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
			a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>				
<u>M<sub>2</sub>Se<sub>3</sub> (Continued)</u>									
Sm <sub>2</sub> Se <sub>3</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.76	--	--	6.93	1.7 x 10 <sup>3</sup>	1,049	1.6
Gd <sub>2</sub> Se <sub>3</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.72	--	--	7.36	1.3 x 10 <sup>3</sup>	21,994	--
Dy <sub>2</sub> Se <sub>3</sub>	Orthorhombic	--	3.69	10.85	11.0	7.21	--	43,250	10.40
Er <sub>2</sub> Se <sub>3</sub>	Fcc	NaCl	5.71	--	--	6.59	7.9 x 10 <sup>5</sup>	38,600	9.63
Yb <sub>2</sub> Se <sub>3</sub>	Fcc	NaCl	5.66	--	--	7.33	--	7,890	4.76
Lu <sub>2</sub> Se <sub>3</sub>	Fcc	NaCl	5.62	--	--	--	--	--	--

Compound	Structure	Lattice Type	a <sub>0</sub> , Å	Density, g/cm <sup>3</sup>	Resistivity, microhm-cm	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole
La <sub>3</sub> Se <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	9.037	6.47	--	10.84
Ce <sub>3</sub> Se <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.973	6.76	8.0 x 10 <sup>3</sup>	--
Pr <sub>3</sub> Se <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.927	6.89	--	--
Nd <sub>3</sub> Se <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.859	7.15	--	--
Sm <sub>3</sub> Se <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.84	7.33	--	--
Gd <sub>3</sub> Se <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	8.718	--	1.1 x 10 <sup>3</sup>	--

Compound	Structure	Lattice Constants, Å		Density, g/cm <sup>3</sup>	Color
		a <sub>0</sub>	c <sub>0</sub>		
<u>M<sub>2</sub>O<sub>2</sub>Se</u>					
La <sub>2</sub> O <sub>2</sub> Se	Hcp	4.09	7.14	--	Beige
Ce <sub>2</sub> O <sub>2</sub> Se	Hcp	4.04	7.08	6.51	Maroon
Pr <sub>2</sub> O <sub>2</sub> Se	Hcp	4.01	7.04	6.65	Beige
Nd <sub>2</sub> O <sub>2</sub> Se	Hcp	3.97	6.97	6.99	Blue-white
Sm <sub>2</sub> O <sub>2</sub> Se	Hcp	3.93	6.93	7.40	Gray
Gd <sub>2</sub> O <sub>2</sub> Se	Hcp	3.90	6.87	7.80	Beige
Dy <sub>2</sub> O <sub>2</sub> Se	Hcp	3.83	6.79	8.39	Light gray
Er <sub>2</sub> O <sub>2</sub> Se	Hcp	3.81	7.58	8.68	Pink
Yb <sub>2</sub> O <sub>2</sub> Se	Hcp	3.76	6.69	9.26	Beige

## SILICIDES

Compound	Structure	Lattice Type	Lattice Constants, Å			Density, g/cm <sup>3</sup>	Heat of Formation, kcal/mole	Melting Point, C	
			a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>				
<u>MSi</u>									
YSi	Orthorhombic	CaSi	4.25	10.52	3.82	4.528	32.2	1,870	
LaSi	Orthorhombic	FeB	8.48	4.02	6.04	--	(64)	--	
CeSi	Orthorhombic	FeB	--	--	--	--	--	--	
Compound	Structure	Lattice Type	Lattice Constants, Å			Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm	α - β Transition Temperature, C
			a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>				
<u>MSi<sub>2</sub>-MSi<sub>2-n</sub></u>									
α-YSi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.04	3.95	13.23	4.5	--	--	--
β-YSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.04	--	13.14	4.39	1,520	--	540
LaSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.31	--	13.80	5.0	1,520	236	--
CeSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.175	--	13.848	5.45	--	408	--
α-PrSi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.23	4.40	13.68	5.38	--	--	--
β-PrSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.140	--	13.65	5.64	--	202	-120
α-NdSi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.18	4.15	13.56	5.82	--	349	--
β-NdSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.103	--	13.53	5.84	1,525	--	20-150
α-SmSi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.105	4.035	13.46	6.13	--	--	--
β-SmSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.041	--	13.33	6.26	--	--	380
β-FuSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.29	--	13.66	5.50	1,500	--	-150
α-CdSi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.09	4.01	13.44	6.43	1,540	263	--
β-CdSi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.10	--	13.61	6.19	2,100	--	400
TbSi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.045	3.96	13.38	--	--	--	--
TbSi <sub>2-n</sub>	Hexagonal	Defect AlB <sub>2</sub>	3.847	--	4.146	--	--	--	--
α-DySi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.04	3.95	13.34	6.8	--	3,020	--
β-DySi <sub>2</sub>	Tetragonal	α-ThSi <sub>2</sub>	4.03	--	13.38	6.68	1,550	--	540
DySi <sub>2-n</sub>	Hexagonal	Defect AlB <sub>2</sub>	3.83	--	4.11	--	--	--	--
HoSi <sub>2</sub>	Orthorhombic	α-YSi <sub>2</sub>	4.03	3.97	13.40	--	--	--	--
HoSi <sub>2-n</sub>	Hexagonal	Defect AlB <sub>2</sub>	3.816	--	4.107	--	--	--	--
ErSi <sub>2</sub>	Hexagonal	--	3.78	--	4.09	--	--	--	--
TmSi <sub>2</sub>	Hexagonal	--	3.76	--	4.07	--	--	--	--
YbSi <sub>2</sub>	Hexagonal	--	3.77	--	4.10	--	--	--	--
LuSi <sub>2</sub>	Hexagonal	--	3.74	--	4.04	--	--	--	--

Compound	Structure	Lattice Constants, Å		Melting Point, C
		a <sub>0</sub>	c <sub>0</sub>	
<u>M<sub>3</sub>Si<sub>5</sub></u>				
Y <sub>3</sub> Si <sub>5</sub>	Hexagonal	3.842	4.104	1,635
Gd <sub>3</sub> Si <sub>5</sub>	Hexagonal	3.877	4.172	--



SILICIDES (Continued)

Compound	Structure	Lattice Type	Lattice Constants, Å		Density, g/cm <sup>3</sup>	Melting Point, C
			a <sub>0</sub>	c <sub>0</sub>		
<u>M<sub>5</sub>Si<sub>3</sub></u>						
Y <sub>5</sub> Si <sub>3</sub>	Hexagonal	Mn <sub>5</sub> Si <sub>3</sub>	8.403	6.303	4.556	1,850

SULFIDES

Compound	Structure	Lattice Type	a <sub>0</sub> , Å	Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
<u>MS</u>								
YS	Cubic	--	5.466	4.92	2,060	--	100	--
LaS	Cubic	--	5.854	5.66	1,970	92	281	--
CeS	Cubic	--	5.778	5.94	2,450	170	2,125	--
PrS	Cubic	--	5.747	6.07	2,230	240	4,730	--
NdS	Cubic	--	5.690	6.36	2,200	242	4,370	--
SmS	Fcc	NaCl	5.967	5.67	1,500	8.5 x 10 <sup>4</sup>	5,070	4.34
EuS	Fcc	NaCl	5.970	5.745	--	--	22,600	--
GdS	Cubic	--	5.574	7.26	--	--	30,300	8.01
TbS	Fcc	NaCl	5.517	--	--	--	35,088	9.63
DyS	Fcc	NaCl	5.490	--	--	--	40,000	10.39
HoS	Fcc	NaCl	5.465	--	--	--	41,464	10.50
ErS	Cubic	--	5.424	--	--	--	35,088	9.50
ErS <sub>1.18</sub>	Cubic	--	5.452	6.75	--	--	--	--
TmS	Fcc	NaCl	5.412	--	--	--	21,505	7.42
YbS	Cubic	--	5.673	6.75	--	--	1,450	--

Compound	Structure	Lattice Constants, Å		Density, g/cm <sup>3</sup>	Melting Point, C	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole
		a <sub>0</sub>	c <sub>0</sub>			
<u>MS<sub>2</sub></u>						
YS <sub>2</sub>	Tetragonal	7.71	7.89	4.33	1,630	125
LaS <sub>2</sub>	Cubic	8.20	--	4.90	1,650	36.3
CeS <sub>2</sub>	Cubic	8.12	--	5.07	1,700	2,286
PrS <sub>2</sub>	Cubic	8.08	--	4.90	1,780	4,800
NdS <sub>2</sub>	Cubic	8.04	--	5.34	1,760	5,082
SmS <sub>2</sub>	Cubic	7.87	--	5.66	1,730	1,238
GdS <sub>2</sub>	Tetragonal	7.85	7.96	5.98	--	21,510
DyS <sub>2</sub>	Tetragonal	7.69	7.85	6.11	--	--

## SULFIDES (Continued)

Compound	Structure	Lattice Constants, Å			$\beta$ , degrees	Density, g/cm <sup>3</sup>	Melting Point, C	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>				
<u>M<sub>2</sub>S<sub>3</sub></u>								
$\delta$ -Y <sub>2</sub> S <sub>3</sub>	Monoclinic	10.71	4.02	17.47	81.17	3.87	1,600	83.4
$\gamma$ -La <sub>2</sub> S <sub>3</sub>	Cubic	8.723	--	--	--	4.99	2,150	27.1
$\gamma$ -Ce <sub>2</sub> S <sub>3</sub>	Cubic	8.635	--	--	--	5.19	1,890	2,520
$\gamma$ -Pr <sub>2</sub> S <sub>3</sub>	Cubic	8.611	--	--	--	5.27	1,795	4,640
$\gamma$ -Nd <sub>2</sub> S <sub>3</sub>	Cubic	8.527	--	--	--	5.50	2,200	4,924
$\gamma$ -Sm <sub>2</sub> S <sub>3</sub>	Cubic	8.448	--	--	--	5.87	1,780	1,020
Eu <sub>2</sub> S <sub>3</sub>	-	8.415	--	--	--	--	--	--
Eu <sub>2</sub> S <sub>3</sub> .81	Tetragonal	7.86	--	8.03	--	5.70	--	5,800
$\gamma$ -Gd <sub>2</sub> S <sub>3</sub>	Cubic	8.387	--	--	--	6.15	1,885	27,800
$\gamma$ -Dy <sub>2</sub> S <sub>3</sub>	Bcc	8.292	--	--	--	6.54	1,480	47,700
$\delta$ -Dy <sub>2</sub> S <sub>3</sub>	Monoclinic	10.17	4.02	17.57	--	5.75	--	--
$\delta$ -Er <sub>2</sub> S <sub>3</sub>	Monoclinic	10.07	4.00	17.33	--	6.07	1,730	38,600
Yb <sub>2</sub> S <sub>3</sub>	Hexagonal	6.784	--	18.29	--	6.04	--	7,130
<u>M<sub>3</sub>S<sub>4</sub></u>								
Compound	Structure	Lattice Constants, Å			Density, g/cm <sup>3</sup>	Melting Point, C	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>				
La <sub>3</sub> S <sub>4</sub>	Cubic	8.748	--	--	5.44	2,100	27.2	
Ce <sub>3</sub> S <sub>4</sub>	Cubic	8.623	--	--	5.675	2,080	2,160	
Pr <sub>3</sub> S <sub>4</sub>	Cubic	8.611	--	--	5.77	2,100	--	
Nd <sub>3</sub> S <sub>4</sub>	Cubic	8.524	--	--	6.02	2,040	4,849	
Sm <sub>3</sub> S <sub>4</sub>	Cubic	8.556	--	--	6.14	1,800	2,350	
Eu <sub>3</sub> S <sub>4</sub>	Cubic	8.537	--	--	6.27	--	11,500	
Yb <sub>3</sub> S <sub>4</sub>	Orthorhombic	12.81	12.97	3.84	6.71	--	4,740	
<u>M<sub>5</sub>S<sub>7</sub></u>								
Compound	Structure	Lattice Constants, Å			$\beta$ , degrees	Density, g/cm <sup>3</sup>	Melting Point, C	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>				
Y <sub>5</sub> S <sub>7</sub>	Monoclinic	12.67	3.81	11.45	74	4.18	1,630	39.3
Dy <sub>5</sub> S <sub>7</sub>	Monoclinic	12.84	3.81	11.61	74	6.14	1,540	--
Er <sub>5</sub> S <sub>7</sub>	Monoclinic	12.63	3.77	11.47	74	6.39	1,620	--

SULFIDES (Continued)

Compound	Structure	Lattice Constants, Å		Density, g/cm <sup>3</sup>	Melting Point, C	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole
		a <sub>0</sub>	c <sub>0</sub>			
<u>M<sub>2</sub>O<sub>2</sub>S</u>						
Y <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.78	6.56	4.95	2,120	0
La <sub>2</sub> O <sub>2</sub> S	Hexagonal	4.051	6.943	5.73	1,940	0
Ce <sub>2</sub> O <sub>2</sub> S	Hexagonal	4.00	6.82	5.99	1,950	2,139
Pr <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.974	6.820	6.16	--	--
Nd <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.946	6.790	6.47	1,990	--
Sm <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.893	6.717	6.90	1,980	1,020
Eu <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.87	6.68	7.04	--	--
Gd <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.851	6.687	7.34	--	--
Tb <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.825	6.626	7.56	--	--
Dy <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.803	6.603	7.84	--	--
Er <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.760	6.552	7.92	--	--
Tm <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.747	6.538	8.59	--	--
Yb <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.723	6.503	8.72	--	--
Lu <sub>2</sub> O <sub>2</sub> S	Hexagonal	3.709	6.486	8.69	--	--

TELLURIDES

Compound	Structure	Lattice Type	a <sub>0</sub> , Å	Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	Effective Magnetic Moment, Bohr magnetons
<u>MTe</u>								
YTe	Fcc	NaCl	6.080	--	--	--	--	--
LaTe	Fcc	NaCl	6.422	6.682	1,725	1.5 x 10 <sup>11</sup>	--	--
CeTe	Fcc	NaCl	6.359	--	--	200	--	--
PrTe	Fcc	NaCl	6.322	--	--	--	--	--
NdTe	Fcc	NaCl	6.249	--	--	40	--	--
SmTe	Fcc	NaCl	6.58	--	1,920	1.64 x 10 <sup>9</sup>	4,292	4.33
EuTe	Fcc	NaCl	6.585	--	--	--	--	--
GdTe	Fcc	NaCl	6.139	--	1,870	700	26,042	7.63
TbTe	Fcc	NaCl	6.101	--	--	--	38,760	9.57
DyTe	Fcc	NaCl	6.075	--	--	--	45,977	10.47
HoTe	Fcc	NaCl	6.049	--	--	--	48,780	10.50
ErTe	Fcc	NaCl	6.021	--	--	140	34,965	9.30
TmTe	--	--	--	--	--	--	25,041	7.63
YbTe	Fcc	NaCl	6.39	--	1,740	7 x 10 <sup>9</sup>	--	--

## TELLURIDES (Continued)

Compound	Structure	Lattice Type	Lattice Constants, A		Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm
			a <sub>0</sub>	c <sub>0</sub>			
<u>MTe<sub>2</sub></u>							
LaTe <sub>2</sub>	Tetragonal	Fe <sub>2</sub> As	4.53	9.22	6.97	1,535	6.6 x 10 <sup>6</sup>
CeTe <sub>2</sub>	Tetragonal	Fe <sub>2</sub> As	4.51	9.10	7.06	--	--
PrTe <sub>2</sub>	Tetragonal	Fe <sub>2</sub> As	4.46	9.05	--	--	--
NdTe <sub>2</sub>	Tetragonal	Fe <sub>2</sub> As	4.41	9.04	--	--	--
GdTe <sub>2</sub>	Tetragonal	Fe <sub>2</sub> As	9.10	9.30	6.8	--	5.5 x 10 <sup>4</sup>
DyTe <sub>2-n</sub>	Tetragonal	Fe <sub>2</sub> As	4.29	8.91	--	--	--

Compound	Structure	Lattice Constants, A			Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>			
<u>M<sub>2</sub>Te<sub>3</sub></u>							
Y <sub>2</sub> Te <sub>3</sub>	--	--	--	--	--	1,525	10 <sup>7</sup>
Ce <sub>2</sub> Te <sub>3</sub>	--	9.535	--	--	6.6	--	1.1 x 10 <sup>4</sup>
Pr <sub>2</sub> Te <sub>3</sub>	--	9.482	--	--	6.6	--	--
Nd <sub>2</sub> Te <sub>3</sub>	Orthorhombic	12.12	11.93	4.37	6.65	1,650	1.1 x 10 <sup>3</sup>
Sm <sub>2</sub> Te <sub>3</sub>	Bcc	9.480	--	--	7.11	(1,475)	--
Gd <sub>2</sub> Te <sub>3</sub>	Tetragonal	--	--	--	--	1,505	1.5 x 10 <sup>4</sup>
Er <sub>2</sub> Te <sub>3</sub>	--	--	--	--	--	--	1.1 x 10 <sup>3</sup>
Yb <sub>2</sub> Te <sub>3</sub>	--	--	--	--	--	--	10 <sup>7</sup>

Compound	Structure	Lattice Type	a <sub>0</sub> , A	Density, g/cm <sup>3</sup>	Melting Point, C	Resistivity, microhm-cm
La <sub>3</sub> Te <sub>4</sub>	Bcc	Ce <sub>2</sub> S <sub>3</sub>	9.619	6.65	1,595	--
Ce <sub>3</sub> Te <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	9.528	6.7	--	1.8 x 10 <sup>3</sup>
Nd <sub>3</sub> Te <sub>4</sub>	Bcc	Th <sub>3</sub> P <sub>4</sub>	9.438	6.8	1,685	350
Gd <sub>3</sub> Te <sub>4</sub>	--	--	--	--	1,410	460
Dy <sub>3</sub> Te <sub>4</sub>	--	--	--	--	--	3.1 x 10 <sup>3</sup>
Er <sub>3</sub> Te <sub>4</sub>	--	--	--	--	--	280

# Properties

## TELLURIDES (Continued)

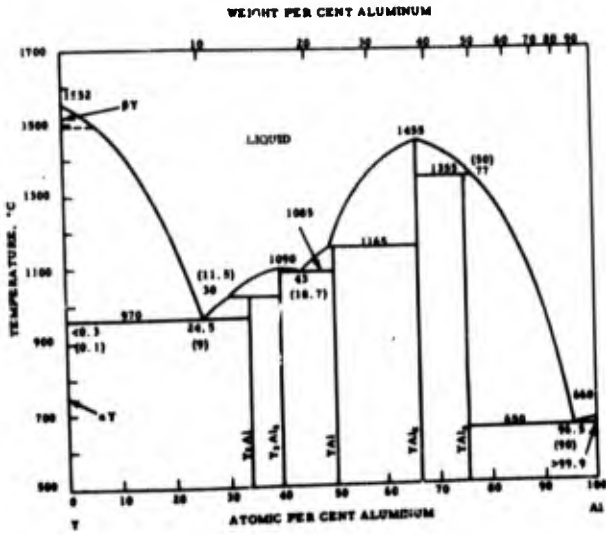
Compound	Structure	Lattice Constants, A		Density, g/cm <sup>3</sup>	Color
		a <sub>0</sub>	c <sub>0</sub>		
<u>M<sub>2</sub>O<sub>2</sub>Te</u>					
La <sub>2</sub> O <sub>2</sub> Te	Hexagonal	4.12	13.10	6.36	Dark green
Ce <sub>2</sub> O <sub>2</sub> Te	Hexagonal	4.09	12.92	6.64	Maroon
Pr <sub>2</sub> O <sub>2</sub> Te	Hexagonal	4.06	12.83	--	Light green
Nd <sub>2</sub> O <sub>2</sub> Te	Hexagonal	4.03	12.77	7.18	Green
Sm <sub>2</sub> O <sub>2</sub> Te	Hexagonal	4.00	12.61	7.58	Dark green
Eu <sub>2</sub> O <sub>2</sub> Te	Hexagonal	3.98	12.57	7.74	Maroon
Gd <sub>2</sub> O <sub>2</sub> Te	Hexagonal	3.96	12.54	8.0	Brown
Dy <sub>2</sub> O <sub>2</sub> Te	Hexagonal	3.92	12.38	8.46	Maroon

### Other Tellurides

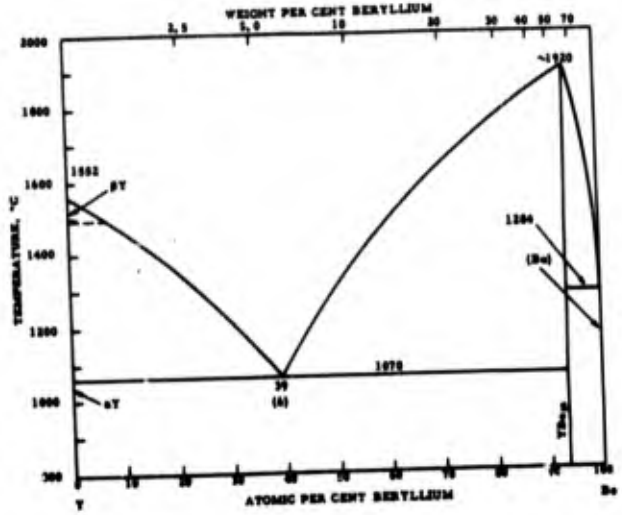
Compound	Structure	Lattice Constants, A			α, degrees	Density, g/cm <sup>3</sup>	Melting Point, C
		a <sub>0</sub>	b <sub>0</sub>	c <sub>0</sub>			
LaTe <sub>3</sub>	Tetragonal	4.407	--	26.14	--	6.92	835
La <sub>4</sub> Te <sub>7</sub>	Orthorhombic	4.607	4.483	9.142	--	--	--
GdTe <sub>4</sub>	Rhombohedral	13.0	--	--	25.5	--	--

Yttrium

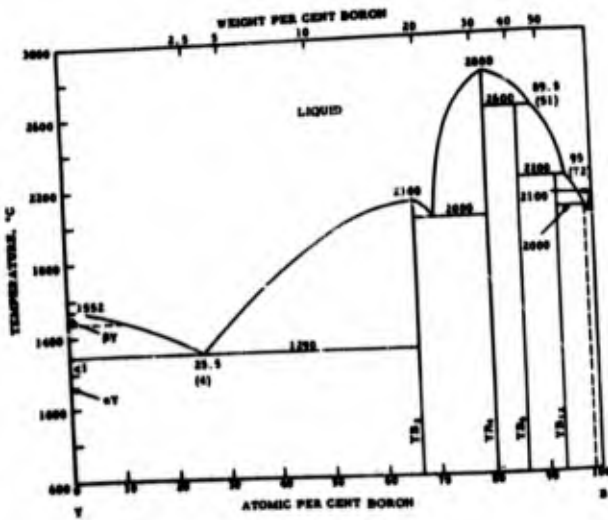
YTTRIUM



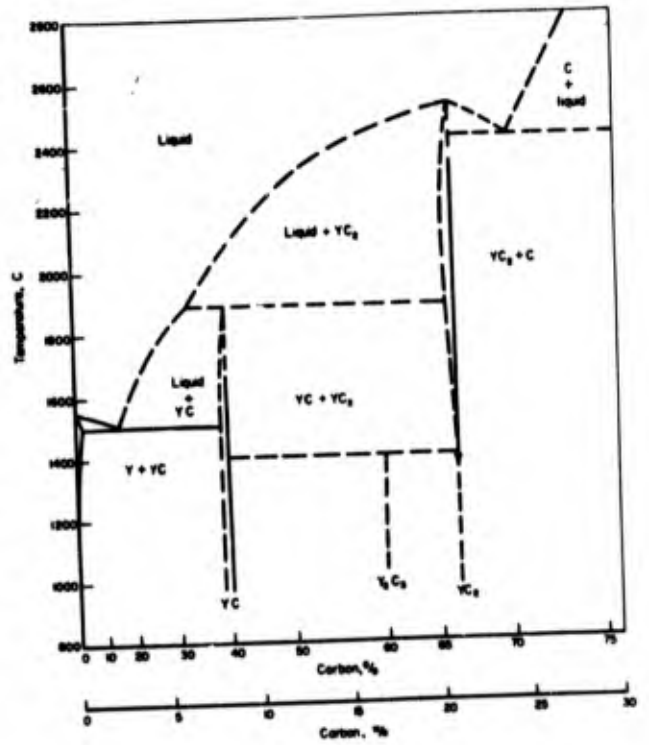
Aluminum (1)  
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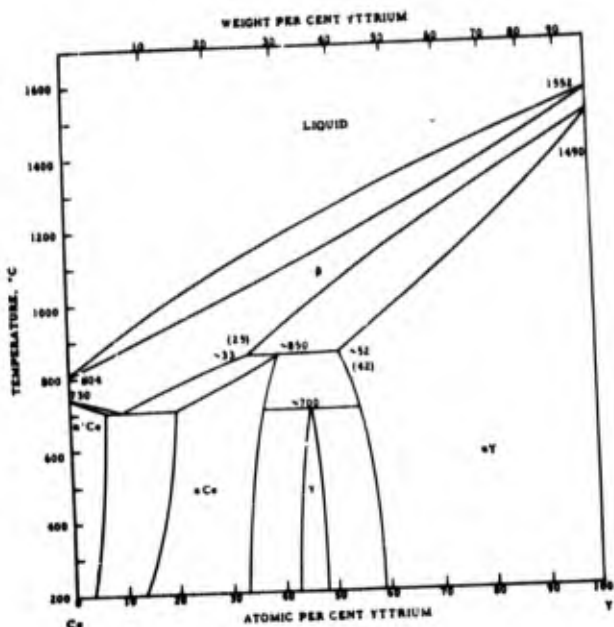
Beryllium (1)  
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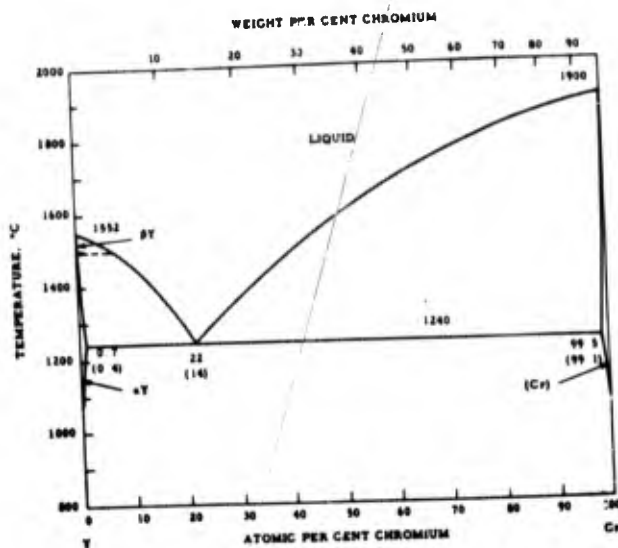
Boron (1)  
(Permission of U. S. AEC)



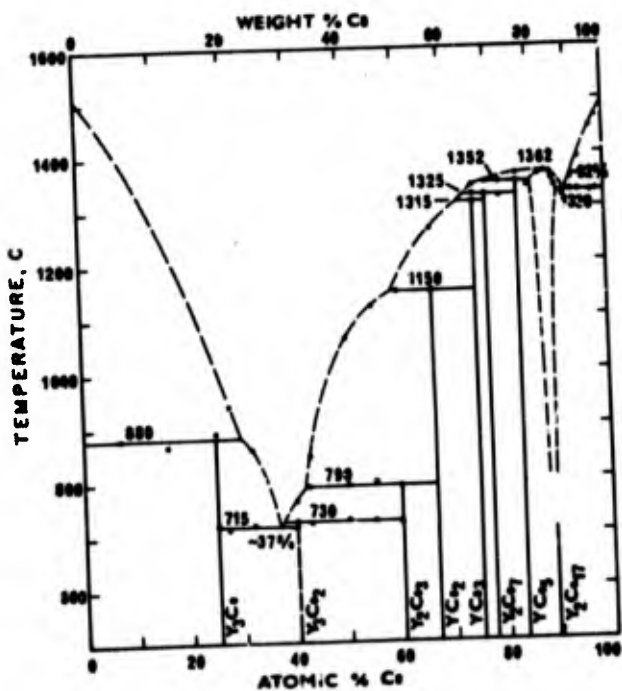
Carbon (2)



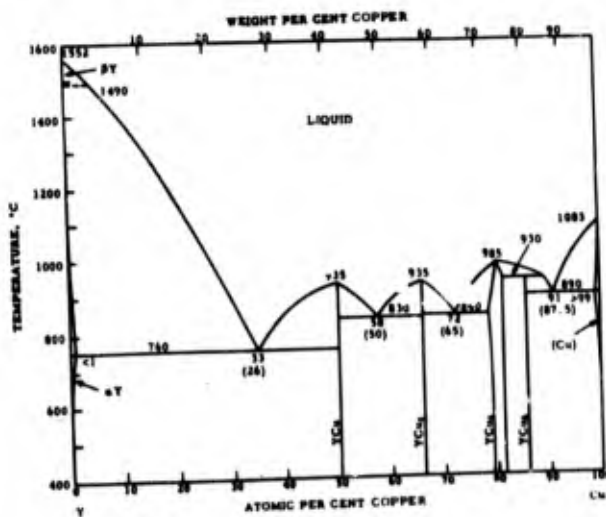
Cerium (1)  
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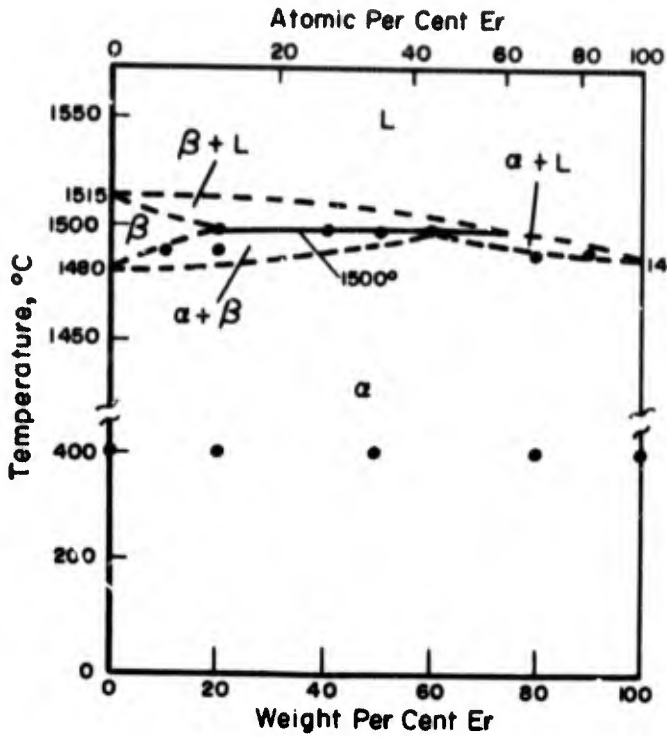
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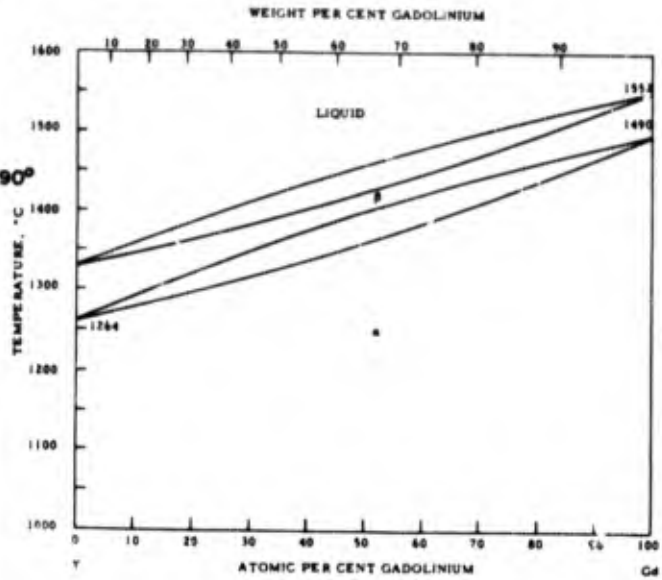
Cobalt (27)



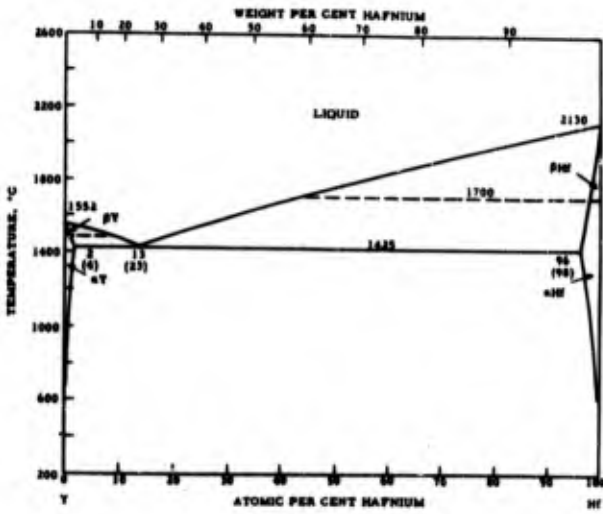
Copper (1)  
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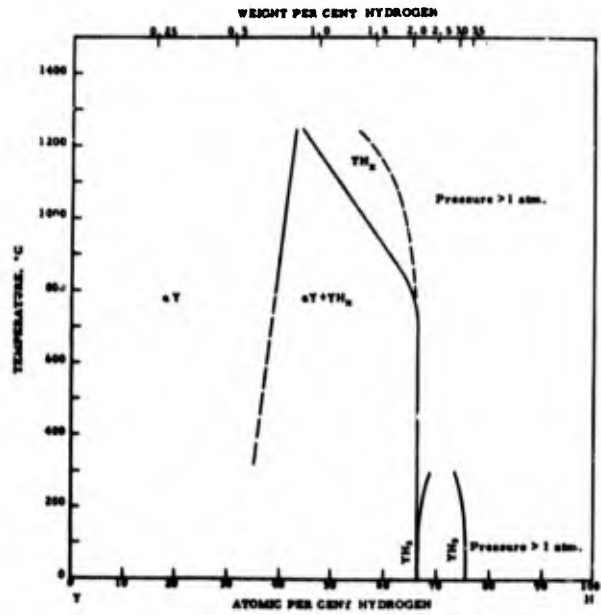
Erbium (3)



Gadolinium (1)  
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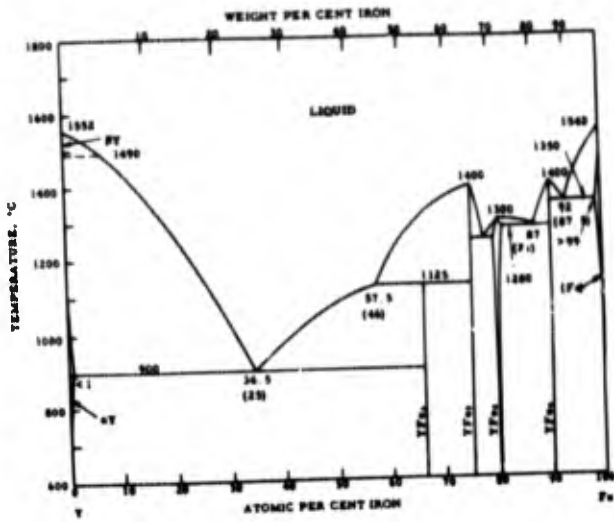


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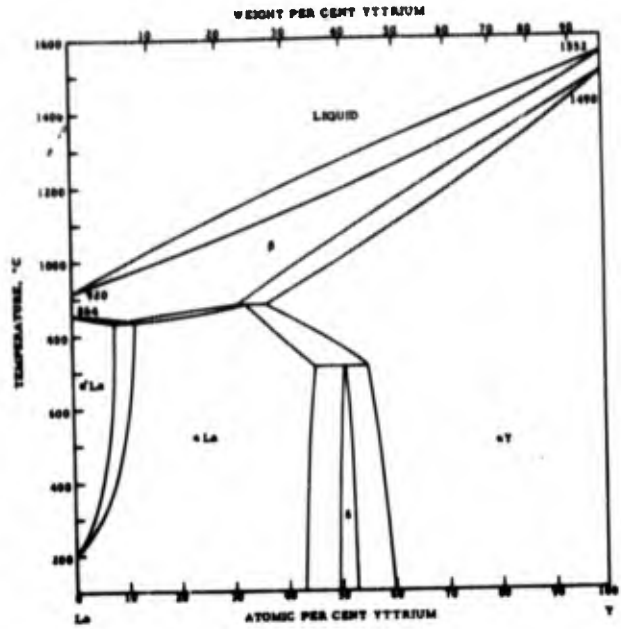


Hydrogen (1)  
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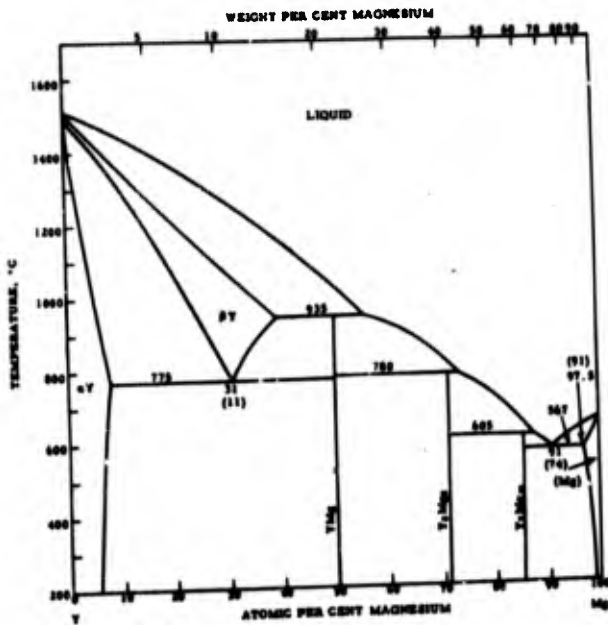




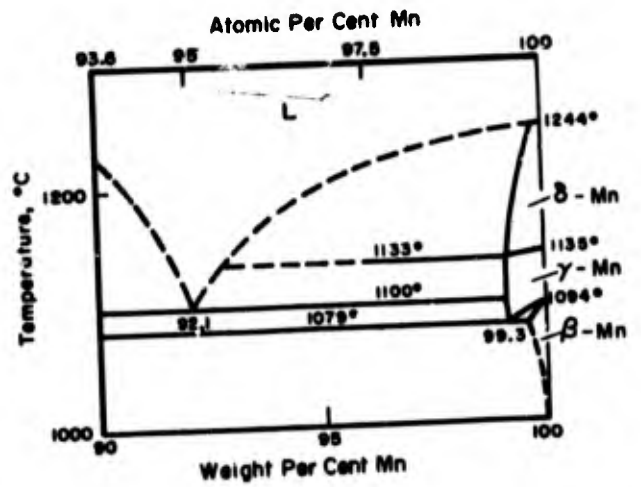
Iron (1)  
(Permission of U. S. AEC)



Lanthanum (1)  
(Permission of U. S. AEC)

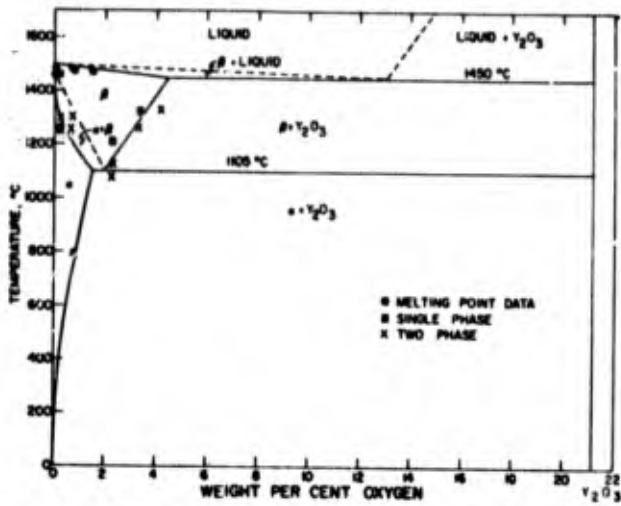


Magnesium (1)  
(Permission of U. S. AEC)

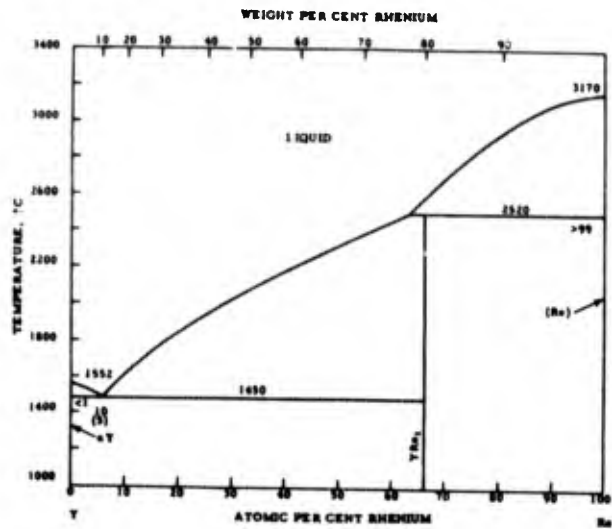


Manganese (4)

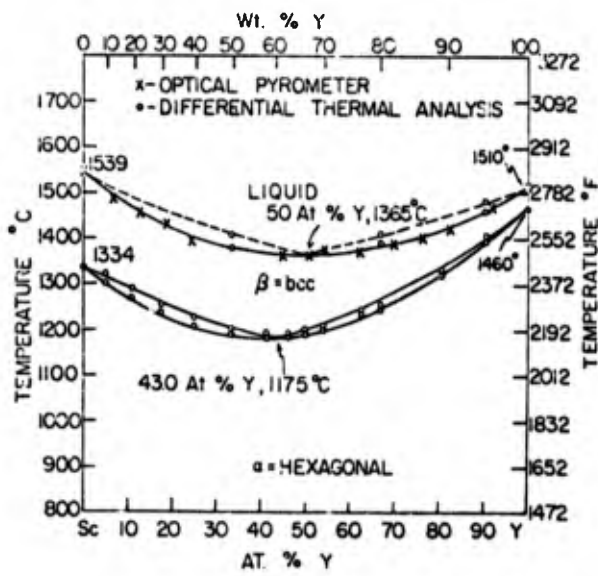




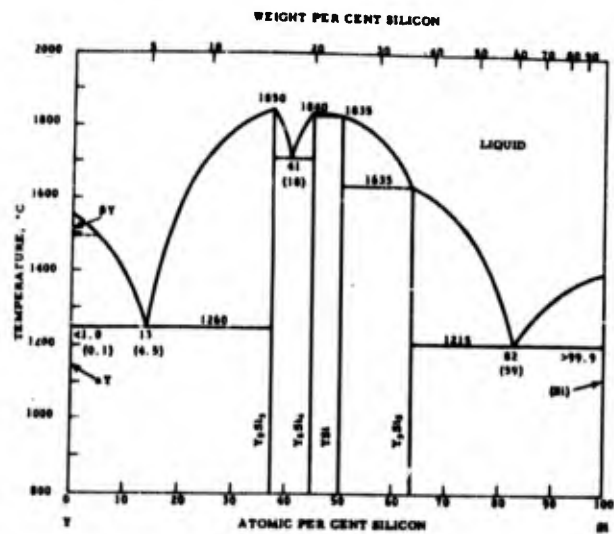
Oxygen (6)



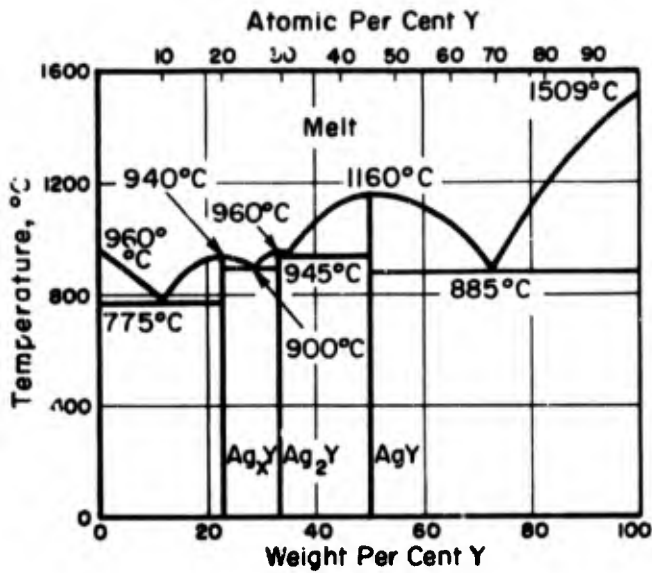
Rhenium (1)  
(Permission of U. S. AEC)



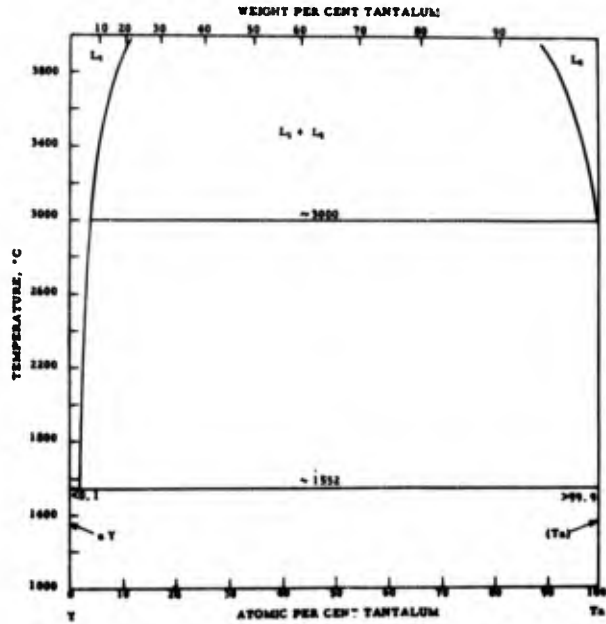
Scandium (28)  
(Permission of Metallurgical Society AIME)



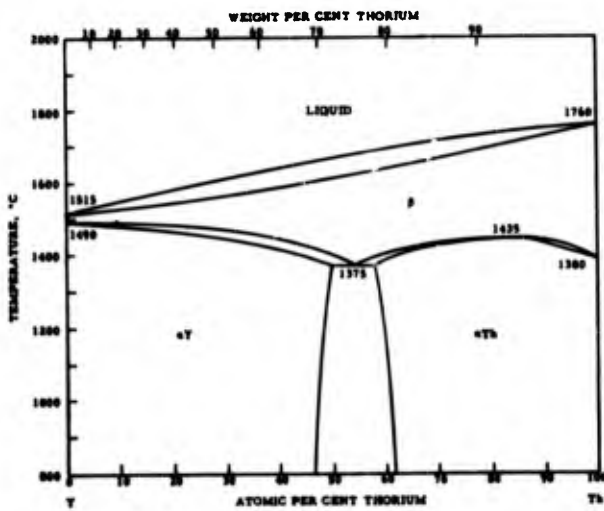
Silicon (1)  
(Permission of U. S. AEC)



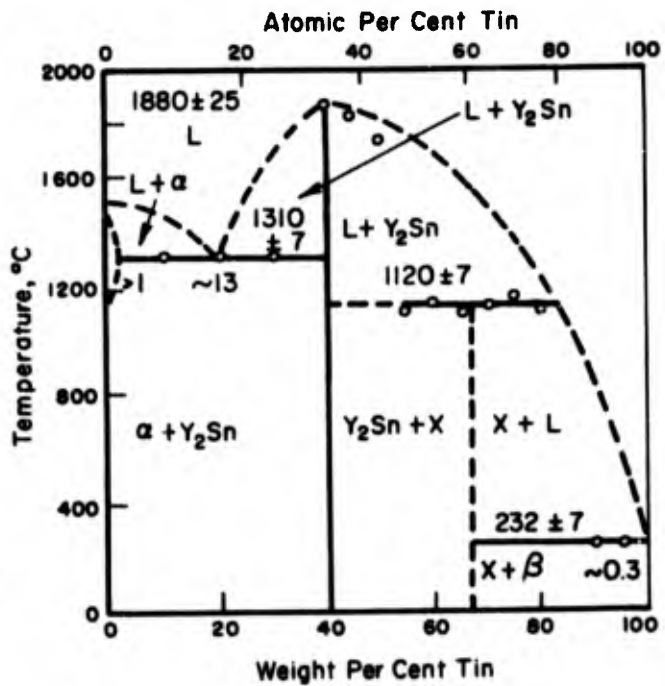
Silver (144)  
(Permission of Metallurgical Society AIME)



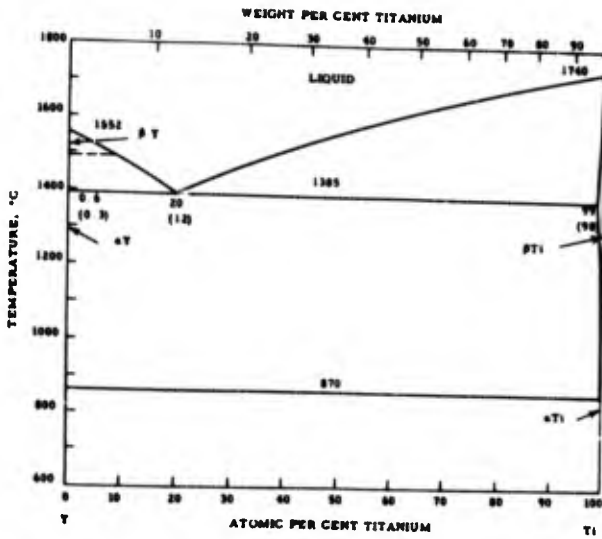
Tantalum (1)  
(Permission of U. S. AEC)



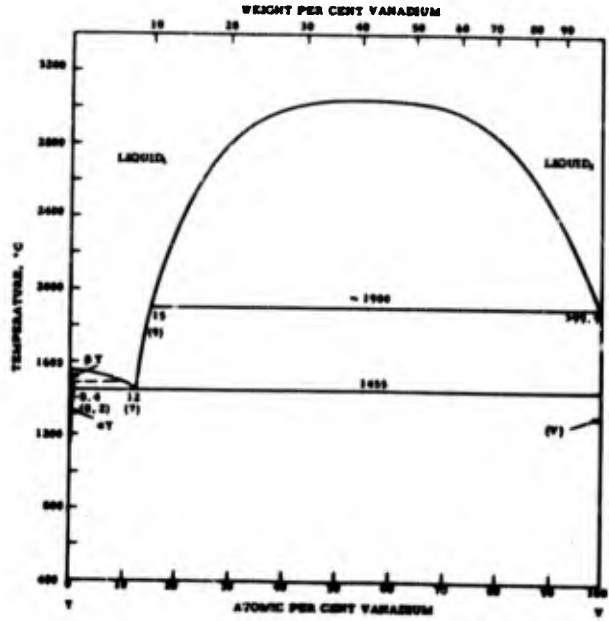
Thorium (1)  
(Permission of U. S. AEC)



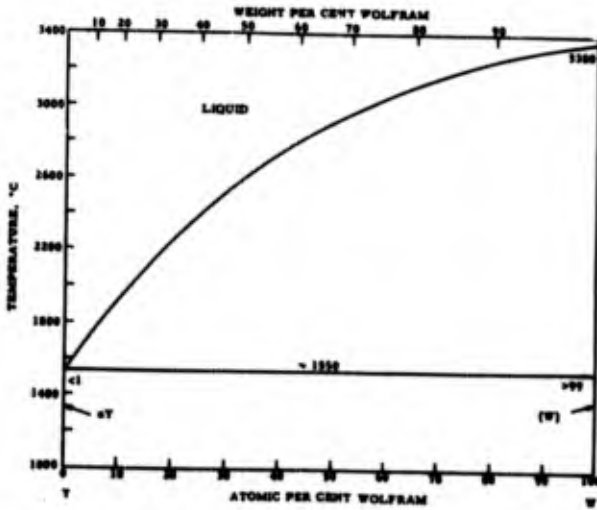
Tin (7)



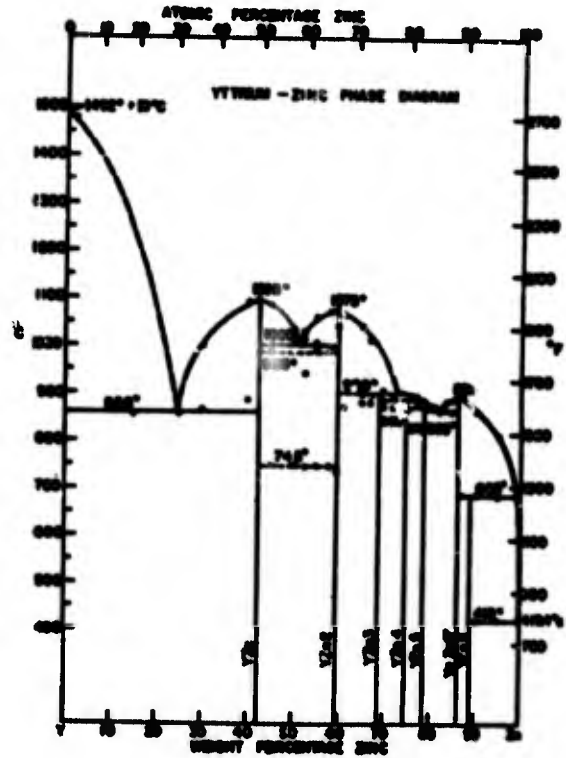
Titanium (1)  
(Permission of U. S. AEC)



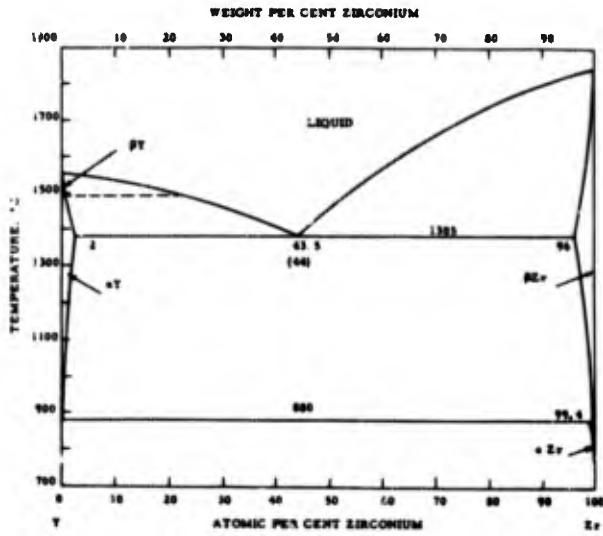
Vanadium (1)  
(Permission of U. S. AEC)



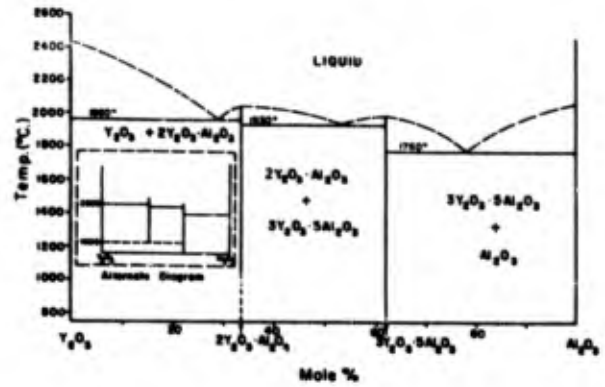
Wolfram (1)  
(Permission of U. S. AEC)



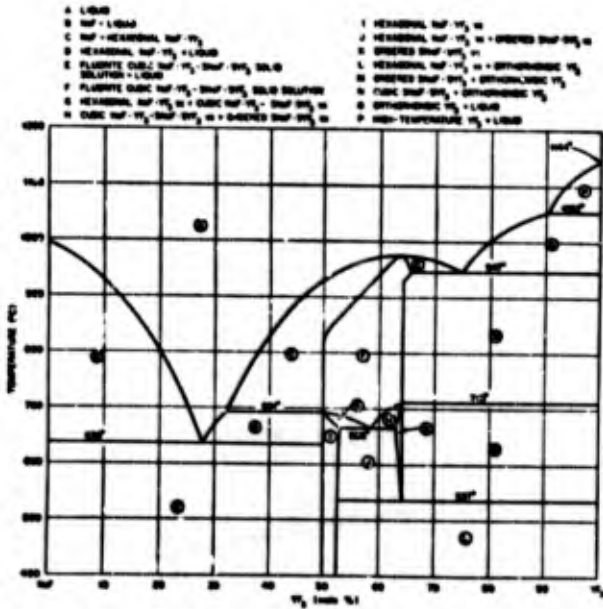
Zinc (8)



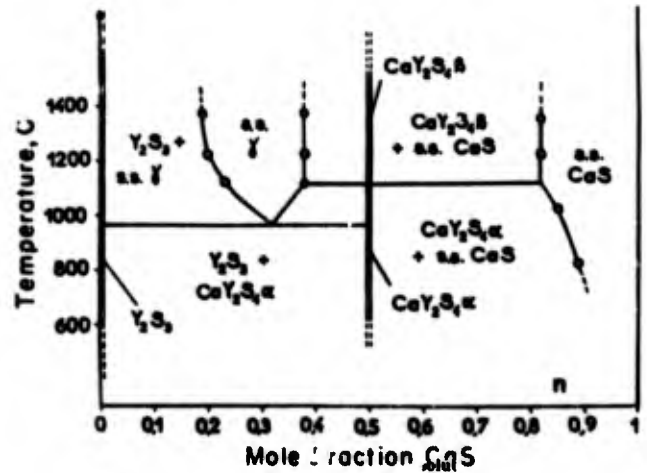
Zirconium (1)  
(Permission of U. S. AEC)



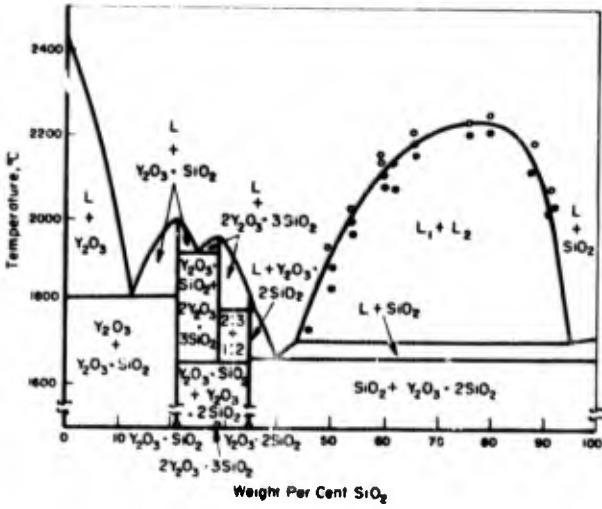
$Y_2O_3-Al_2O_3$   
(Permission of American Ceramic Society)



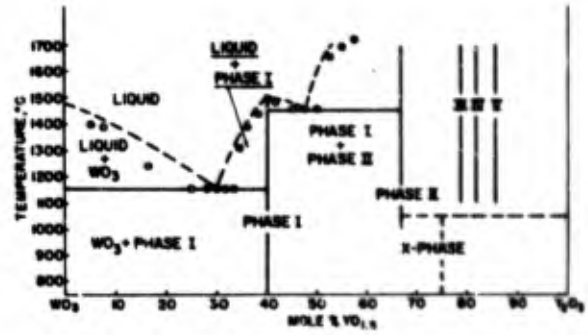
$YF_3-NaF$   
(Permission of Gordon and Breach,  
Science Publishers, Inc.)



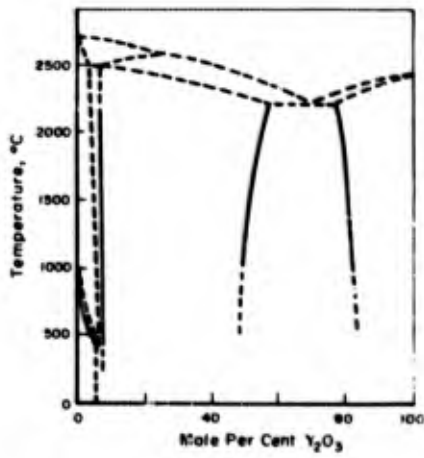
Yttrium-Sulfur-Calcium (12)



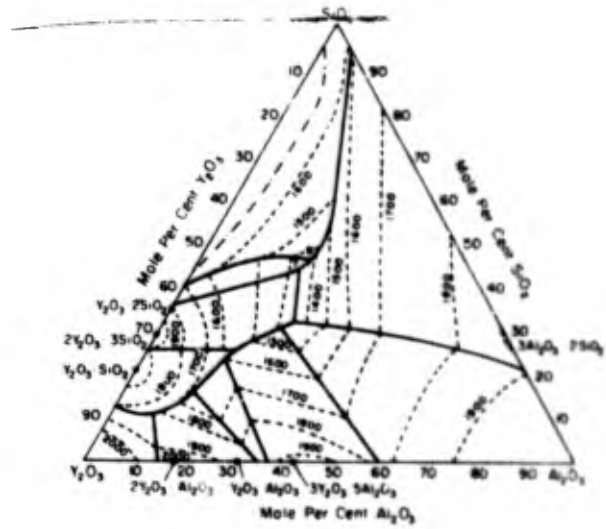
$Y_2O_3-SiO_2$  (13)



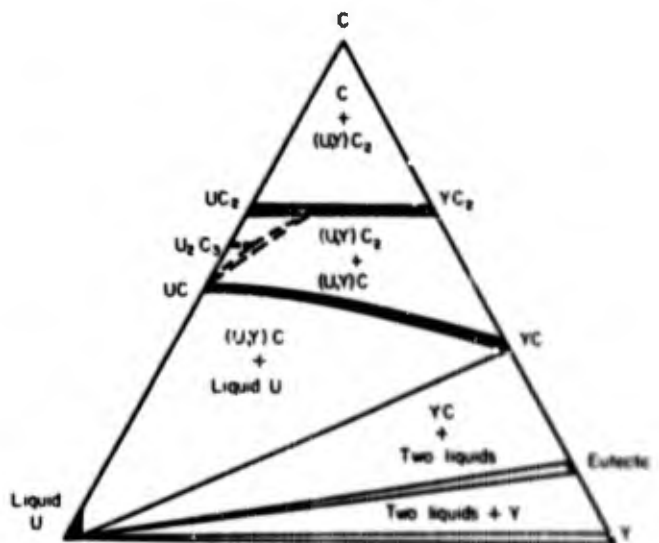
$Y_2O_3-WO_3$  (14)  
(Reprinted from *Inorganic Chemistry*)



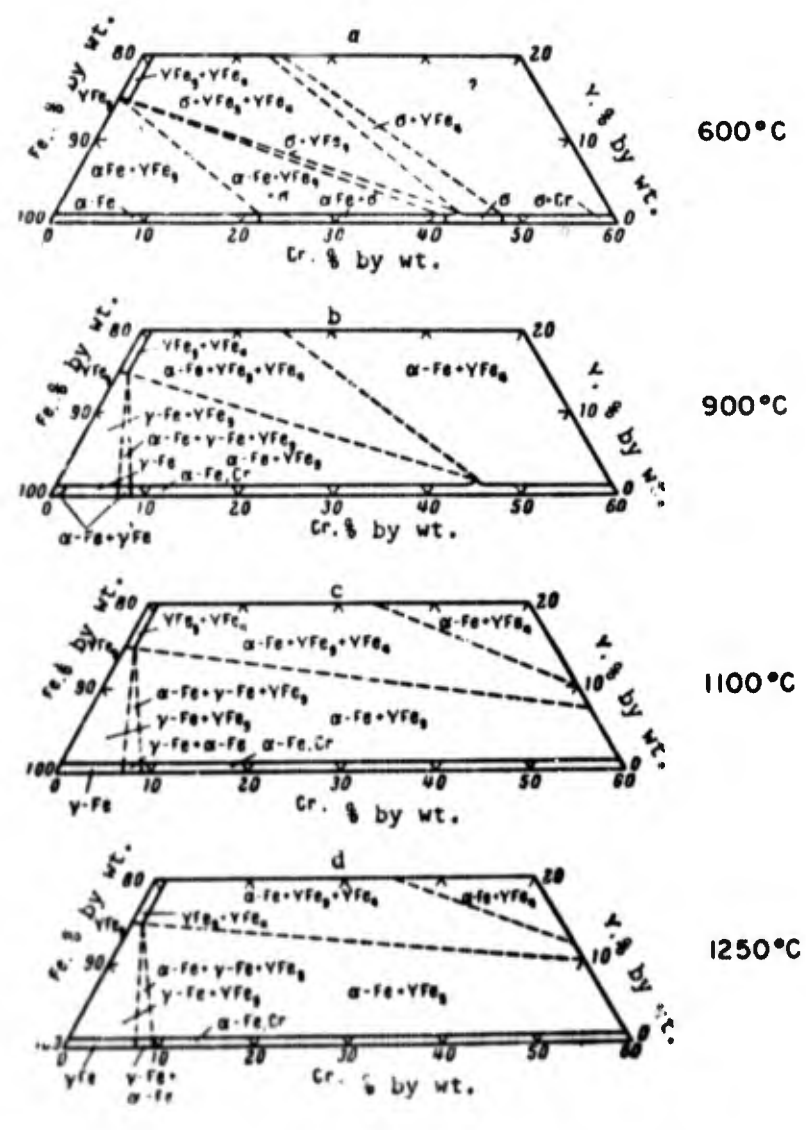
$Y_2O_3-ZrO_2$  (15)



$Y_2O_3-Al_2O_3-SiO_2$  (9)



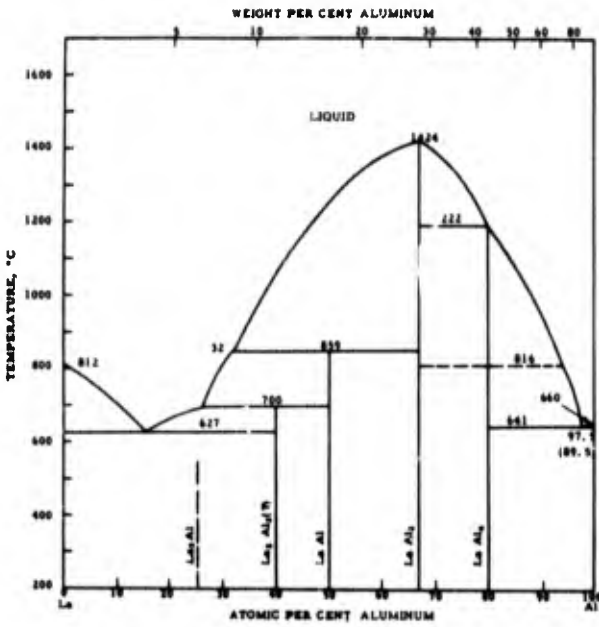
Yttrium-Uranium-Carbon at 1500 C (2)



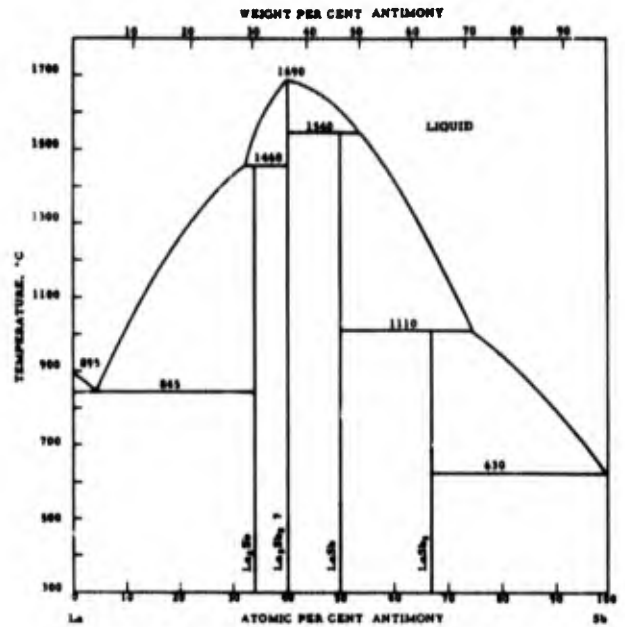
Yttrium-Iron-Chromium (4)



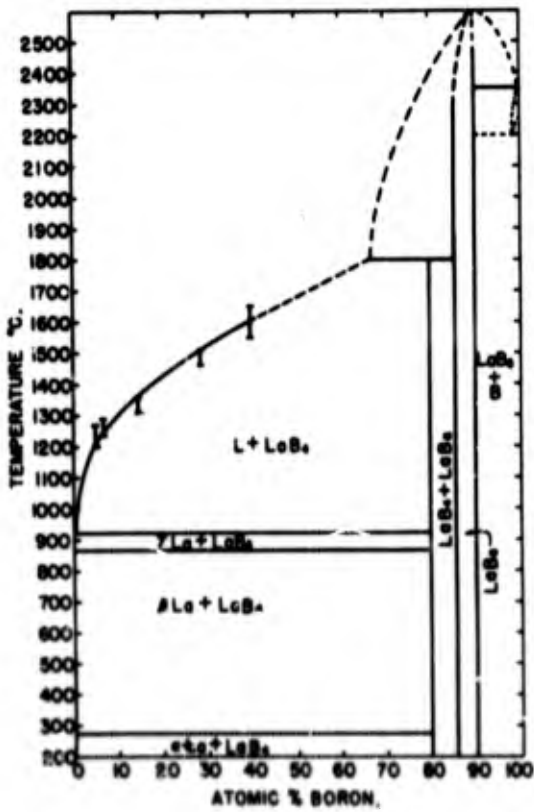
LANTHANUM



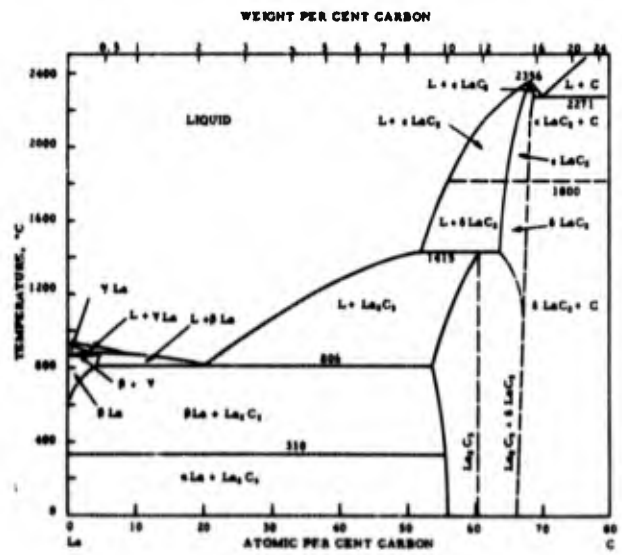
Aluminum (1)  
(Permission of U. S. AEC)



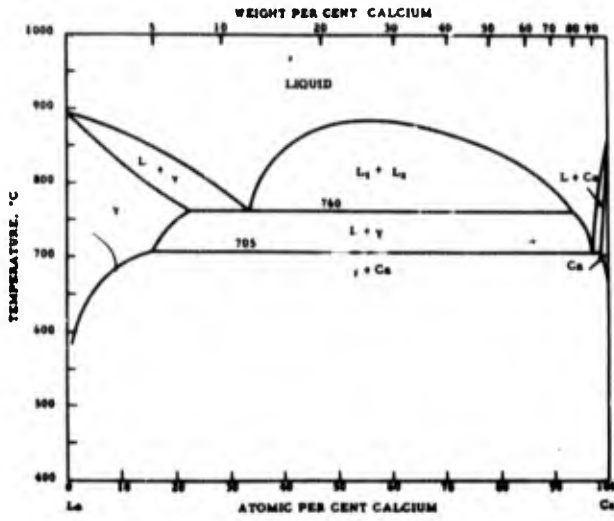
Antimony (1)  
(Permission of U. S. AEC)



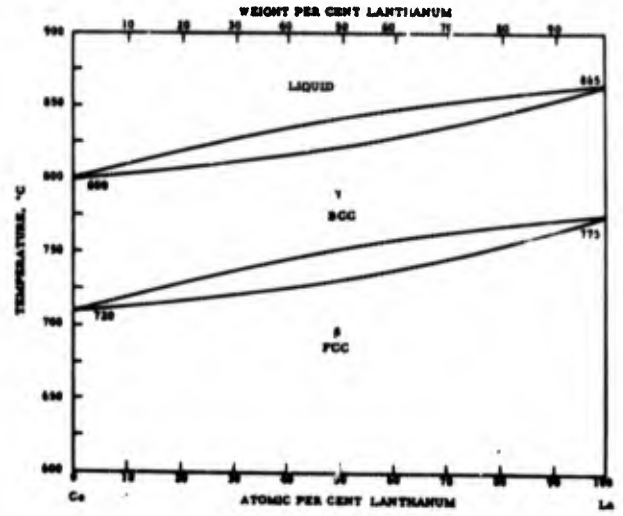
Boron (178)  
(Reprinted from Journal of Physical Chemistry)



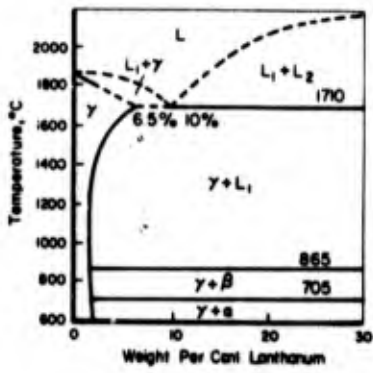
Carbon (1)  
(Permission of U. S. AEC)



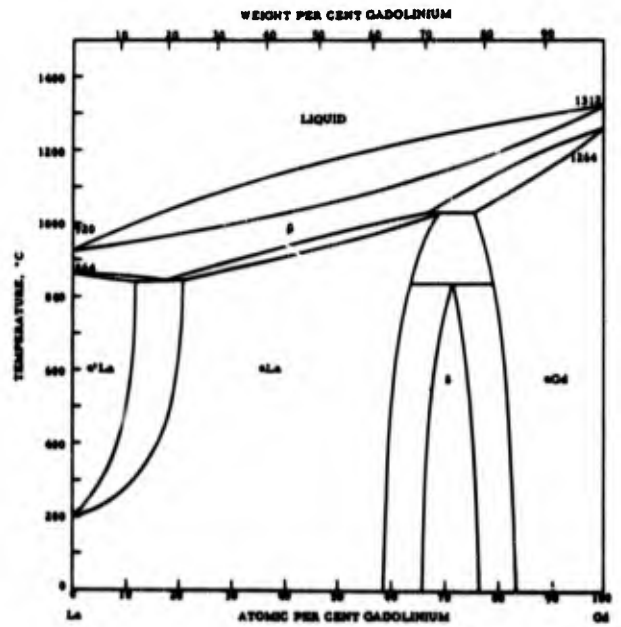
Calcium (1)  
(Permission of U. S. AEC)



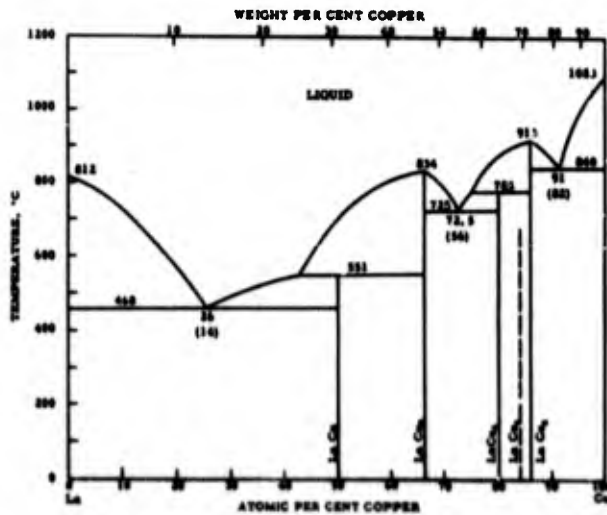
Cerium (1)  
(Permission of U. S. AEC)



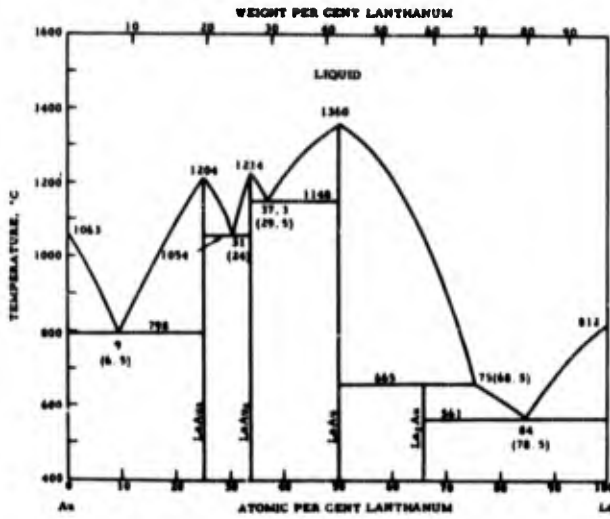
Chromium (16)



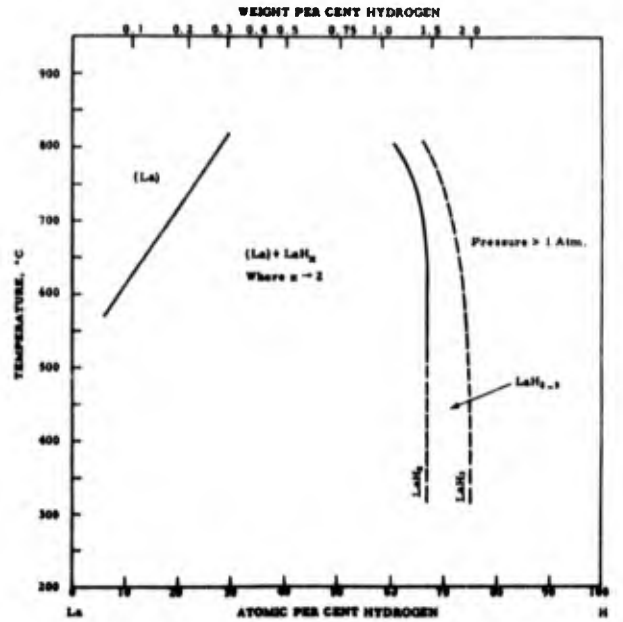
Gadolinium (1)  
(Permission of U. S. AEC)



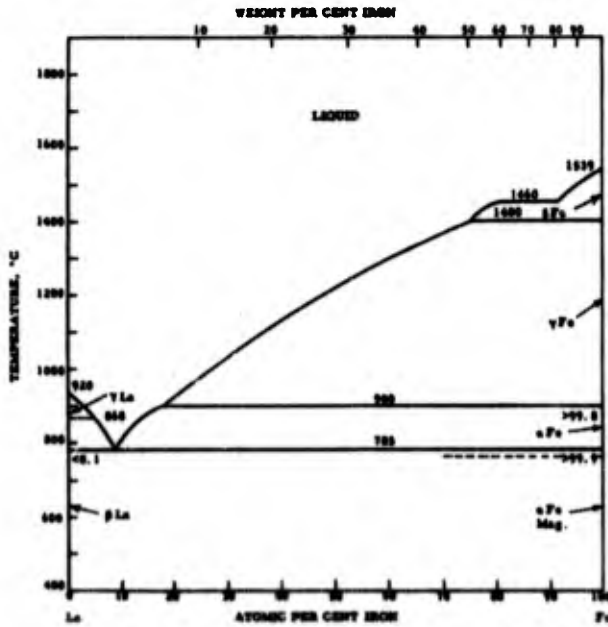
Copper (1)  
(Permission of U. S. AEC)



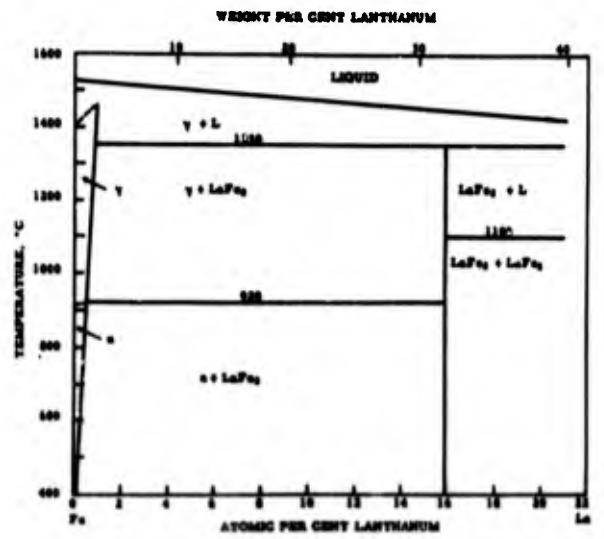
Gold (1)  
(Permission of U. S. AEC)



Hydrogen (1)  
(Permission of U. S. AEC)

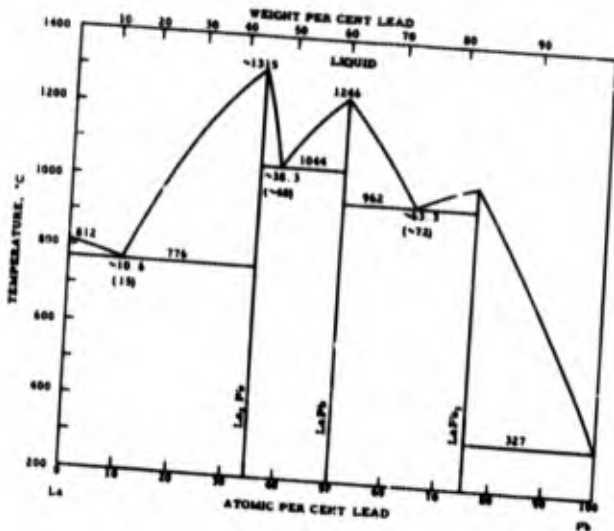


Complete Diagram

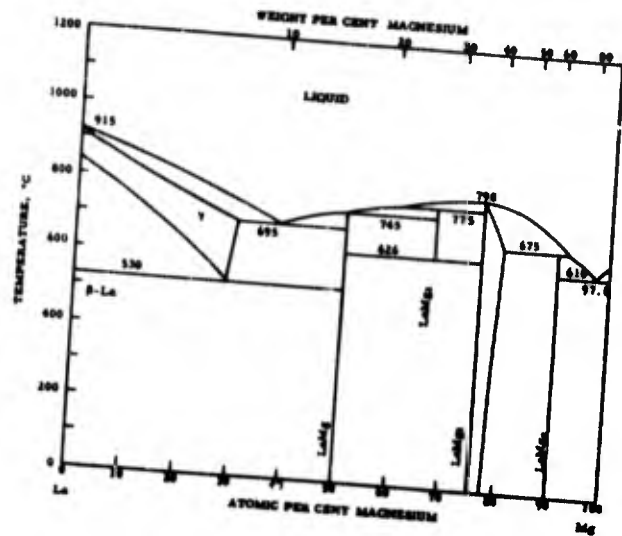


Partial Diagram - Iron-Rich Region

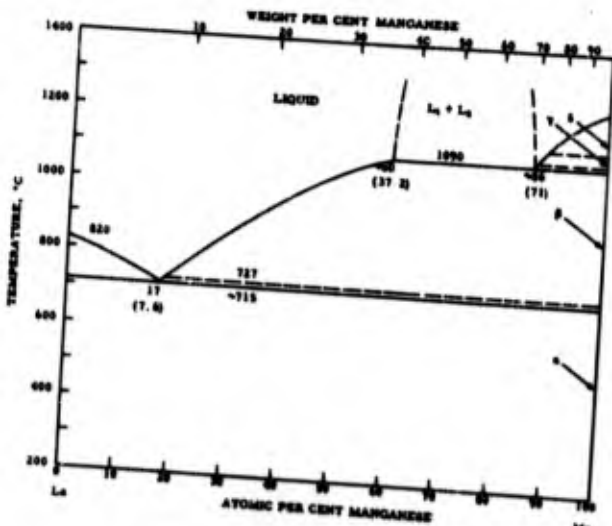
Iron (1)  
(Permission of U. S. AEC)



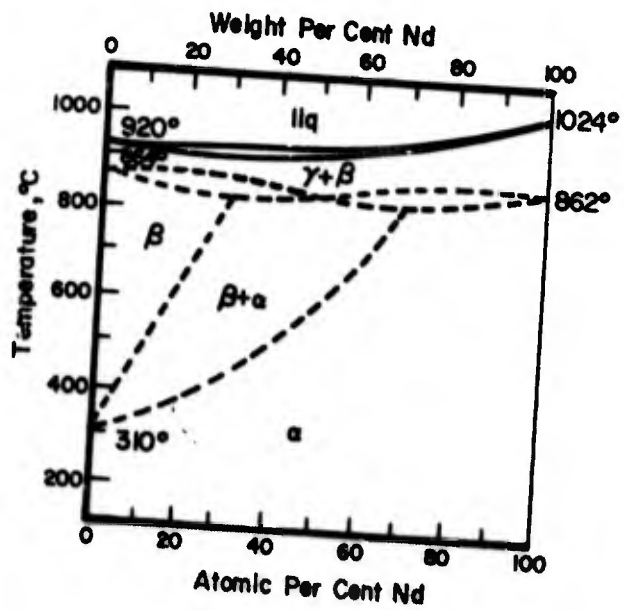
Lead (1)  
(Permission of U. S. AEC)



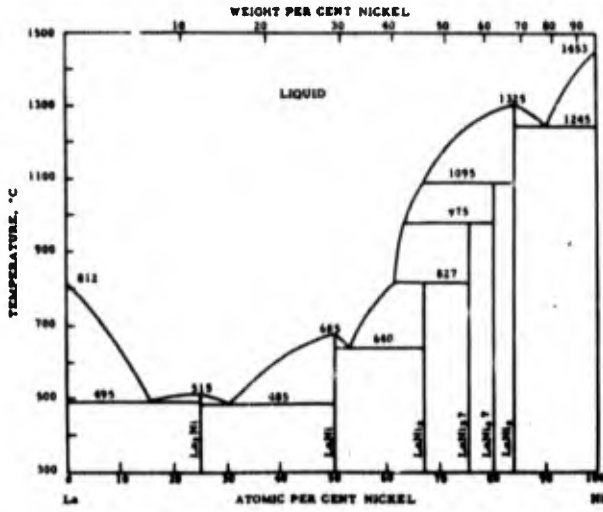
Magnesium (1)  
(Permission of U. S. AEC)



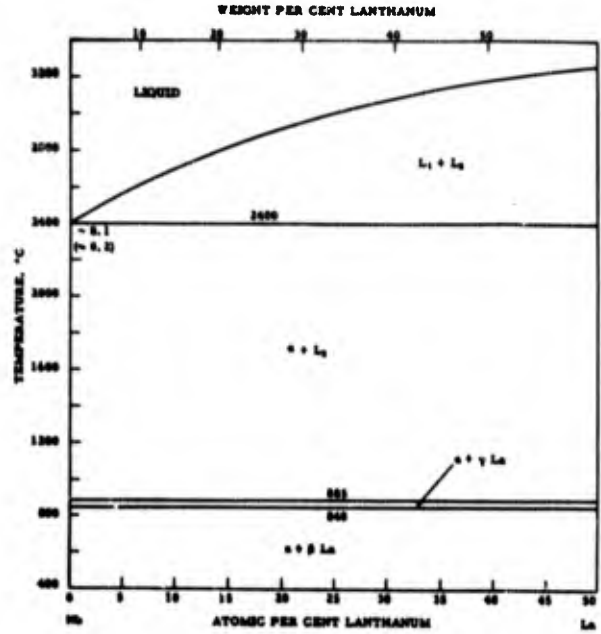
Manganese (1)  
(Permission of U. S. AEC)



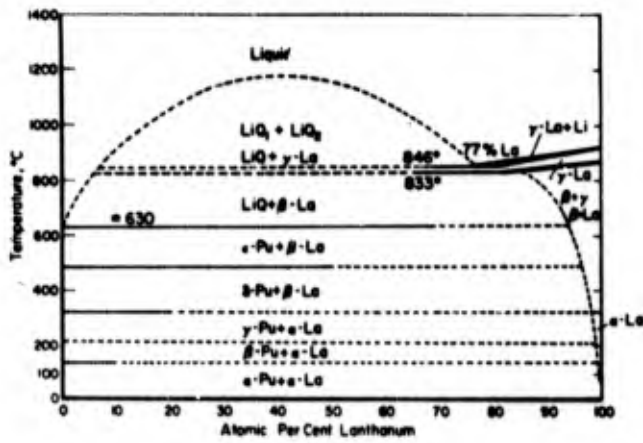
Neodymium (4)



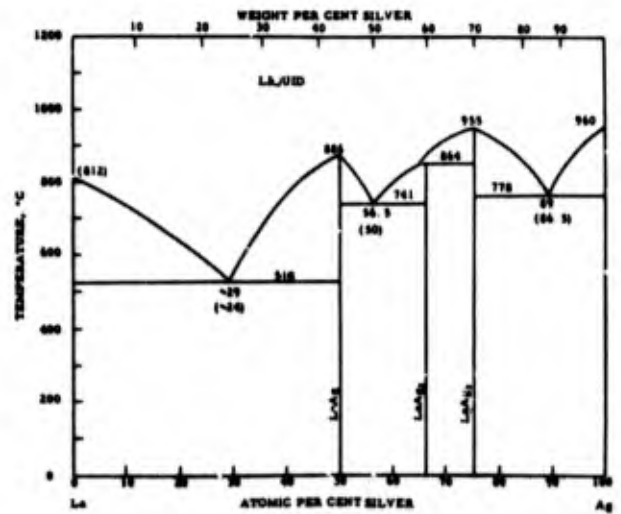
Nickel (1)  
(Permission of U. S. AEC)



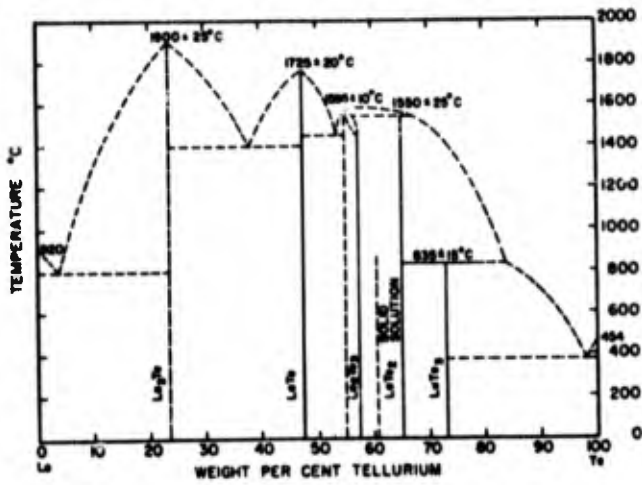
Niobium (1)  
(Permission of U. S. AEC)



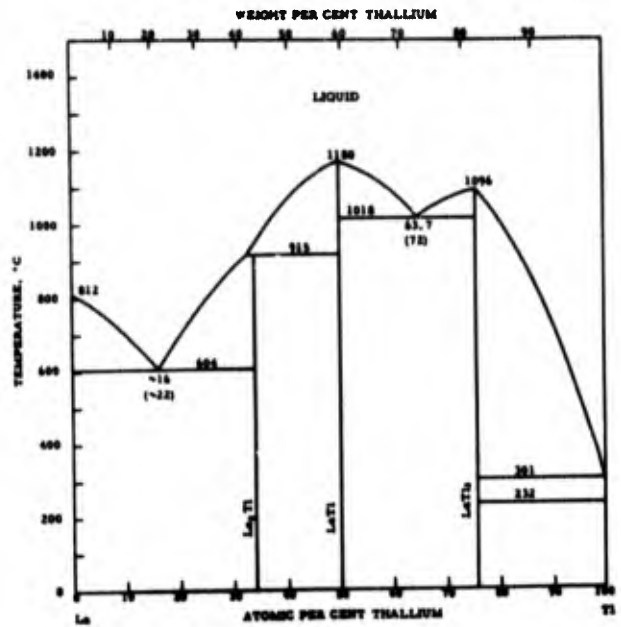
Plutonium (17)



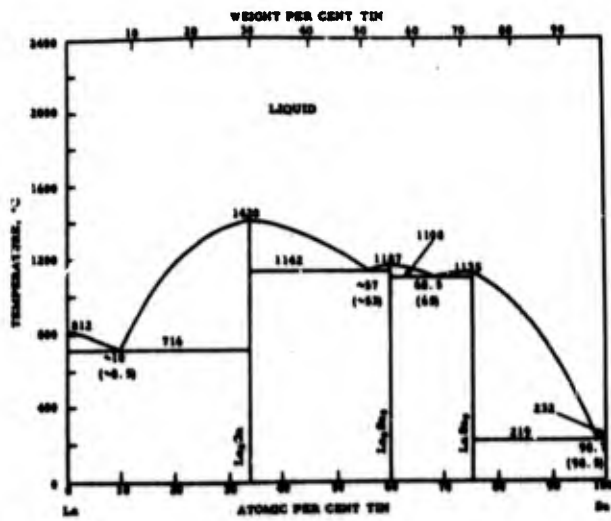
Silver (1)  
(Permission of U. S. AEC)



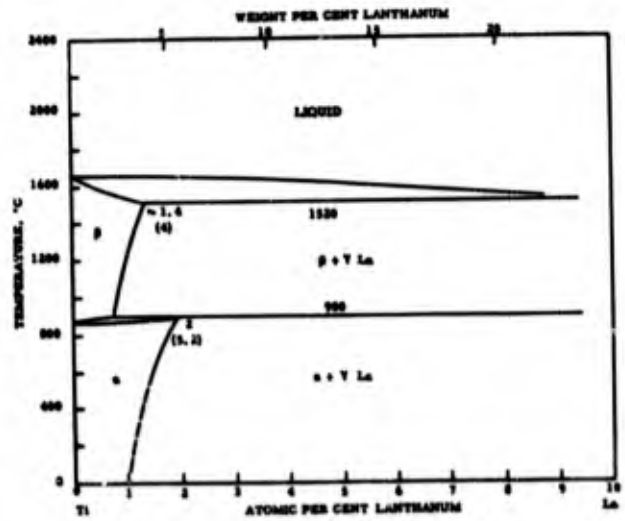
Tellurium (18)  
(Permission of Gordon and Breach, Science Publishers, Inc.)



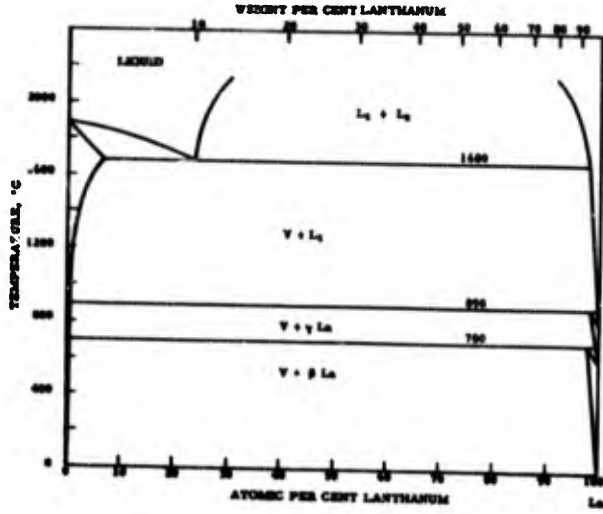
Thallium (1)  
(Permission of U. S. AEC)



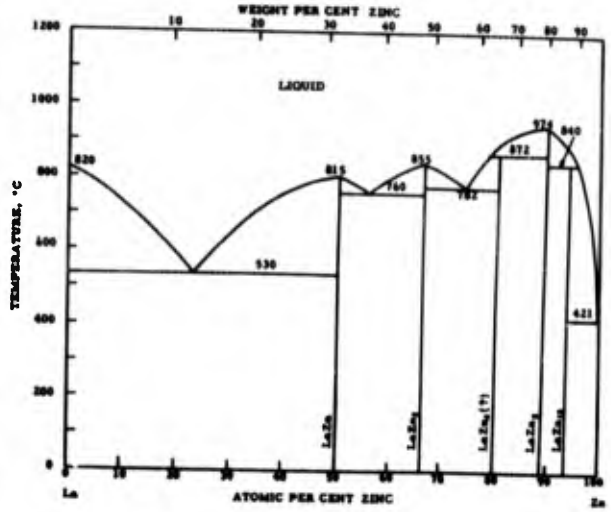
Tin (1)  
(Permission of U. S. AEC)



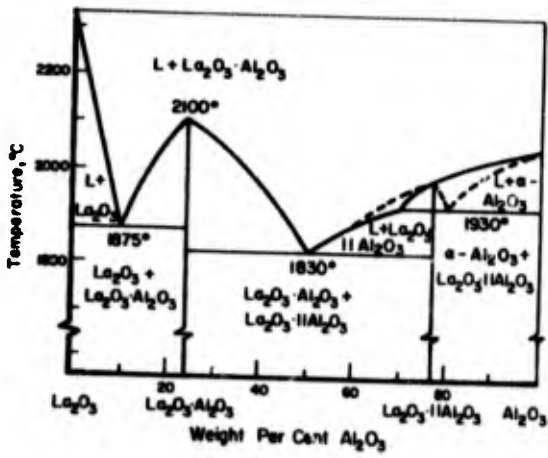
Titanium (1)  
(Permission of U. S. AEC)



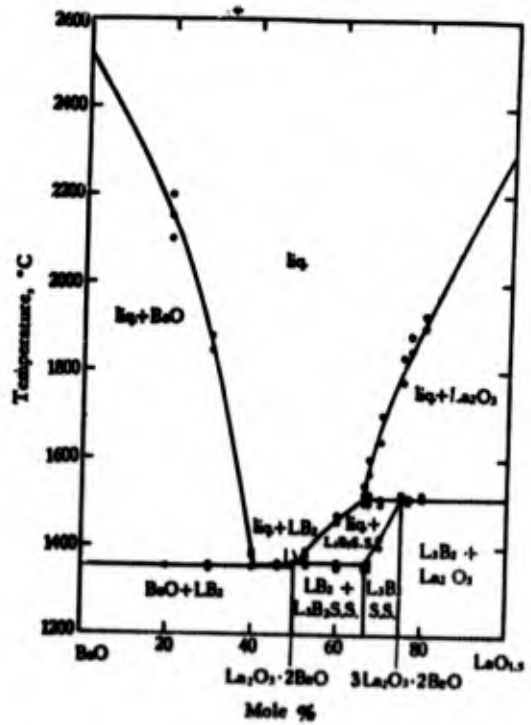
Vanadium (1)  
(Permission of U. S. AEC)



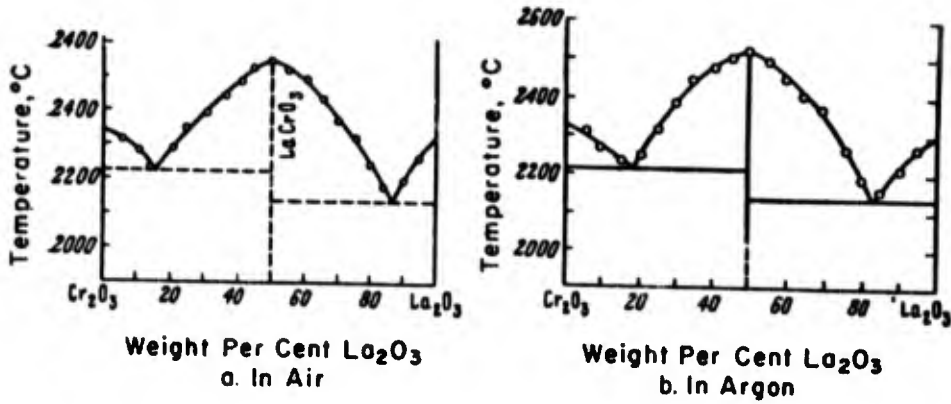
Zinc (1)  
(Permission of U. S. AEC)



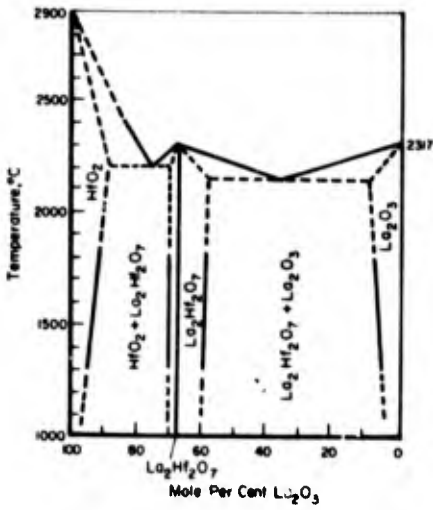
La<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>O<sub>3</sub> (19)



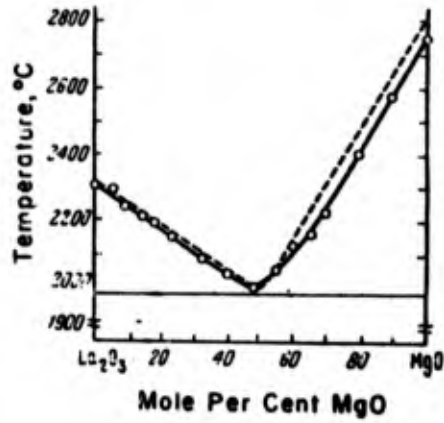
La<sub>2</sub>O<sub>3</sub>-BeO (20)



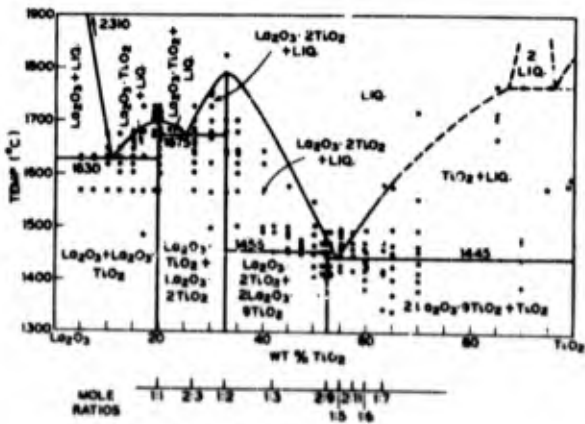
La<sub>2</sub>O<sub>3</sub>-Cr<sub>2</sub>O<sub>3</sub> (21)



La<sub>2</sub>O<sub>3</sub>-HfO<sub>2</sub> (22)

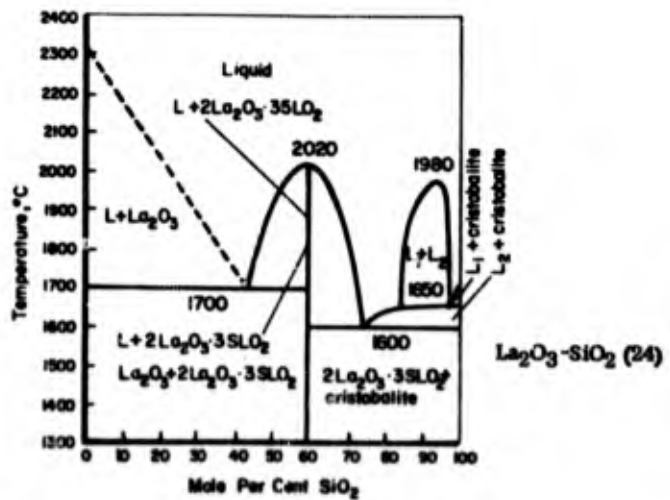


La<sub>2</sub>O<sub>3</sub>-MgO (23)



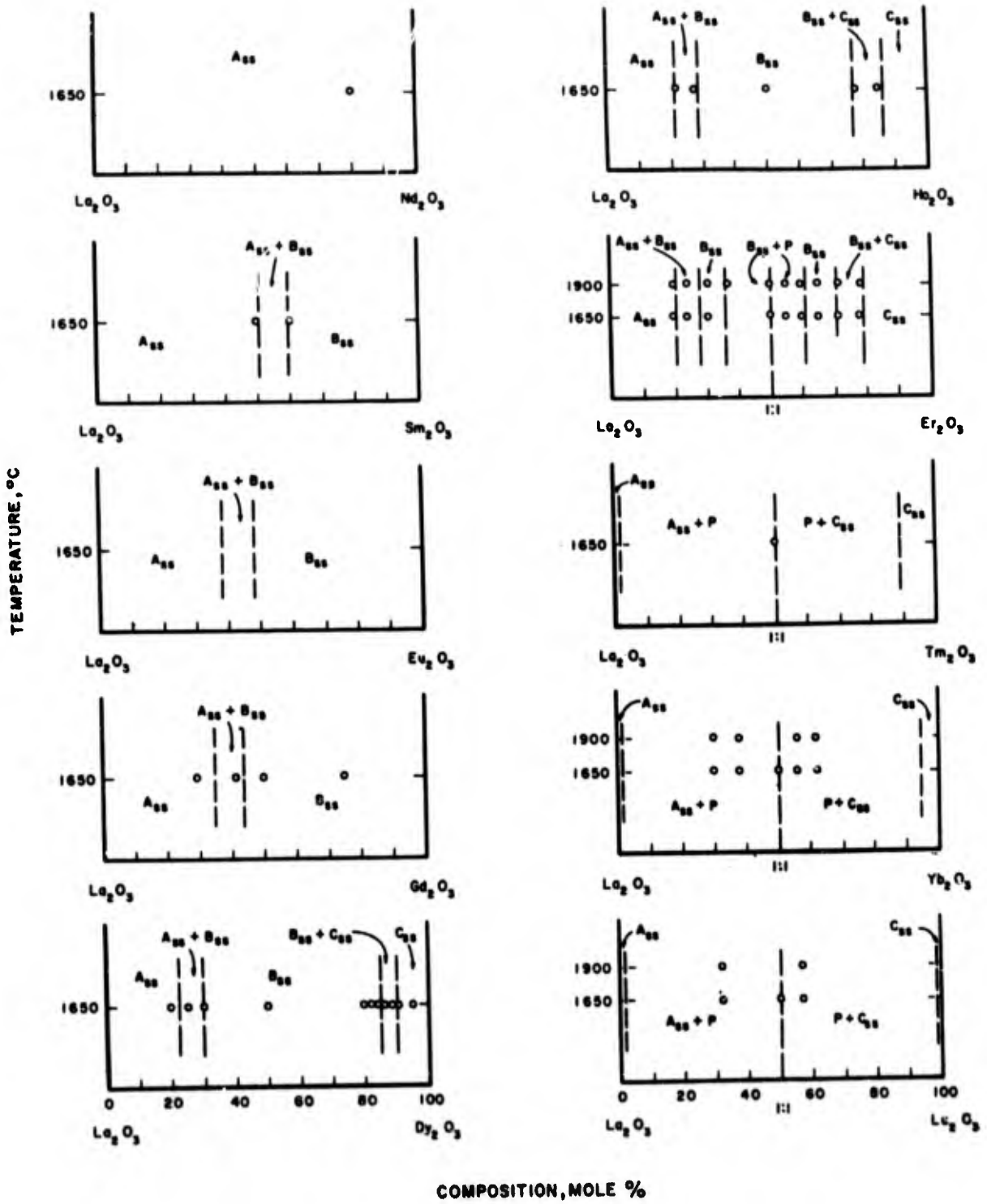
La<sub>2</sub>O<sub>3</sub>-TiO<sub>2</sub> (25)

(Permission of American Ceramic Society)

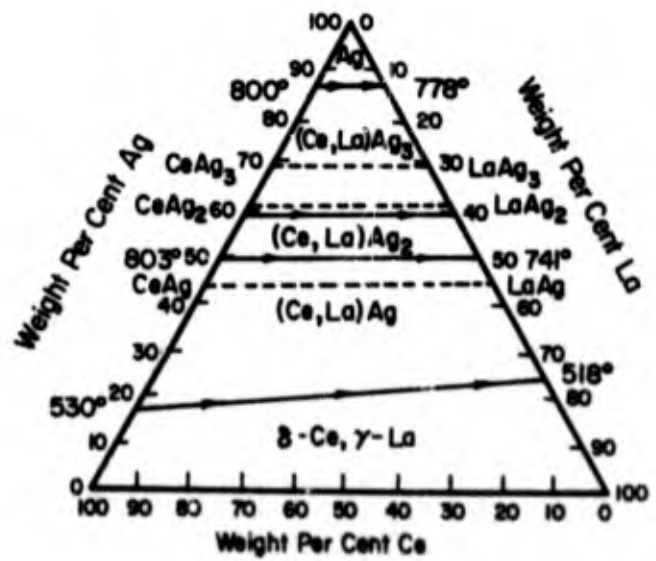
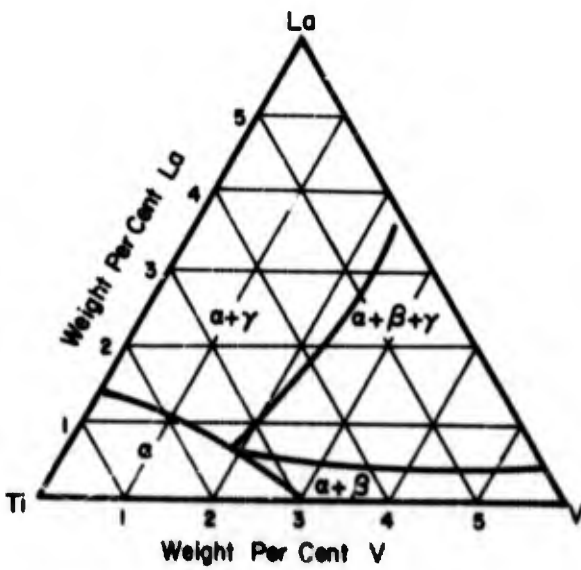
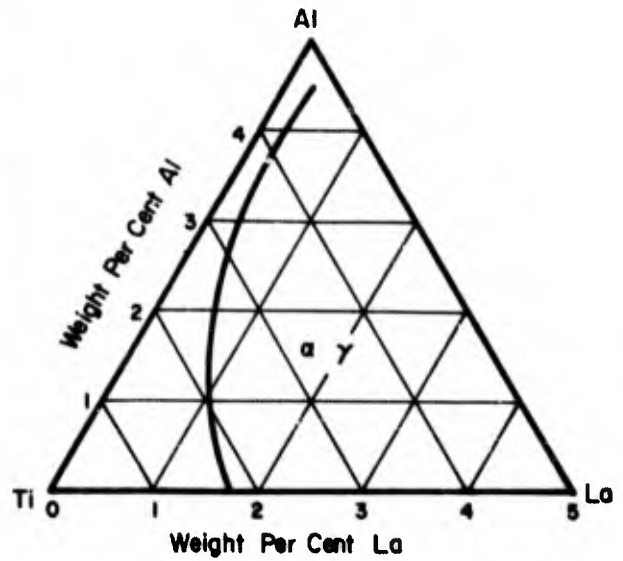
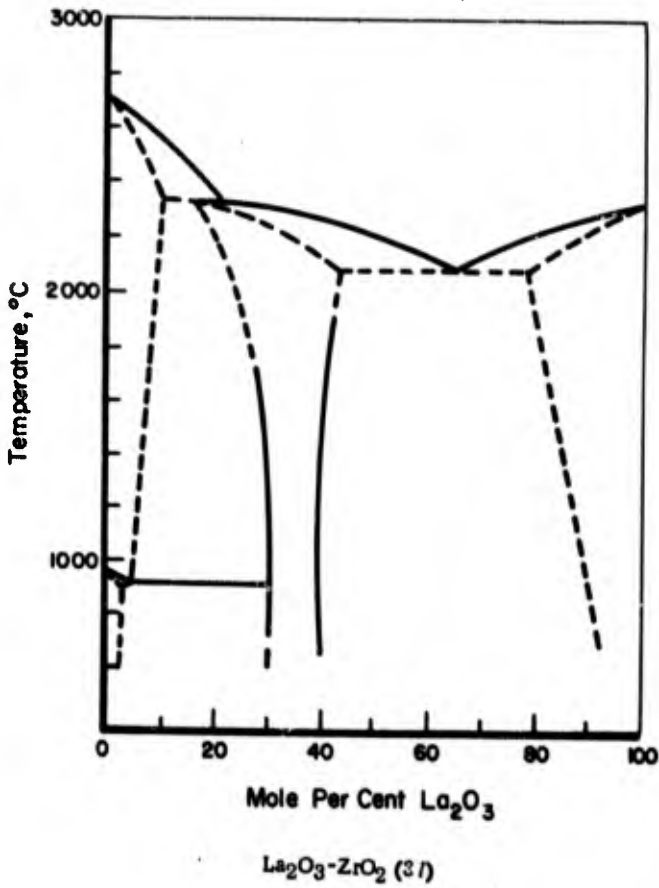


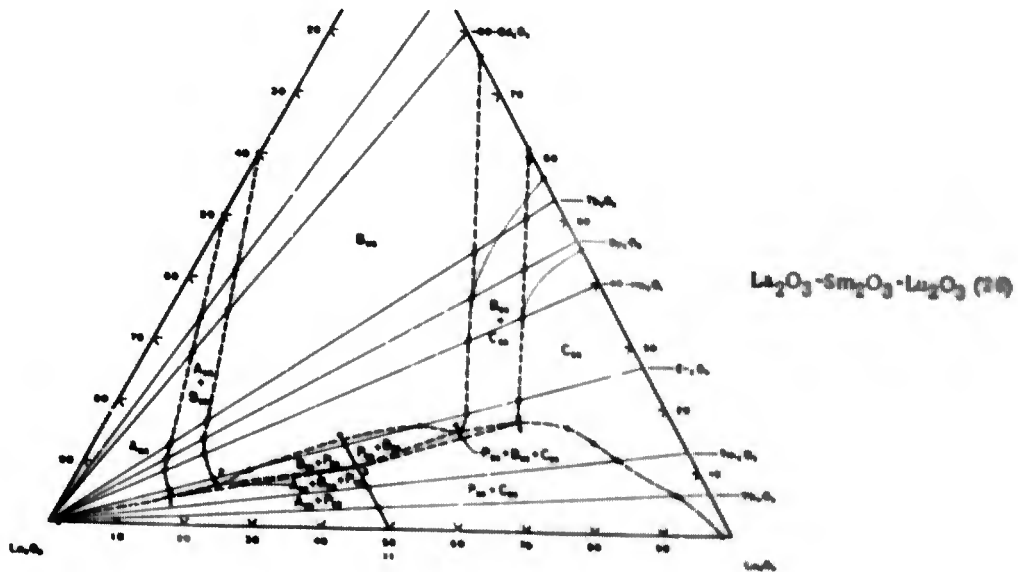
La<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> (24)



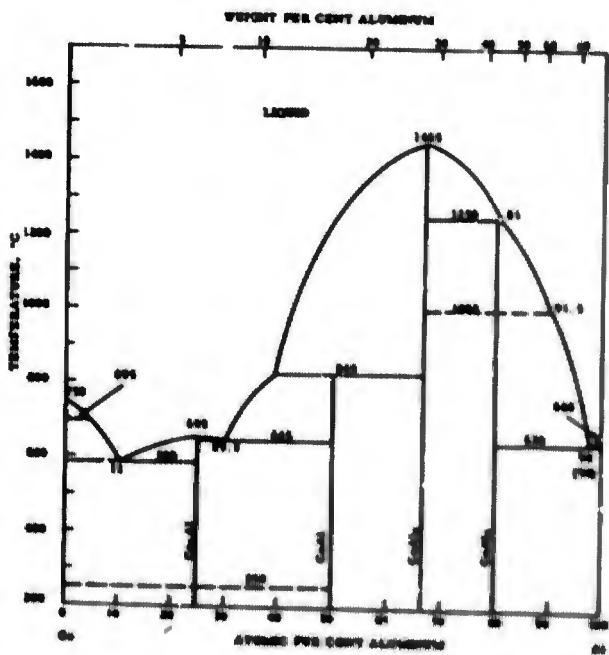


$\text{La}_2\text{O}_3$  - Rare-Earth Oxides (26)

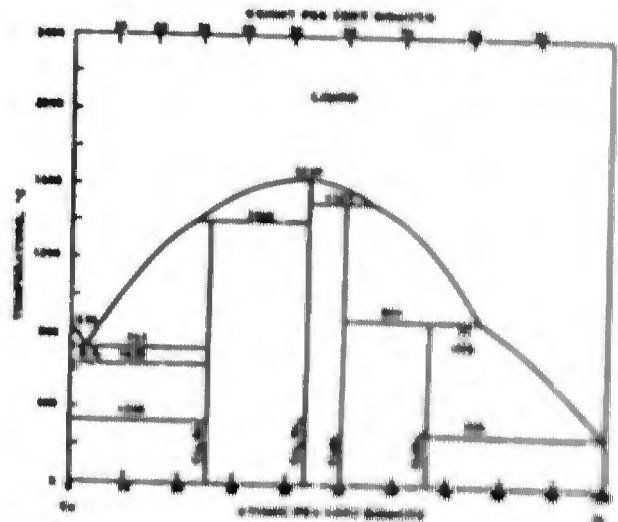




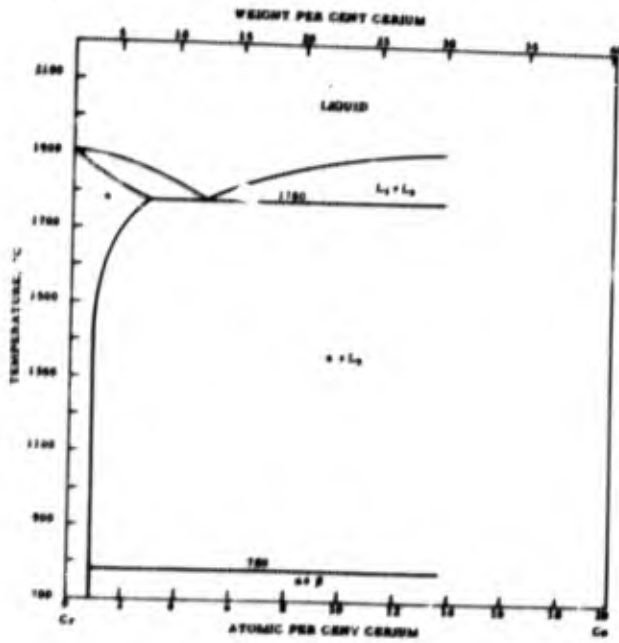
CERIUM



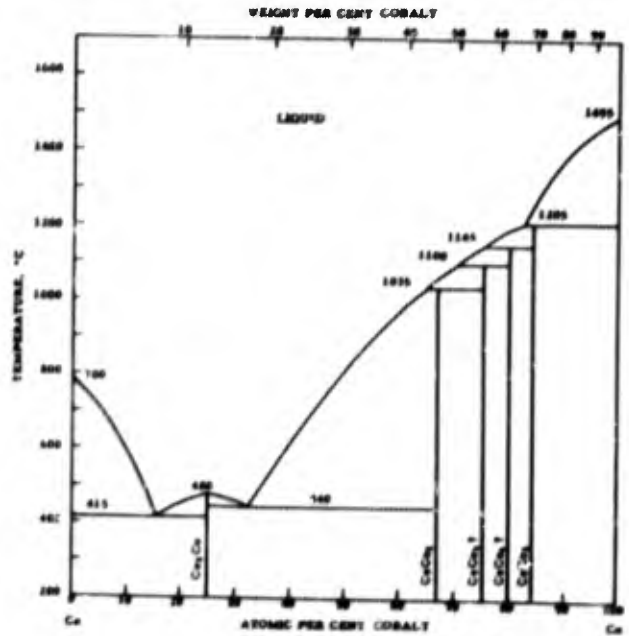
Aluminum (1)  
(Permission of U. S. AEC)



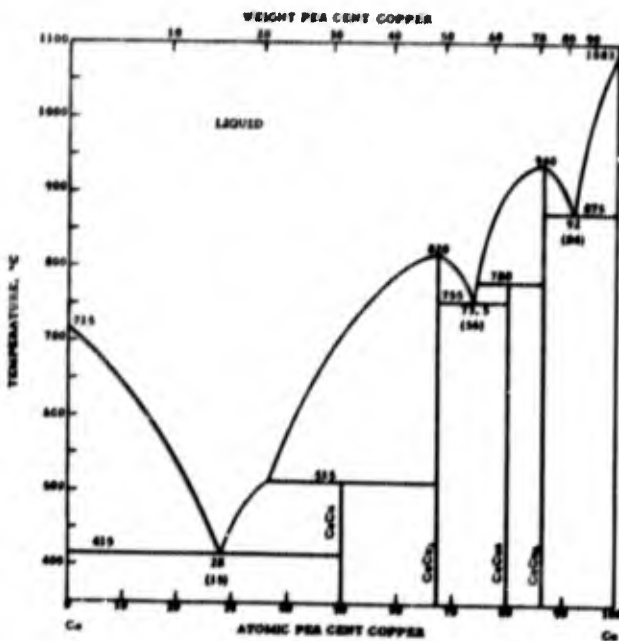
Cerium (2)  
(Permission of U. S. AEC)



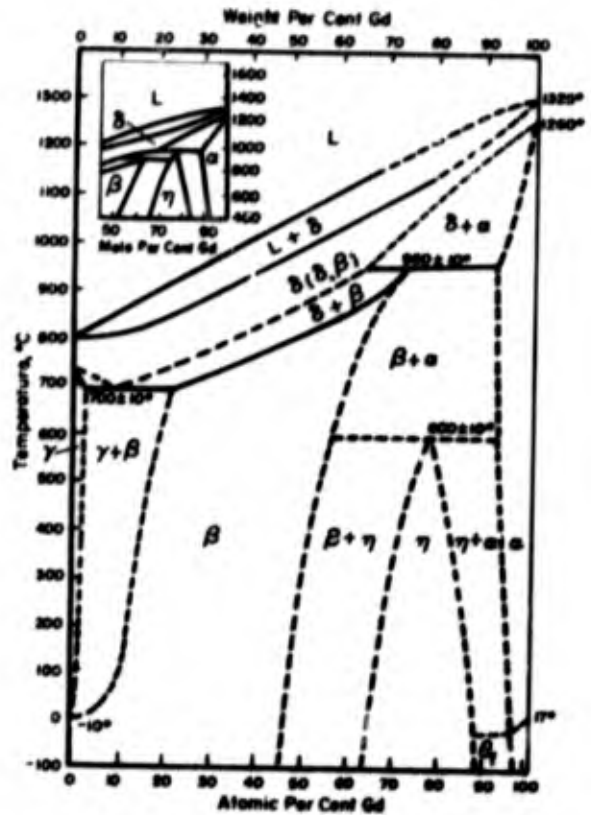
Chromium (1)  
(Permission of U. S. AEC)



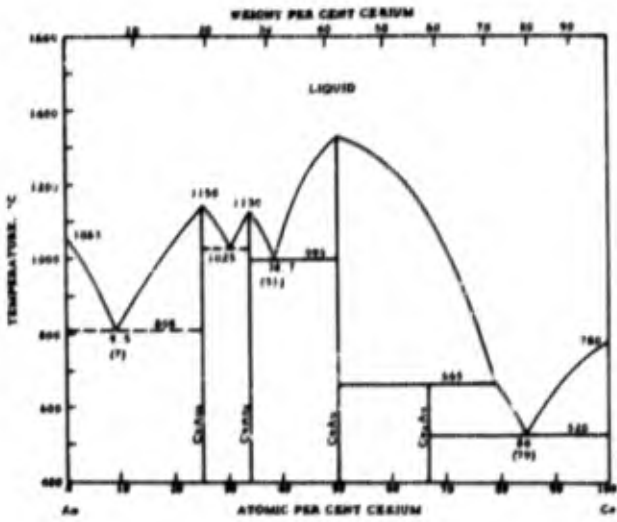
Cobalt (1)  
(Permission of U. S. AEC)



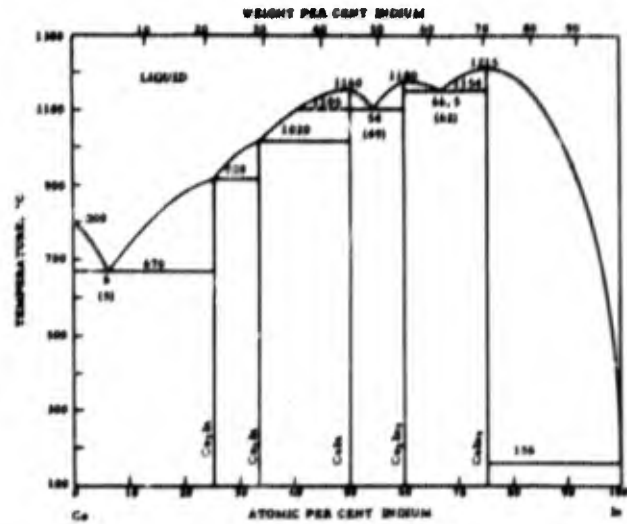
Copper (1)  
(Permission of U. S. AEC)



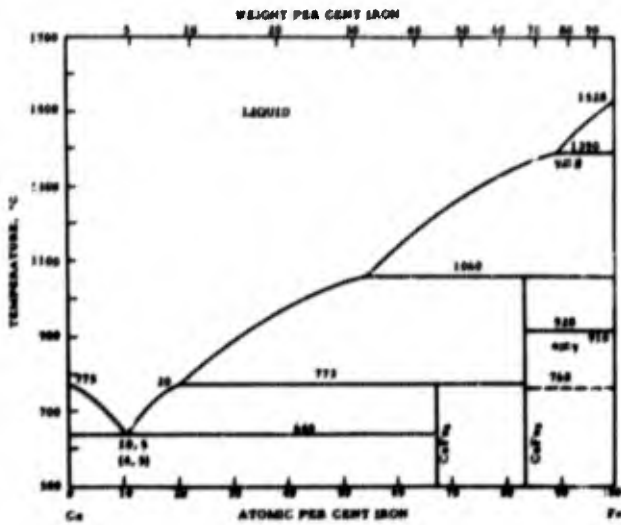
Gadolinium (29)



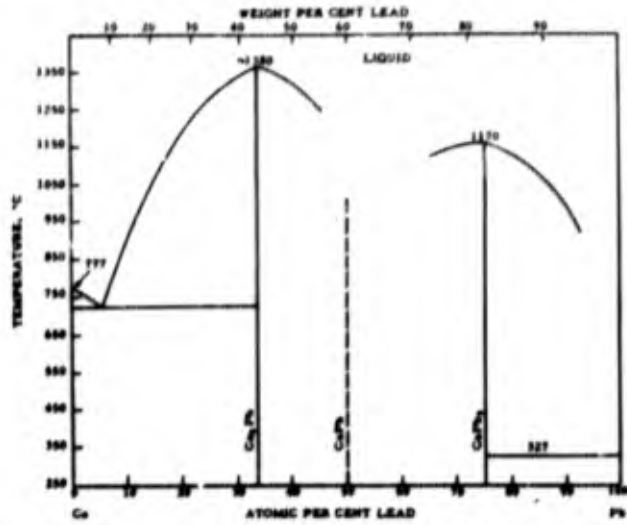
Gold (1)  
(Permission of U. S. AEC)



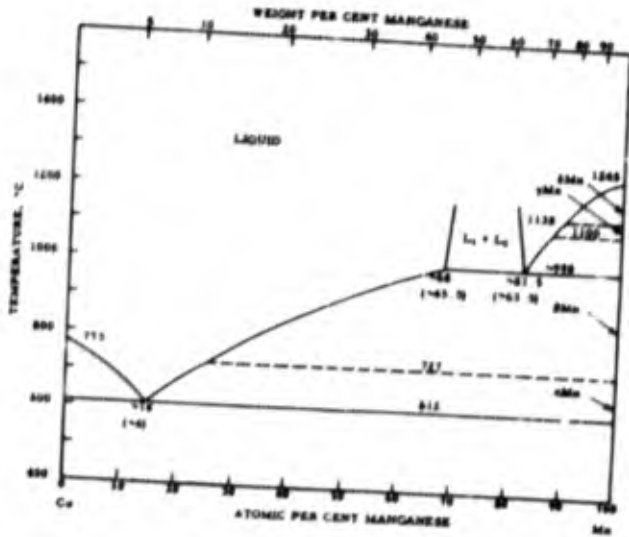
Indium (1)  
(Permission of U. S. AEC)



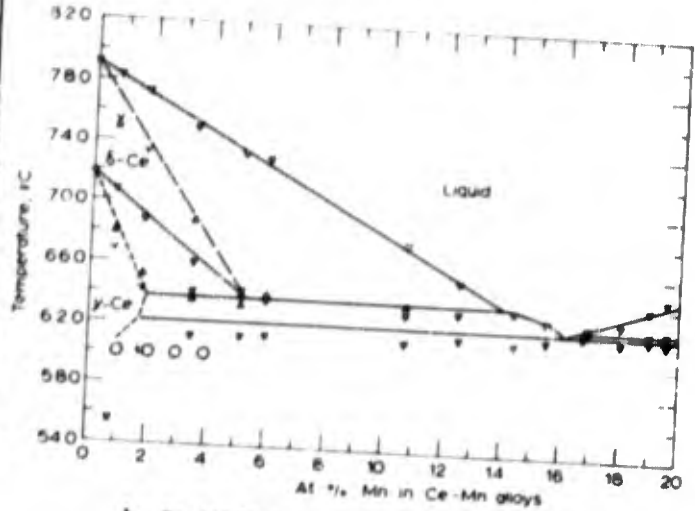
Iron (1)  
(Permission of U. S. AEC)



Lead (1)  
(Permission of U. S. AEC)

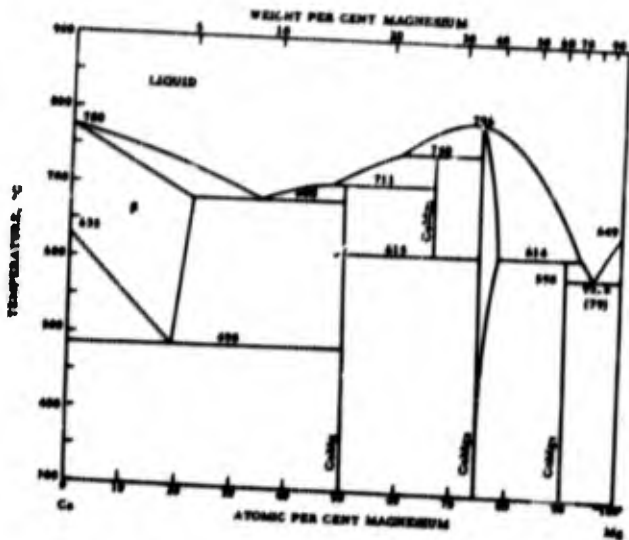


a. Full Diagram (1)  
(Permission of U. S. AEC)

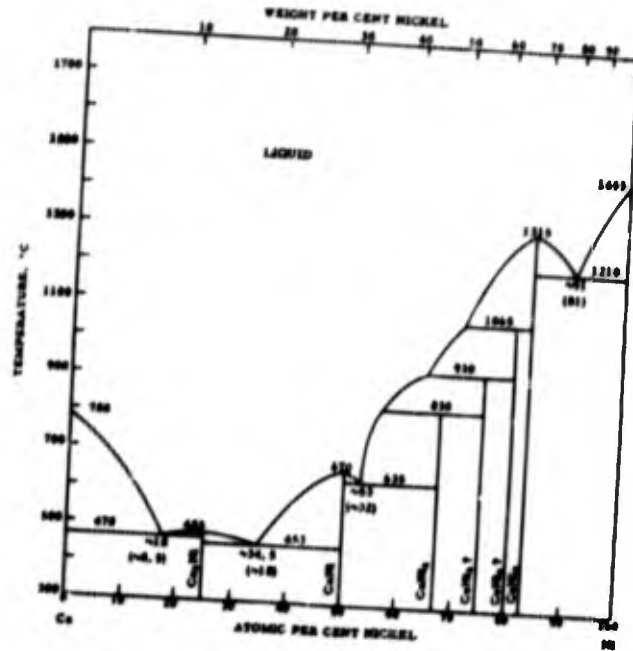


b. Partial Diagram - Cerium-Rich Region (30)  
(Permission of Elsevier Publishing Co.)

Manganese

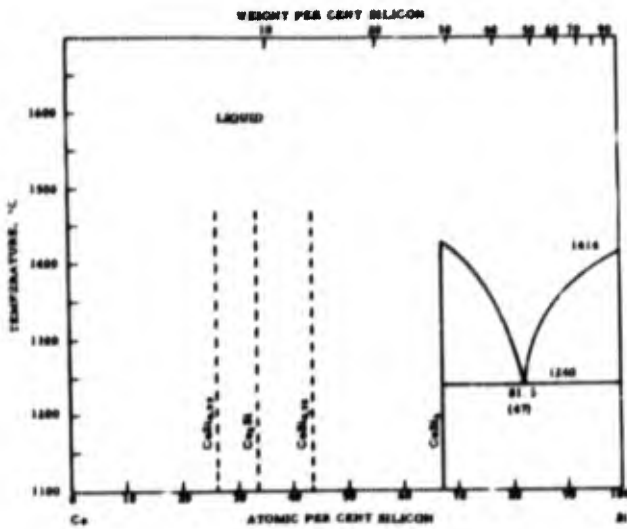


Magnesium (1)  
(Permission of U. S. AEC)

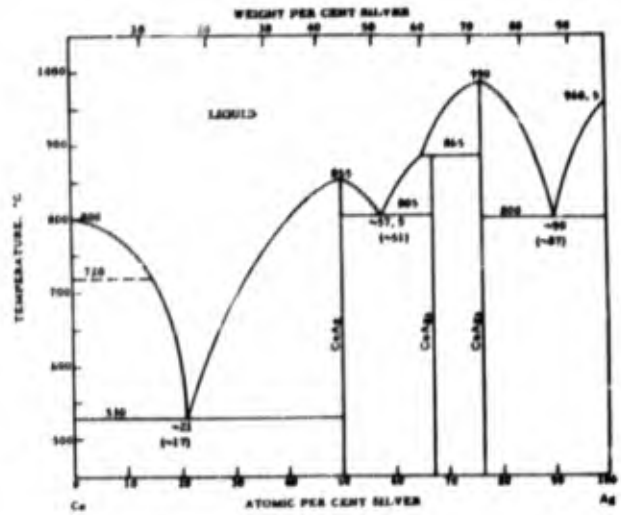


Nickel (1)  
(Permission of U. S. AEC)

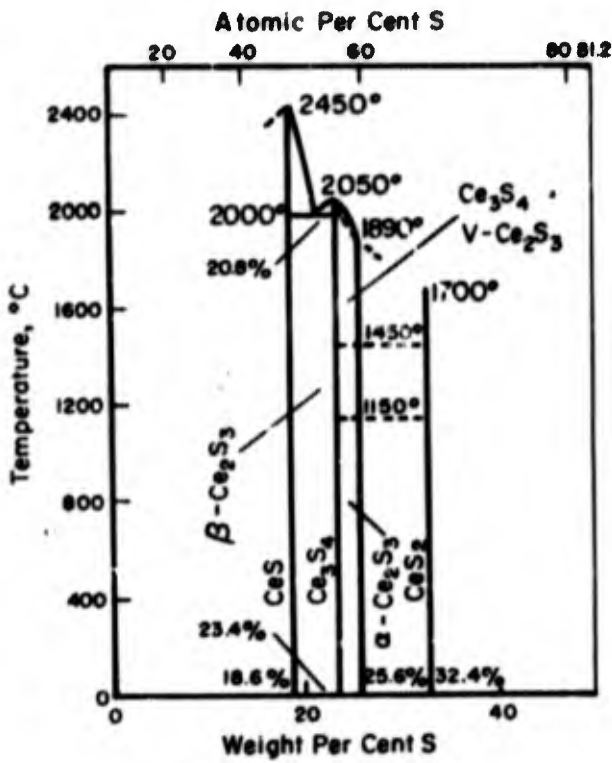




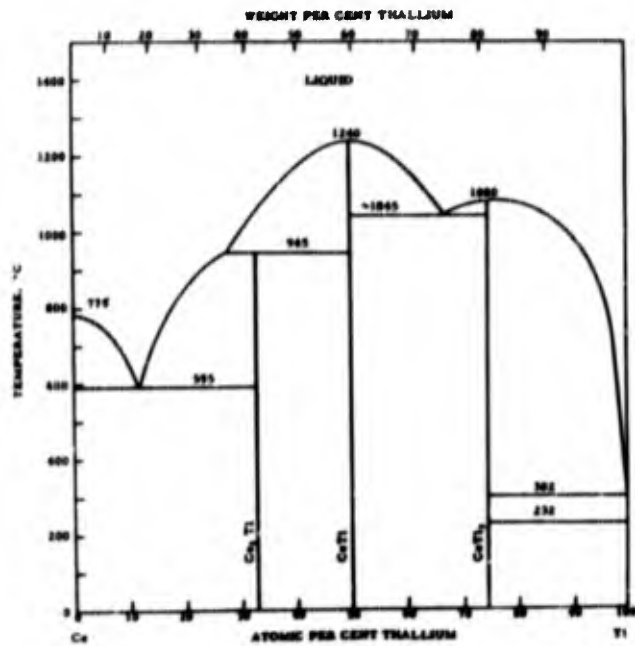
Silicon (1)  
(Permission of U. S. AEC)



Silver (1)  
(Permission of U. S. AEC)

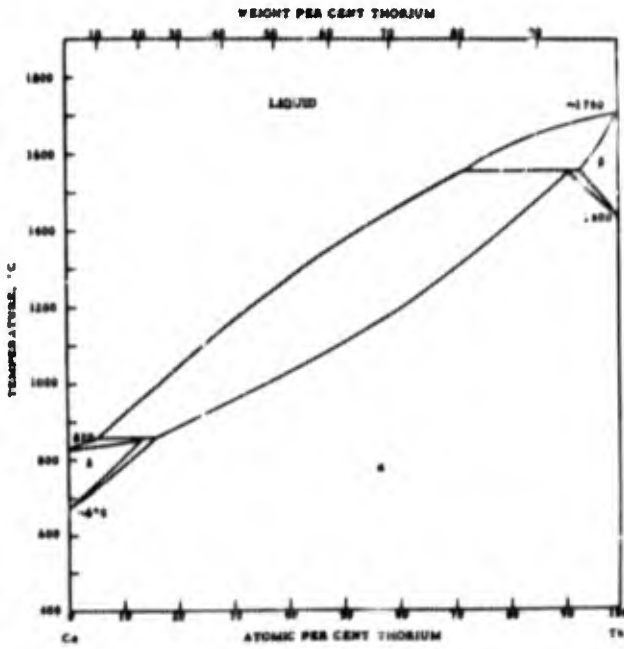


Sulfur (4)

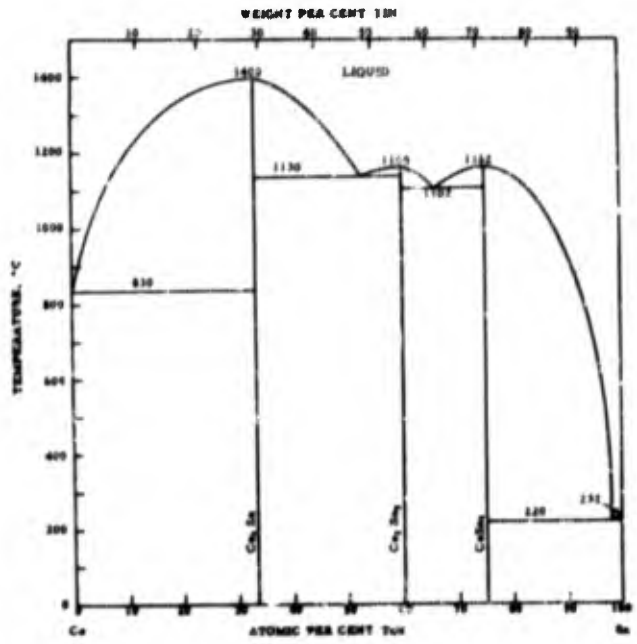


Thallium (1)  
(Permission of U. S. AEC)

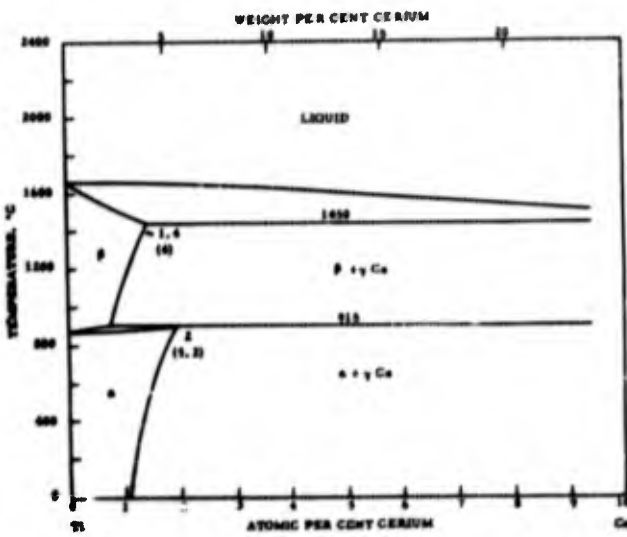




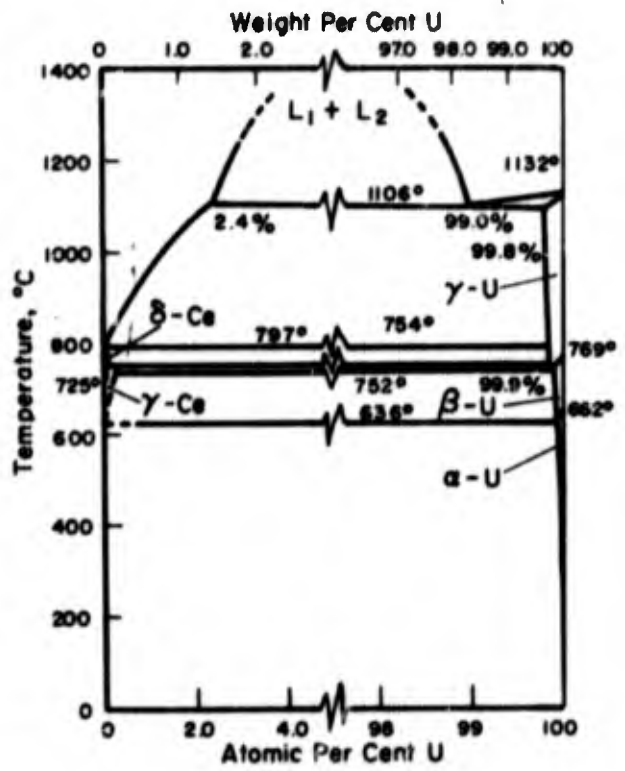
Thorium (1)  
(Permission of U. S. AEC)



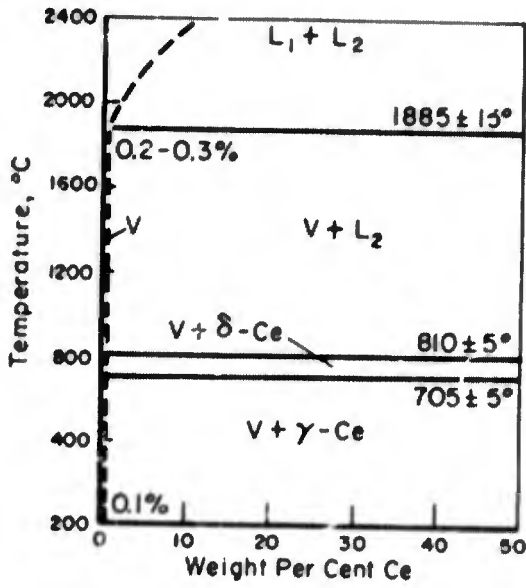
Tin (1)  
(Permission of U. S. AEC)



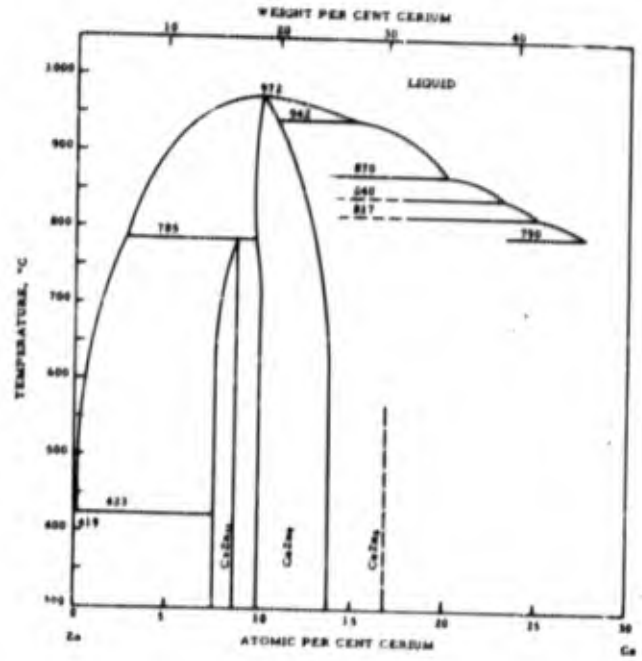
Titanium (1)  
(Permission of U. S. AEC)



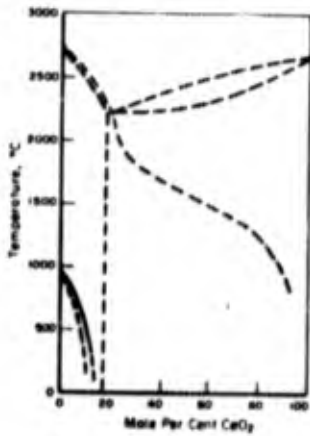
Uranium (4)



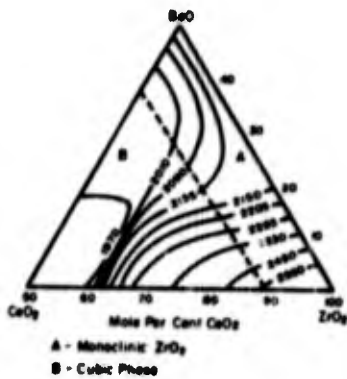
Vanadium (33)



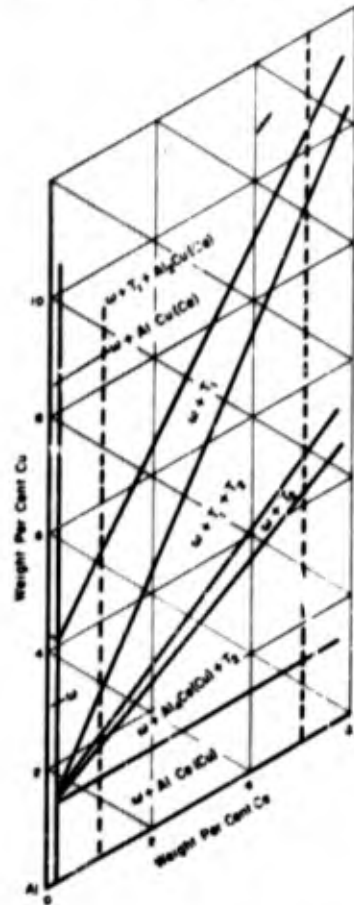
Zinc (1)  
(Permission of U. S. AEC)



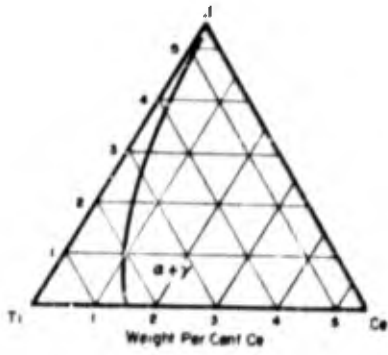
$\text{CeO}_2\text{-ZrO}_2$  (37)



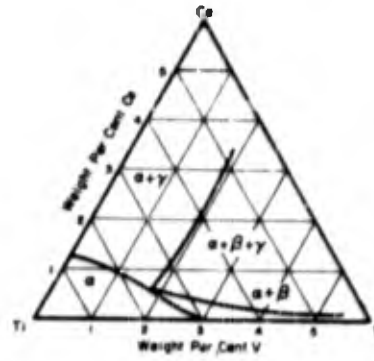
$\text{CeO}_2\text{-BaO-ZrO}_2$  (37)



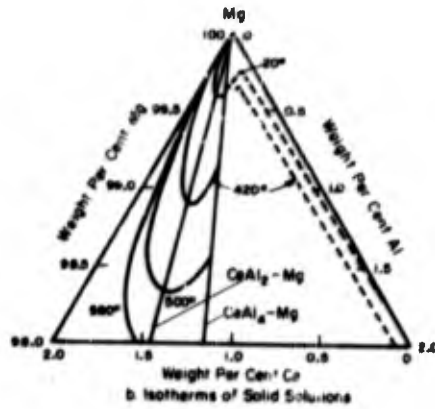
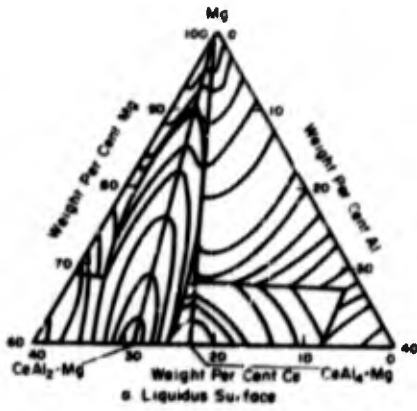
Cerium-Aluminum-Copper (34)  
Isothermal Section at 500°C



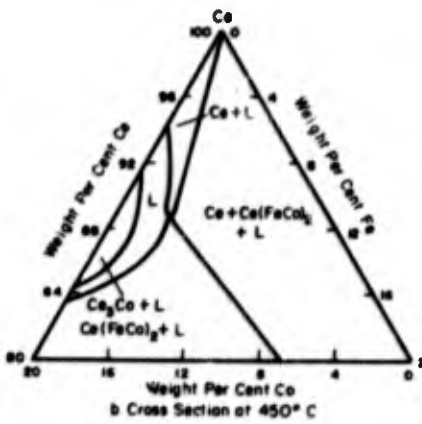
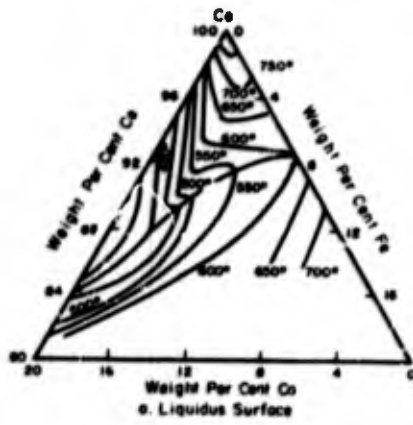
Cerium-Aluminum-Titanium (4)



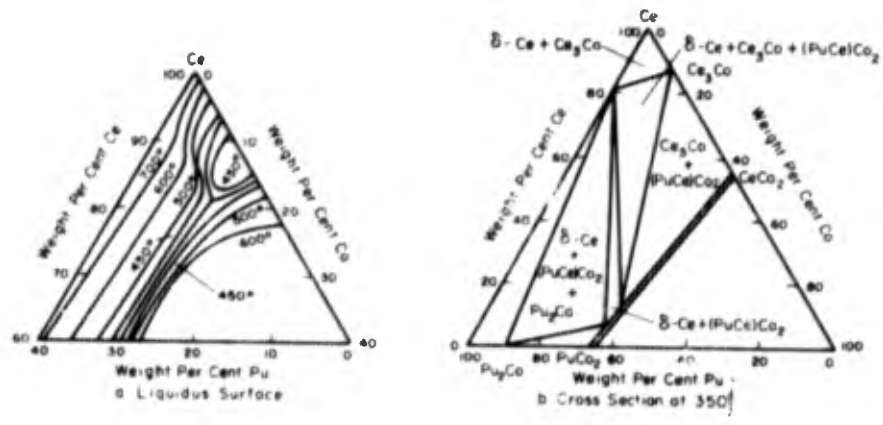
Cerium-Vanadium-Titanium (4)



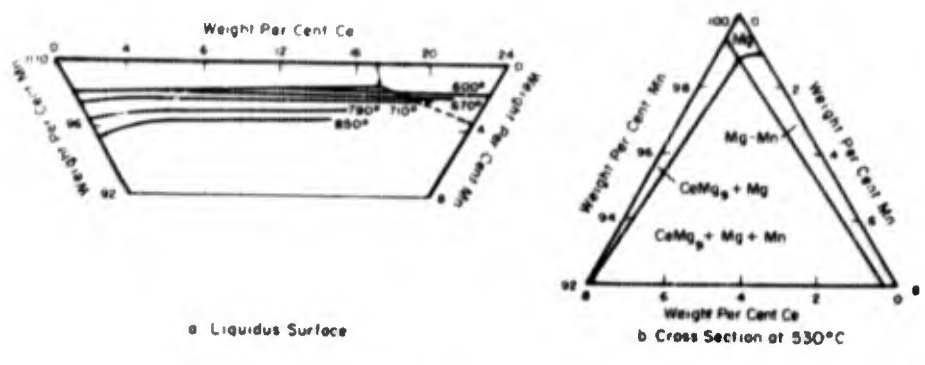
Cerium-Magnesium-Aluminum (4)



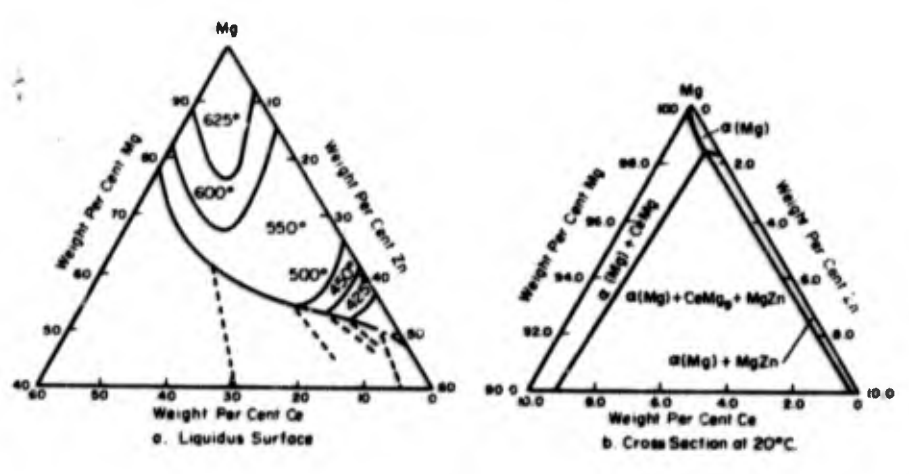
Cerium-Cobalt-Iron (4)



Cerium-Cobalt-Plutonium (4)

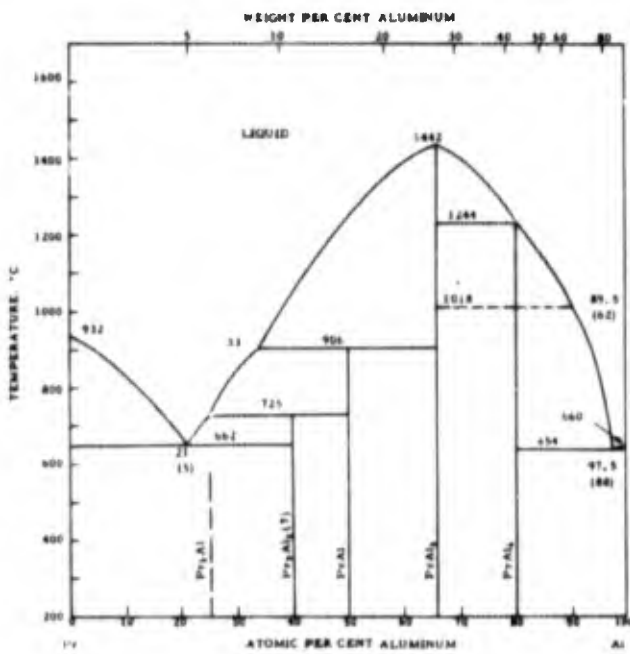


Cerium-Magnesium-Manganese (4)

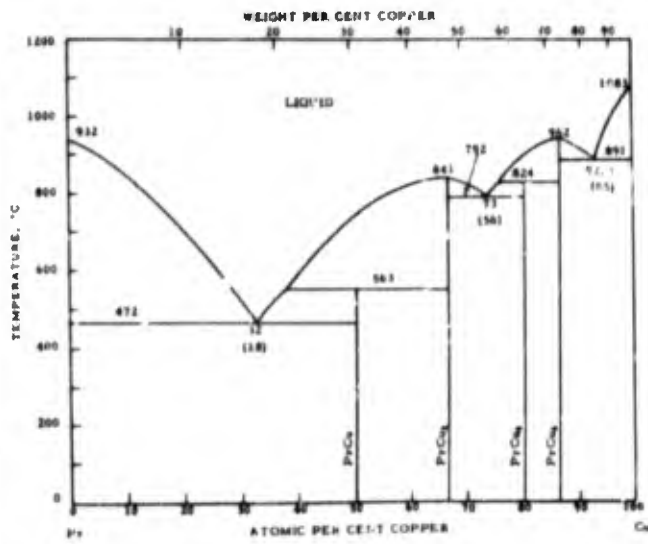


Cerium-Magnesium-Zinc (4)

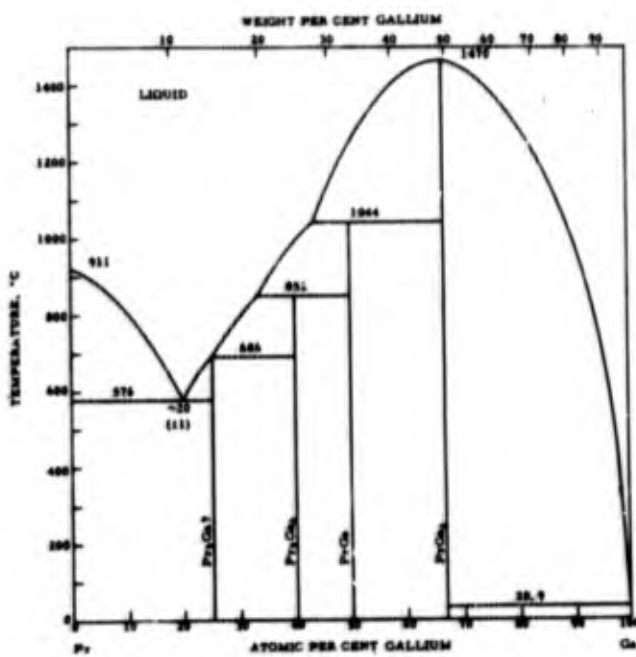
PRASEODYMIUM



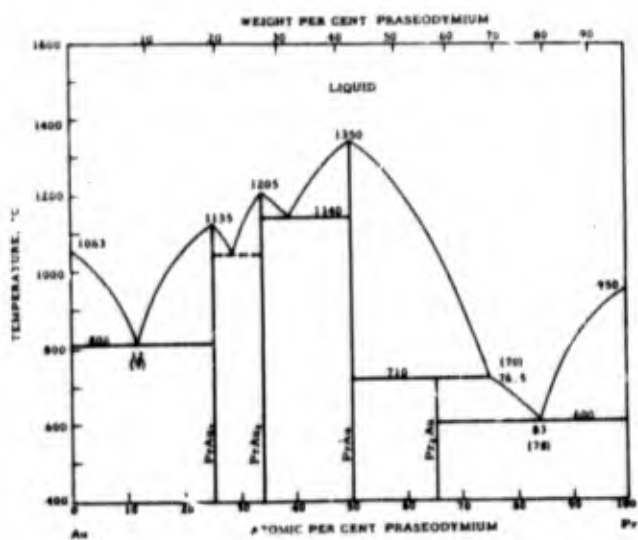
Aluminum (1)  
(Permission of U. S. AEC)



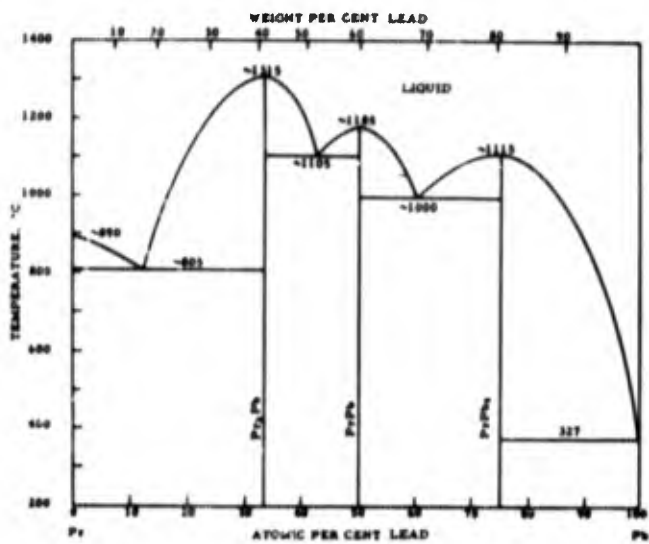
Copper (1)  
(Permission of U. S. AEC)



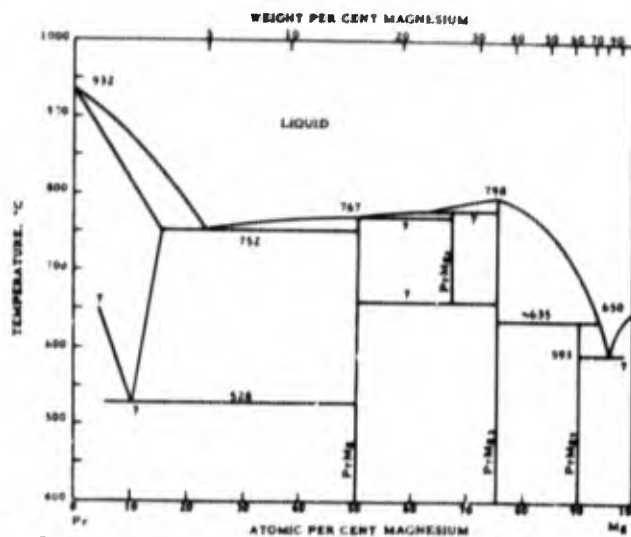
Gallium (1)  
(Permission of U. S. AEC)



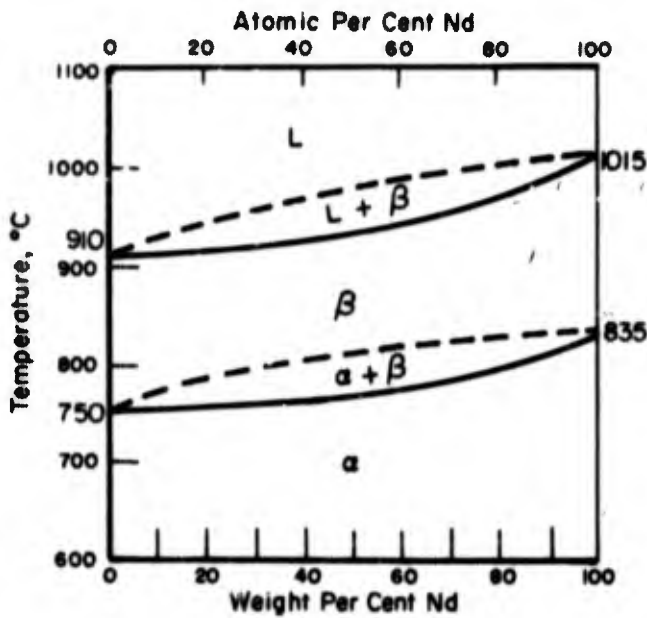
Gold (1)  
(Permission of U. S. AEC)



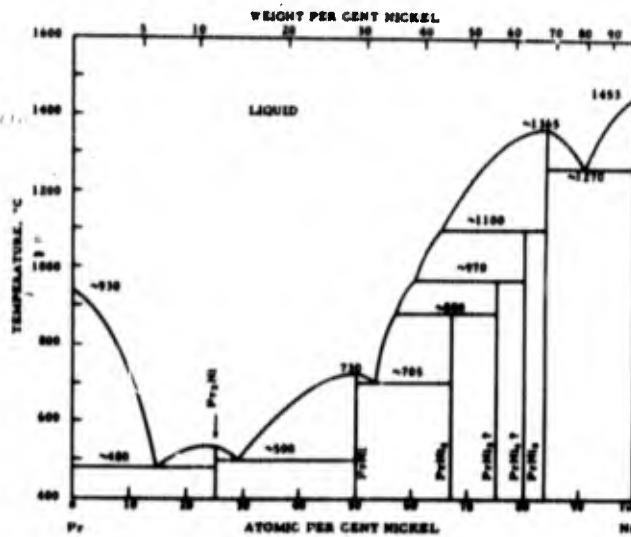
Lead (1)  
(Permission of U. S. AEC)



Magnesium (1)  
(Permission of U. S. AEC)

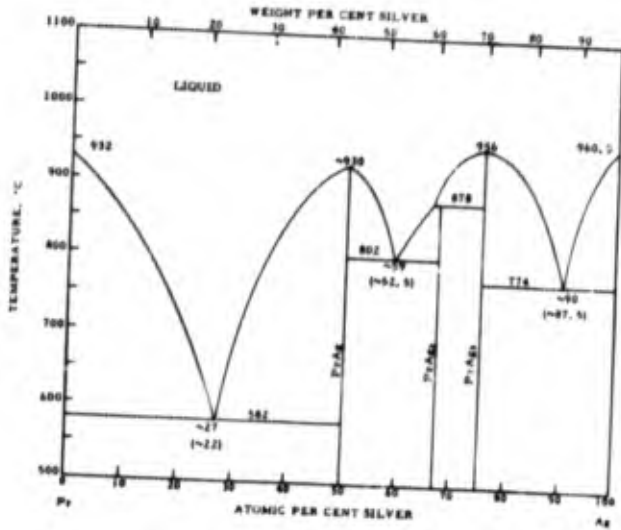


Neodymium (35)

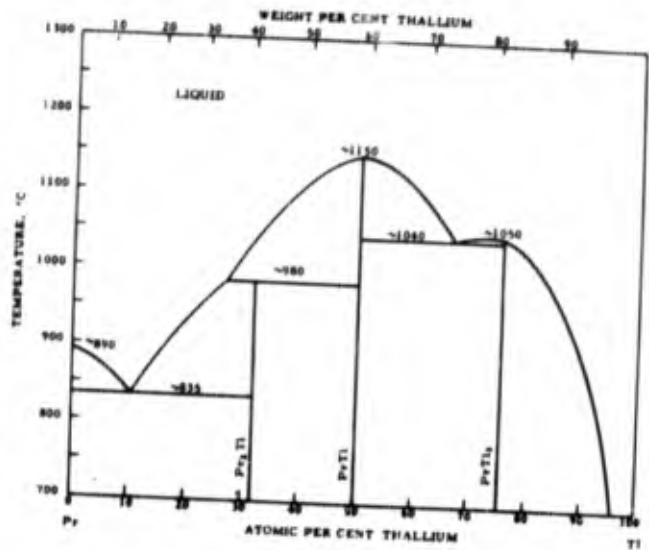


Nickel (1)  
(Permission of U. S. AEC)

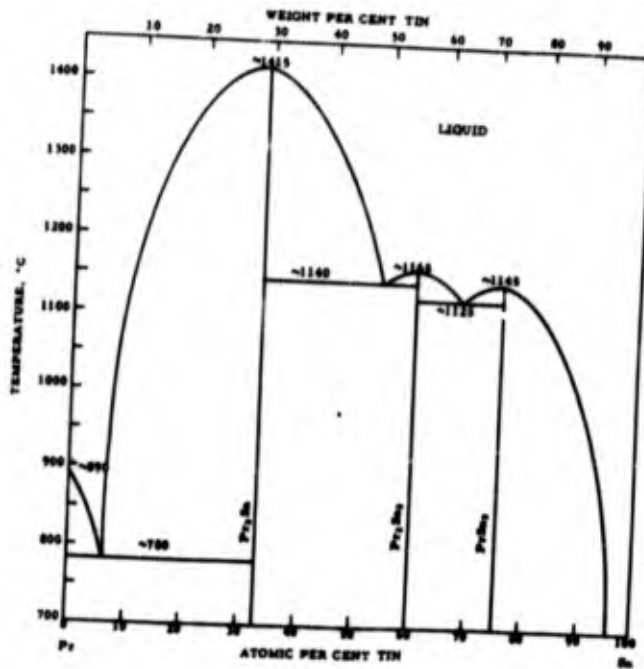
PHASE DIAGRAMS



Silver (1)  
(Permission of U. S. AEC)

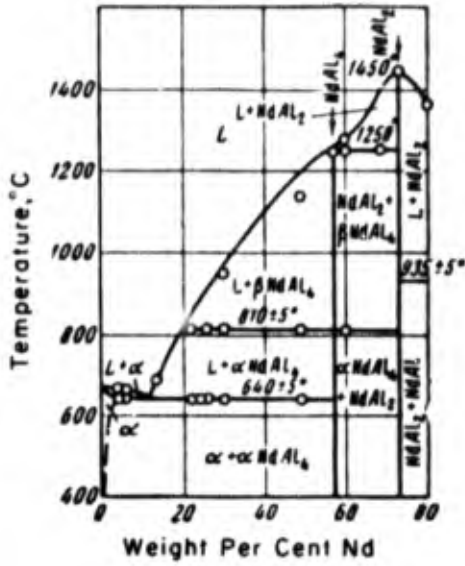


Thallium (1)  
(Permission of U. S. AEC)

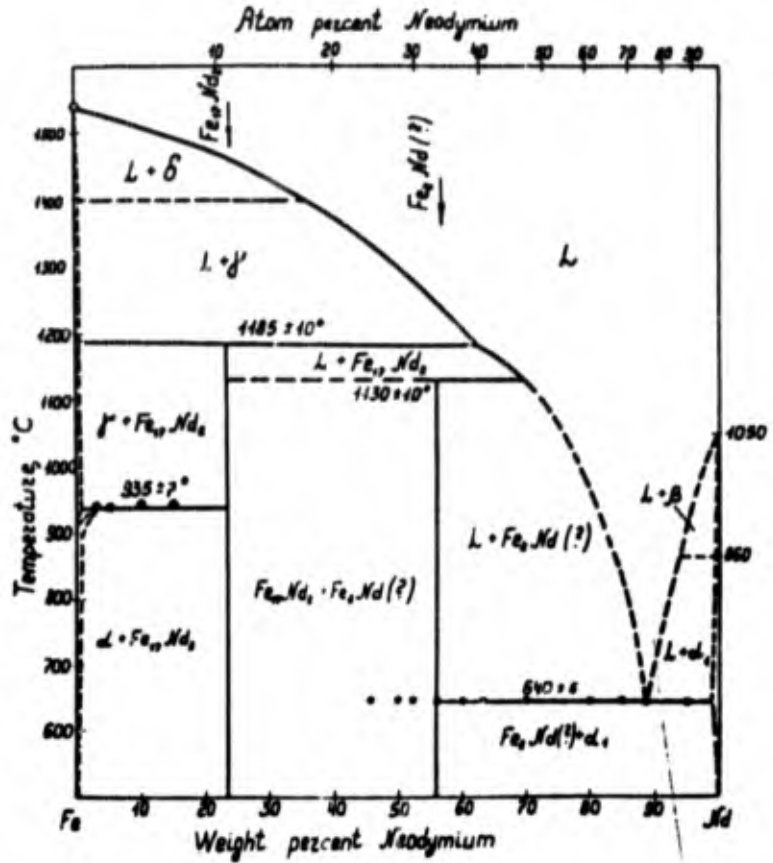


Tin (1)  
(Permission of U. S. AEC)

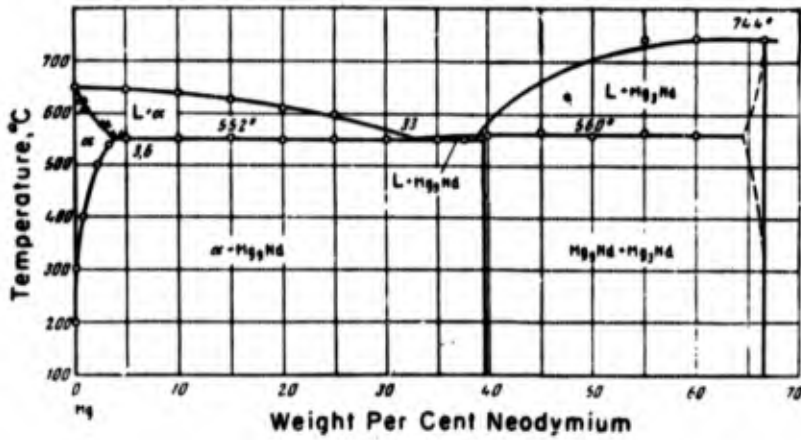
NEODYMIUM



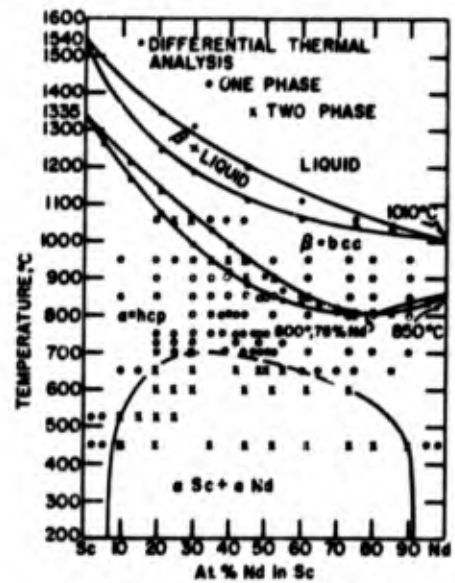
Aluminum (30)



Iron (38)

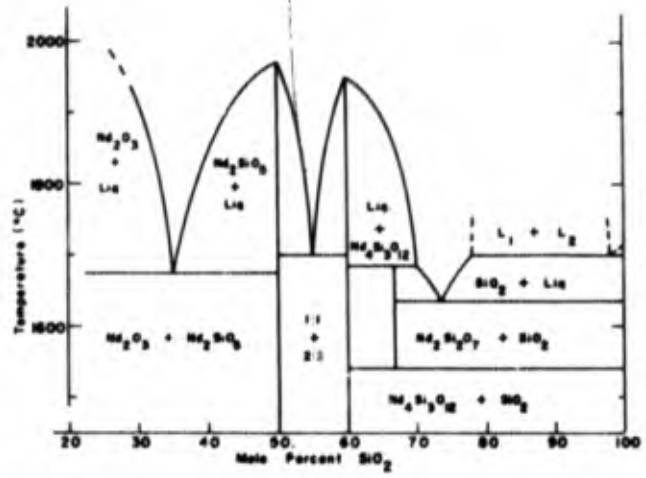
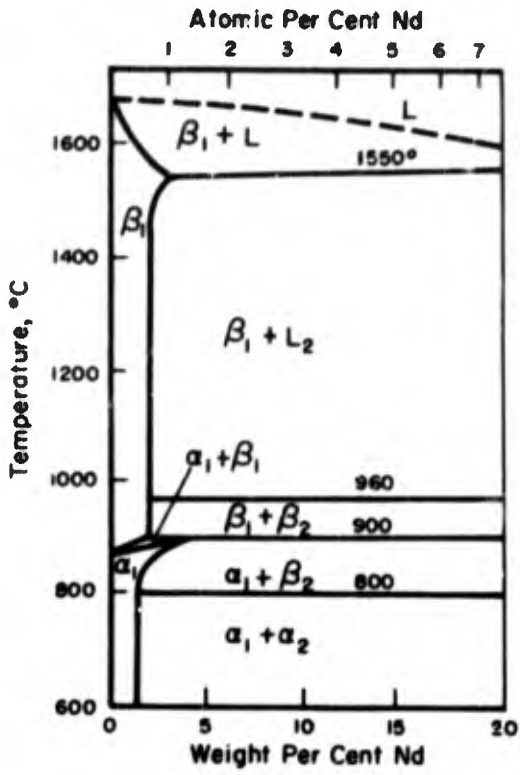


Magnesium (39)



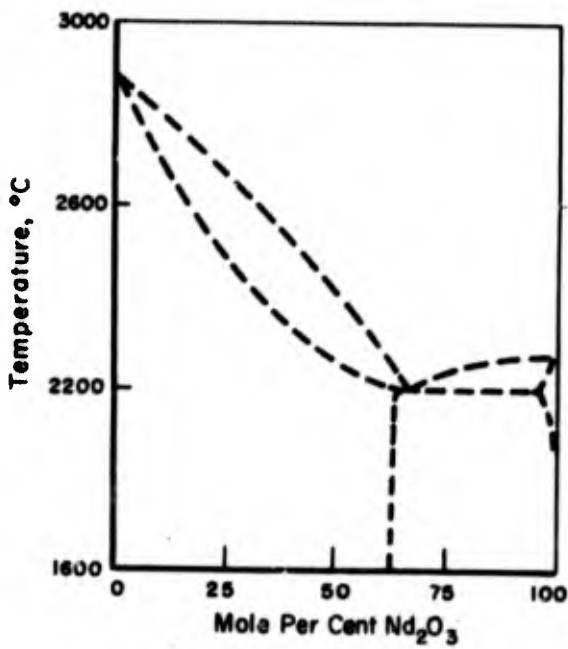
Scandium (5)



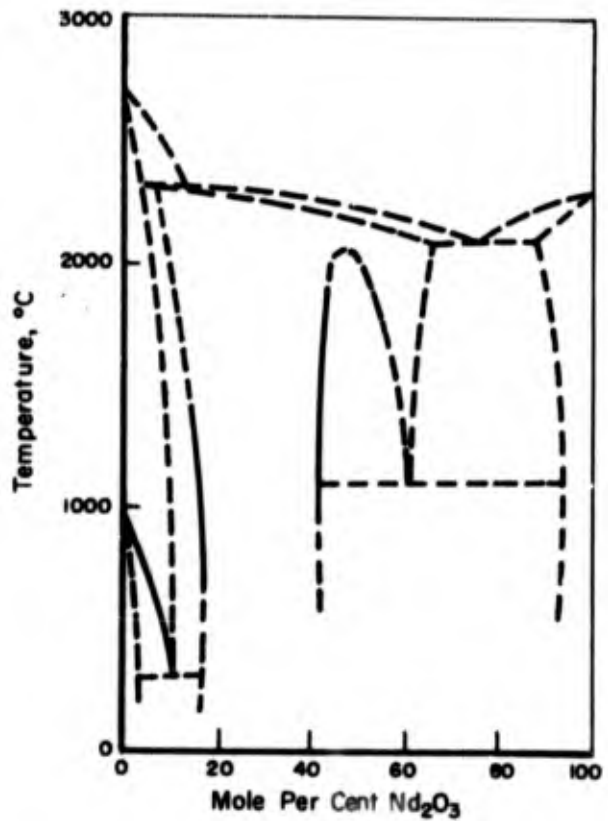


Nd<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> (41)  
(Permission of American Ceramic Society)

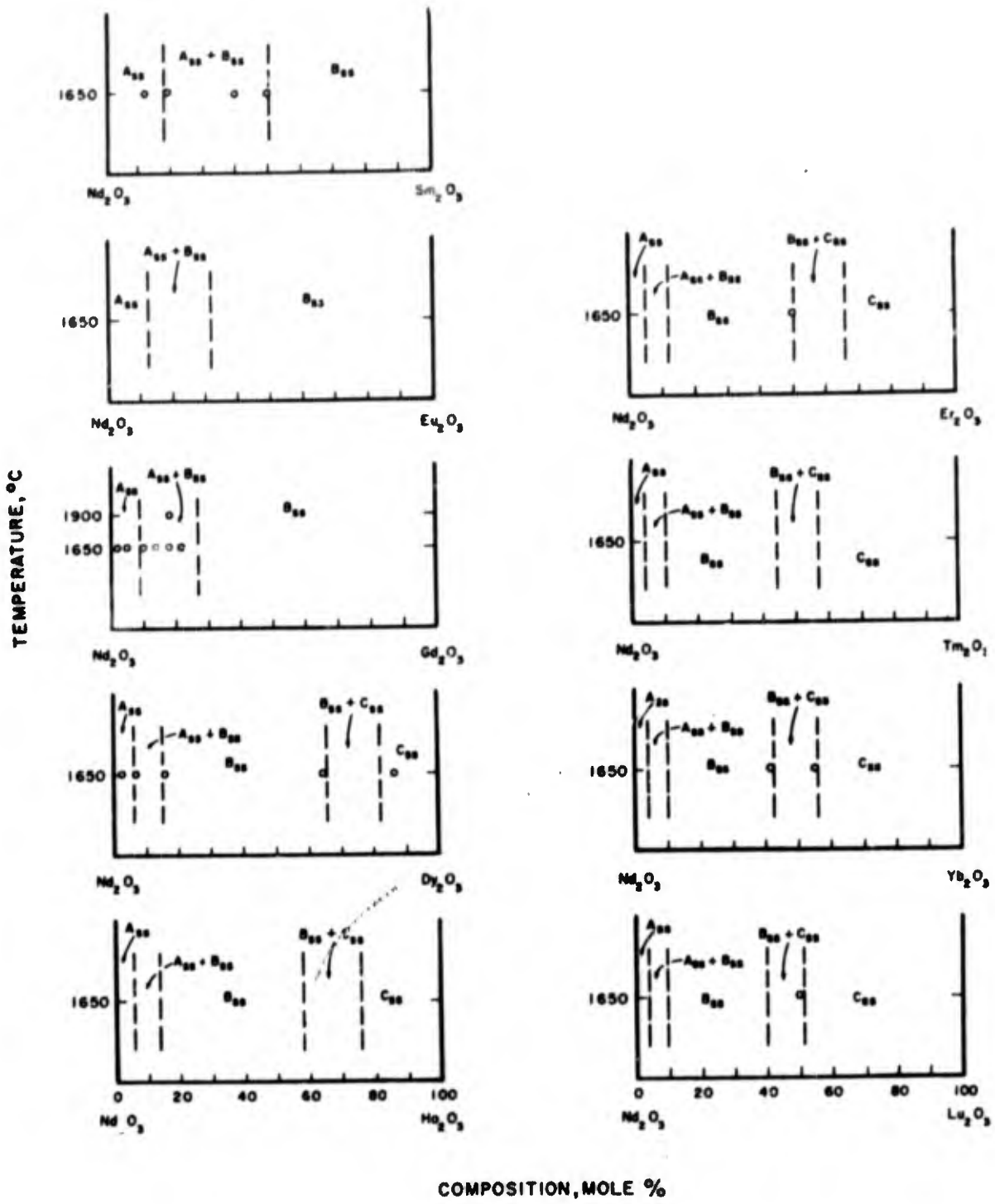
Titanium (40)  
(Permission of Elsevier Publishing Co.)



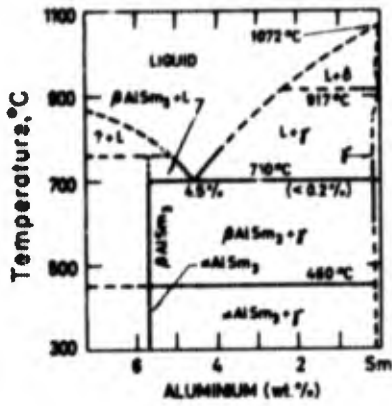
Nd<sub>2</sub>O<sub>3</sub>-UO<sub>2</sub> (37)



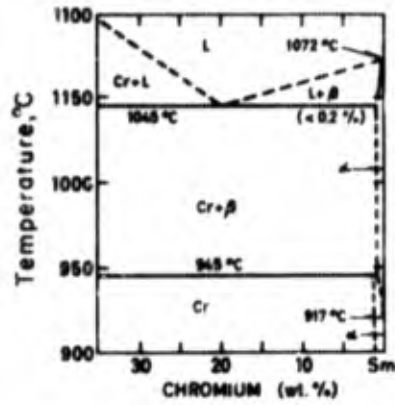
Nd<sub>2</sub>O<sub>3</sub>-ZrO<sub>2</sub> (37)



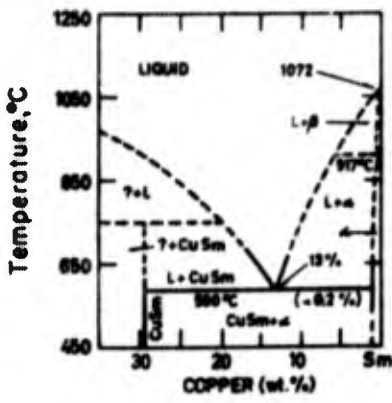
SAMARIUM



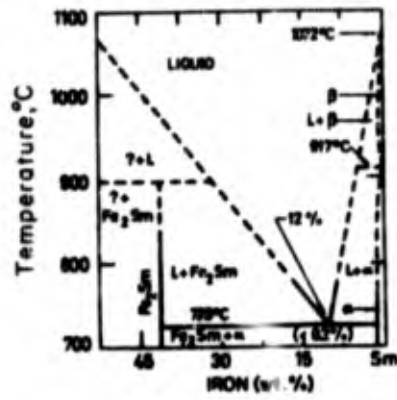
Aluminum (214)



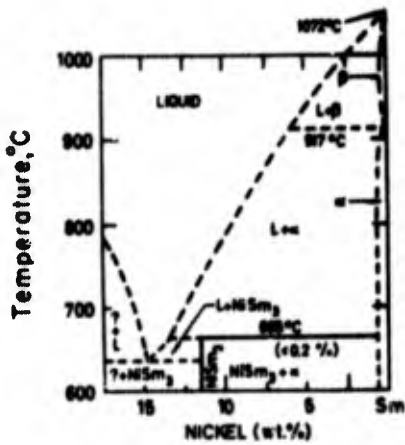
Chromium (214)



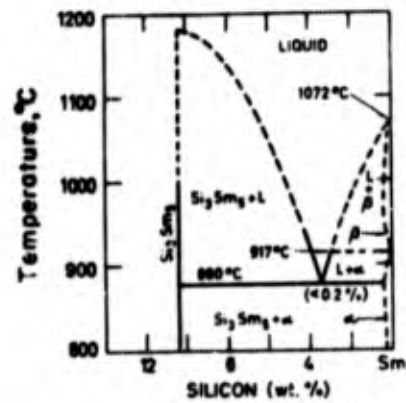
Copper (214)



Iron (214)

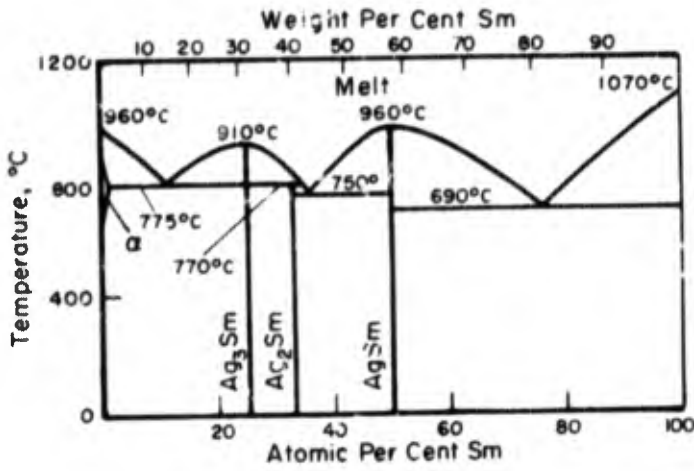


Nickel (214)

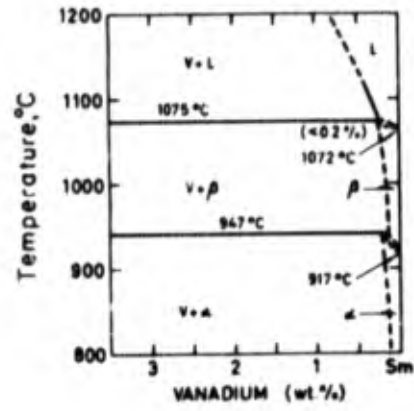


Silicon (214)

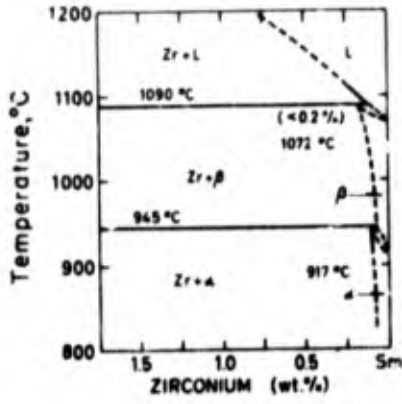
Sumarium



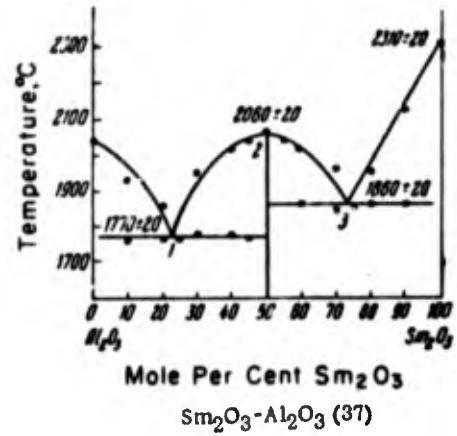
Silver (144)  
(Permission of Metallurgical Society AIME)



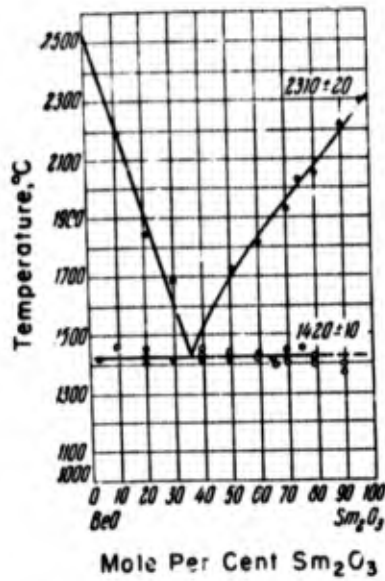
Vanadium (214)



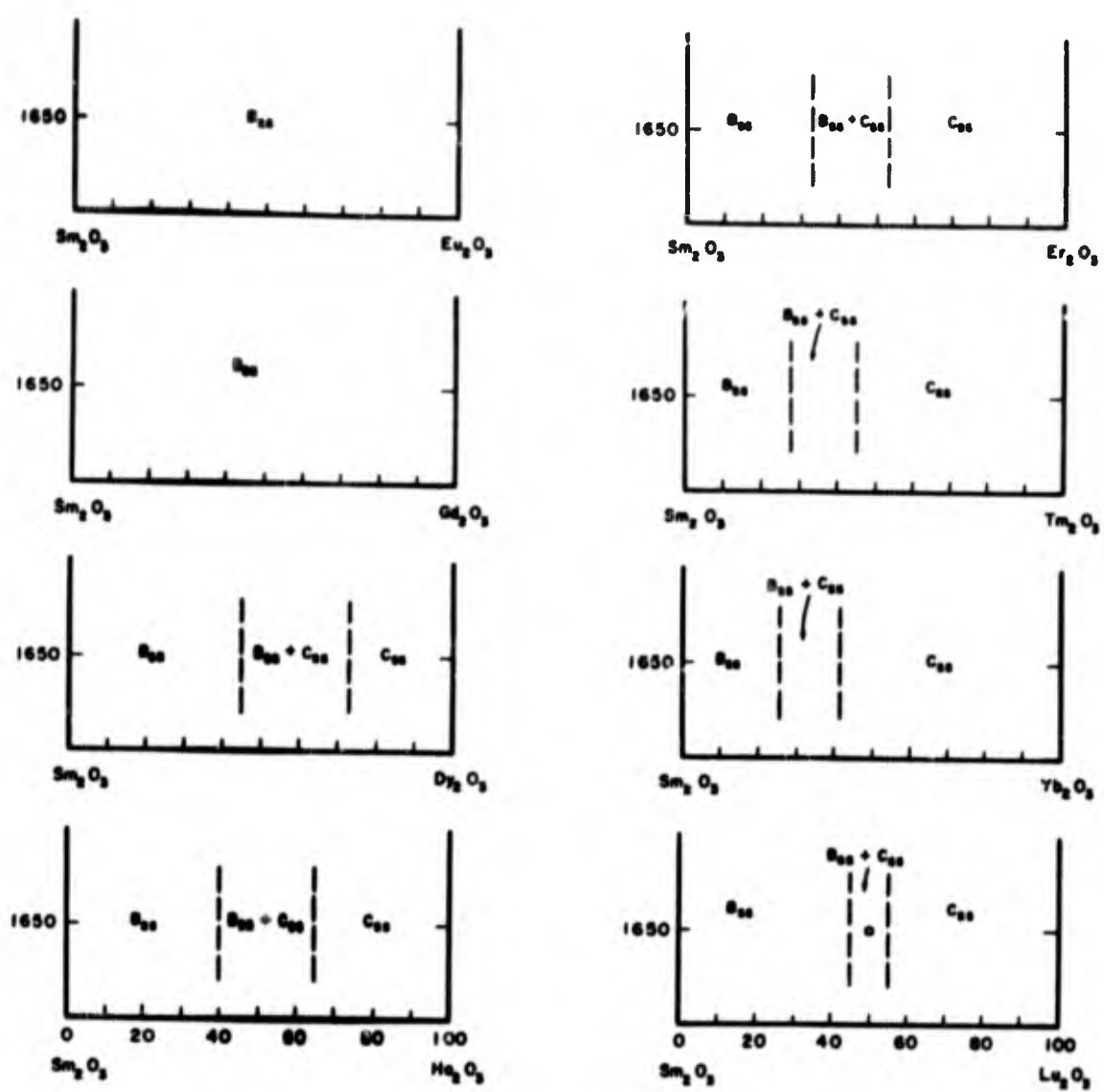
Zirconium (214)



Sm<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>O<sub>3</sub> (37)



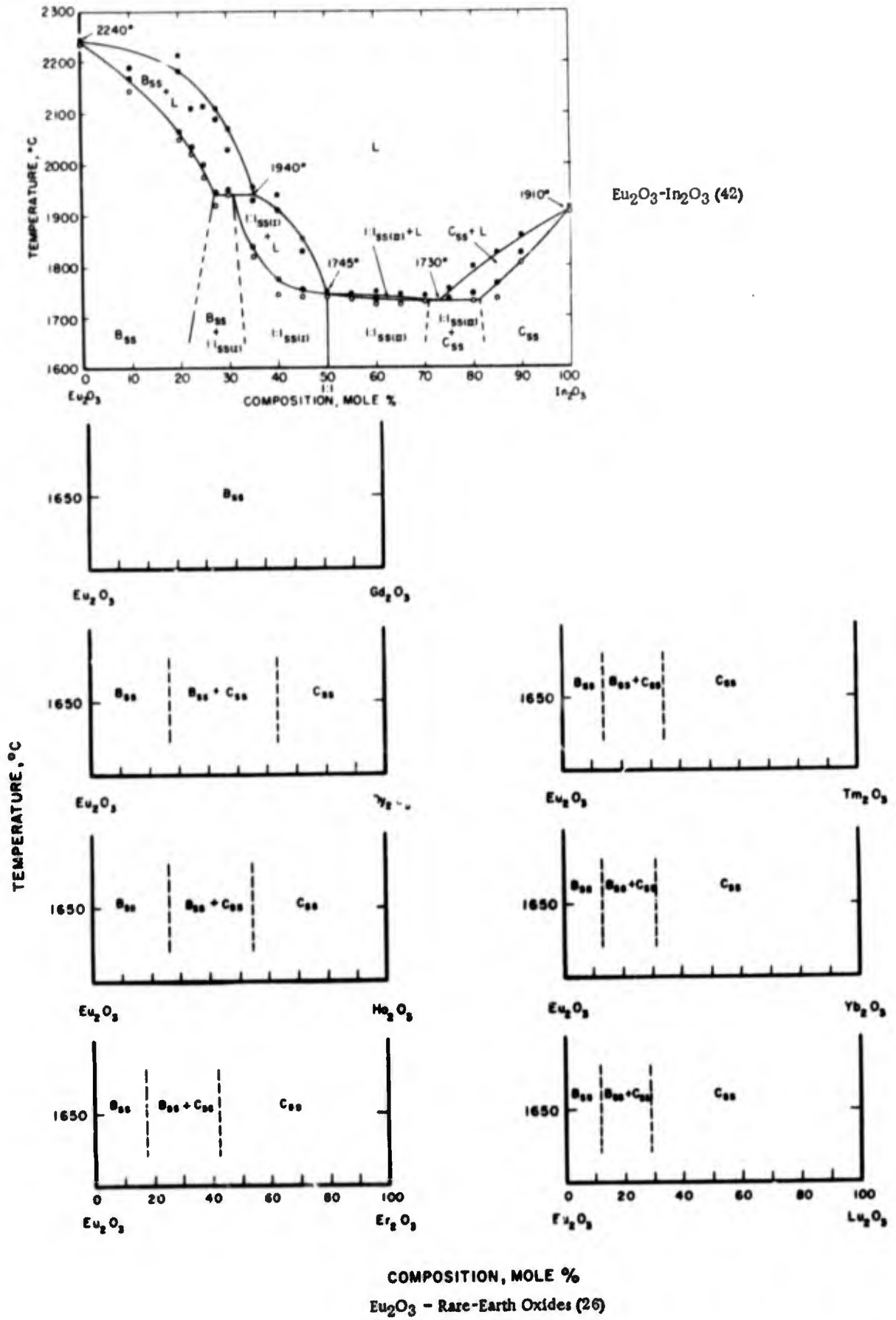
Sm<sub>2</sub>O<sub>3</sub>-BeO (37)



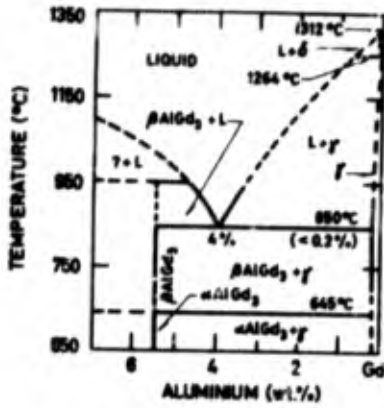
COMPOSITION, MOLE %

$\text{Sm}_2\text{O}_3$  - Rare-Earth Oxides (26)

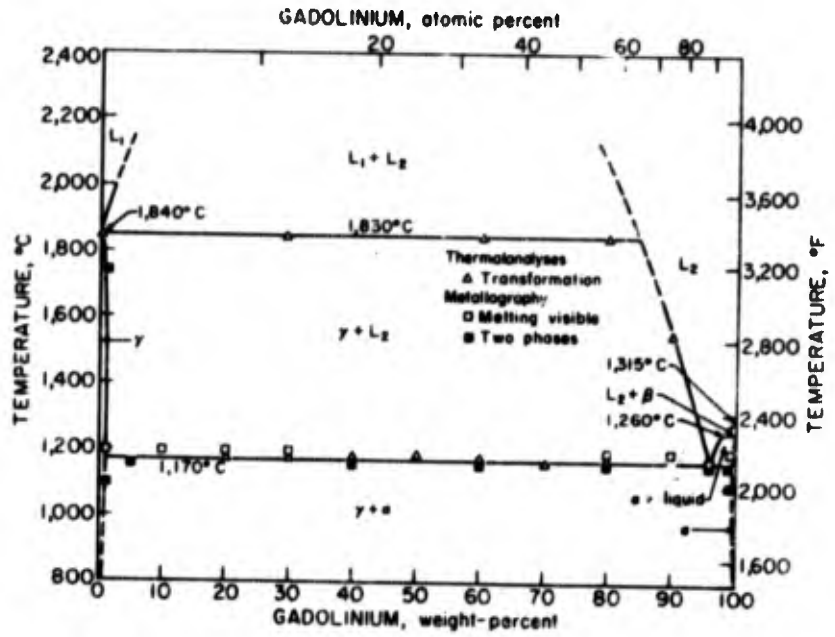
EUROPIUM



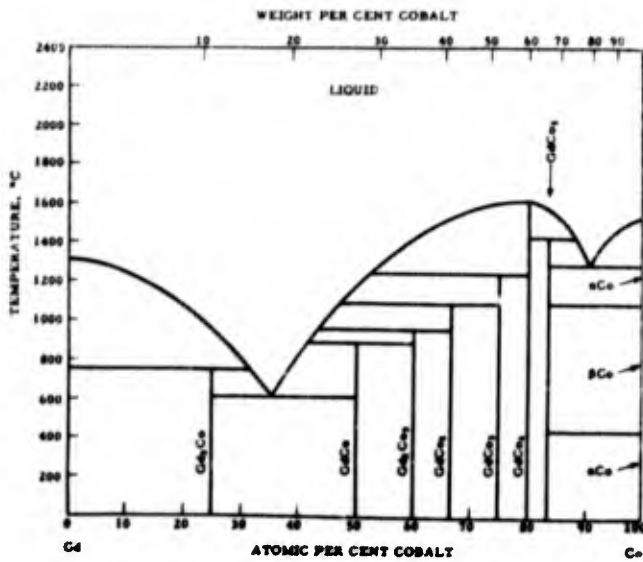
GADOLINIUM



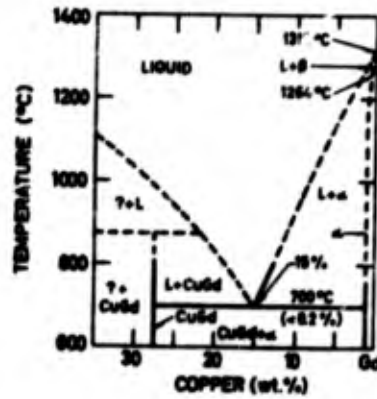
Aluminum (214)



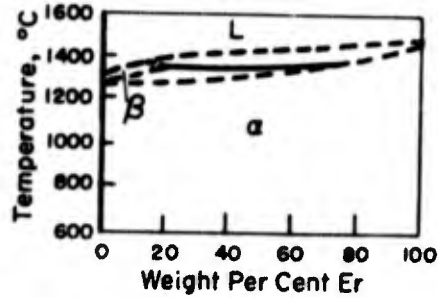
Chromium (43)



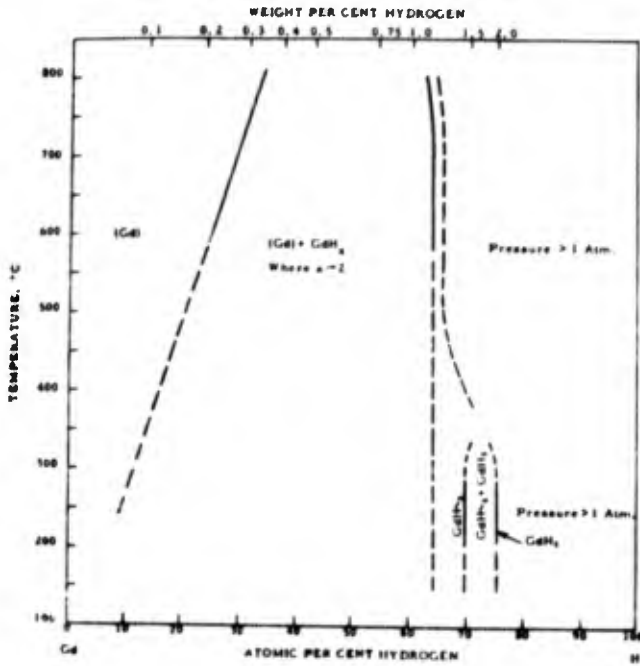
Cobalt (1)  
(Permission of U. S. AEC)



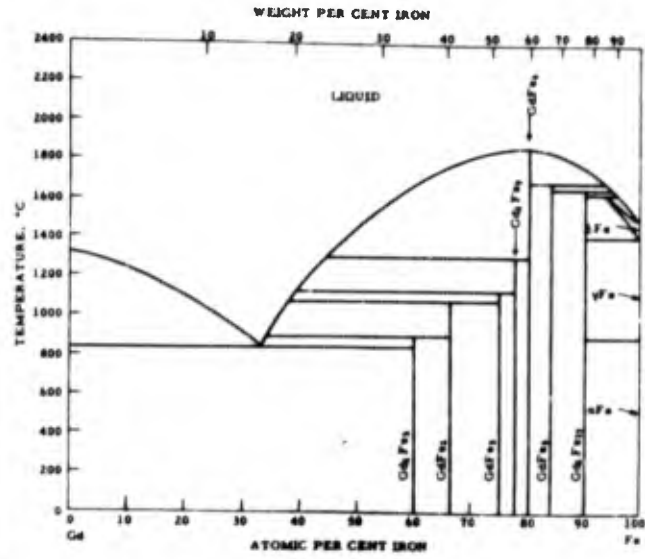
Copper (214)



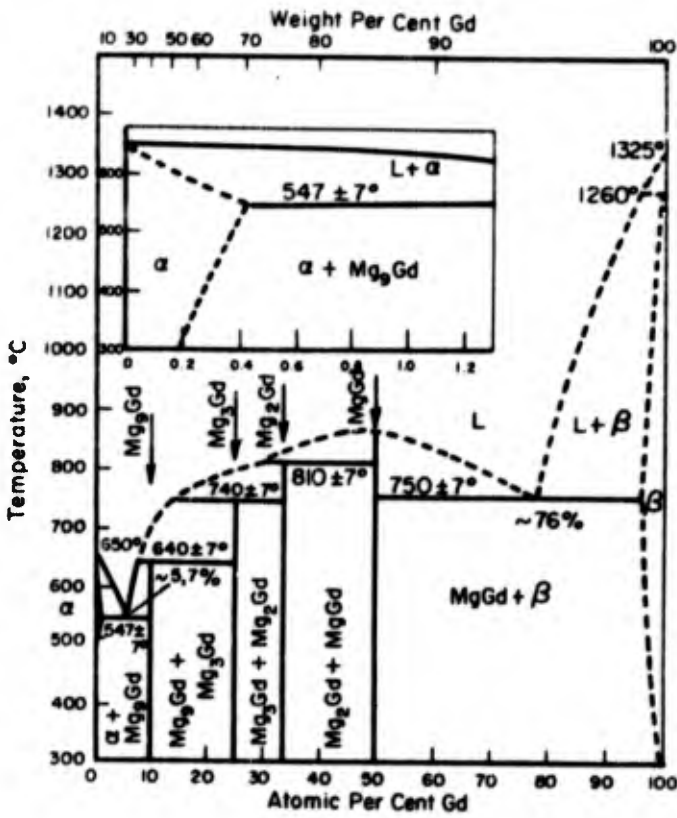
Erbium (44)



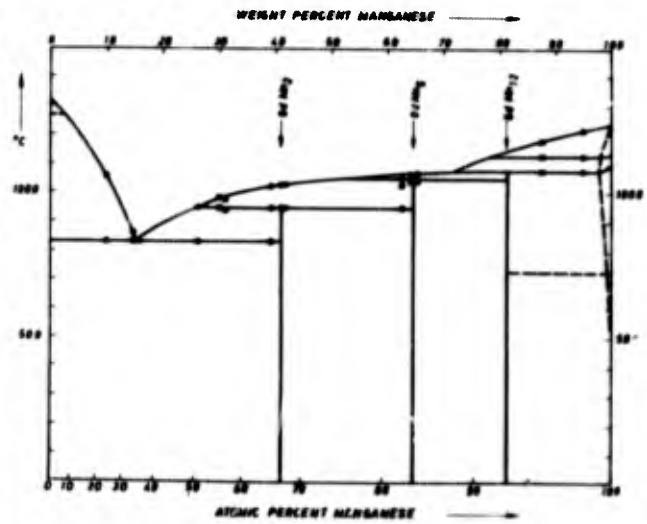
Hydrogen (1)  
(Permission of U. S. AEC)



Iron (1)  
(Permission of U. S. AEC)

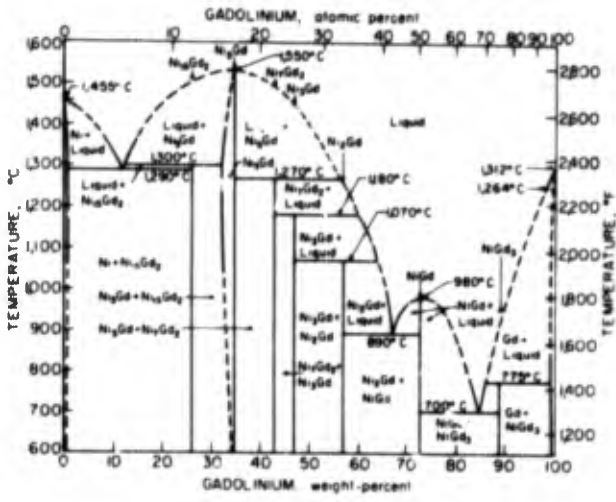


Magnesium (29)

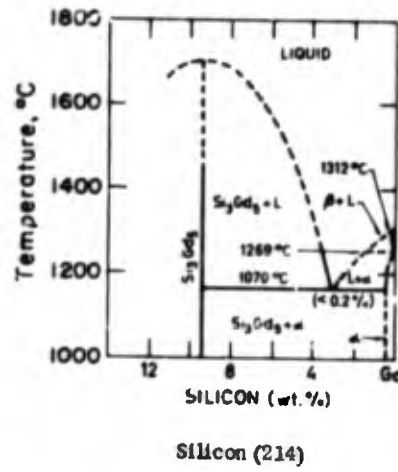


Manganese (274)

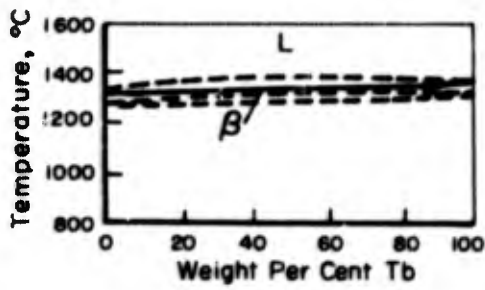




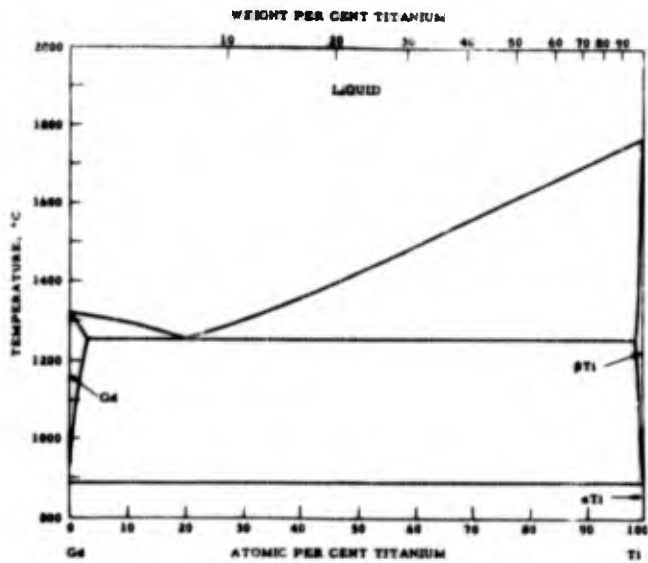
Nickel (45)



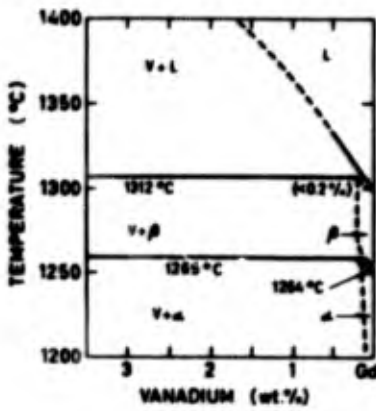
Silicon (214)



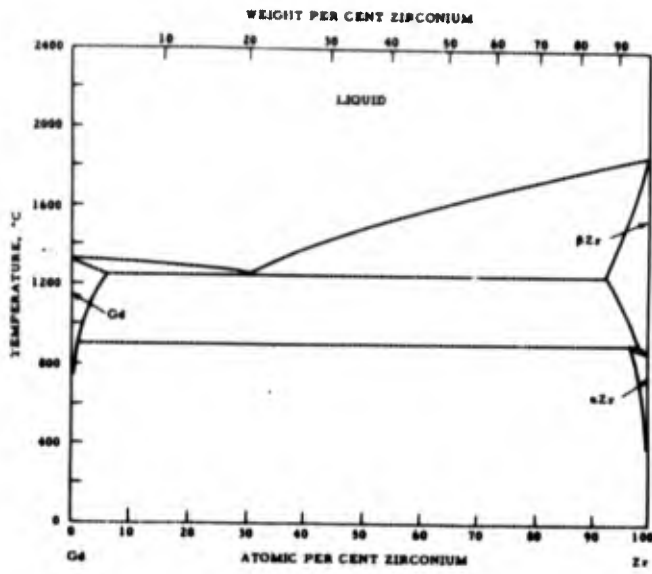
Terbium (44)



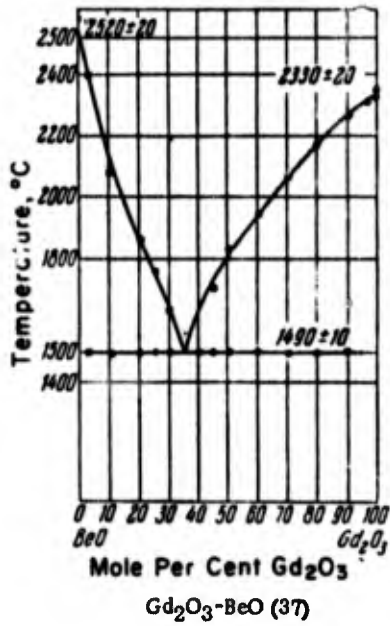
Titanium (1)  
(Permission of U. S. AEC)



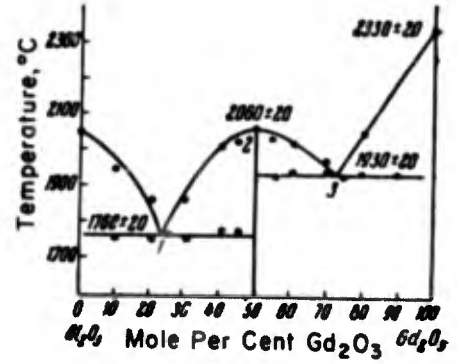
Vanadium (214)



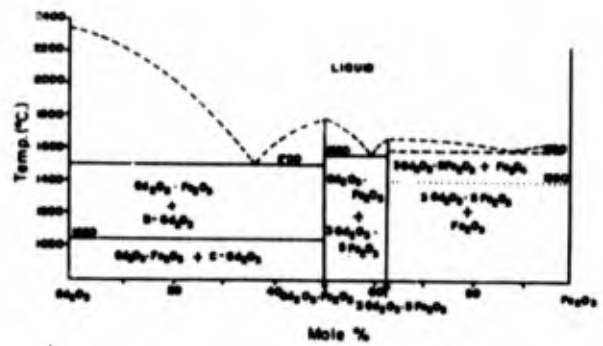
Zirconium (1)  
(Permission of U. S. AEC)



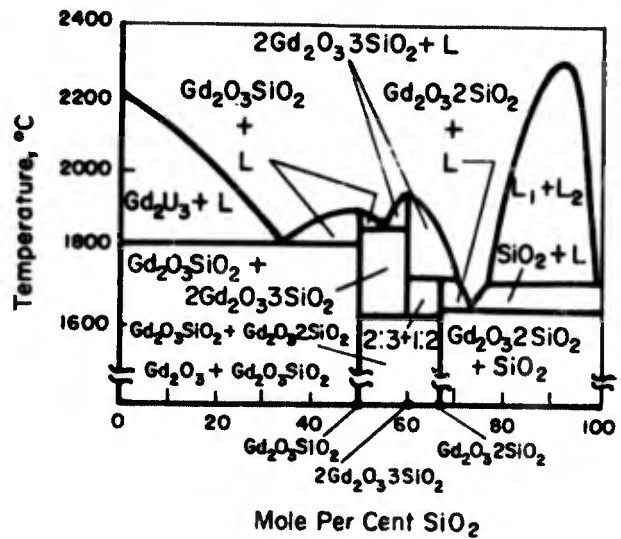
$Gd_2O_3-BeO$  (37)



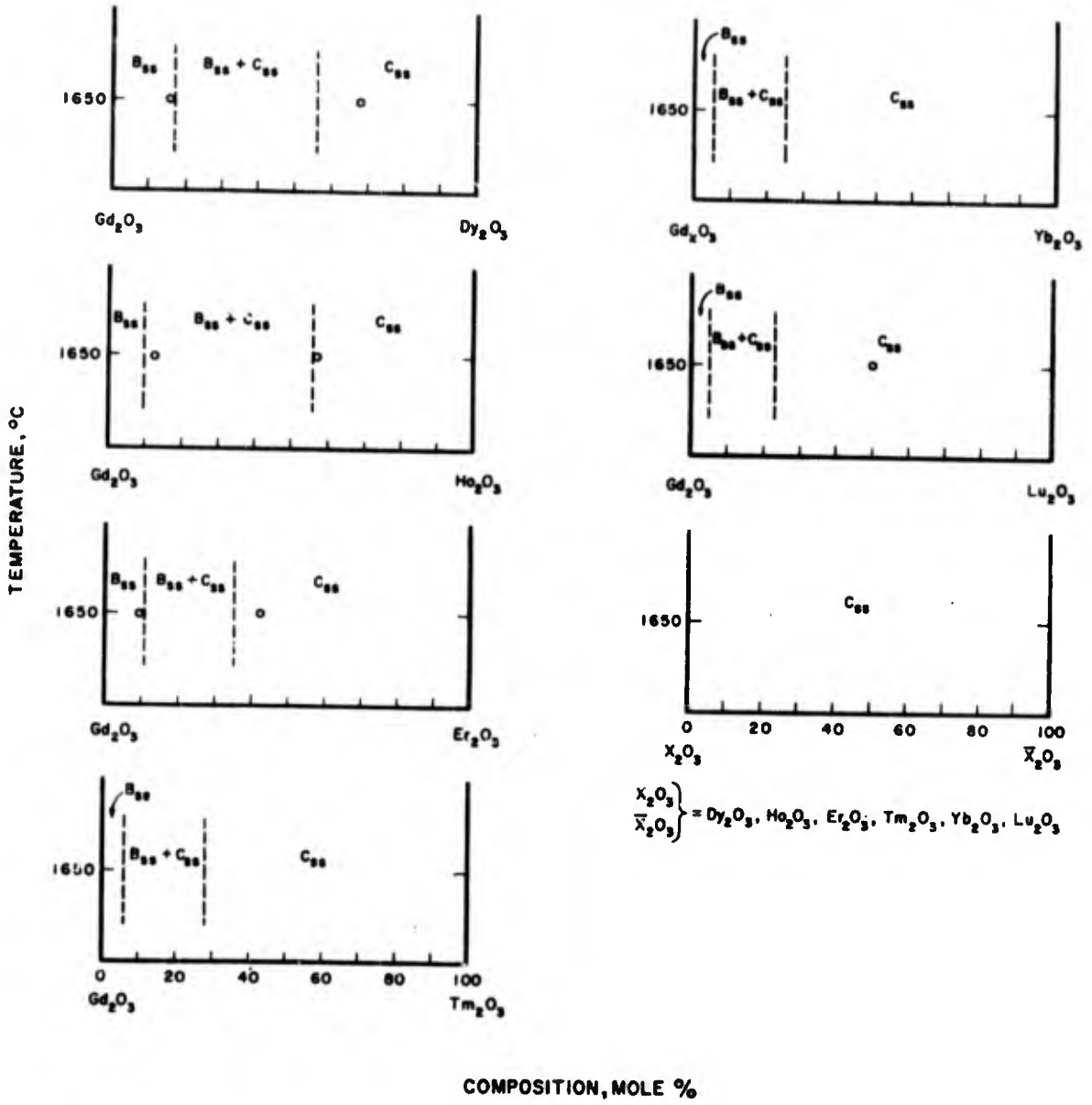
$Gd_2O_3-Al_2O_3$  (37)



$Gd_2O_3-Fe_2O_3$  (10)  
(Permission of American Ceramic Society)

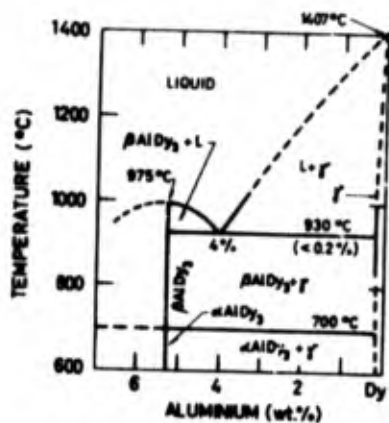


$Gd_2O_3-SiO_2$  (46)

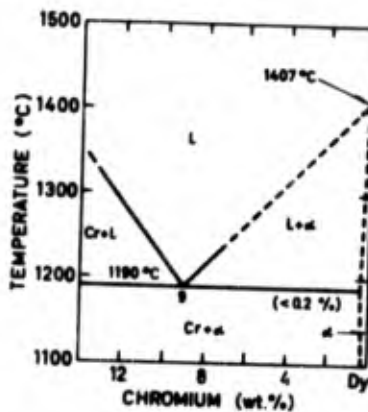


Gd<sub>2</sub>O<sub>3</sub> - Rare-Earth Oxides (26)

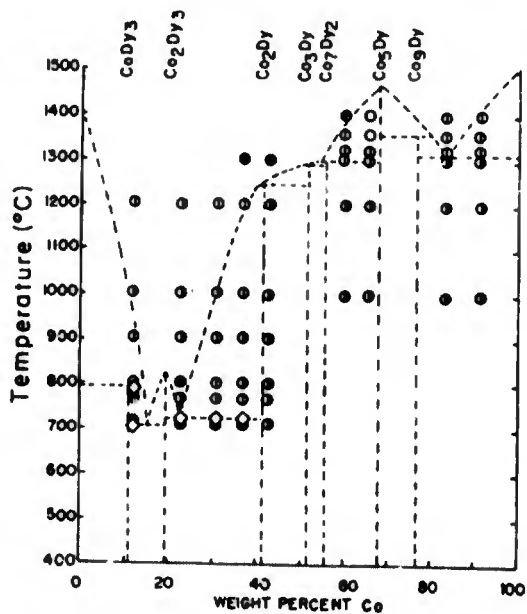
DYSPROSIUM



Aluminum (214)

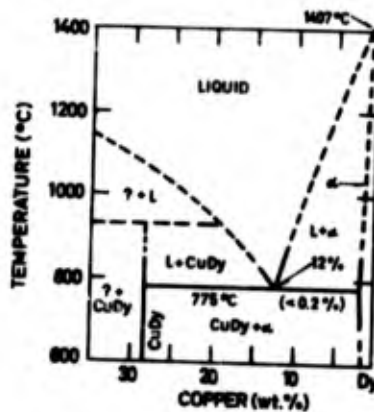


Chromium (214)

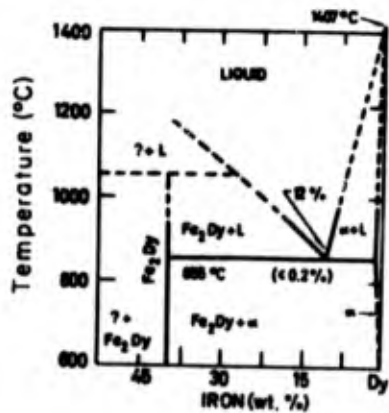


Cobalt (47)

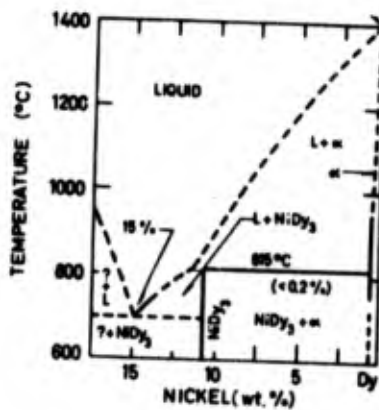
(Permission of Gordon and Breach, Science Publishers, Inc.)



Copper (214)



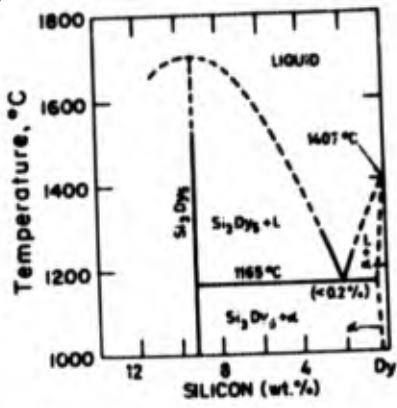
Iron (214)



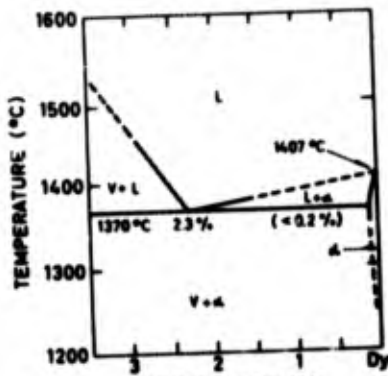
Nickel (214)

# PHASE DIAGRAMS

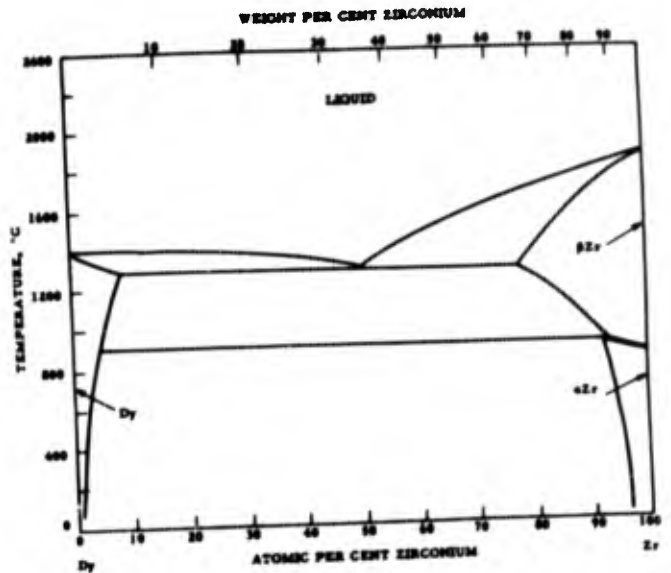
78



Silicon (214)

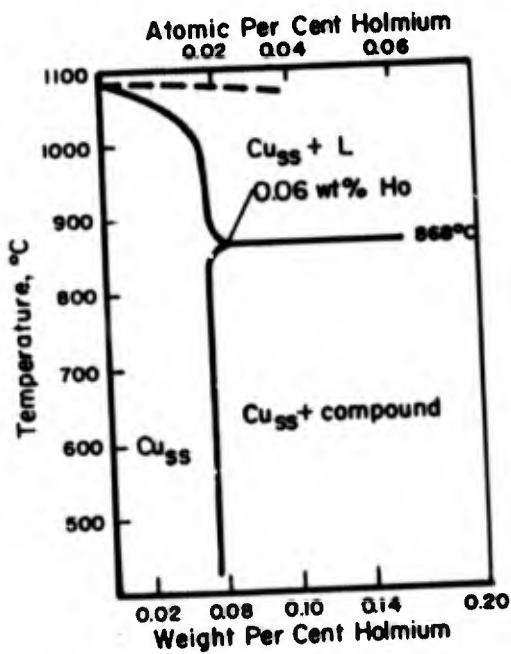


Vanadium (214)

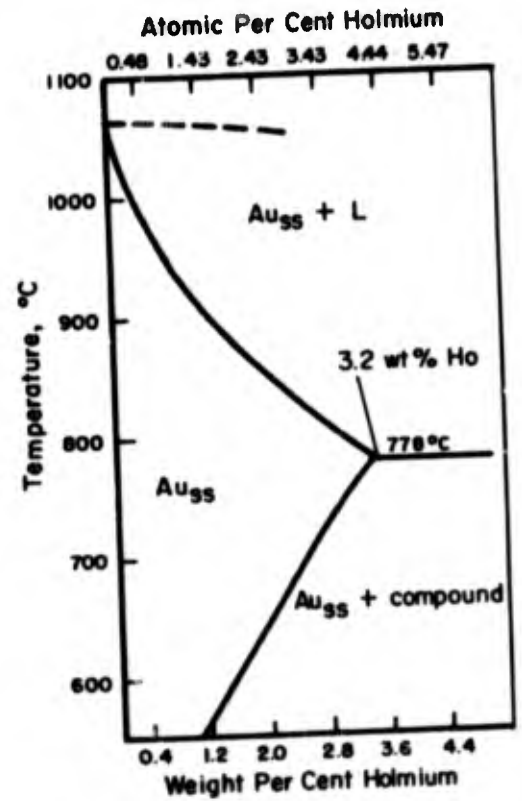


Zirconium (1)  
(Permission of U. S. AEC)

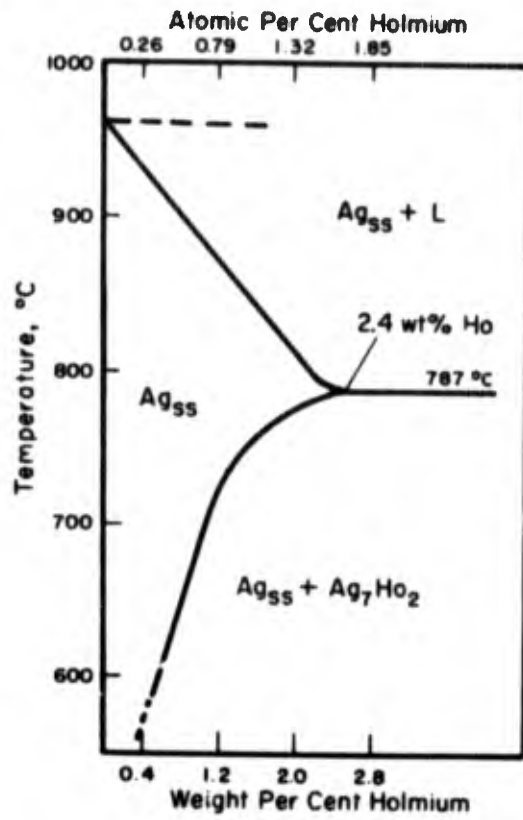
## HOLMIUM



Copper (48)  
(Permission of Metallurgical Society AIME)

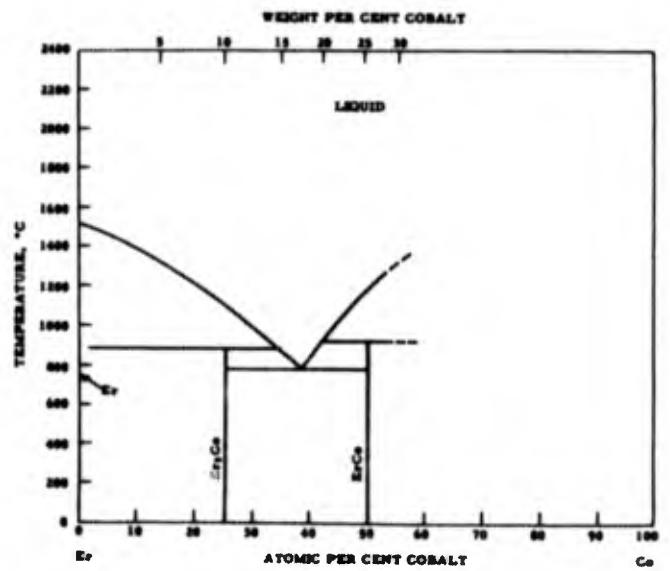
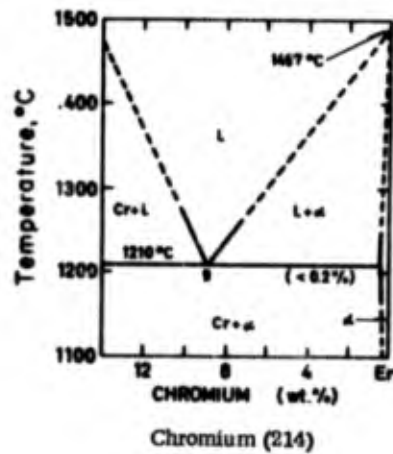
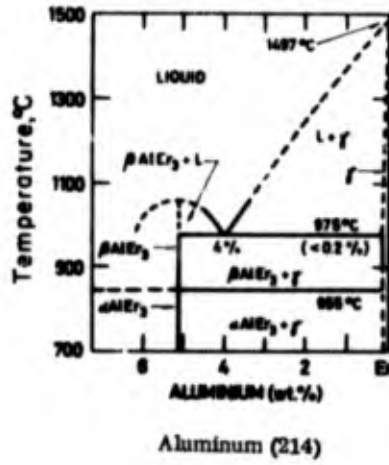


Gold (48)  
(Permission of Metallurgical Society AIME)

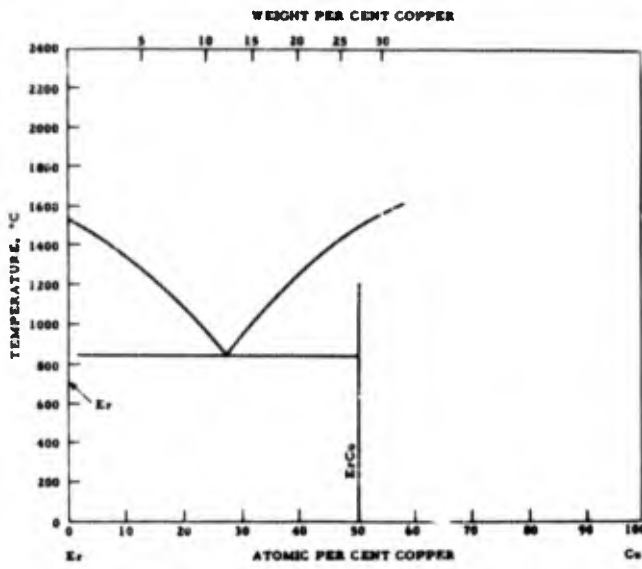


Silver (48)  
(Permission of Metallurgical Society AIME)

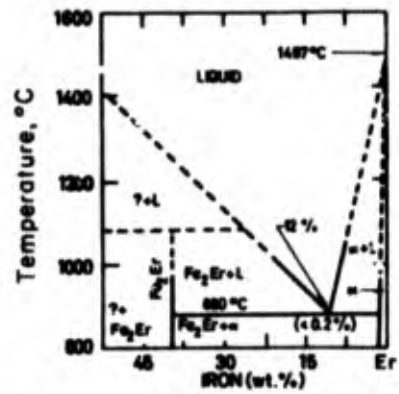
ERBIUM



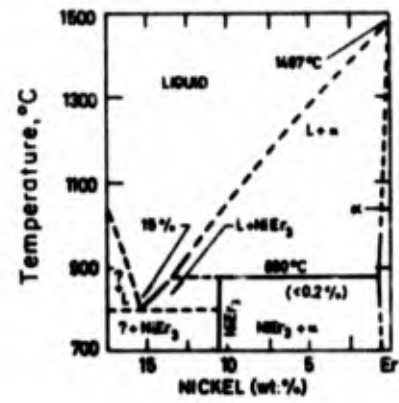
Cobalt (1)  
(Permission of U. S. AEC)



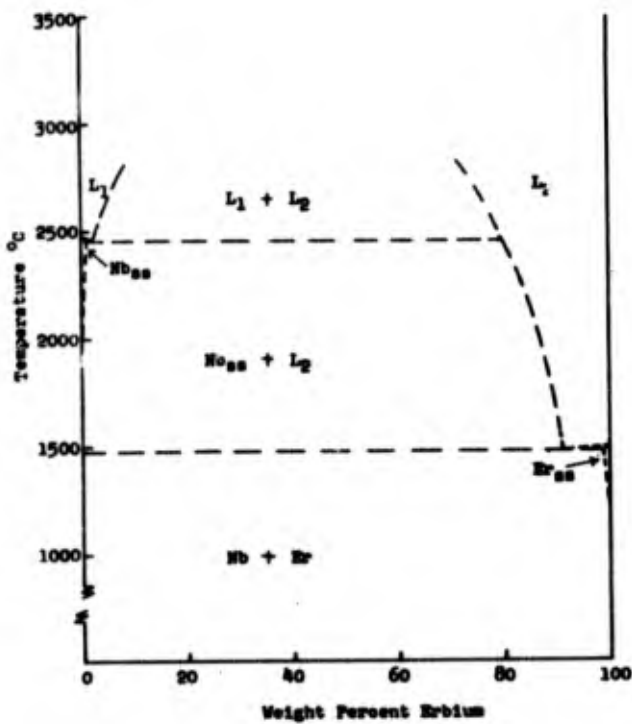
Copper (1)  
(Permission of U. S. AEC)



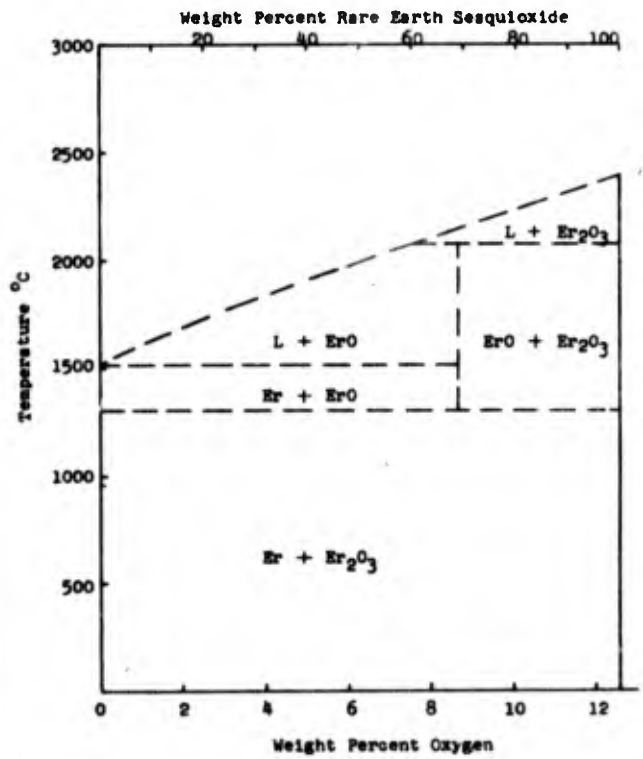
Iron (214)



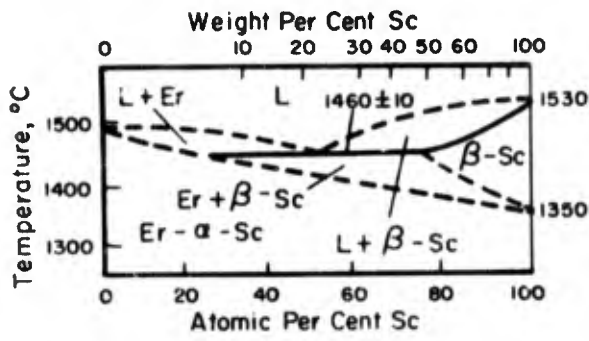
Nickel (214)



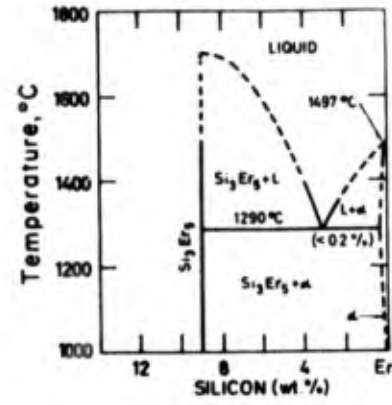
Niobium (53)



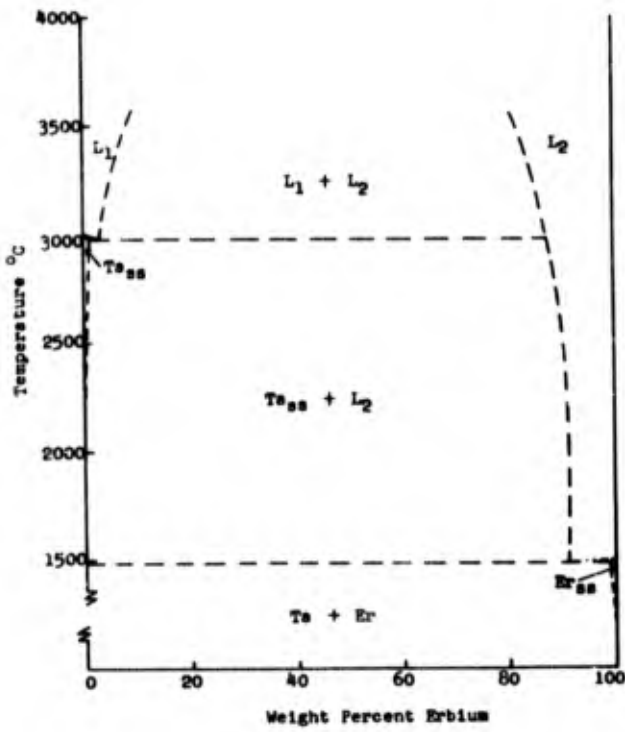
Oxygen (50)



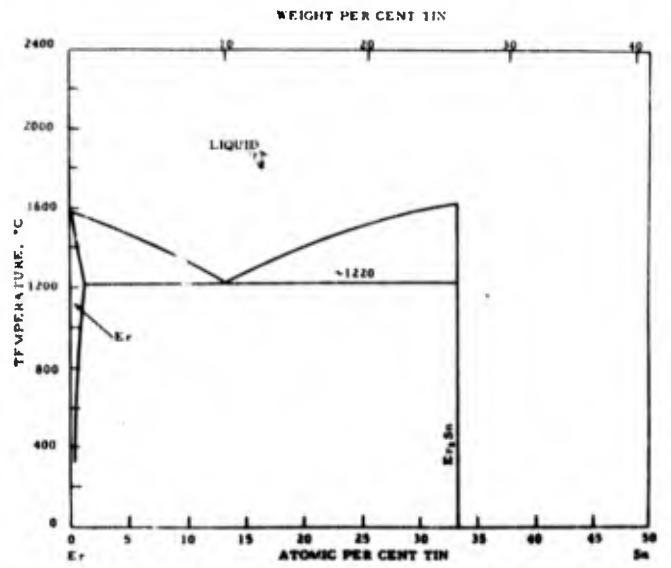
Scandium (32)



Silicon (214)

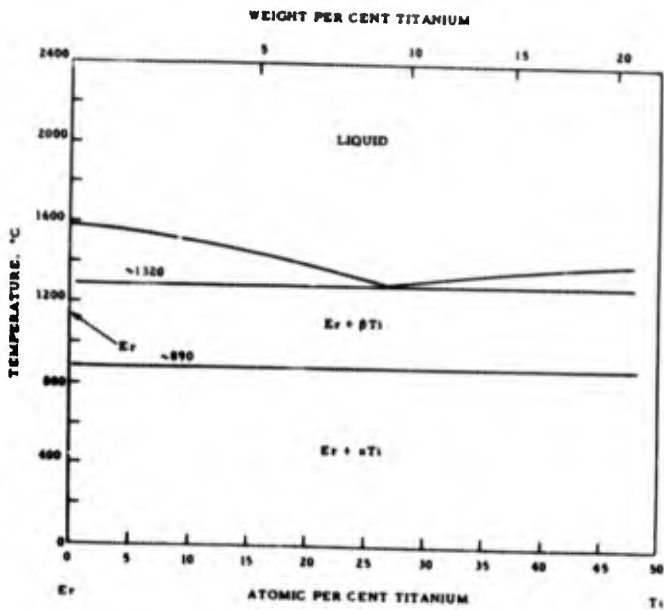


Tantalum (50)

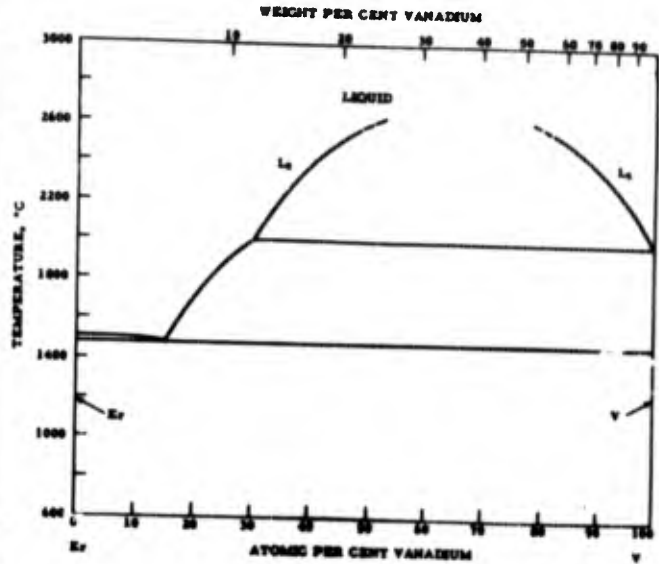


Tin (1)  
(Permission of U. S. AEC)

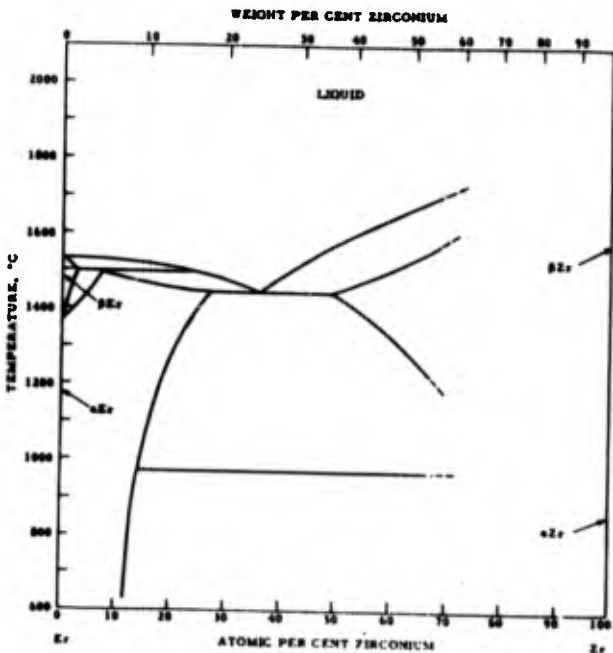




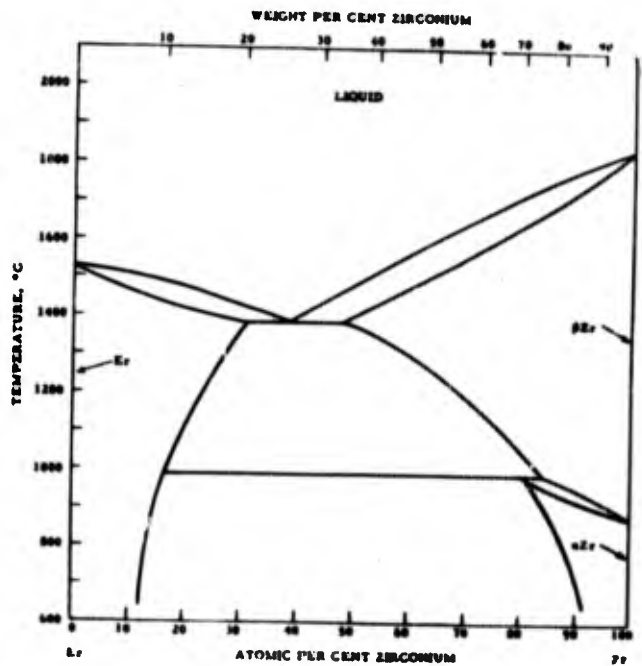
Titanium (1)  
(Permission of U. S. AEC)



Vanadium (1)  
(Permission of U. S. AEC)



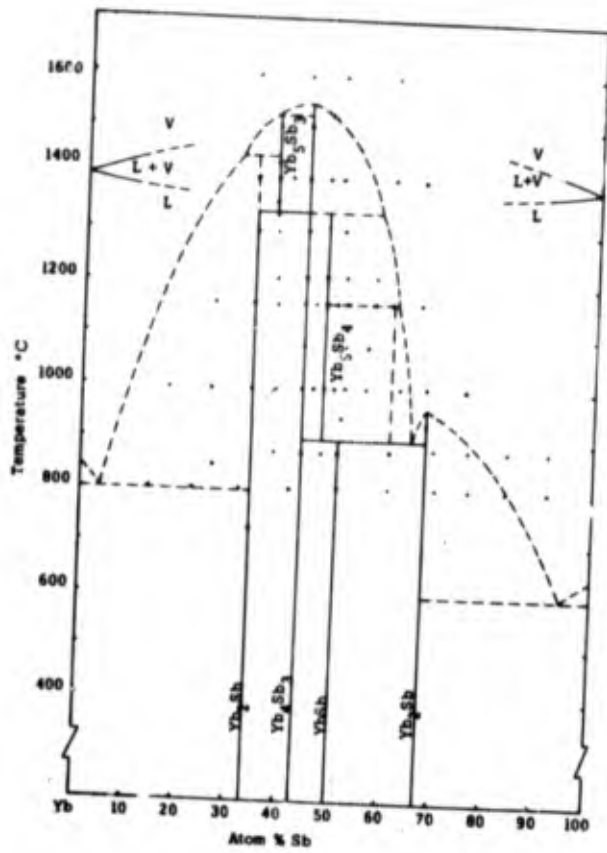
a. Tentative Partial Diagram



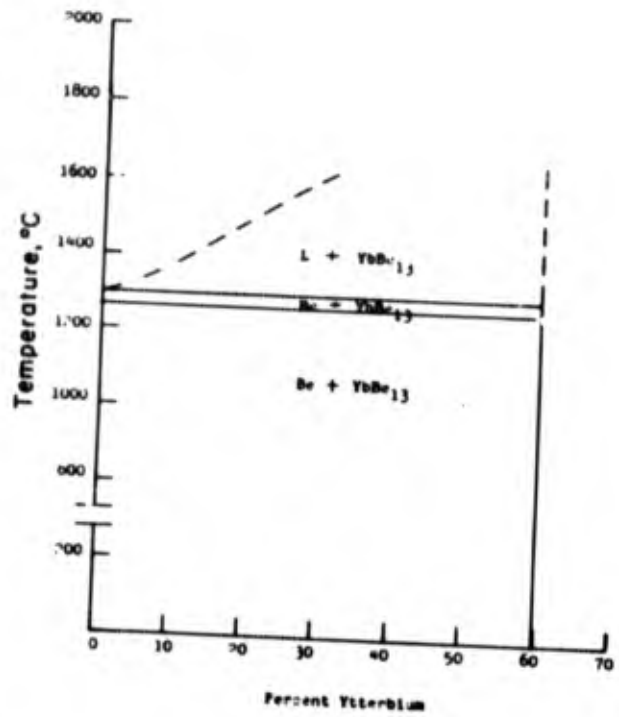
b. Complete Diagram.

Zirconium (1)  
(Permission of U. S. AEC)

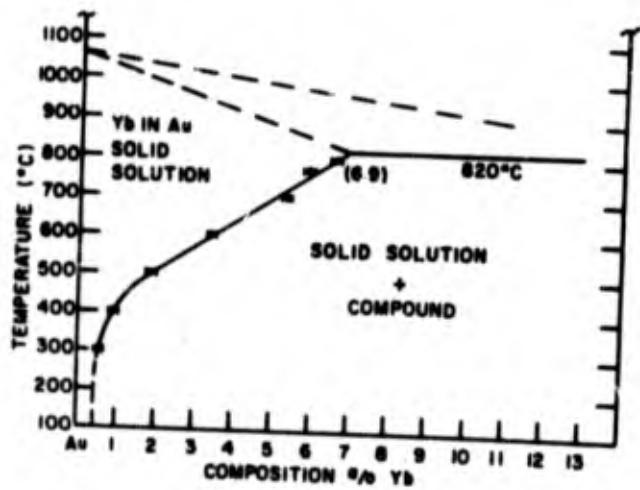
YTTERBIUM



Antimony (273)



Beryllium (49)



Gold (272)

## YTTRIUM

Symbol Y

Atomic Number 39

Atomic Weight 88.92

Authority

## PHYSICAL PROPERTIES

Abundance	28-70 ppm (approx. 28)	51
Density	4.472 g/cm <sup>3</sup>	67
Melting Point	1509 C	66
Heat of Fusion	4.1 kcal/mole	52
Boiling Point	2927 C	57
Heat of Vaporization (25 C)	93 kcal/mole	57
Vapor Pressure (1780-2185 K)	$\text{Log } P_{(\text{mm Hg})} = 8.836 - \frac{20685}{T}$	60
Specific Heat (25 C)	0.01 cal/(mole)(C)	53
Heat of Combustion	227.72 kcal/g-atom	134
Coefficient of Linear Thermal Expansion (20-897 C)	$10.8 \times 10^{-6}/C$	61
Thermal Conductivity (28 C)	0.035 cal/(cm <sup>2</sup> )(sec)(C/cm)	54
Heat of Sublimation	84.71 kcal/mole	59
Cohesive Energy	103 kcal/mole	89
Work Function	3.3 ev	75
Debye Temperature		
Expansion on Melting		
Surface Tension		

## CRYSTAL PROPERTIES

Authority

	HCP	BCC	
	Structure		
Lattice Constants	$a_0 = 3.6474$ $c_0 = 5.7306$	$a_0 = 4.11 \text{ \AA}$ -- $\text{ \AA}$	61
Density	4.472	4.25 g/cm <sup>3</sup>	67
Metallic Radius	1.801	1.83 $\text{ \AA}$	67
Atomic Volume	19.886	-- cm <sup>3</sup> /mole	65
Transition Temperature		1460 C	66
Heat of Transition		1.18 kcal/mole	61
Ionic Radius (Trivalent Ion)		0.88 $\text{ \AA}$	55
Closest Approach of Atoms		3.59 $\text{ \AA}$	56
Allotropic Modifications			

## CHEMICAL PROPERTIES

Stable Oxidation State	+3		58
Electrode Potential			
Ionization Potential		1st = 6.377, 2nd = 12.333, 3rd = 20.4 volts	82
Metallographic Polishing and Etching		Quite resistant to corrosion and may be sectioned, mounted and polished by conventional techniques. Recommended etchant: 5% HF, 5% HNO <sub>3</sub> , 90% diethylene glycol.	62
Corrosion Rates (In Air)		<1 mil/year up to 200 C 13 mil/year at 400 C 600 mil/year at 600 C	68
Corrosion Data		Improves oxidation resistance of Fe-Cr alloys up to 1260 C.	65

## ELECTRICAL PROPERTIES

Resistivity (25 C)	64.9 microhm-cm		61
Temperature Coefficient of Resistivity (25 C)	$2.71 \times 10^{-3}/\text{C}$		63

Authority

**MAGNETIC PROPERTIES**

Susceptibility (25 C)	191 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical - 0.00 Bohr Magnetons Measured - 0.67 Bohn Magnetons	61
Curie Temperature	None	61
Néel Temperature	None	61

**MECHANICAL PROPERTIES**

Young's Modulus	6.63 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	64
Shear Modulus	2.62 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	64
Poisson's Ratio	0.265	64
Compressibility	2.09 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	64
Hardness	38 DPH	57
Tensile Strength (70 F)	22.0 x 10 <sup>3</sup> psi	72
Yield Strength (70 F)	9.7 x 10 <sup>3</sup> psi	72
Elongation (70 F)	25 per cent	72
Ultimate Compressive Strength	113.8 x 10 <sup>3</sup> psi	65
Impact Strength (Izod)	1.50 ft-lb	71
Workability	Good	88
General Fabrication	See references	70, 72, 113

Note: Room-temperature mechanical properties depend on oxygen content.

## NUCLEAR PROPERTIES

58

## Isotopes

<u>Whole Number Mass</u>	<u>Relative Abundance, per cent</u>	<u>Half life</u>	<u>Decay Mode</u>
87	--	80 hr 14 hr	K $\gamma$ , $e^-$
88	--	2 hr 104 days	$\beta^+$ $\beta^+$ , $\gamma$
89	100	Stable	--
90	--	60-72 hr	$\beta^-$
91	--	57 days 51 min	$\beta^-$ $\gamma$ , $e^-$
92	--	3.5 hr	$\beta^-$ , $\gamma$
93	--	10 hr	$\beta^-$ , $\gamma$
94	--	20 min	$\beta^-$ , $\gamma$
95	--	<3 hr	$\beta^-$
97	--	Short	$\beta^-$

Thermal-Neutron  
Cross Section

$1.38 \pm 0.14$  barns/atom, or  
 $0.0094 \text{ cm}^2/\text{g}$

73

## SAFETY

65

Toxicity: Not classed as an industrial poison; sparse physiological data.

Fire hazard: Fine turnings and powders should be handled with care as they ignite easily and burn with intense heat; should be gathered and stored under an oil having a high flash point.

## THERMODYNAMIC PROPERTIES

76,77

	<u>Room Temperature</u>	<u>Melting Point</u>
Entropy	$S_{298} = 11.0$	$S_{1773} = 22.66 \text{ eu}$
Heat Capacity	$C_{p298} = 6.01$	$C_{p1773} = 7.49 \text{ cal}/(\text{mole})(\text{C})$

Thermodynamic Functions of Yttrium,  
joules/(g-atom)(K)

79

T, K	C <sub>p</sub>	S <sup>o</sup>	(H <sup>o</sup> -H <sub>0</sub> <sup>o</sup> )/T	(-F <sup>o</sup> -H <sub>0</sub> <sup>o</sup> )/T
5	0.06	0.064	0.026	0.038
10	0.23	0.150	0.081	0.069
15	0.79	0.322	0.197	0.125
20	1.89	0.693	0.476	0.217
30	5.29	2.063	1.479	0.584
40	8.95	4.121	2.892	1.229
50	12.19	6.478	4.439	2.039
60	14.80	8.953	5.965	2.988
70	16.84	11.398	7.379	4.019
80	18.43	13.757	8.664	5.093
90	19.71	16.006	9.822	6.184
100	20.71	18.136	10.862	7.274
120	22.14	22.054	12.631	9.423
140	23.17	25.541	14.065	11.476
160	23.98	28.686	15.255	13.431
180	24.63	31.547	16.259	15.288
200	25.10	34.169	17.122	17.057
220	25.46	36.577	17.862	18.715
240	25.78	38.805	18.508	20.297
260	26.05	40.880	19.079	21.801
273.15	26.24	42.169	19.422	22.747
280	26.31	42.820	19.587	23.233
298.15	26.52	44.476	20.005	24.471
300	26.54	44.643	20.043	24.640
320	26.74	46.362	20.455	25.907
340	26.92	47.989	20.830	27.159

Heat Content and Entropy of Solid and Liquid Yttrium  
(Base: crystals at 298.15 K)

77

T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)	T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)
400	615	1.78	1600	8,680	10.90
500	1,235	3.15	1700	9,420	11.35
600	1,860	4.29	1773(s)	9,960	11.66
700	2,495	5.27	1773(l)	14,060	13.97
800	3,140	6.14	1800	14,280	14.10
900	3,800	6.91	1900	15,080	14.53
1000	4,465	7.61	2000	15,880	14.94
1100	5,140	8.26	2200	17,480	15.70
1200	5,830	8.86	2400	19,080	16.40
1300	6,525	9.41	2600	20,680	17.04
1400	7,235	9.94	2800	22,280	17.63
1500	7,955	10.43	3000	23,880	18.18

For solid yttrium:

$$H_T - H_{298.15} = 5.72T + 0.50 \times 10^{-3} T^2 - 1,750$$

(0.2 percent; 298° - 1,773°K.)

$$C_p = 5.72 + 1.00 \times 10^{-3} T$$

$$\Delta H_{1773} \text{ (fusion)} = 4,100.$$

For liquid yttrium:

$$H_T - H_{298.15} = 8.00T - 120 \text{ (0.1 percent; } 1,773^\circ - 3,000^\circ \text{K.)}$$

$$C_p = 8.00.$$

Heat Content and Entropy of Gaseous Yttrium  
(Base: ideal gas at 298.15 K)

<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K)(mole)</u>	<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K)(mole)</u>
400	625	1.80	1,900	8,595	10.26
500	1,220	3.13	2,000	9,115	10.52
600	1,790	4.17	2,200	10,175	11.03
700	2,350	5.03	2,400	11,270	11.50
800	2,890	5.76	2,600	12,415	11.96
900	3,425	6.39	2,800	13,620	12.41
1,000	3,955	6.94	3,000	14,895	12.85
1,100	4,475	7.44	3,500	18,475	13.95
1,200	4,995	7.89	4,000	22,655	15.06
1,300	5,510	8.31	4,500	27,390	16.18
1,400	6,025	8.69	5,000	32,560	17.27
1,500	6,535	9.04	6,000	43,665	19.27
1,600	7,050	9.37	7,000	54,665	20.98
1,700	7,560	9.68	8,000	65,370	22.42
1,800	8,075	9.98			

For gaseous yttrium:

$$H_T - H_{298.15} = 2.77T + 0.74 \times 10^{-3}T^2 - 2.64 \times 10^5 T^{-1} - 6 \quad (0.7 \text{ percent; } 3,000^\circ - 6,000^\circ\text{K.});$$

$$C_p = 2.77 + 1.48 \times 10^{-3}T + 2.64 \times 10^5 T^{-2}.$$



## YTTRIUM COMPOUNDS

		<u>Authority</u>
<b>Antimonides</b>		162, 168
	<u>YSb</u>	
Structure	Cubic	
Lattice Type	N . Cl	
$a_0$ , A	6.16	
Melting Point, C	1925	
Resistivity, microhm-cm	65	
<b>Arsenides</b>		169
	<u>YAs</u>	
Lattice Type	NaCl	
$a_0$ , A	5.805	
<b>Beryllides</b>		146, 161
	<u>YBe<sub>13</sub></u>	
Structure	Cubic	
Lattice Type	NaZn <sub>13</sub>	
$a_0$ , A	10.238	
Heat of Vaporization, kcal/mole	75.0	
Dissociatic Rate, g/(cm <sup>2</sup> )(sec)	3.63 x 10 <sup>-7</sup> at 1040 C 3.01 x 10 <sup>-5</sup> at 1290 C	

		<u>Authority</u>					
Bismuthides		162, 168					
	<u>YBi</u>						
Structure	Cubic						
Lattice Type	NaCl						
$a_0$ , A	6.23						
Resistivity, microhm-cm	196						
Borides		153, 154, 155, 171					
	<u>YB<sub>2</sub></u>	<u>YB<sub>3</sub></u>	<u>YB<sub>4</sub></u>	<u>YB<sub>6</sub></u>	<u>YB<sub>12</sub></u>	<u>YB<sub>70</sub></u>	
Molecular Weight	110.56	121.28	132.20	153.84	218.56	846.32	
Structure	Hexag- onal	Tetrag- onal	Tetrag- onal	Cubic	Cubic	Tetrag- onal	
$a_0$ , A	3.298	3.78	7.111	4.113	7.500	11.75	
$c_0$ , A	3.843	3.55	4.017	--	--	12.62	
Density, g/cm <sup>3</sup>	2.91	3.97	4.36	3.76	3.44	--	
Heat of Formation kcal/mole	--	--	--	24	--	--	
Melting Point, C	2100	--	2800	2300	(2200)	(2000)	
Resistivity, microhm-cm	39	--	28.5	40.0	94.8	--	
Temperature Coefficient of Resistivity, 10 <sup>-6</sup> /C	--	--	--	1.24	--	--	
Coefficient of Thermal Expan- sion, 10 <sup>-6</sup> /C	--	--	--	6.24	--	--	
Thermal Conduc- tivity, cal/ (cm)(sec)(C)	--	--	--	0.070	--	--	

(Continued)

Borides (Continued)

	<u>YB<sub>2</sub></u>	<u>YB<sub>3</sub></u>	<u>YB<sub>4</sub></u>	<u>YB<sub>6</sub></u>	<u>YB<sub>12</sub></u>	<u>YB<sub>70</sub></u>
Effective Magnetic Moment, Bohr magnetons	--	--	--	0.0	--	--
Work Function, e	--	--	--	2.22	--	--
Microhardness, kg/mm <sup>2</sup>	--	--	--	3264	--	--
Color	--	--	Gray brown	Blue violet	--	--
Emissivity at 1500 C (λ = 0.655 μ), C	--	--	--	0.7	--	--
Metallic Radius, A	--	--	--	2.18	--	--

Carbides

148,153

	<u>YC</u>	<u>YC<sub>2</sub></u>	<u>Y<sub>2</sub>C<sub>3</sub></u>	<u>Y<sub>3</sub>C</u>
Molecular Weight	100.92	112.92	213.84	278.76
Structure	--	Tetragonal	--	Cubic
Lattice Type	--	CaC <sub>2</sub>	--	Fe <sub>4</sub> N
a <sub>0</sub> , A	--	3.664	--	5.102
c <sub>0</sub> , A	--	6.169	--	--
Density, g/cm <sup>3</sup>	--	4.528	--	5.41
Melting Point, C	1950	2300	1800	--
Resistivity, microhm-cm	4.54 x 10 <sup>4</sup>	88.7	3.5 x 10 <sup>2</sup>	--
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	1.36	--	--	--
Microhardness, kg/mm <sup>2</sup>	120	700	900	--
Emissivity (λ = 0.655 μ)				
1100 C	0.81	0.87	0.78	--
1800 C	0.81	0.73	0.91	--

Authority

170

## Germanides

	<u>YGe<sub>2</sub></u>
Structure	Imperfect
a <sub>0</sub> , A	3.96
c <sub>0</sub> , A	4.14

## Halides

58, 108, 147,  
157, 158, 159,  
207, 208, 209,  
211, 210

	<u>YBr<sub>3</sub></u>	<u>YCl<sub>3</sub></u>	<u>YF<sub>3</sub></u>	<u>YI<sub>3</sub></u>	<u>YOCl</u>	<u>YOF</u>
Structure	Hexag- onal	Mono- clinic	Ortho- rhombic Cubic	Hexag- onal	Tetrag- onal	--
a <sub>0</sub> , A	4.102	11.94	6.353 (orth.) 5.644 (cubic)	4.340	3.903	--
b <sub>0</sub> , A	--	--	6.850	--	--	--
c <sub>0</sub> , A	6.399	--	4.393	6.960	6.597	--
β, deg	--	111.0	--	--	--	--
Density, g/cm <sup>3</sup>	--	--	5.069	--	--	5.13
Heat of Forma- tion, kcal/ mole	--	239.16	--	148	--	--
Entropy of Formation, eu	--	(59)	--	4	--	--
Melting Point, C	904	700	1148	1000	--	--
Heat of Fusion, kcal/mole	9	9	13	12	--	--
Entropy of Fusion, eu	8	9	8	9	--	--

(Continued)

Halides (Continued)

	YBr <sub>3</sub>	YCl <sub>3</sub>	YF <sub>3</sub>	YI <sub>3</sub>	YOCl	YOF
Boiling Point, C	1463	1507	2227	1307	--	--
Heat of Vaporization, kcal/mole	44	45	60	41	--	--
Entropy of Vaporization, eu	25	25	24	26	--	--
Refractive Index	--	--	--	--	--	1.78

Thermodynamic Data

212

Glasner has supplied in ANL-5750 the following equations for calculating thermodynamic quantities. The reactions concerned and the constants for use in these equations are tabulated.

$$\Delta C_p = \Delta a + (\Delta b \times 10^{-3})T + (\Delta c \times 10^{-6})T^2 + \frac{\Delta d \times 10^5}{T^2}$$

$$\Delta H - \Delta H_{F298} = (\Delta a)T + \frac{1}{2} (\Delta b \times 10^{-3})T^2 + \frac{1}{3} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} + \Delta A$$

$$\Delta S = (2.303 \Delta a) \log T + (\Delta b \times 10^{-3})T + \frac{1}{2} (\Delta c \times 10^{-6})T^2 - \frac{1/2(\Delta d \times 10^5)}{T^2} - \Delta B$$

$$\Delta F - \Delta H_{F298} = - (2.303 \Delta a) T \log T - \frac{1}{2} (\Delta b \times 10^{-3})T^2 - \frac{1}{6} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} - T\Delta(B - a) - \Delta A$$

Reaction	Temperature Range, K	$-\Delta H_{F298}$ , kcal/mole	$-\Delta F_{298}$ , kcal/mole	$\Delta a$	$\Delta b$	$\Delta c$	$\Delta d$	$\Delta A$ , kcal/mole	$-\Delta B$ , eu	$-\Delta(B - a)$
$Y(s) + \frac{3}{2} F_2(g) = YF_3(s)$	298-1660	397	380	1.4	8.3	--	1.2	-0.375	65.4	66.8
$Y(s) + \frac{3}{2} F_2(g) = YF_3(l)$	1660-1750	--	--	14.0	-2.9	--	1.2	7.141	132.4	146.4
$Y(l) + \frac{3}{2} F_2(g) = YF_3(l)$	1750-2300	--	--	12.1	-0.7	--	1.2	3.097	124.4	136.5
$Y(l) + \frac{3}{2} F_2(g) = YF_3(g)$	2300-2500	--	--	0.1	-0.7	--	1.2	84.90	7.6	7.7
$Y(s) + \frac{3}{2} Cl_2(g) = YCl_3(s)$	298-973	235	219	1.5	11.6	--	1.0	-0.619	64.1	65.6
$Y(s) + \frac{3}{2} Cl_2(g) = YCl_3(l)$	973-1725	--	--	14.3	-2.6	--	1.0	2.650	129.1	143.4
$Y(s) + \frac{3}{2} Cl_2(g) = YCl_3(g)$	1725-2500	--	--	1.3	-2.6	--	1.0	70.08	6.1	7.4

Authority

## Hydrides

163,164,165

	<u>YH<sub>2</sub></u>	<u>YD<sub>2</sub></u>	<u>YH<sub>3</sub></u>	<u>YD<sub>3</sub></u>
Structure	--	--	Hcp	Hcp
a <sub>0</sub> , A	5.205	--	3.672	3.659
c <sub>0</sub> , A	--	--	6.625	6.586
Heat Capacity at 298 K, cal/ (mole)(C)	8.243	10.773	10.363	13.727
Enthalpy at 298 K, kcal/mole	1.403	1.659	1.613	2.025
Entropy at 298 K, eu	9.175	10.294	10.019	12.028

## Nitrides

149,153,167

	<u>YN</u>
Molecular Weight	102.93
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , A	4.877
Density, g/cm <sup>3</sup>	5.60
Heat of Formation, kcal/mole	71.5
Entropy of Forma- tion, eu	25
Resistivity, microhm-cm	93
Temperature Coeffi- cient of Resistivity (-193 to 827 C), 10 <sup>-3</sup> /C	1.9

Oxides	<u>Y<sub>2</sub>O<sub>3</sub></u>	<u>Authority</u>
Molecular Weight	225.81	156, 172, 173, 176, 177
Structure	Bcc	
a <sub>0</sub> , A	10.60	
Density, g/cm <sup>3</sup>	5.03	
Heat of Formation, kcal/g-atom	227.73	
Entropy of Forma- tion, eu/g-atom	35.54	
Melting Point, C	2410	
Coefficient of Ther- mal Expansion, 10 <sup>-6</sup> /C		
0-1400 C	8.2	
500-1400 C	8.9	
Color	White	

Thermodynamic Data

212

The equations given on page 95 may be used in calculating thermodynamic quantities for the following reactions:

Reaction	Temper- ature Range, K	-ΔH <sub>F298</sub> , kcal/mole	-ΔF <sub>298</sub> , kcal/mole	Δ <sub>a</sub>	Δ <sub>b</sub>	Δ <sub>c</sub>	Δ <sub>d</sub>	ΔA, kcal/mole	-ΔB, eu	-Δ(B-a)
$2Y(s) + \frac{3}{2}O_2(g) = Y_2O_3(s)$	298-1750	420	400.5	2.4	3.4	--	0.6	-0.802	80.2	82.6
$2Y(l) + \frac{3}{2}O_2(g) = Y_2O_3(s)$	1750-2500	--	--	-1.4	7.8	--	0.6	-8.890	64.2	62.8

(Continued)

## Oxides (Continued)

Thermodynamic Functions for  $Y_2O_3$ 

174

$T, K$	$C_p,$ cal/(mole)(K)	$S_0,$ cal/(mole)(K)	$H^0-H_0^0,$ cal/mole	$(-F^0-H_0^0)/T,$ cal/(mole)(K)
16	0.323	0.1120	1.342	0.02812
20	.405	.1928	2.796	.05300
30	.777	.4120	8.320	.1347
40	1.717	.7575	20.56	.2436
50	2.796	1.255	43.06	.3941
60	3.966	1.867	76.77	.5873
70	5.236	2.572	122.71	.8194
80	6.545	3.357	181.61	1.0867
90	7.854	4.204	252.88	1.3937
100	9.152	5.098	338.66	1.7117
120	11.66	6.991	547.07	2.4324
140	13.96	8.965	803.70	3.2240
160	16.03	10.966	1103.9	4.0666
180	17.86	12.963	1443.3	4.9443
200	19.37	14.925	1816.1	5.8447
220	20.64	16.833	2216.6	6.7573
240	21.75	18.677	2640.6	7.6742
260	22.77	20.459	3086.1	8.5895
280	23.70	22.181	3550.9	9.4992
298.16	24.50	23.693	3989.3	10.313
300	24.58	23.846	4033.7	10.400

Heat Content and Entropy Increments for  $Y_2O_3$   
(smooth values)

175

$T, K$	$H_T-H_{298.15},$ cal/mole	$S_T-S_{298.15},$ cal/(K)(mole)
400	2,640	7.60
500	5,390	13.73
600	8,250	18.94
700	11,190	23.47
800	14,180	27.46
900	17,200	31.02
1000	20,240	34.22
1100	23,280	37.12
1200	26,320	39.77
1300	29,380	42.22
1330	30,310( $\alpha$ )	42.92( $\alpha$ )
1330	30,620( $\beta$ )	43.16( $\beta$ )
1400	32,820	44.77
1500	35,970	46.94
1600	39,120	48.97
1700	42,270	50.88
1800	45,420	52.68
1900	48,570	54.39
2000	51,720	56.00



Authority

Phosphides

169

	<u>YP</u>
Structure	Fcc
Lattice Type	NaCl
$a_0$ , A	5.662

Selenides

166,168,  
169,213

	<u>YSe</u>	<u>Y<sub>2</sub>Se<sub>3</sub></u>
Structure	NaCl	Fcc
$a_0$ , A	5.703	5.75
Density, g/cm <sup>3</sup>	--	4.81
Melting Point, C	--	>1800
Color	--	Gray black

Silicides

152,153,  
160

	<u>YSi</u>	<u><math>\alpha</math>-YSi<sub>2</sub></u>	<u><math>\beta</math>-YSi<sub>2</sub></u>	<u>Y<sub>3</sub>Si<sub>5</sub></u>	<u>Y<sub>5</sub>Si<sub>3</sub></u>
Molecular Weight	117.01	145.10	145.10	407.06	528.87
Structure	Ortho-rhombic	Ortho-rhombic	Tetrag-onal	Hexag-onal	Hexag-onal
Lattice Type	CaSi	$\alpha$ -YSi <sub>2</sub>	$\alpha$ -ThSi <sub>2</sub>	--	Mn <sub>5</sub> Si <sub>3</sub>
$a_0$ , A	4.25	4.04	4.04	3.842	8.403
$b_0$ , A	10.52	3.95	--	--	--
$c_0$ , A	3.82	13.23	13.42	4.140	6.303
Density, g/cm <sup>3</sup>	4.528	4.5	4.39	--	4.556
Heat of Formation, kcal/mole	32.2	--	--	--	--
Melting Point, C	1870	--	1520	1635	1850

(Continued)

Authority

## Silicides (Continued)

	YSi	$\alpha$ -YSi <sub>2</sub>	$\beta$ -YSi <sub>2</sub>	Y <sub>3</sub> Si <sub>5</sub>	Y <sub>5</sub> Si <sub>3</sub>
Curie Temperature, K	--	Para-magnetic	--	--	--
Transformation Temperature, C	--	$\alpha \rightarrow \beta$ at 540	--	--	--

## Sulfides

153

	YS	YS <sub>2</sub>	$\delta$ -Y <sub>2</sub> S <sub>3</sub>	Y <sub>5</sub> S <sub>7</sub>	Y <sub>2</sub> O <sub>2</sub> S
Molecular Weight	120.99	153.05	274.04	669.06	241.91
Structure	Cubic	Tetragonal	Monoclinic	Monoclinic	Hexagonal
a <sub>0</sub> , A	5.466	7.71	10.71	12.67	3.78
b <sub>0</sub> , A	--	--	4.02	3.81	--
c <sub>0</sub> , A	--	7.89	17.47	11.45	6.56
$\beta$ , deg	--	--	81.17	74	--
Density, g/cm <sup>3</sup>	4.92	4.33	3.87	4.18	4.95
Melting Point, C	2060	1630	1600	1630	2120
Magnetic Susceptibility at 20 C, 10 <sup>6</sup> emu/mole	100	125	83.4	39.3	>0
Color	Ruby red	Brown violet	Yellow	--	Gray white

Properties

101

Authority

Tellurides

168,169

	<u>YTe</u>	<u>Y<sub>2</sub>Te<sub>3</sub></u>
Structure	Fcc	--
Lattice Type	NaCl	--
a <sub>0</sub> , A	6.080	--
Melting Point, C	--	1525
Resistivity at 20 C, microhm-cm	--	10 <sup>7</sup>

Miscellaneous

150,151

	<u>Structure</u>	<u>Lattice Constants, A</u>		<u>Superconducting Transition Temperature, K</u>
		<u>a<sub>0</sub></u>	<u>c<sub>0</sub></u>	
YIr <sub>2</sub>	Cubic	7.500	--	2.18
YOs <sub>2</sub>	Hexagonal	5.307	8.786	4.7
YPd <sub>3</sub>	Cu <sub>3</sub> Au	4.074	--	--
YPt <sub>3</sub>	Cu <sub>3</sub> Au	4.075	--	--
YRe <sub>2</sub>	Hexagonal	5.396	8.819	1.83
YRh <sub>2</sub>	Cubic	7.459	--	--
YRu <sub>2</sub>	Hexagonal	5.256	8.792	1.52
YPt <sub>2</sub>	Cubic	7.590	--	1.57
YAl <sub>2</sub>	Cubic	7.860	--	--

**LANTHANUM**

Symbol La

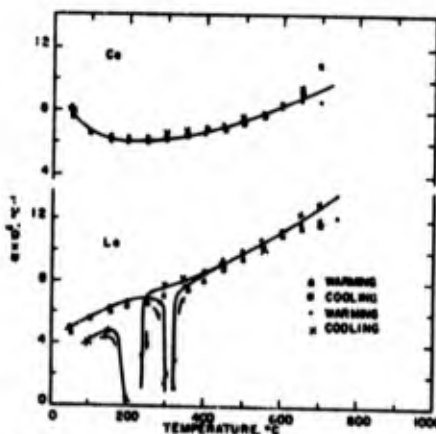
Atomic Number 57

Atomic Weight 138.92

**PHYSICAL PROPERTIES**

Authority

Abundance	5-18 ppm (approx. 18)	51
Density	6.162 g/cm <sup>3</sup>	67
Melting Point	920 C	66
Heat of Fusion	2.75 kcal/mole	77
Boiling Point	3469 C	57
Heat of Vaporization (25 C)	96 kcal/mole	57
Vapor Pressure (1874-2182 K)	$\text{Log}P_{\text{mm Hg}} = 8.876 - \frac{22019}{T}$	60
Specific Heat (25 C)	6.65 cal/(mole)(C)	53
Heat of Combustion	214.28 kcal/g-atom	134
Coefficient of Linear Thermal Expansion	$4.9 \times 10^{-6}/\text{C} (-173 - 310 \text{ C})$	61



(Permission of American Physical Society)

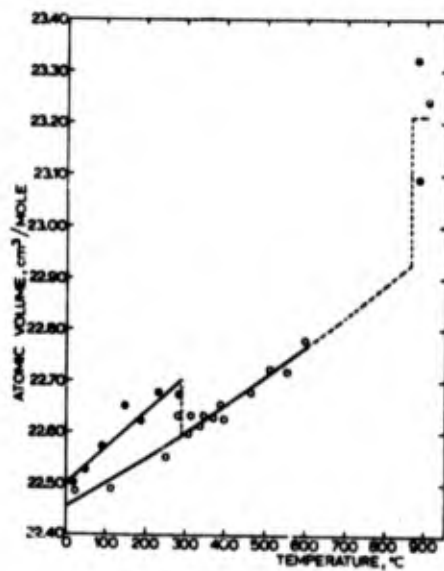
Thermal Conductivity	0.033 cal/(cm <sup>2</sup> )(sec)(C/cm)	54
Heat of Sublimation		

90

		<u>Authority</u>
Cohesive Energy	88 kcal/mole	89
Work Function	3.3 ev	75
Debye Temperature	142 K	97
Expansion on Melting		
Surface Tension (950 C)	719 dynes/cm	85

**CRYSTAL PROPERTIES**

Structure	<u>(α) HCP</u>	<u>(β) FCC</u>	<u>(γ) BCC</u>	
Lattice Constants	$a_0 = 3.770$ $c_0 = 12.159$	$a_0 = 5.304$ --	$a_0 = 4.26$ A -- A	61
Density	6.162	6.190	5.97 g/cm <sup>3</sup>	67
Metallic Radius	1.877	1.875	1.90 A	67
Atomic Volume	22.50	22.46	23.2 cm <sup>3</sup> /mole	66
Atomic Volume Versus Temperature (Permission of Elsevier Publishing Co.)				87



Transition Temperature	Hcp/Fcc at 310 C, Fcc/Bcc at 868 C	66
Heat of Transition	Hcp/Fcc = 0.095, Fcc/Bcc = 0.76 kcal/mole	61
Ionic Radius (Trivalent Ion)	1.061 A	55

**Properties**

105

Closest Approach  
of Atoms

3.73 Å

56

Allotropic  
ModificationsA Fcc structure with  $a_0 = 5.17 \text{ Å}$  occurs  
at 20 C when metal is subjected to a static  
pressure of 23 kilobars.

84

**CHEMICAL PROPERTIES**

Stable Oxidation State

+3

81

Electrode Potential

 $[\text{La} = \text{La}^{+3} + 3e^-] + 2.4 \text{ volts}$  (standard  
hydrogen electrode)

81

Ionization Potential

1st = 5.6, 2nd = 11.4, 3rd = (20.4) volts

82

Metallographic Polishing  
and Etching

62

Samples of lanthanum may be sectioned in an inert atmosphere or in air by using liberal quantities of oil to protect the surface. Conventional techniques for mounting in bakelite or lucite may be employed. Standard motorized, wet-belt, rough grinding equipment may be used with a kerosene lubricant. Both the rough and fine polishing may be done on conventional equipment using kerosene as a carrier for the abrasive. It is extremely important that the polished surface be kept covered with a layer of kerosene at all times.

After final polishing, the sample may be rinsed with mineral oil and immediately immersed in an oil bath in the stage aperture plate of a metallograph. The unetched surface may be photographed through the bottom of this cup. The cup is constructed of a recessed stage aperture plate by cementing a microscope cover glass to the bottom.

Lanthanum may be etched by exposure to air after the mineral oil has been removed by ether or other solvents. Phosphoric and nitric acid etchants have also been used with some success.

Corrosion Rates  
(In Air)7 mil/year at 200 C  
745 mil/year at 400 C  
3300 mil/year at 600 C

68

Oxidation rate increases drastically with increasing relative humidity.

Corrosion Data

91

Corrosive attack on crucible materials:

<u>Material</u>	<u>Onset of Attack</u>
BeO	None < 1150 C
CaO	Mild at 1250 C
La <sub>2</sub> O <sub>3</sub>	590 C
Ta	None < 1200 C

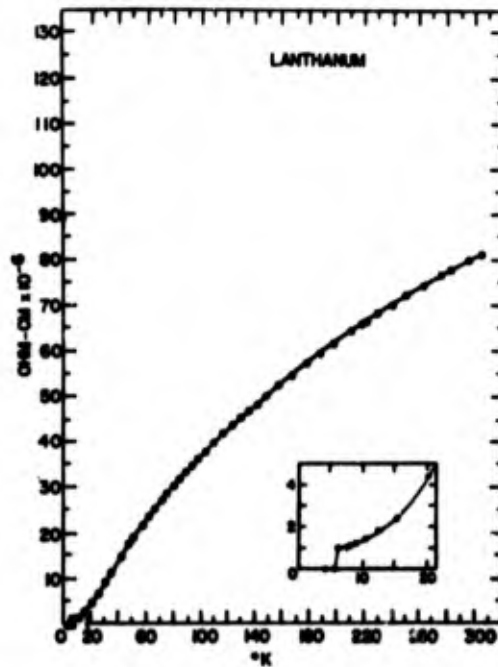
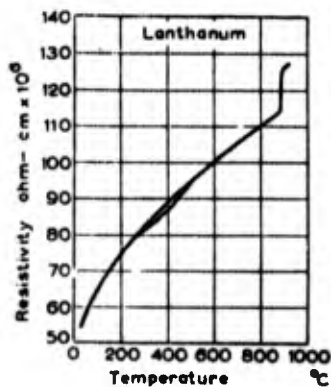
ELECTRICAL PROPERTIES

Resistivity Hcp ( $\alpha$ , 25 C) - 56.8 microhm-cm 61  
 Fcc ( $\beta$ , 560 C) - 96 microhm-cm  
 Bcc ( $\gamma$ , 890 C) - 126 microhm-cm

Temperature Coefficient of Resistivity (25 C)  $2.18 \times 10^{-3}/C$  61

Temperature Versus Resistivity

53, 86



(Permission of the American Physical Society)

MAGNETIC PROPERTIES

Susceptibility (25 C)  $101 \times 10^{-6}$  emu/mole 61

Effective Magnetic Moment Theoretical - 0.00 Bohr magnetons 61  
 Measured - 0.49 Bohr magnetons

**Properties**

107

Authority

Curie Temperature	None	61
Néel Temperature	None	61

**MECHANICAL PROPERTIES**

Young's Modulus	3.84 x 10 <sup>11</sup> dynes/cm <sup>2</sup>			57	
Shear Modulus	1.49 x 10 <sup>11</sup> dynes/cm <sup>2</sup>			57	
Poisson's Ratio	0.228			61	
Compressibility	3.24 x 10 <sup>-6</sup> cm <sup>2</sup> /kg			57	
Hardness (DPH)	37			57	
Tensile Strength	<u>70 F</u> 18.9	<u>400 F</u> 15.3	<u>800 F</u> 6.7	10 <sup>3</sup> psi	88
Yield Strength	18.2	12.4	3.75	10 <sup>3</sup> psi	88
Elongation	8	9.4	21	per cent	88
Ultimate Compressive Strength	41.2 x 10 <sup>3</sup> psi			61	
Impact Strength (Izod)	4.5 ft-lb			71	
Workability	Fair			88	
General Fabrication	(See references)			70, 113	



## NUCLEAR PROPERTIES

## Isotopes

94, 58, 145

<u>Whole- Number Mass</u>	<u>Relative Abundance, per cent</u>	<u>Half Life</u>	<u>Decay Mode</u>
135	--	19 5 hr	K, $\gamma$
136	--	2.1 hr	$\beta^+$
137	--	>400 yr	--
138	0.089	Stable	--
139	99.911	Stable	--
140	--	40 hr	$\beta^-$ , $\gamma$
141	--	3.7 hr	$\beta^-$ , $\gamma$
142	--	75 min	$\beta^-$ , $\gamma$
143	--	19 min	$\beta^-$
144	--	Short	$\beta^-$
145	--	Short	$\beta^-$

Thermal Neutron  
Cross Section8.9  $\pm$  0.3 barns/atom or  
0.039 cm<sup>2</sup>/g

73

## SAFETY

## Lanthanum

83

Toxicity - Acute local: unknown.  
Acute systematic: slight.  
Chronic local: unknown.  
Chronic systematic: unknown.

Radiation hazard - See National Bureau of Standards  
Handbook No. 42.

Fire hazard - Dangerous in the form of dust when  
exposed to flame; can react vigorously  
with oxidizers.

Explosion hazard - Moderate in form of dust when  
exposed to flame.

Lanthanum Boride

Fire hazard - Moderate, on contact with moisture or acids boron hydride is evolved.

Lanthanum Bromate

Toxicity - Acute systematic: ingestion, moderate.  
inhalation, moderate.

Lanthanum Hexaantipyrine  
Perchlorate

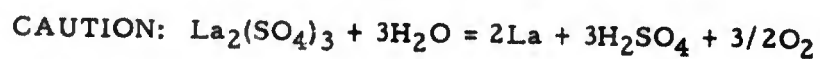
Toxicity - Moderate.  
Fire hazard - Dangerous.  
Explosion hazard - Moderate.  
Disaster control - Dangerous.

Lanthanum Oxide

Toxicity - Acute systematic: inhalation, moderate.

Lanthanum Sulfate

Toxicity - Acute local: irritant, moderate.  
ingestion, moderate.  
inhalation, moderate.



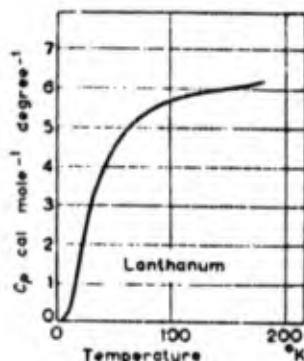
THERMODYNAMIC PROPERTIES

53, 76, 77

	<u>Room Temperature</u>	<u>Melting Point</u>
Entropy	$S_{298} = 13.6$	$S_{1193} = 23.6$ eu
Heat Capacity	$C_{p298} = 6.65$	$C_{p1193} = 8.08$ cal/(mole)(C)

Specific Heat

53



0 to 180 K

Heat Content and Entropy of Solid and Liquid Lanthanum  
(Base: Crystals at 298.15 K)

<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K) (mole)</u>	<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K) (mole)</u>
400	685	1.98	1400	11,000	13.57
500	1,370	3.51	1500	11,800	14.13
600	2,080	4.80	1600	12,600	14.64
700	2,800	5.91	1700	13,400	15.13
800	3,540	6.90	1800	14,200	15.58
900	4,290	7.78	1900	15,000	16.02
1000	5,060	8.59	2000	15,800	16.43
1100	5,840	9.33	2200	17,400	17.19
1193(s)	6,590	9.99	2400	19,000	17.88
1193(l)	9,340	12.29	2600	20,600	18.52
1200	9,400	12.34	2800	22,200	19.12
1300	10,200	12.98	3000	23,800	19.67

For solid lanthanum:

$$H_T - H_{298.15} = 6.17T + 0.80 \times 10^{-3}T^2 - 1,911$$

(0.1 percent; 298-1193 K)

$$C_p = 6.17 + 1.60 \times 10^{-3}T$$

$$\Delta H_{1193}(\text{fusion}) = 2,750$$

For liquid lanthanum:

$$H_T - H_{298.15} = 8.00T - 200$$

(0.1 percent; 1193-3000 K)

$$C_p = 8.00.$$

Heat Content and Entropy of Gaseous Lanthanum  
(Base: ideal gas at 298.15 K)

<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K) (mole)</u>	<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K) (mole)</u>
400	580	1.66	1900	11,385	12.51
500	1,185	3.02	2000	12,150	12.91
600	1,820	4.17	2200	13,680	13.64
700	2,475	5.18	2400	15,210	14.30
800	3,155	6.09	2600	16,740	14.91
900	3,850	6.91	2800	18,270	15.48
1000	4,565	7.66	3000	19,810	16.01
1100	5,300	8.36	3500	23,705	17.21
1200	6,045	9.01	4000	27,690	18.28
1300	6,800	9.61	4500	31,785	19.24
1400	7,560	10.18	5000	35,995	20.13
1500	8,320	10.70	6000	44,710	21.72
1600	9,085	11.20	7000	53,620	23.09
1700	9,855	11.66	8000	62,500	24.28
1800	10,620	12.10			

For gaseous lanthanum:

$$H_T - H_{298.15} = 6.19T + 0.48 \times 10^{-3}T^2 + 0.92 \times 10^5T^{-1} - 2,197$$

(0.8 percent; 298-2000 K)

$$C_p = 6.19 + 0.96 \times 10^{-3}T - 0.92 \times 10^5T^{-2}$$

$$H_T - H_{298.15} = 7.20T + 0.10 \times 10^{-3}T^2 + 1.60 \times 10^5T^{-1} - 2,730$$

(0.2 percent; 2000-5000 K)

$$C_p = 7.20 + 0.20 \times 10^{-3}T - 1.60 \times 10^5T^{-2}$$

LANTHANUM COMPOUNDS

				<u>Authority</u>	
Antimonides		<u>LaSb</u>		162, 168	
	Structure	NaCl			
	a <sub>0</sub> , A	6.49			
	Melting Point, C	1540			
	Resistivity, microhm-cm	120			
Arsenides		<u>LaAs</u>		169	
	Structure	NaCl			
	a <sub>0</sub> , A	6.137			
Beryllides		<u>LaBe<sub>13</sub></u>		161, 179	
	a <sub>0</sub> , A	10.450			
	Heat of Vaporization (kcal/mole)	75.8			
	Dissociation Rate	1.35 x 10 <sup>-6</sup> g/(cm <sup>2</sup> )(sec) at 1082 C 3.70 x 10 <sup>-5</sup> g/(cm <sup>2</sup> )(sec) at 1267 C			
Bismuthides		<u>LaBi</u>		162	
	Structure	NaCl			
	a <sub>0</sub> , A	6.58			
Borides		<u>LaB<sub>3</sub></u>	<u>LaB<sub>4</sub></u>	<u>LaB<sub>6</sub></u>	153, 171
	Molecular Weight	171.38	182.20	203.84	
	Structure	Tetragonal	Tetragonal	Cubic	
	a <sub>0</sub> , A	3.82	7.30	4.154	
	c <sub>0</sub> , A	3.96	4.17	--	

(Continued)

## Borides (Continued)

Authority

	<u>LaB<sub>3</sub></u>	<u>LaB<sub>4</sub></u>	<u>LaB<sub>6</sub></u>
Density, g/cm <sup>3</sup>	4.92	5.44	4.721
Heat of Formation, kcal/mole	--	--	112
Melting Point, C	--	--	2100
Heat of Vaporization, kcal/mole	--	--	169
Heat Capacity, cal/(g)(C)	--	--	137.0
Resistivity, microhm-cm	--	--	17.4
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	--	--	2.68
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	--	5.6
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	0.114
Effective Magnetic Moment, Bohr magnetons	--	--	9.0
Work Function at 1427 C ev	--	--	2.66
Microhardness, kg/mm <sup>2</sup>	--	--	2770
Color	--	--	Violet
Emissivity at 1500 C (λ = 0.655 μ)	--	--	0.7
Metallic Radius, A	--	--	2.20

**Properties**

113

Authority

Carbides

153

	<u><math>\alpha</math>-LaC<sub>2</sub></u>	<u><math>\beta</math>-LaC<sub>2</sub></u>	<u>La<sub>2</sub>C<sub>3</sub></u>
Molecular Weight	162.94	162.94	313.84
Structure	Tetragonal	Cubic	Bcc
Lattice Type	CaC <sub>2</sub>	FeS <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>
a <sub>0</sub> , A	3.92	6.0	8.8185
c <sub>0</sub> , A	6.56	--	--
Density, g/cm <sup>3</sup>	5.35	5.0	6.079
Melting Point, C	2438	2438	2020
Resistivity, microhm-cm	68	--	144
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	12.1	--	9.9

Germanides

170,180,183

	<u><math>\alpha</math>-LaGe<sub>2</sub></u>	<u><math>\beta</math>-LaGe<sub>2</sub></u>	<u>La<sub>5</sub>Ge<sub>3</sub></u>
Structure	--	--	Hexagonal
Lattice Type	ThSi <sub>2</sub>	GdSi <sub>2</sub>	--
a <sub>0</sub> , A	4.321	4.41	8.958
b <sub>0</sub> , A		4.30	
c <sub>0</sub> , A	14.209	14.190	6.795
Density, g/cm <sup>3</sup>	--	7.059	3.72
Volume of Unit Cell, A <sup>3</sup>	266.8	269.1	--

	<u>Authority</u>								
	LaBr <sub>3</sub>	LaCl <sub>3</sub>	LaF <sub>3</sub>	LaI <sub>3</sub>	LaOBr	LaOCl	LaOF	LaOI	
Halides									93,108,157, 159,181, 182,184, 185,186, 211,215, 216,217, 218,222, 235,236, 269,279
Molecular Weight	--	--	195.92	--	--	--	--	--	
Structure	Hexagonal	Hexagonal	Hcp	--	Tetragonal	Tetragonal	Cubic	Tetragonal	
Lattice Type	UCl <sub>3</sub>	UCl <sub>3</sub>	--	--	--	--	--	PbFCl	
a <sub>0</sub> , Å	--	--	7.186	--	4.149	4.149	7.132	4.144	
c <sub>0</sub> , Å	--	--	7.352	--	7.359	7.359	--	9.126	
Density, g/cm <sup>3</sup>	--	--	5.94	--	--	--	6.00	--	
Heat of Formation, kcal/mole	--	255.91	--	160	--	242.6	--	--	
Entropy of Formation, eu	--	(59)	--	(4)	--	(41)	--	--	
Melting Point, C	788	852	1490	761	--	--	--	--	
Heat of Fusion, kcal/mole	13.0	13.0	8	8	--	--	--	--	
Entropy of Fusion, eu	12.3	11.5	5	8	--	--	--	--	
Boiling Point, C	1580	1750	2327	1405	--	--	--	--	
Heat of Vaporization, kcal/mole	48.2	53.3	62	40	--	--	--	--	
Entropy of Vaporization, eu	24	27	24	24	--	--	--	--	
Vapor Pressure (T in K), log P/mm Hg	$\left[ \frac{12.568}{T} - \frac{15446}{T^2} \right]$	$\left[ \frac{11.828}{T} - \frac{15796}{T^2} \right]$	--	$\left[ \frac{12.845}{T} - \frac{15397}{T^2} \right]$	--	--	--	--	
Heat of Sublimation, kcal/mole	71.0	71.3	--	--	--	--	--	--	
Entropy of Sublimation, eu	40	40	--	--	--	--	--	--	
Heat Capacity (to mp), cal/(mole)(C)	33.0	34.7	--	--	--	--	--	--	
Coefficient of Thermal Expansion 10 <sup>-6</sup> /C	--	--	15.0	--	--	--	--	--	
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	0.025	--	--	--	--	--	
ΔH <sub>mp</sub> - ΔH <sub>298</sub> , kcal/mole	20.3	22.8	--	--	--	--	--	--	
Refractive Index	--	--	--	--	--	1.80	--	--	
Color	--	--	White	--	--	--	--	--	
Young's Modulus, 10 <sup>7</sup> psi	--	--	1.2	--	--	--	--	--	
Compressive Strength, 10 <sup>3</sup> psi	--	--	100	--	--	--	--	--	

Halides (Continued)

Thermodynamic Data

212

Glasner has supplied in ANL-5750 the following equations for calculating thermodynamic quantities. The reactions concerned and the constants for use in these equations are tabulated.

$$\Delta C_p = \Delta a + (\Delta b \times 10^{-3})T + (\Delta c \times 10^{-6})T^2 + \frac{\Delta d \times 10^5}{T^2}$$

$$\Delta H - \Delta H_{F298} = (\Delta a)T + \frac{1}{2} (\Delta b \times 10^{-3})T^2 + \frac{1}{3} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} + \Delta A$$

$$\Delta S = (2.303 \Delta a) \log T + (\Delta b \times 10^{-3})T + \frac{1}{2} (\Delta c \times 10^{-6})T^2 - \frac{1/2(\Delta d \times 10^5)}{T^2} - \Delta B$$

$$\Delta F - \Delta H_{F298} = - (2.303 \Delta a) T \log T - \frac{1}{2} (\Delta b \times 10^{-3})T^2 - \frac{1}{6} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} - T\Delta(B - a) - \Delta A .$$

Reaction	Temperature Range, K	$-\Delta H_{F298}$ , kcal/mole	$-\Delta F_{298}$ , kcal/mole	$\Delta a$	$\Delta b$	$\Delta c$	$\Delta d$	$\Delta A$ , kcal/mole	$-\Delta B$ , eu	$-\Delta(B-a)$
$\text{La}(s) + \frac{3}{2} \text{F}_2(g) = \text{LaF}_3(s)$	298-1153	421	406	1.6	6.7	--	1.2	-0.372	70.0	71.6
$\text{La}(l) + \frac{3}{2} \text{F}_2(g) = \text{LaF}_3(s)$	1153-1800	--	--	0.5	8.3	--	1.2	-2.433	65.9	66.4
$\text{La}(l) + \frac{3}{2} \text{F}_2(g) = \text{LaF}_3(l)$	1800-2500	--	--	11.8	-0.7	--	1.2	2.807	128.8	140.6
$\text{La}(s) + \frac{3}{2} \text{Cl}_2(g) = \text{LaCl}_3(s)$	298-1125	255.68	238.8	3.1	7.4	--	1.0	-0.918	75.9	79.0
$\text{La}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{LaCl}_3(s)$	1125-1153	--	--	12.7	-2.0	--	1.0	3.230	124.7	137.4
$\text{La}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{LaCl}_3(l)$	1153-2020	--	--	11.6	-0.4	--	1.0	1.169	120.6	132.2
$\text{La}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{LaCl}_3(g)$	2020-2500	--	--	-0.4	-0.4	--	1.0	69.41	7.5	7.1

Hydrides

91,186,  
187

	<u>LaH<sub>2</sub></u>	<u>LaH<sub>3</sub></u>
Structure	--	Amorphous
$a_0$ , A	5.667	--
Density, g/cm <sup>3</sup>	5.14	5.26
Heat of Formation, kcal/mole of H <sub>2</sub>	49.7	40.09
Entropy of Formation, eu/mole of H <sub>2</sub>	49	--

(Continued)



Authority

## Hydrides (Continued)

	<u>LaH<sub>2</sub></u>	<u>LaH<sub>3</sub></u>
Heat Capacity, cal/(mole)(C)	--	12.3
Color	--	Blue black

## Nitrides

149,153,  
167

	<u>LaN</u>
Molecular Weight	152.93
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , A	5.286
Density, g/cm <sup>3</sup>	6.73
Heat of Formation, kcal/mole	72
Entropy of Formation, eu/mole	25
Heat Capacity, cal/(mole)(C)	11.0
Resistivity, microhm-cm	100
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /(C) (-173 - 427 C)	9.0

		<u>Authority</u>
Oxides	<u>La<sub>2</sub>O<sub>3</sub></u>	156, 172, 173, 174, 176, 186, 199, 212, 218, 219, 220
Molecular Weight	325.82	
Structure	Hcp	
a <sub>0</sub> , A	3.94	
c <sub>0</sub> , A	6.15	
Density, g/cm <sup>3</sup>	6.51	
Heat of Formation, kcal/mole metal	214.29	
Entropy of Formation, eu/mole metal	35.18	
Melting Point, C	2300	
Heat Capacity at 25 C, cal/(mole)(C)	12.7	
Effective Magnetic Moment, Bohr magnetons	0	
Work Function at 1700 K, ev	4.18	
Color	White	
Cation Radius, A	1.14	

Thermodynamic Data

The equations given on page 115 may be used in calculating thermodynamic quantities for the following reactions:

Reaction	Temper- ature Range, K	-ΔH <sub>F</sub> <sup>298</sup> , kcal/mole	-ΔF <sub>298</sub> , kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	-ΔB, eu	-Δ(B-a)
$2\text{La}(s) + \frac{3}{2}\text{O}_2(g) = \text{La}_2\text{O}_3(s)$	298-1153	428.6	409.5	4.12	-0.51	--	-0.5	-1.508	88.0	92.1
$2\text{La}(l) + \frac{3}{2}\text{O}_2(g) = \text{La}_2\text{O}_3(s)$	1153-2500	--	--	1.9	2.7	--	-0.5	-5.630	79.8	81.7

Thermodynamic Functions for  $\text{La}_2\text{O}_3$ 

174

<u>T, K</u>	<u>C<sub>p</sub>, cal/(mole)(K)</u>	<u>S° cal/(mole)(K)</u>	<u>H°-H°<sub>0</sub>, cal/mole</u>	<u>-(F°-H°<sub>0</sub>)/T, cal/(mole)(K)</u>
16	0.526	0.1535	1.838	0.03862
20	0.860	0.3049	4.573	0.07610
30	2.094	0.8713	18.600	0.2513
40	3.742	1.6920	47.525	0.5039
50	5.480	2.7143	93.662	0.8411
60	7.135	3.8612	156.82	1.2475
70	8.697	5.0794	236.05	1.7073
80	10.18	6.3390	330.54	2.2072
90	11.60	7.6209	439.51	2.7375
100	12.94	8.9131	562.28	3.2903
120	15.35	11.491	845.79	4.4427
140	17.39	14.016	1173.9	5.6310
160	19.08	16.451	1539.0	6.8322
180	20.57	18.787	1935.9	8.0320
200	21.86	21.022	2360.6	9.2190
220	22.91	23.157	2808.7	10.390
240	23.83	25.191	3276.3	11.540
260	24.61	27.130	3761.0	12.665
280	25.27	28.979	4260.0	13.765
298.16	25.79	30.580	4724.2	14.735
300	25.84	30.742	4771.2	14.838
500	--	45.02	--	24.39
1000	--	66.08	--	40.49
1500	--	79.22	--	51.33
2000	--	89.04	--	59.58
2500	--	97.01	--	66.28

## Phosphides

188

	<u>LaP</u>
Structure	Fcc
Lattice Type	$\text{NaCl}$
$a_0$ , Å	6.016
Density, $\text{g/cm}^3$	5.18
Microhardness, $\text{kg/mm}^2$	158

**Properties**

Authority

**Selenides**

189, 190,  
191, 192,  
193, 194

	<u>LaSe</u>	<u>LaSe<sub>2</sub></u>	<u>La<sub>2</sub>Se<sub>3</sub></u>	<u>La<sub>3</sub>Se<sub>4</sub></u>	<u>La<sub>2</sub>O<sub>2</sub>Se</u>
Structure	Fcc	Tetragonal	Bcc	Bcc	Hcp
Lattice Type	NaCl	--	Th <sub>3</sub> P <sub>4</sub>	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub>	6.048 kX	8.47 kX	9.037 kX	9.037 kX	4.09 A
c <sub>0</sub>	--	8.53 kX	--	--	7.14 A
Density, g/cm <sup>3</sup>	6.34	6.33	6.15	6.47	--
Resistivity, microhm-cm	50	1.46 x 10 <sup>6</sup>	2.4 x 10 <sup>4</sup>	--	--
Temperature Coefficient of Resistivity at 27 C, 10 <sup>-3</sup> /C	1.7	--	--	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.058	--	--	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	7.08	32	69.77	10.84	--
Effective Magnetic Moment, Bohr magnetons	0.46	0.0	0.0	--	--
Color	Gold	Black	Bright red	Blue black	Beige

**Silicides**

152, 195,  
196, 197

	<u>LaSi</u>	<u>LaSi<sub>2</sub></u>
Structure	Orthorhombic	Tetragonal
Lattice Type	FeB	α-ThSi <sub>2</sub>
a <sub>0</sub> , A	8.48	4.31
b <sub>0</sub> , A	4.02	--
c <sub>0</sub> , A	6.04	13.80
Density, g/cm <sup>3</sup>	--	5.0
Heat of Formation, kcal/mole	≈64	≈52

(Continued)

Authority

## Silicides (Continued)

	<u>LaSi</u>	<u>LaSi<sub>2</sub></u>
Melting Point, C	--	1520
Resistivity, microhm-cm	--	236
Coefficient of Thermal Expansion $10^{-6}/C$ (20 - 750 C)	--	7.67
Microhardness, kg/mm <sup>2</sup>	--	324
Transverse Rupture Strength, $10^3$ psi	--	37.3

## Sulfides

153, 193,  
198, 199,  
239, 200,  
186

	<u>LaS</u>	<u>LaS<sub>2</sub></u>	<u>γ-La<sub>2</sub>S<sub>3</sub></u>	<u>La<sub>3</sub>S<sub>4</sub></u>	<u>La<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	170.99	203.05	374.04	545.04	341.91
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal
a <sub>0</sub> , Å	5.854	8.20	8.723	8.748	4.051
c <sub>0</sub> , Å	--	--	--	--	6.943
Density, g/cm <sup>3</sup>	5.66	4.90	4.99	5.44	5.73
Heat of Formation, kcal/mole	180	147	284	--	--
Entropy of Formation, eu/mole	--	(10)	(9)	--	--
Melting Point, C	1970	1650	2150	2100	1940
Heat Capacity, cal/(mole)(C)	12.11	--	29.89	--	--
Resistivity, microhm-cm	92	--	$2 \times 10^{12}$	$2.4 \times 10^4$	--
Temperature Coefficient of Resistivity at 27 C, $10^{-3}/C$	1.63	--	--	--	--
Coefficient of Thermal Expansion (20 - 1020 C) $10^{-6}/C^{-1}$	11.62	--	9.90	--	--

(Continued)

Properties

Authority

Sulfides (Continued)

	<u>LaS</u>	<u>LaS<sub>2</sub></u>	<u>γ-La<sub>2</sub>S<sub>3</sub></u>	<u>La<sub>3</sub>S<sub>4</sub></u>	<u>La<sub>2</sub>O<sub>2</sub>S</u>
Thermal Conductivity, cal/(cm)(sec)(C)	0.054	--	0.0061	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> (emu/mole)	281	+36.3	+27.1	27.2	>0
Work Function at 1700 K, ev	4.15	--	4.16	--	--
Debye Temperature, K	669	--	913	--	--
Emissivity (λ = 0.655μ)	0.45	--	--	--	--
Color	Gold	--	Yellow	--	--

Tellurides

	<u>LaTe</u>	<u>LaTe<sub>2</sub></u>	<u>LaTe<sub>3</sub></u>	<u>La<sub>3</sub>Te<sub>4</sub></u>	<u>La<sub>4</sub>Te<sub>7</sub></u>	<u>La<sub>2</sub>O<sub>2</sub>Te</u>	169,201, 202,203, 204,205
Structure	Fcc	Tetragonal	Tetragonal	Bcc	Orthorhombic	Hexagonal	
Lattice Type	NaCl	Fe <sub>2</sub> As	--	Ce <sub>2</sub> S <sub>3</sub>	--	--	
a <sub>0</sub> , Å	4.422	4.53	4.407	9.619	4.607	4.12	
b <sub>0</sub> , Å	--	--	--	--	4.483	--	
c <sub>0</sub> , Å	--	6.82	26.14	--	9.142	13.10	
Density, g/cm <sup>3</sup>	6.682	6.97	6.92	6.65	--	6.36	
Melting Point, C	1725	1535	835	1595	--	--	
Resistivity, microhm-cm	1.5 x 10 <sup>11</sup>	6.4 x 10 <sup>6</sup>	--	--	--	--	
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	--	0.008	--	--	
Color	Blue purple	Black	Gold	Silver gray	--	Dark green	
Hardness	Brittle hard	Very brittle	Very soft	Brittle hard	--	--	

## Miscellaneous

	<u>Structure</u>	<u>a<sub>0</sub>, Å</u>	<u>Melting Point, C</u>	<u>Superconducting Transition Temperature, K</u>
LaIr <sub>2</sub>	Cubic	7.686	--	--
LaOs <sub>2</sub>	Cubic	7.737	--	6.5
LaPt <sub>2</sub>	Cubic	7.774	--	--
LaRh <sub>2</sub>	Cubic	7.746	--	--
LaRu <sub>2</sub>	Cubic	7.702	1431	1.63

**CERIUM**

Symbol Ce

Atomic Number 58

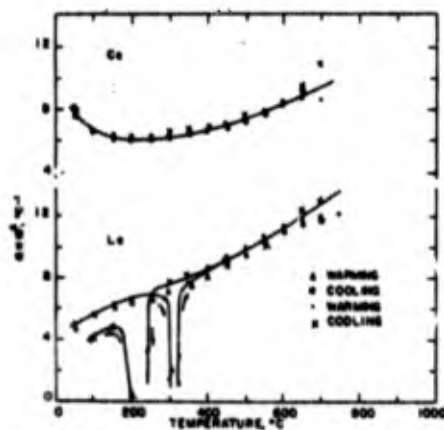
Atomic Weight 140.13

Authority

**PHYSICAL PROPERTIES**

Abundance	20-46 ppm (approx. 46)	51
Density	6.678 g/cm <sup>3</sup>	67
Melting Point	795 C	66
Heat of Fusion	2.20 kcal/mole	77
Boiling Point	3468 C	57
Heat of Vaporization (25 C)	95 kcal/mole	57
Vapor Pressure (1861-2292 K)	$\text{Log } P_{\text{mm Hg}} = 9.396 - \frac{22990}{T}$	60
Specific Heat (25 C)	6.44 cal/(mole)(C)	95
Heat of Combustion	213.50 kcal/g-atom	134
Coefficient of Linear Thermal Expansion	$8.5 \times 10^{-6}/\text{C}$ (25-725 C)	61

90



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		<u>Authority</u>
Thermal Conductivity (28 C)	0.026 cal/(cm <sup>2</sup> )(sec)(C/cm)	52
Heat of Sublimation		
Cohesive Energy	94 kcal/mole	89
Work Function	2.6 ev	82
Debye Temperature	147 K	97
Expansion on Melting	0.3 per cent	91
Surface Tension (1000 C)	708 dynes/cm	85

## CRYSTAL PROPERTIES

	<u>(α) FCC</u>	<u>(β) HCP</u>	<u>(γ) FCC</u>	<u>(δ) BCC</u>	
Structure					61
Lattice Constants	a <sub>0</sub> = 4.85 --	a <sub>0</sub> = 3.68 c <sub>0</sub> = 11.92	a <sub>0</sub> = 5.1612 --	a <sub>0</sub> = 4.11 Å --	62
Density	8.23	6.66	6.768	6.70 g/cm <sup>3</sup>	67
Metallic Radius	1.71	1.82	1.825	1.83 Å	67
Atomic Volume	--	--	20.695	21.0 cm <sup>3</sup> / mole	66
Transition Temperature	Fcc/hcp at -150 C, hcp/fcc at -10 C fcc/bcc at 730 C				66
Heat of Transition	Hcp/fcc = 0.065 kcal/mole				61
Ionic Radius	+2 = 1.2, +3 = 1.034, +4 = 1.01 Å				92, 93
Closest Approach of Atoms	3.46 Å				56
Allotropic Modifications	(1) a Fcc structure with a <sub>0</sub> = 4.82 Å occurs at 20 C when metal is subjected to a static pressure of 15 kilobars.				84

## CHEMICAL PROPERTIES

Stable Oxidation State	+3, +4	81
Electrode Potential	[Ce = Ce <sup>+3</sup> + 3e <sup>-</sup> ] +2.335 volts (standard hydrogen electrode)	81

		<u>Authority</u>
Ionization Potential	1st = 6.54, 2nd = 14.8, 4th = (36.5)volts	82
Metallographic Polishing and Etching		62

Samples of cerium may be prepared in an inert atmosphere or in air by using liberal quantities of oil to protect the metal surface. The sample may then be mounted and polished in a manner like that used for lanthanum. Metallographic examination reveals that intergranular corrosion appears on the surface within 30 seconds after the protective organic solvent has been removed. Intergranular corrosion becomes apparent after exposure to air for several minutes. The time factors here depend on the previous treatment of the cerium metal surface.

Corrosion Rates (In Air)	35,000 mil/year at 400 C	68
Corrosion Data		91

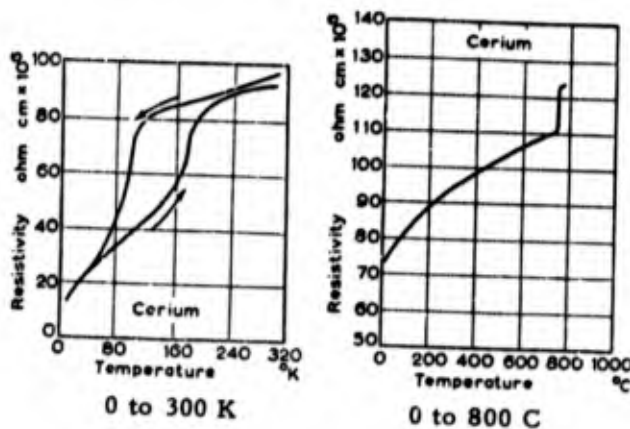
Corrosive attack on crucible materials:

<u>Material</u>	<u>Onset of Attack</u>
BeO	None < 1090 C
CaO	None < 1150 C
MgO	None < 1200 C
Ta	None < 1700 C
Mo	None < 1400 C

**ELECTRICAL PROPERTIES**

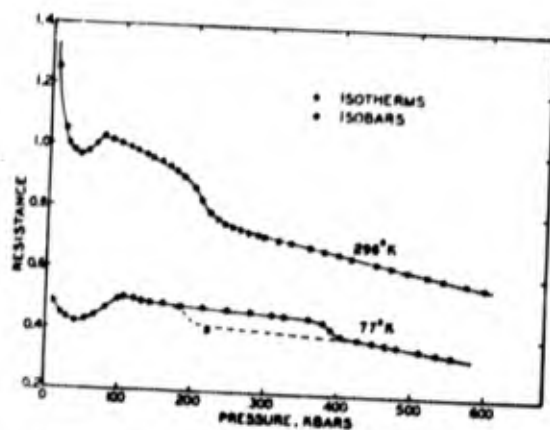
	<u>(α) FCC (-249 C)</u>	<u>(γ) FCC (25 C)</u>	<u>(δ) BCC (770 C)</u>	
Resistivity	34	75.3	123 microhm-cm	61
Temperature Coefficient of Resistivity (25 C)	$0.87 \times 10^{-3}/C$			61

Resistivity Versus Temperature



53

## Resistance Versus Pressure



(Permission of the American Physical Society)

## MAGNETIC PROPERTIES

Susceptibility (25 C)  $2,430 \times 10^{-6}$  emu/mole 61

Effective Magnetic Moment  
Theoretical 2.56 Bohr magnetons 61  
Measured 2.51 Bohr magnetons

Curie Temperature

Néel Temperature

## MECHANICAL PROPERTIES

Young's Modulus  $3.00 \times 10^{11}$  dynes/cm<sup>2</sup> 57

Shear Modulus  $1.20 \times 10^{11}$  dynes/cm<sup>2</sup> 57

Poisson's Ratio 0.248 61

Compressibility  $4.95 \times 10^{-6}$  cm<sup>2</sup>/kg 57

Hardness (DPH) 24 (not annealed) 57

Tensile Strength  $\frac{70 F}{15.0}$   $\frac{400 F}{5.7}$   $10^3$  psi 88

Yield Strength 13.2 4.7  $10^3$  psi 88

Elongation 24 21.4 per cent 88

Ultimate Compressive Strength 42.5 --  $10^3$  psi 61

		<u>Authority</u>
Impact Strength (Izod)	2.2 ft-lb	71
Workability	Good	88
General Fabrication	(See references)	70, 72, 113

**NUCLEAR PROPERTIES**

Isotopes

<u>Whole- Number Mass</u>	<u>Relative Abundance, per cent</u>	<u>Half Life</u>	<u>Decay Mode</u>
135	--	16 hr	$\beta^+$
136	0.193	Stable	--
137	--	36 hr	K, $\gamma$ , $e^-$
138	0.250	Stable	--
139	--	140 days	K, $\gamma$ , $e^-$
140	88.48	Stable	--
141	--	30 days	$\beta^-$ , $\gamma$
142	11.07	Stable	--
143	--	33 hr	$\beta^-$ , $\gamma$
144	--	275 days	$\beta^-$
145	--	1.8 hr	$\beta^-$
146	--	15 min	$\beta^-$

Thermal Neutron Cross Section	0.70 $\pm$ 0.08 barns/atom or 0.0030 cm <sup>2</sup> /g	73
----------------------------------	--	----

**SAFETY**

83

Cerium

Toxicology - Cerium resembles aluminum in its pharmacological action as well as in its chemical properties. The insoluble salts such as the oxalate are stated to be nontoxic even in large doses. It is used to prevent vomiting in pregnancy. The average dose is from 0.05 to 0.5 g. Cerium tartrate has been found to produce a direct injurious action on the hearts of small animals. The effect on the nervous system of the rare-earth metals following inhalation may preclude welding operations with these materials to any large extent. Cerium is stated to produce polycythemia but is useless in the treatment of anemia owing to its toxic effects. The salts of cerium increase the blood coagulation rate.

Authority

Toxicity - Acute local: none.  
 Acute systematic: ingestion, slight.  
 Chronic local: none.  
 Chronic systematic: ingestion, slight.  
 inhalation, slight.

Radiation hazard - See National Bureau of Standards  
Handbook No. 42.

Fire hazard - Moderate, ignites spontaneously in air  
 at 150 to 180 C.

Explosion hazard - Moderate in the form of dust when  
 exposed to flame.

## Cerium Compounds

Toxicity - The toxicity of cerium compounds may be  
 taken as that of cerium except where the  
 anion has a toxicity of its own.

## THERMODYNAMIC PROPERTIES

	<u>Room Temperature</u>	<u>Melting Point</u>	
Entropy	$S_{298} = 18.12$	$S_{1077} = 28.48$ eu	95
Heat Capacity	$C_{p298} = 6.44$	$C_{p1077} = 9.05$ (cal)(mole)(C)	
Thermodynamic Functions of Cerium			95

$T, K$	$C_p,$ cal/(K)(mole)	$S^0 - S_0^0,$ cal/(K)(mole)	$H^0 - H_{298.15}^0,$ cal/(K)(mole)	$-\left(\frac{F^0 - H_{298.15}^0}{T}\right),$ cal/(K)(mole)
208.15	6.44	18.12	0.0	18.12
300	6.45	18.16	0.040	18.12
350	6.60	19.16	0.966	18.19
400	6.76	20.06	1.680	18.38
450	6.92	20.86	2.253	18.61
500	7.10	21.60	2.729	18.87
550	7.27	22.29	3.134	19.16
600	7.46	22.93	3.487	19.44
650	7.65	23.53	3.799	19.73
700	7.84	24.10	4.081	20.02
750	8.04	24.65	4.338	20.31
800	8.25	25.18	4.576	20.60
850	8.46	25.68	4.798	20.88
900	8.68	26.17	5.008	21.16
950	8.90	26.65	5.207	21.44
1000	9.14	27.11	5.398	21.71
1003.15	9.15	27.14	5.409	21.73
1003.15	9.05	27.84	6.107	21.73

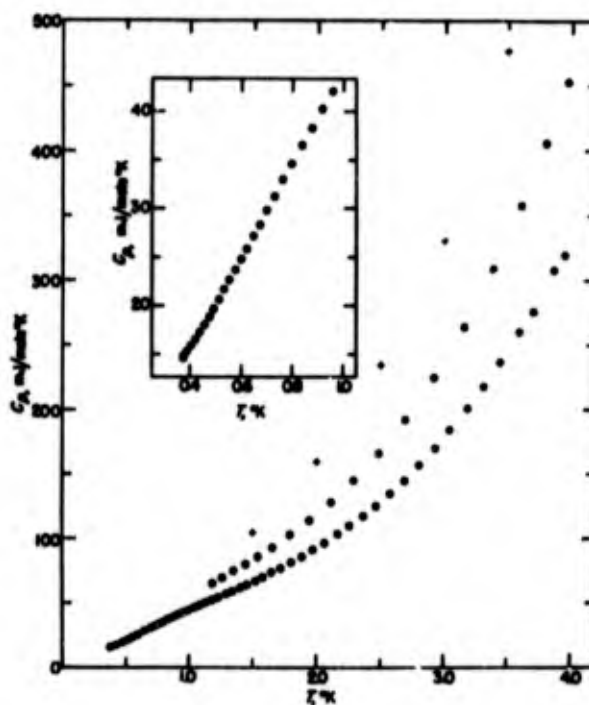
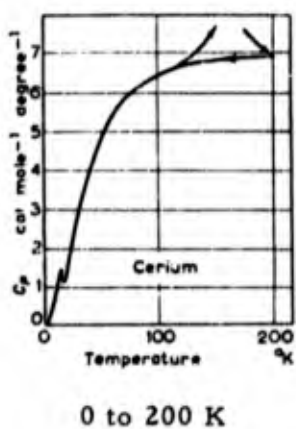
(Continued)

Thermodynamic Functions of Cerium (Continued)

T, K	C <sub>p</sub> , cal/(K)(mole)	S <sup>o</sup> -S <sub>0</sub> <sup>o</sup> , cal/(K)(mole)	H <sup>o</sup> -H <sub>298.15</sub> <sup>o</sup> (a), cal/(K)(mole)	$\frac{F^o-H_{298.15}^o}{T}$ , cal/(K)(mole)
1050	9.05	28.25	6.238	22.01
1077.15	9.05	28.43	6.309	22.17
1077.15	9.35	29.63	7.458	22.17
1100	9.35	29.83	7.497	22.33
1150	9.35	30.24	7.577	22.66
1200	9.35	30.64	7.651	22.99
1250	9.35	31.02	7.719	23.30
1300	9.35	31.39	7.781	23.61
1350	9.35	31.74	7.839	23.90
1373.15	9.35	31.90	7.865	24.03

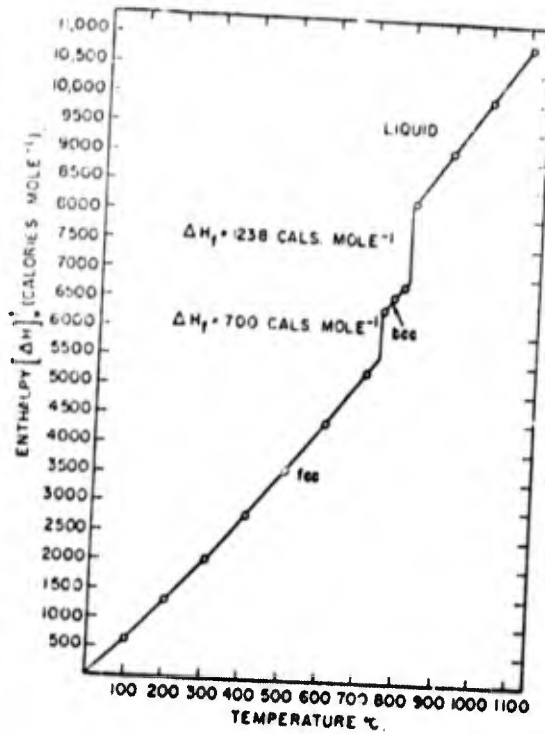
(a)  $(H_{298.15}^o - H_0^o)/T = 7.63 \text{ cal. degree}^{-1} \text{ mole}^{-1}$  based on a private communication from Jennings.

Specific Heat



O-62% of  $\alpha$ -cerium; ●-39% of  $\alpha$ -cerium; +-3% of  $\alpha$ -cerium (Permission of Gordon and Breach, Science Publishers, Inc.)

High-Temperature Enthalpy Versus Temperature  
(Reprinted from Journal of Physical Chemistry)



CERIUM COMPOUNDS

Antimonides

169

Structure

CeSb

Cubic

Lattice Type

NaCl

$a_0$ , Å

6.412

Arsenides

169

Structure

CeAs

Cubic

Lattice Type

NaCl

$a_0$ , Å

6.072

Properties				Authority
Beryllides				179
	$a_0$ , A	<u>CeBe<sub>13</sub></u>		
		10.378		
Bismuthides				169
	Structure	<u>CeBi</u>		
	Lattice Type	Cubic		
	$a_0$ , A	NaCl		
		6.500		
Borides				153
		<u>CeB<sub>4</sub></u>	<u>CeB<sub>6</sub></u>	
	Molecular Weight	182.86	205.05	
	Structure	Tetragonal	Cubic	
	$a_0$ , A	7.205	4.137	
	$c_0$ , A	4.090	--	
	Density, g/cm <sup>3</sup>	5.74	4.80	
	Heat of Formation, kcal/mole	84	81	
	Melting Point, C	--	2190	
	Resistivity, microhm-cm	--	43.3	
	Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	--	1.0	
	Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	6.2	
	Thermal Conductivity, cal/(cm)(sec)(C)	--	0.081	
	Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	--	2260	
	Effective Magnetic Moment, Bohr magnetons	--	2.60	

(Continued)



Authority

## Borides (Continued)

	<u>CeB<sub>4</sub></u>	<u>CeB<sub>6</sub></u>
Work Function, ev	--	2.59
Microhardness, kg/mm <sup>2</sup>	--	3140
Color	Gray brown	Blue violet
Emissivity at 1500 C ( $\lambda = 0.655 \mu$ )	--	0.68

## Carbides

153

	<u>CeC<sub>2</sub></u>	<u>Ce<sub>2</sub>C<sub>3</sub></u>
Molecular Weight	164.15	316.24
Structure	Body-centered tetragonal	Bcc
Lattice Type	CaC <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>
a <sub>0</sub> , A	3.88	8.448
c <sub>0</sub> , A	6.49	--
Density, g/cm <sup>3</sup>	5.56	6.969
Melting Point, C	2540	--
Resistivity, microhm-cm	58.8	202
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	10.1	10.4
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	1640	--
Effective Magnetic Moment, Bohr magnetons	2.19	--

Properties

Germanides

Authority

170, 183,  
221

	<u><math>\alpha</math>-CeGe<sub>2</sub></u>	<u><math>\beta</math>-CeGe<sub>2</sub></u>	<u>Ce<sub>5</sub>Ge<sub>3</sub></u>
Structure	--	--	Hcp
Lattice Type	$\alpha$ -ThSi <sub>2</sub>	$\alpha$ -GdSi <sub>2</sub>	--
a <sub>0</sub> , A	4.27	4.36	8.875
b <sub>0</sub> , A	--	4.26	--
c <sub>0</sub> , A	14.08	14.07	6.570
Density, g/cm <sup>3</sup>	--	--	3.92
Volume of Unit Cell, A <sup>3</sup>	256.7	262.5	--

Halides

	<u>CeBr<sub>3</sub></u>	<u>CeCl<sub>3</sub></u>	<u>CeF<sub>3</sub></u>	<u>CeI<sub>3</sub></u>	<u>CeOCl</u>	<u>CeOF</u>
Structure	Hexagonal	Hexagonal	Hexagonal	Orthorhombic	Tetragonal	Fcc
Lattice Type	UCl <sub>3</sub>	UCl <sub>3</sub>	--	PuBr <sub>3</sub>	--	--
a <sub>0</sub> , A	--	7.450	7.114	14.0	4.080	5.703
b <sub>0</sub> , A	--	--	--	4.4	--	--
c <sub>0</sub> , A	--	4.315	7.273	10.1	6.831	--
Density, g/cm <sup>3</sup>	--	--	5.99	--	--	--
Heat of Formation, kcal/mole	--	252.98	--	158	--	--
Entropy of Formation, eu/mole	--	(62)	--	(7)	--	--
Melting Point, C	732	802	1437	752	--	--
Heat of Fusion, kcal/mole	--	--	--	12.4	--	--
Entropy of Fusion, eu/mole	8	8	5	12.0	--	--
Boiling Point, C	1560	1730	2327	(1400)	--	--
Heat of Vaporization, kcal/mole	47.5	52.8	62	--	--	--
Entropy of Vaporization, eu/mole	24	23	24	24	--	--

55, 93, 108, 158,  
159, 181, 184,  
185, 186, 211,  
215, 218, 235,  
236, 237, 279

(Continued)

## Halides (Continued)

Authority

	CeBr <sub>3</sub>	CeCl <sub>3</sub>	CeF <sub>3</sub>	CeI <sub>3</sub>	CeOCl	CeOF
Vapor Pressure (T in K), log P <sub>mm Hg</sub>	$\left[ \begin{array}{c} 12.334 \\ - \\ \frac{14990}{T} \end{array} \right]$	$\left[ \begin{array}{c} 12.035 \\ - \\ \frac{15544}{T} \end{array} \right]$	--	--	--	--
Heat of Sublimation, kcal/mole	68.3	70.7	--	--	--	--
Entropy of Sublimation, eu/mole	43	41.5	--	--	--	--
Heat Capacity (25-300 C), cal/(mole)(C)	--	15.4 + 0.175 T	--	36.5	--	--
$\Delta H_{mp} - \Delta H_{298}$ , kcal/mole	--	--	--	20.8	--	--
Color	--	--	White	--	--	--
Cation Radius, A	1.034	1.034	--	--	--	--

## Thermodynamic Data

212

Glasco has supplied in ANL-5750 the following equations for calculating thermodynamic quantities. The reactions concerned and the constants for use in these equations are tabulated.

$$\Delta C_p = \Delta a + (\Delta b \times 10^{-3})T + (\Delta c \times 10^{-6})T^2 + \frac{\Delta d \times 10^5}{T^2}$$

$$\Delta H - \Delta H_{298} = (\Delta a)T + \frac{1}{2}(\Delta b \times 10^{-3})T^2 + \frac{1}{3}(\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} + \Delta A$$

$$\Delta S = (2.303 \Delta a) \log T + (\Delta b \times 10^{-3})T + \frac{1}{2}(\Delta c \times 10^{-6})T^2 - \frac{1/2(\Delta d \times 10^5)}{T^2} - \Delta B$$

$$\Delta F - \Delta H_{298} = - (2.303 \Delta a) T \log T - \frac{1}{2}(\Delta b \times 10^{-3})T^2 - \frac{1}{6}(\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} - T\Delta(B - a) - \Delta A$$

Reaction	Tempera- ture Range, K	$-\Delta H_{298}$ , kcal/mole	$-\Delta F_{298}$ , kcal/mole	$\Delta a$	$\Delta b$	$\Delta c$	$\Delta d$	$\Delta A$ , kcal/mole	$-\Delta B$ , eu	$-\Delta(B-a)$
$\text{Ce}(s) + \frac{3}{2} \text{F}_2(g) = \text{CeF}_3(s)$	298-1048	416	398	3.5	1.1	--	1.2	-0.680	78.5	82.0
$\text{Ce}(l) + \frac{3}{2} \text{F}_2(g) = \text{CeF}_3(s)$	1048-1733	--	--	--	7.1	--	1.2	-2.407	62.5	62.5
$\text{Ce}(l) + \frac{3}{2} \text{F}_2(g) = \text{CeF}_3(l)$	1733-2500	--	--	11.7	-0.7	--	1.2	-1.970	131.0	142.7
$\text{Ce}(s) + 2\text{F}_2(g) = \text{CeF}_4(s)$	298-1048	442	420	4.0	2.1	--	1.6	-0.755	96.5	100.5
$\text{Ce}(l) + 2\text{F}_2(g) = \text{CeF}_4(s)$	1048-1250	--	--	0.5	8.1	--	1.6	-2.482	80.5	81.0
$\text{Ce}(l) + 2\text{F}_2(g) = \text{CeF}_4(l)$	1250-2000	--	--	13.5	-0.9	--	1.6	-0.701	153.2	166.7
$\text{Ce}(l) + 2\text{F}_2(g) = \text{CeF}_4(g)$	2000-2500	--	--	-4.5	4.1	--	1.6	73.30	2.3	-2.2
$\text{Ce}(s) + \frac{3}{2} \text{Cl}_2(g) = \text{CeCl}_3(s)$	298-1048	252.84	235.1	4.5	2.4	--	1.0	-1.104	84.8	89.5
$\text{Ce}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{CeCl}_3(s)$	1048-1085	--	--	1.0	8.4	--	1.0	-2.831	68.8	69.8
$\text{Ce}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{CeCl}_3(l)$	1085-2000	--	--	11.0	-0.4	--	1.0	0.189	121.1	132.1
$\text{Ce}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{CeCl}_3(g)$	2000-2500	--	--	-1.0	-0.4	--	1.0	70.19	6.9	5.9

**Properties**

135

Authority

Hydrides

91, 187

	<u>CeH<sub>2</sub></u>	<u>CeH<sub>3</sub></u>
Structure	Fluorite	Fluorite
a <sub>0</sub> , A	5.581	--
Density, g/cm <sup>3</sup>	5.43	5.55
Heat of Formation, kcal/mole H <sub>2</sub>	33.9	42.26
Color	--	Dark blue

Nitrides

153, 167,  
258

	<u>CeN</u>
Molecular Weight	154.14
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , A	5.02
Density, g/cm <sup>3</sup>	7.89
Heat of Formation, kcal/mole	78.0
Entropy of Formation, eu/mole	25
Heat Capacity, cal/(mole)(C)	11.1
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	30.0
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	433
Color	Bronze

Oxides			<u>Authority</u>
	<u>CeO<sub>2</sub></u>	<u>Ce<sub>2</sub>O<sub>3</sub></u>	
Structure	Fcc	Hexagonal	156, 172, 176, 177, 212, 218, 219, 220, 224, 245, 259
a <sub>0</sub> , A	5.41	3.880	
c <sub>0</sub> , A	--	6.057	
Density, g/cm <sup>3</sup>	7.2	--	
Heat of Formation, kcal/mole	--	217.46	
Entropy of Formation, eu/mole	--	35.2	
Melting Point, C	1950	~1690	
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	10.7	--	
Effective Magnetic Moment, Bohr magnetons	--	2.6	
Color	White		

#### Thermodynamic Data

The equations given on page 134 may be used in calculating thermodynamic quantities for the following reactions:

(Continued)

Oxides (Continued)

Thermodynamic Properties of CeO<sub>2</sub> and Ce<sub>2</sub>O<sub>3</sub>

224,245

CeO <sub>2</sub>			Ce <sub>2</sub> O <sub>3</sub>		
T, K	H <sub>T</sub> -H <sub>298,15</sub> , cal/mole	S <sub>T</sub> -S <sub>298,15</sub> , cal/(K)(mole)	T, K	H <sub>T</sub> -H <sub>298,15</sub> , cal/mole	S <sub>T</sub> -S <sub>298,15</sub> , cal/(K)(mole)
400	1,580	4.55	400	3,000	8.63
500	3,220	8.21	500	6,150	15.66
600	4,940	11.34	600	9,410	21.60
700	6,720	14.08	700	12,740	26.73
800	8,540	16.51	800	16,140	31.27
900	10,380	18.68	900	19,620	35.37
1000	12,250	20.65	1000	23,180	39.12
1100	14,140	22.45			
1200	16,050	24.11			
1300	17,980	25.66			
1400	19,930	27.10			
1500	21,900	28.46			
1600	23,890	29.74			
1700	25,910	30.97			
1800	27,960	32.14			

Phosphides

169

	CeP
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , Å	5.909

Selenides

169,189,191,  
192,193,194,  
225,226,227,  
228,229

	CeSe	CeSe <sub>2</sub>	Ce <sub>2</sub> Se <sub>3</sub>	Ce <sub>3</sub> Se <sub>4</sub>	Ce <sub>2</sub> O <sub>2</sub> Se
Structure	Fcc	Tetrago		Bcc	Hcp
Lattice Type	NaCl	--	Th <sub>3</sub> P <sub>4</sub>	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , Å	5.992	8.43	3.960	8.973	7.04
c <sub>0</sub> , Å	--	8.49	--	--	7.06
Density, g/cm <sup>3</sup>	6.55	6.45	6.30	6.76	6.51
Melting Point, C	1820	--	1825	--	--

(Continued)

Authority

## Selenides (Continued)

	<u>CeSe</u>	<u>CeSe<sub>2</sub></u>	<u>Ce<sub>2</sub>Se<sub>3</sub></u>	<u>Ce<sub>3</sub>Se<sub>4</sub></u>	<u>Ce<sub>2</sub>O<sub>2</sub>Se</u>
Resistivity, microhm-cm	100	2.92 x 10 <sup>8</sup>	3.3 x 10 <sup>3</sup>	8.0 x 10 <sup>3</sup>	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.03	--	--	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	2186	2220	2068	--	--
Effective Magnetic Moment, Bohr magnetons	2.3	2.2	2.2	--	--
Color	--	--	Violet	--	Maroon

## Silicides

	<u>CeSi</u>	<u>CeSi<sub>2</sub></u>
Molecular Weight	168.22	196.31
Structure	Orthorhombic	Tetragonal
Lattice Type	FeB	$\alpha$ -ThSi <sub>2</sub>
a <sub>0</sub> , A	--	4.175
c <sub>0</sub> , A	--	13.848
Heat of Formation, kcal/mole	--	50
Density, g/cm <sup>3</sup>	--	5.45
Resistivity, microhm-cm	--	408
Microhardness, kg/mm <sup>2</sup>	--	540

153

Authority

## Selenides (Continued)

	<u>CeSe</u>	<u>CeSe<sub>2</sub></u>	<u>Ce<sub>2</sub>Se<sub>3</sub></u>	<u>Ce<sub>3</sub>Se<sub>4</sub></u>	<u>Ce<sub>2</sub>O<sub>2</sub>Se</u>
Resistivity, microhm-cm	100	2.92 x 10 <sup>8</sup>	3.3 x 10 <sup>3</sup>	8.0 x 10 <sup>3</sup>	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.03	--	--	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	2186	2220	2068	--	--
Effective Magnetic Moment, Bohr magnetons	2.3	2.2	2.2	--	--
Color	--	--	Violet	--	Maroon

## Silicides

153

	<u>CeSi</u>	<u>CeSi<sub>2</sub></u>
Molecular Weight	168.22	196.31
Structure	Orthorhombic	Tetragonal
Lattice Type	FeB	α-ThSi <sub>2</sub>
a <sub>0</sub> , A	--	4.175
c <sub>0</sub> , A	--	13.848
Heat of Formation, kcal/mole	--	50
Density, g/cm <sup>3</sup>	--	5.45
Resistivity, microhm-cm	--	408
Microhardness, kg/mm <sup>2</sup>	--	540



Sulfides

Authority

	<u>CeS</u>	<u>CeS<sub>2</sub></u>	<u>γ-Ce<sub>2</sub>S<sub>3</sub></u>	<u>Ce<sub>3</sub>S<sub>4</sub></u>	<u>Ce<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	172.20	204.26	376.46	548.65	344.33
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal
a <sub>0</sub> , Å	5.778	8.12	8.635	8.623	4.00
c <sub>0</sub> , Å	--	--	--	--	6.82
Density, g/cm <sup>3</sup>	5.94	5.07	5.19	5.675	5.99
Heat of Formation, kcal/mole	117.9	--	300.5	421.5	430
Entropy of Formation, eu/mole	(5)	(13)	(12)	(10)	--
Melting Point, C	2450	1700	1890	2080	1950
Heat Capacity, cal/(mole)(C)	12.24	--	30.15	--	--
Resistivity, microhm-cm	170	--	1.19 x 10 <sup>12</sup>	400	--
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	0.67	--	--	--	--
Coefficient of Thermal Expansion, (20-1000 C), 10 <sup>-6</sup> /C	12.37	--	10.45	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.036	--	0.0093	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	2125	2286	2520	2160	2139
Work Function at 1700 K, ev	3.95	--	3.95	--	--
Debye Temperature, C	677	--	928	--	--
Color	Gold	Dark brown	Red	Black	Dark brown
Emissivity (λ = 0.655 μ)	0.56	--	--	--	--
Temperature of Transition to Semiconductor, C	--	--	670	--	--

153, 186,  
193, 198,  
200, 230,  
231, 239

Authority

## Tellurides

	CeTe	CeTe <sub>2</sub>	Ce <sub>2</sub> Te <sub>3</sub>	Ce <sub>3</sub> Te <sub>4</sub>	Ce <sub>2</sub> O <sub>2</sub> Te
Structure	Fcc	Tetragonal	--	Bcc	Hexagonal
Lattice Type	NaCl	Fe <sub>2</sub> As	--	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , Å	6.359	4.51	9.535	9.528	4.09
c <sub>0</sub> , Å	--	9.10	--	--	12.92
Density, g/cm <sup>3</sup>	--	7.06	6.6	6.7	6.64
Resistivity, microhm-cm	200	--	1.1 x 10 <sup>4</sup>	1.8 x 10 <sup>3</sup>	--
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	1.2	--	--	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.027	--	0.0029	0.005	--
Color	--	--	--	--	Maroon

169, 193,  
202, 205,  
233

## Miscellaneous

	Structure	a <sub>0</sub> , Å	Melting Point, C	Superconducting Transition Temperature, K
CeIr <sub>2</sub>	Cubic	7.571	--	--
CeOs <sub>2</sub>	Cubic	7.593	--	--
CeRh <sub>2</sub>	Cubic	7.538	--	--
CeRu <sub>2</sub>	Cubic	7.5364	1539	4.9

150, 206

**PRASEODYMIUM**

Symbol Pr

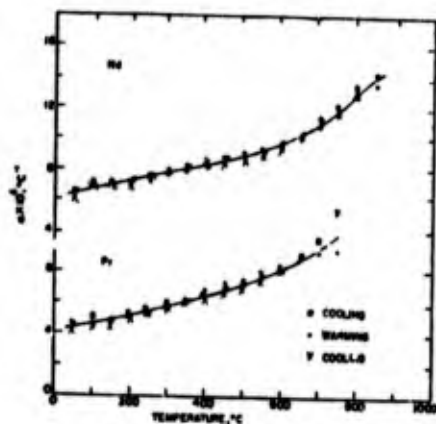
Atomic Number 59

Atomic Weight 140.92

Authority

**PHYSICAL PROPERTIES**

Abundance	3.5-5.5 ppm (approx. 5.5)	51
Density	6.769 g/cm <sup>3</sup>	67
Melting Point	935 C	66
Heat of Fusion	1.650 kcal/mole	66
Boiling Point	3127 C	57
Heat of Vaporization (25 C)	79 kcal/mole	57
Vapor Pressure (1644-2120 K)	$\text{Log } P_{\text{mm Hg}} = 8.069 - \frac{18083}{T}$	60
Specific Heat (25 C)	6.48 cal/(mole) (C)	53
Heat of Combustion (25 C)	218.4 kcal/g-atom	57
Coefficient of Linear Thermal Expansion	$4.8 \times 10^{-6}/\text{C} (-173 - 800 \text{ C})$	61



(Permission of the American Physical Society)

90

		<u>Authority</u>
Thermal Conductivity (28 C)	0.028 cal/(cm <sup>2</sup> )(sec)(C/cm)	54
Heat of Sublimation		
Cohesive Energy	85 kcal/mole	89
Work Function	2.7 ev	75
Debye Temperature	152 K	97
Expansion on Melting		
Surface Tension		

## CRYSTAL PROPERTIES

Structure	<u>HCP</u>	<u>BCC</u>	61
Lattice Constants	$a_o = 3.6725$ $c_o = 11.8354$	$a_o = 4.13$ A -- A	61
Density	6.769	6.64 g/cm <sup>3</sup>	67
Metallic Radius	1.828	1.84 A	67
Atomic Volume	20.778	21.2 cm <sup>3</sup> /mole	66
Transition Temperature	798 C		66
Heat of Transition	0.760 kcal/mole		61
Ionic Radius	+3 = 1.013, +4 = 0.99 A		55,93
Closest Approach of Atoms	3.633 A		56
Allotropic Modifications	(1) a Fcc structure with $a_o = 4.88$ A occurs at 20 C when metal is subjected to a static pressure of 40 kilobars		84

## CHEMICAL PROPERTIES

Stable Oxidation State	+3, +4	81
	(standard hydrogen electrode)	
Electrode Potential	$[Pr = Pr^{+3} + 3e^-] + 2.2$ volts	81
Ionization Potential	1 <sup>st</sup> = 5.8 volts	82

Authority

Metallographic Polishing and Etching

Praseodymium may be sectioned, mounted and polished in a manner similar to that used for lanthanum. Praseodymium etches readily in air and reacts with various inorganic acid etchants as does lanthanum.

62

Corrosion Rates (In Air)

17 mil/year at 200 C  
8,100 mil/year at 400 C  
27,600 mil/year at 600 C  
Oxidation rate increases rapidly with increasing relative humidity.

68

Corrosion Data

Corrosive attack on crucible materials:

91

Material	Onset of Attack
MgO	None <1150 C
Ta	None <1200 C

**ELECTRICAL PROPERTIES**

Temperature Coefficient of Resistivity

$1.71 \times 10^{-3}/C$

61

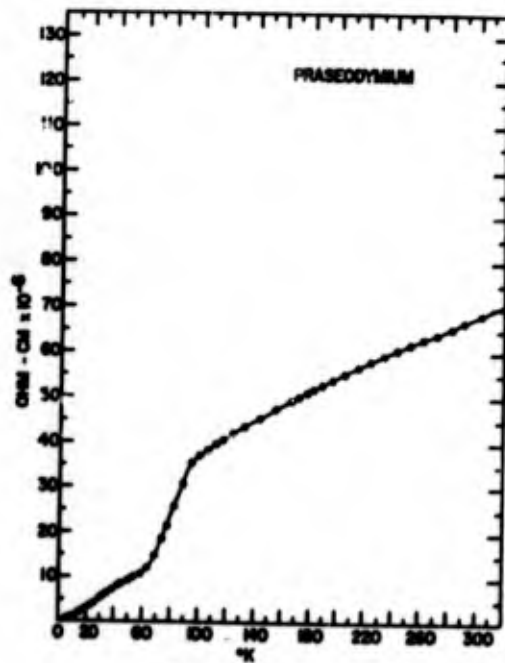
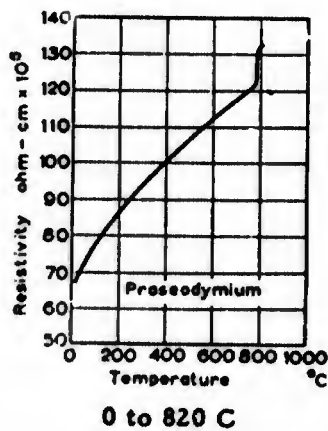
Resistivity

( $\alpha$ ) HCP (25 C)      ( $\beta$ ) BCC (820 C)  
68                              132 microhm-cm

61

Resistivity Versus Temperature

53, 86

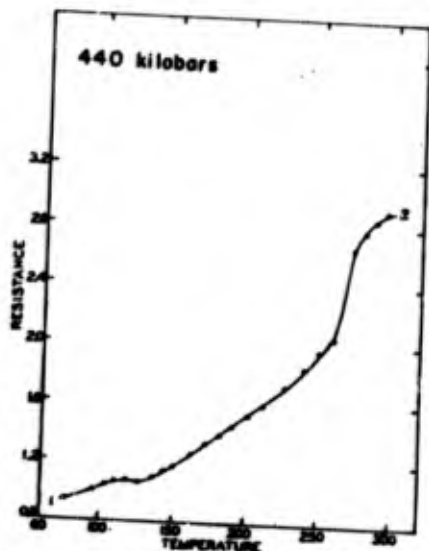


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Authority

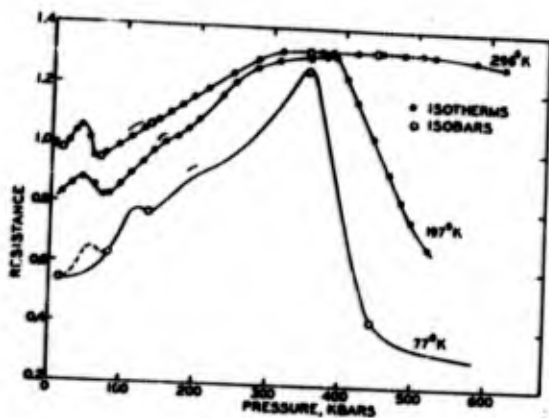
Resistance Versus Temperature (K)  
(Permission of the American Physical Society)

96



Resistance Versus Pressure  
(Permission of the American Physical Society)

96



**MAGNETIC PROPERTIES**

Susceptibility (25 C)	$5,320 \times 10^{-6}$ emu/mole	61
Effective Magnetic Moment	Theoretical 3.62 Bohr magnetons	61
	Measured 3.56 Bohr magnetons	
Curie Temperature	None	61
Néel Temperature	None	61

Authority

**MECHANICAL PROPERTIES**

Young's Modulus	3.52 x 10 <sup>11</sup> dynes/cm <sup>2</sup>			57
Shear Modulus	1.32 x 10 <sup>11</sup> dynes/cm <sup>2</sup>			57
Poisson's Ratio	0.305			61
Compressibility	3.28 x 10 <sup>-6</sup> cm <sup>2</sup> /kg			57
Hardness (DPH)	37 (not annealed)			57
Tensile Strength	<u>70 F</u> 15.9	<u>400 F</u> 20.1	<u>800 F</u> 6.7 10 <sup>3</sup> psi	88
Yield Strength	14.5	14.7	5.8 10 <sup>3</sup> psi	88
Elongation	10	15.8	30 per cent	88
Ultimate Compressive Strength	41.2 10 <sup>3</sup> psi			61
Impact Strength (Izod)	4.75 ft-lb			71
Workability	Poor			88
General Fabrication	(See references)			70, 113

**NUCLEAR PROPERTIES**

Isotopes 58, 98

<u>Whole Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay, Mode</u>
140	--	3.5 min	β <sup>+</sup>
141	100	Stable	--
142	--	19.3 hr	β <sup>-</sup>
143	--	14 days	β <sup>-</sup>
144	--	17.5 min	β <sup>-</sup> , e <sup>-</sup> , γ
145	--	4.5 hr	β <sup>-</sup>
146	--	25 min	β <sup>-</sup> , γ

Thermal Neutron Cross Section 73  
 11.2 ± 0.6 barns/atom  
 or 0.048 cm<sup>2</sup>/g

Authority

## SAFETY

83

## Praseodymium

Toxicity - Unknown.

Radiation hazard - See National Bureau of Standards Handbook No. 42.

Fire hazard - Moderate in the form of dust; when exposed to heat or flame fine dust ignites readily.

## Praseodymium Oxalate

Toxicity - Highly toxic.

## Praseodymium Selenate

Toxicity - Highly toxic.

## THERMODYNAMIC PROPERTIES

	<u>Room Temperature</u>	<u>Melting Point</u>	76, 77
Entropy	$S_{298} = 17.6$	$S_{1208} = 28.37$ eu	
Heat Capacity	$C_{p298} = 6.48$	$C_{p1208} = 8.00$ cal/(mole)(C)	

## Heat Capacities of Praseodymium

76

<u>Cal/(Deg)(Mole at Indicated Temperature)</u>						
<u>10 K</u>	<u>25 K</u>	<u>50 K</u>	<u>100 K</u>	<u>150 K</u>	<u>200 K</u>	<u>298.15 K</u>
(.99)	4.36	6.03	6.36	6.42	6.45	6.48

## Heat Content and Entropy of Solid and Liquid Praseodymium

(Base:  $\alpha$ -crystals at 298.15 K)

<u>T, K</u>	<u><math>H_T - H_{298.15}</math>, cal/mole</u>	<u><math>S_T - S_{298.15}</math>, cal/(deg)(mole)</u>	<u>T, K</u>	<u><math>H_T - H_{298.15}</math>, cal/mole</u>	<u><math>S_T - S_{298.15}</math>, cal/(deg)(mole)</u>
400	670	1.93	1208(l)	10,160	13.08
500	1,370	3.49	1300	10,900	13.67
600	2,090	4.80	1400	11,700	14.26
700	2,850	5.97	1600	13,300	15.33
800	3,640	7.03	1800	14,900	16.27
900	4,460	7.99	2000	16,500	17.12
1000	5,320	8.90	2200	18,100	17.88
1071( $\alpha$ )	5,950	9.51	2400	19,700	18.58
1071( $\beta$ )	6,270	9.81	2600	21,300	19.22
1100	6,500	10.02	2800	22,900	19.81
1200	7,300	10.72	3000	24,500	20.36
1208( $\beta$ )	7,360	10.77			

(Continued)



Heat Capacities of Praseodymium (Continued)

For  $\alpha$ -praseodymium solid:

$$H_T - H_{298.15} = 5.50 T + 1.60 \times 10^{-3} T^2 - 1,782$$

(0.2 percent; 298 - 1071 K);

$$C_p = 5.50 + 3.20 \times 10^{-3} T;$$

$$\Delta H_{1071} \text{ (transition)} = 320.$$

For  $\beta$ -praseodymium solid:

$$H_T - H_{298.15} = 8.00 T - 2,300$$

(0.1 percent; 1071 - 1208 K);

$$C_p = 8.00;$$

$$\Delta H_{1208} \text{ (fusion)} = 2,800.$$

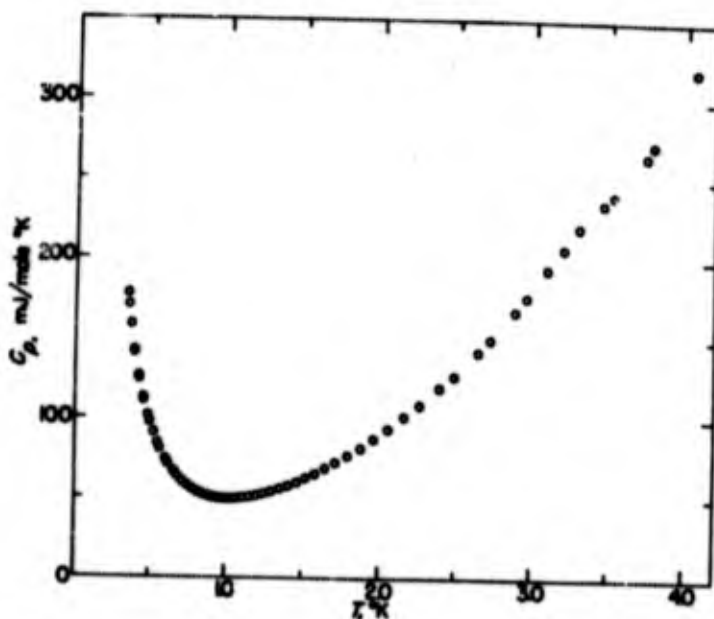
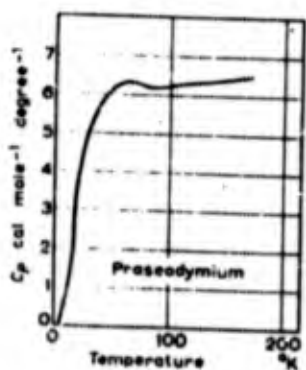
For Liquid praseodymium:

$$H_T - H_{298.15} = 8.00 T + 500$$

(0.1 percent; 1208 - 3000 K);

$$C_p = 8.00.$$

Specific Heat



Below 2 K the specific heat of praseodymium can be written with 1 per cent accuracy.

$$C_p = 4.53T^3 + 24.4T + 20.9T^{-2}.$$

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## PRASEODYMIUM COMPOUNDS

				<u>Authority</u>
Antimonides	<u>PrSb</u>			169, 270
Structure	Cubic			
Lattice Type	NaCl			
$a_0$ , A	6.366			
Effective Magnetic Moment, Bohr magnetons	3.63			
Arsenides	<u>PrAs</u>			169, 270
Structure	Cubic			
Lattice Type	NaCl			
$a_0$ , A	6.009			
Effective Magnetic Moment, Bohr magnetons	3.80			
Beryllides	<u>PrBe<sub>13</sub></u>			179
$a_0$ , A	10.367			
Bismuthides	<u>PrBi</u>			169, 270
Structure	Cubic			
Lattice Type	NaCl			
$a_0$ , A	6.461			
Effective Magnetic Moment, Bohr magnetons	3.52			
Borides	<u>PrB<sub>3</sub></u>	<u>PrB<sub>4</sub></u>	<u>PrB<sub>6</sub></u>	153, 155, 171
Molecular Weight	173.38	184.20	205.84	
Structure	Pseudo-cubic	Tetragonal	Cubic	
$a_0$ , A	3.81	7.20	4.130	
$c_0$ , A		4.11		

(Continued)

Borides (Continued)	<u>PrB<sub>3</sub></u>	<u>PrB<sub>4</sub></u>	<u>PrB<sub>6</sub></u>	
Density, g/cm <sup>3</sup>	5.20	5.74	4.851	
Resistivity, microhm-cm	--	--	20	
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	--	--	1.92	
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	--	7.55	
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	0.98	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	--	--	4800	
Effective Magnetic Moment, Bohr magnetons	--	--	3.37	
Work Function, ev	--	--	3.12	
Debye Temperature, K	--	--	737	
Color	--	Gray brown	Dark blue	
Metallic Radius, A	--	--	2.19	
Emissivity (λ = 0.655 μ)	--	--	0.67	
<b>Carbides</b>	<u>PrC<sub>2</sub></u>	<u>Pr<sub>2</sub>C<sub>3</sub></u>		153
Molecular Weight	164.94	317.84		
Structure	Body-centered tetragonal	Bcc		
Lattice Type	CaC <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>		
a <sub>0</sub> , A	3.85	8.7072		
c <sub>c</sub> , A	6.42			
Density, g/cm <sup>3</sup>	5.73	6.621		

(Continued)

Authority

## Carbides (Continued)

	<u>PrC<sub>2</sub></u>	<u>Pr<sub>2</sub>C<sub>3</sub></u>
Melting Point, C	2535	--
Resistivity, microhm-cm	25.7	--
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	11.4	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	4500	--
Effective Magnetic Moment, Bohr magnetons	(3.15)	--
Curie Temperature, K	5.2	--

## Germanides

	<u>PrGe<sub>2</sub></u>
Lattice Type	$\alpha$ -ThSi <sub>2</sub>
a <sub>0</sub> , A	4.26
c <sub>0</sub> , A	13.98
Volume of Unit Cell, A <sup>3</sup>	253.7

183

## Halides

	<u>PrBr<sub>3</sub></u>	<u>PrCl<sub>3</sub></u>	<u>PrF<sub>3</sub></u>	<u>PrI<sub>3</sub></u>	<u>PrOCl</u>	<u>PrOF</u>
Structure	--	Hexagonal	Hexagonal	Orthorhombic	Tetragonal	Rhombohedral
Lattice Type	--	UCl <sub>3</sub>	--	PuBr <sub>3</sub>	--	--
a <sub>0</sub> , A	--	7.422	7.061	13.9	4.051	7.016
b <sub>0</sub> , A	--	--	--	4.3	--	--
c <sub>0</sub> , A	--	4.275	7.218	10.0	6.810	--
B, deg	--	--	--	--	--	33.03
Density, g/cm <sup>3</sup>	--	--	6.18	--	--	6.39
Heat of Formation, kcal/mole	--	252.09	--	157	242.8	--

55,93,  
108,157,  
158,181,  
182,184,  
185,186,  
212,215,  
218,235,  
236,211,  
279

(Continued)

Halides (Continued)

	<u>PrBr<sub>3</sub></u>	<u>PrCl<sub>3</sub></u>	<u>PrF<sub>3</sub></u>	<u>PrI<sub>3</sub></u>	<u>PrOCl</u>	<u>PrOF</u>
Entropy of Formation, eu/mole	--	63	--	8	45	--
Melting Point, C	693	786	1395	738	--	--
Heat of Fusion, kcal/mole	11.3	12.1	8	12.7	--	--
Entropy of Fusion, eu/mole	11.7	11.4	5	12.6	--	--
Boiling Point, C	1550	1710	2327	1380	--	--
Heat of Vaporization, l/mole	45	52.3	62	41	--	--
Entropy of Vaporization, eu/mole	2	23	24	25	--	--
Vapor Pressure (T in K) log P <sub>mm Hg</sub>	$\left[ \begin{array}{c} 12.508 \\ -14916/T \end{array} \right]$	$\left[ \begin{array}{c} 12.1 \\ -15439 \\ T \end{array} \right]$	--	$\left[ \begin{array}{c} 12.703 \\ -14640 \\ T \end{array} \right]$	--	--
Heat Capacity, cal/(mole)(C)	31.5	32.3	--	31.3	--	--
Color	--	--	Green	--	--	--
$\Delta H_{mp}$ - $\Delta H_{298}$ , kcal/mole	18.0	21.5	--	19.5	--	--
Refractive Index	--	--	--	--	--	1.82

(Continued)

Authority

## Halides (Continued)

## Thermodynamic Data

212

Glasner has supplied in ANL-5750 the following equations for calculating thermodynamic quantities. The reactions concerned and the constants for use in these equations are tabulated.

$$\Delta C_p = \Delta a + (\Delta b \times 10^{-3})T + (\Delta c \times 10^{-6})T^2 + \frac{\Delta d \times 10^5}{T^2}$$

$$\Delta H - \Delta H_{298} = (\Delta a)T + \frac{1}{2} (\Delta b \times 10^{-3})T^2 + \frac{1}{3} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} + \Delta A$$

$$\Delta S = (2.303 \Delta a) \log T + (\Delta b \times 10^{-3})T + \frac{1}{2} (\Delta c \times 10^{-6})T^2 - \frac{1/2(\Delta d \times 10^5)}{T^2} - \Delta B$$

$$\Delta F - \Delta H_{298} = - (2.303 \Delta a) T \log T - \frac{1}{2} (\Delta b \times 10^{-3})T^2 - \frac{1}{6} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} - T\Delta(B - a) - \Delta A$$

Reaction	Temperature Range, K	$-\Delta H_{298}$ , kcal/mole	$-\Delta F_{298}$ , kcal/mole	$\Delta a$	$\Delta b$	$\Delta c$	$\Delta d$	$\Delta A$ , kcal/mole	$-\Delta B$ , ev	$-\Delta(B-a)$
$\text{Pr}(s) + \frac{3}{2} \text{F}_2(g) = \text{PrF}_3(s)$	298-1205	413	395	2.4	4.3	--	1.2	-0.485	73.4	75.8
$\text{Pr}(l) + \frac{3}{2} \text{F}_2(g) = \text{PrF}_3(s)$	1205-1643	--	--	-0.6	8.9	--	1.2	-2.709	59.8	59.2
$\text{Pr}(l) + \frac{3}{2} \text{F}_2(g) = \text{PrF}_3(l)$	1643-2500	--	--	11.1	-0.7	--	1.2	-0.975	125.8	176.9
$\text{Pr}(s) + \frac{3}{2} \text{Cl}_2(g) = \text{PrCl}_3(s)$	298-1049	253.02	235.4	3.7	3.4	--	1.0	-0.900	80.2	83.9
$\text{Pr}(s) + \frac{3}{2} \text{Cl}_2(g) = \text{PrCl}_3(l)$	1049-1205	--	--	13.9	-5.0	--	1.0	0.22	139.7	148.5
$\text{Pr}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{PrCl}_3(l)$	1205-1980	--	--	10.9	-0.4	--	1.0	-1.202	121.1	132.0
$\text{Pr}(l) + \frac{3}{2} \text{Cl}_2(g) = \text{PrCl}_3(s)$	1980-2500	--	--	-1.1	-0.4	--	1.0	68.56	6.8	5.7

## Hydrides

186, 187

	<u>PrH<sub>2</sub></u>	<u>PrH<sub>3</sub></u>
Structure	Fluorite	Fluorite
$a_0$ , Å	5.517	--
Density, g/cm <sup>3</sup>	5.65	5.56
Heat of Formation, kcal/mole H <sub>2</sub>	47.8	39.52

(Continued)

Authority

Nitrides

	<u>PrN</u>
Molecular Weight	154.93
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	5.16
Density, g/cm <sup>3</sup>	7.467
Resistivity, microhm-cm	110
Temperature Coefficient of Resistivity (80-500 K), 10 <sup>-3</sup> /C	1.9
Coefficient of Thermal Expansion (60-500 K), 10 <sup>-6</sup> /C	13.0
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	4460
Effective Magnetic Moment, Bohr magnetons	3.66
Curie Temperature, K	0.0

149, 153,  
169, 223

Oxides

	<u>PrO<sub>2</sub></u>	<u>Pr<sub>2</sub>O<sub>3</sub></u>	<u>Pr<sub>6</sub>O<sub>11</sub></u>
Structure	--	Cubic; Hexagonal	Cubic
$a_0$ , A	--	10.9	5.4695
Density, g/cm <sup>3</sup>	--	7.0	--
Heat of Formation, kcal/mole	--	218.4	217.9
Entropy of Formation, eu/mole	--	35.4	35.4

156, 172,  
177, 238

(Continued)

Authority

## Oxides (Continued)

	<u>PrO<sub>2</sub></u>	<u>Pr<sub>2</sub>O<sub>3</sub></u>	<u>Pr<sub>6</sub>O<sub>11</sub></u>
Melting Point, C	--	2200	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	1910	4410	2540
Effective Magnetic Moment, Bohr magnetons	--	3.6	--

## Thermodynamic Data

212

The equations given on page 152 may be used in calculating thermodynamic quantities for the following reactions:

Reaction	Temperature Range, K	-ΔH <sub>F298</sub> kcal/mole	-ΔF <sub>F298</sub> kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	-ΔB, eu	-Δ(B-a)
2Pr(s) + 3/2 O <sub>2</sub> (g) = Pr <sub>2</sub> O <sub>3</sub> (s)	298-1205	433.8	414.5	6.6	-5.6	--	-1.2	-2.246	101.5	108.1
2Pr(l) + 3/2 O <sub>2</sub> (g) = Pr <sub>2</sub> O <sub>3</sub> (s)	1205-2200	--	--	0.6	3.6	--	-1.2	-6.694	74.3	74.9
2Pr(l) + 3/2 O <sub>2</sub> (g) = Pr <sub>2</sub> O <sub>3</sub> (l)	2200-2500	--	--	7.6	-0.4	--	-2.8	-9.778	109.4	117.0
Pr(s) + O <sub>2</sub> (g) = PrO <sub>2</sub> (s)	298-700	230	216.5	4.3	-1.5	--	-0.9	-1.626	70.2	74.6

## Phosphides

169, 270

	<u>PrP</u>
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , Å	5.872
Effective Magnetic Moment, Bohr magnetons	3.77

## Selenides

	<u>PrSe</u>	<u>PrSe<sub>2</sub></u>	<u>Pr<sub>2</sub>Se<sub>3</sub></u>	<u>Pr<sub>3</sub>Se<sub>4</sub></u>	<u>Pr<sub>2</sub>O<sub>2</sub>Se</u>
Structure	Fcc	Tetrag- onal	Bcc	Bcc	Hcp
Lattice Type	--	--	Th <sub>3</sub> P <sub>4</sub>	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , Å	5.940	8.37	8.909	8.927	4.01
c <sub>0</sub> , Å	--	8.44	--	--	7.04

189, 191,  
192, 193,  
194, 225,  
226, 227

(Continued)



Selenides (Continued)

	<u>PrSe</u>	<u>PrSe<sub>2</sub></u>	<u>Pr<sub>2</sub>Se<sub>3</sub></u>	<u>Pr<sub>3</sub>Se<sub>4</sub></u>	<u>Pr<sub>2</sub>O<sub>2</sub>Se</u>
Density, g/cm <sup>3</sup>	6.80	6.68	--	6.89	6.65
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	0.9	--	--	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.022	--	--	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	4611	4631	4465	--	--
Magnetic Moment, Bohr magnetons	3.3	3.3	3.38	--	--
Color	--	Dark gray	Green	--	Beige

Silicides

153, 160

	<u>α-PrSi<sub>2</sub></u>	<u>β-PrSi<sub>2</sub></u>
Molecular Weight	197.0	197.0
Structure	Orthorhombic	Tetragonal
Lattice Type	α-YSi <sub>2</sub>	α-ThSi <sub>2</sub>
a <sub>0</sub> , Å	4.23	4.140
b <sub>0</sub> , Å	4.40	--
c <sub>0</sub> , Å	13.68	13.65
Density, g/cm <sup>3</sup>	5.38	5.64
Resistivity, microhm-cm	--	202
Curie Temperature, K	10.5	--
Transformation Temperature, K	α → β at 153	

## PRASEODYMIUM COMPOUNDS

Sulfides						Authority
	PrS	PrS <sub>2</sub>	γPr <sub>2</sub> S <sub>3</sub>	Pr <sub>3</sub> S <sub>4</sub>	Pr <sub>2</sub> O <sub>2</sub> S	153, 198, 230, 239
Molecular Weight	172.99	205.04	378.05	551.02	345.91	
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal	
a <sub>0</sub> , Å	5.747	8.08	8.611	8.611	3.974	
c <sub>0</sub> , Å	--	--	--	--	6.825	
Density, g/cm <sup>3</sup>	6.07	4.90	5.27	5.77	6.16	
Melting Point, C	2230	1780	1795	2100	--	
Heat Capacity, cal/(mole) (C)	12.37	--	30.4	--	--	
Resistivity, microhm-cm	240	--	1.1 x 10 <sup>12</sup>	--	--	
Temperature Coefficient of Resistivity (20-1000C), 10 <sup>-3</sup> /C	0.54	--	--	--	--	
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	14.3	--	12.09	--	--	
Thermal Conductivity, 10 <sup>-2</sup> cal(cm) (sec)(C)	3.3	--	0.716	--	--	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	4730	4800	4640	--	--	

(Continued)

Properties

Authority

Sulfides (Continued)

	<u>PrS</u>	<u>PrS<sub>2</sub></u>	<u>γPr<sub>2</sub>S<sub>3</sub></u>	<u>Pr<sub>3</sub>S<sub>4</sub></u>	<u>Pr<sub>2</sub>O<sub>2</sub>S</u>
Work Function, ev	3.90	--	3.84	--	--
Debye Temperature, K	638	--	855	--	--
Emissivity (λ = 0.655 μ)	0.73	--	--	--	--
Color	Gold	--	--	--	--

Tellurides

	<u>PrTe</u>	<u>PrTe<sub>2</sub></u>	<u>Pr<sub>2</sub>Te<sub>3</sub></u>	<u>Pr<sub>2</sub>O<sub>2</sub>Te</u>	169, 202, 205, 240, 242
Structure	Fcc	Tetragonal	--	Hexagonal	
Lattice Type	NaCl	Fe <sub>2</sub> As	--	--	
a <sub>0</sub> , Å	6.322	4.46	9.482	4.06	
c <sub>0</sub> , Å	--	9.05	--	12.83	
Density, g/cm <sup>3</sup>	--	--	6.6	--	
Thermal Conductivity, cal/(cm)(sec)(C)	0.019	--	--	--	
Color	--	--	--	Light green	

Miscellaneous

150, 206

	<u>Structure</u>	<u>Lattice Type</u>	<u>a<sub>0</sub>, Å</u>	<u>c<sub>0</sub>, Å</u>	<u>Melting Point, C</u>	<u>Curie Temperature, K</u>	<u>Superconducting Transition Temperature, K</u>
PrIr <sub>2</sub>	--	--	7.921	--	--	18.5	--
PrMg <sub>12</sub>	Body-centered tetragonal	ThMn <sub>12</sub>	10.34	5.98	--	--	--
PrOs <sub>2</sub>	--	--	7.663	--	--	>35	--
PrPt <sub>2</sub>	--	--	7.709	--	--	7.9	--
PrRh <sub>2</sub>	--	--	7.575	--	--	5.6	--
PrRu <sub>2</sub>	--	--	7.6223	--	1681	40	21

**NEODYMIUM**

Symbol Nd

Atomic Number 60

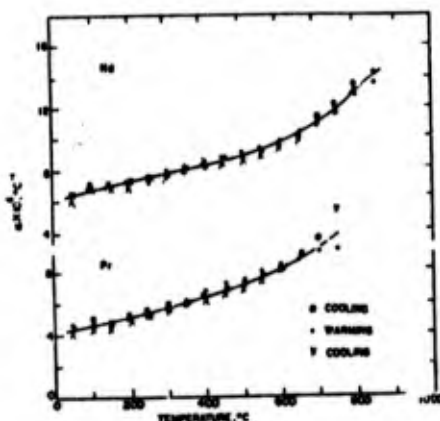
Atomic Weight 144.27

**PHYSICAL PROPERTIES**

Authority

Abundance	12-24 ppm (approx. 24)	51
Density	7.016 g/cm <sup>3</sup>	67
Melting Point	1024 C	66
Heat of Fusion	1.705 kcal/mole	66
Boiling Point	3027 C	57
Heat of Vaporization (25 C)	69 kcal/mole	57
Vapor Pressure (1528-1923 K)	$\text{Log } P_{\text{mm Hg}} = 8.102 - \frac{16320}{T}$	60
Specific Heat (25 C)	6.57 cal/mole C	53
Heat of Combustion	216.08 kcal/g-atom	134
Coefficient of Linear Thermal Expansion	$6.7 \times 10^{-6}/\text{C} (-173 - 850 \text{ C})$	61

90



(Permission of American Physical Society)

		<u>Authority</u>
Thermal Conductivity (28 C)	0.031 cal/(cm <sup>2</sup> )(seg)(C/cm)	54
Heat of Sublimation		
Cohesive Energy	77 kcal/mole	89
Work Function	3.3 ev	75
Debye Temperature	157 K	97
Expansion on Melting		
Surface Tension as a Function of Temperature		101

<u>T, C</u>	<u><math>\sigma</math>, dyne/cm</u>
1030	688
1054	685
1072	684
1094	681
1110	682
1154	680
1167	681
1186	674

## CRYSTAL PROPERTIES

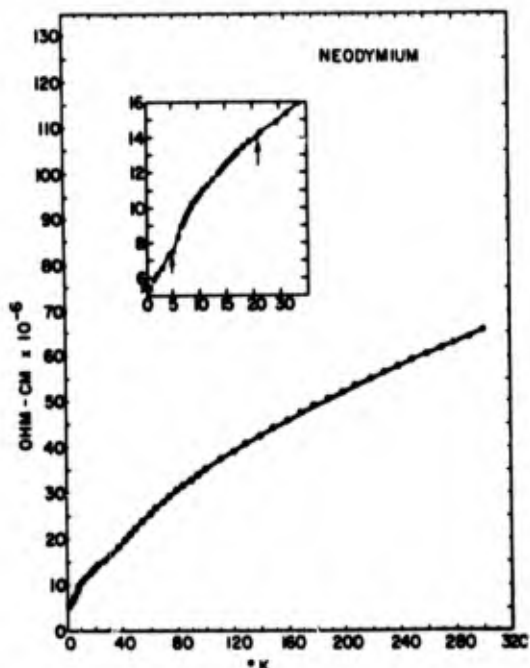
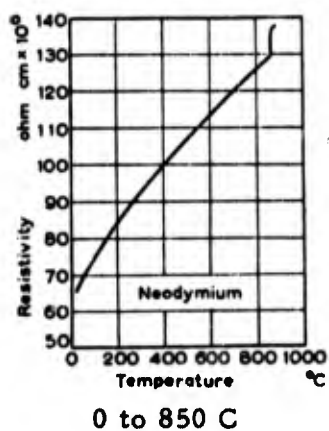
Structure	<u>HCP</u>	<u>BCC</u>	61
Lattice Constants	$a_0 = 3.6579$ $c_0 = 11.7992$	$a_0 = 4.13 \text{ \AA}$ $\text{A}$	61
Density	7.016	6.80 g/cm <sup>3</sup>	67
Metallic Radius	1.821	1.84 \AA	67
Atomic Volume	20.60	21.2 cm <sup>3</sup> /mole	66
Transition Temperature	868 C		66
Heat of Transition	0.713 kcal/mole		61
Ionic Radius (Trivalent Ion)	0.995 \AA		55
Closest Approach of Atoms	3.62 \AA		56

		<u>Authority</u>								
Allotropic Modification	(1) a Fcc structure with $a_0 = 4.80 \text{ \AA}$ occurs at 20 C when metal is subjected to a static pressure of 50 kilobars	84								
<b>CHEMICAL PROPERTIES</b>										
Stable Oxidation State	+3	81								
Electrode Potential	$[\text{Nd} = \text{Nd}^{3+} + 3\text{e}^-] + 2.24 \text{ volts}$ (standard hydrogen electrode)	81								
Ionization Potential	1st = 6.3 volts	82								
Metallographic Polishing and Etching	Neodymium samples may be sectioned in air. Although the metal is considerably more stable than lanthanum with respect to atmospheric corrosion, it must be polished in a similar manner. The unetched surface after polishing need not be examined through a mineral bath.	62								
Corrosion Rates (In Air)	14 mil/year at 200 C 78 mil/year at 400 C 983 mil/year at 600 C  Oxidation rate increases rapidly with increasing relative humidity.	68								
Corrosion Data										
	Corrosive attack on crucible materials:	91								
	<table border="0" style="margin-left: 40px;"> <thead> <tr> <th style="text-align: left;"><u>Material</u></th> <th style="text-align: left;"><u>Onset of Attack</u></th> </tr> </thead> <tbody> <tr> <td>CaO</td> <td>Mild &gt; 900 C</td> </tr> <tr> <td>MgO</td> <td>None &lt; 1200 C</td> </tr> <tr> <td>Ta</td> <td>None &lt; 1100 C</td> </tr> </tbody> </table>	<u>Material</u>	<u>Onset of Attack</u>	CaO	Mild > 900 C	MgO	None < 1200 C	Ta	None < 1100 C	
<u>Material</u>	<u>Onset of Attack</u>									
CaO	Mild > 900 C									
MgO	None < 1200 C									
Ta	None < 1100 C									
<b>ELECTRICAL PROPERTIES</b>										
	<u>(<math>\alpha</math>) HCP (25 C)</u>	<u>(<math>\beta</math>) BCC (890 C)</u>								
Resistivity	64.3	137 microhm-cm	61							
Temperature Coefficient of Resistivity	$1.64 \times 10^{-3}/\text{C}$		61							

Authority

53,86

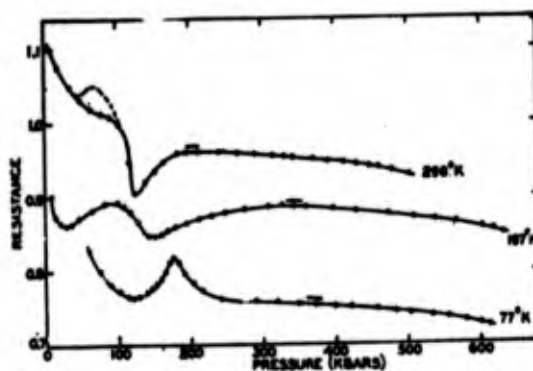
Resistivity Versus Temperature



(Permission of the American Physical Society)

Resistance Versus Pressure  
(Permission of the American Physical Society)

96



**Properties**

**MAGNETIC PROPERTIES**

		<u>Authority</u>
Susceptibility (25 C)	5,650 x 10 <sup>-6</sup> cmu/mole	61
Effective Magnetic Moment	Theoretical 3.68 Bohr magnetons	61
	Measured 3.3 Bohr magnetons	
Curie Temperature		
Néel Temperature	7.7 K	61

**MECHANICAL PROPERTIES**

Young's Modulus	3.79 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Shear Modulus	1.45 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Poisson's Ratio	0.306	61
Compressibility	3.02 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	57
Hardness (DPH)	35	57
	<u>70 F</u>	<u>800 F</u>
Tensile Strength	24.7                      6.0 10 <sup>3</sup> psi	88
Yield Strength	23.9                      5.7 10 <sup>3</sup> psi	88
Elongation	11                              13 per cent	88
Ultimate Compressive Strength	35.5 10 <sup>3</sup> psi	61
Impact Strength (Izod)	8.3 ft-lb	71
Workability	Good	88
General Fabrication	(See references)	70, 113



## NUCLEAR PROPERTIES

Authority

## Isotopes

58, 98

<u>Whole- Number Mass</u>	<u>Relative Abundance, per cent</u>	<u>Half Life</u>	<u>Decay Mode</u>
141	--	2.5 hr	$\beta^+$
142	27.13	Stable	--
143	12.20	Stable	--
144	23.87	Stable	--
145	8.30	Stable	--
146	17.18	Stable	--
147	--	11 hr	X, $\beta^-$ , $e^-$ , $\gamma$
148	5.72	Stable	--
149	--	1.7 days	$\beta^-$ , $\gamma$ or X
150	5.60	Stable	--
151	--	Short	$\beta^-$
Thermal Neutron Cross Section	46 $\pm$ 2 barns/atom or 0.19 cm <sup>2</sup> /cm		73

## SAFETY

83

## Neodymium

Toxicity - Unknown.

## Neodymium Bromate

Toxicity - Unknown.

Disaster control - Moderately dangerous because it emits highly toxic bromine fumes when heated; it reacts vigorously with reducing materials.

## Neodymium Bromide

Toxicity - Unknown.

Disaster control - Slightly dangerous because it emits highly toxic bromine fumes when heated.

## Neodymium Compounds

Toxicities - Unknown.

Fire hazard and disaster control depend on the nature of the anion present.

Properties

THERMODYNAMIC PROPERTIES

Authority

	<u>Room Temperature</u>	<u>Melting Point</u>	
Entropy	$S_{298} = 17.5$	$S_{1297} = 37.21 \text{ eu}$	95
Heat Capacity	$C_{p298} = 6.57$	$C_{p1297} = 10.65 \text{ cal/(mole)(C)}$	

Thermodynamic Functions of Neodymium 95

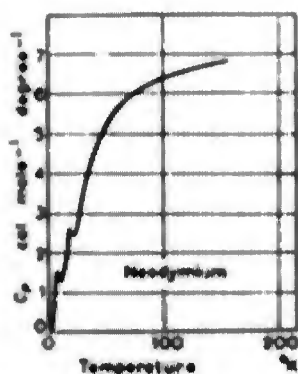
T, K	$C_p$	$S^0 - S_0^0$ cal/(K)(mole)	$\frac{H^0 - H_{298.15}^0}{T}$ <sup>(4)</sup> cal/(K)(mole)	$\frac{F^0 - H_{298.15}^0}{T}$ cal/(K)(mole)
298.15	6.57	17.50	0.0	17.50
300	6.58	17.54	0.041	17.50
350	6.72	18.56	0.964	17.58
400	6.87	19.47	1.710	17.76
450	7.06	20.29	2.394	16.00
500	7.24	21.04	2.770	18.26
550	7.44	21.74	3.193	18.55
600	7.67	22.40	3.654	18.84
650	7.90	23.02	3.882	19.14
700	8.16	23.62	4.178	19.44
750	8.43	24.16	4.422	19.74
800	8.72	24.74	4.710	20.03
850	9.02	25.28	4.954	20.33
900	9.34	25.81	5.185	20.62
950	9.68	26.32	5.416	20.90
1000	10.03	26.82	5.638	21.18
1050	10.40	27.32	5.856	21.46
1100	10.78	27.81	6.071	21.74
1135.15	11.06	28.16	6.221	21.94
1135.15	10.65	28.79	6.854	21.94
1150	10.65	28.93	6.905	22.02
1200	10.65	29.38	7.061	22.32
1250	10.65	29.82	7.205	22.61
1297.15	10.65	30.21	7.330	22.88
1297.15	11.66	31.52	8.644	22.88
1300	11.66	31.55	8.651	22.90
1350	11.66	31.99	8.763	23.23
1373.15	11.66	32.18	8.817	23.37

(4)  $(H_{298.15}^0 - H_3^0)/T = 6.01 \text{ cal. degree}^{-1} \text{ mole}^{-1}$

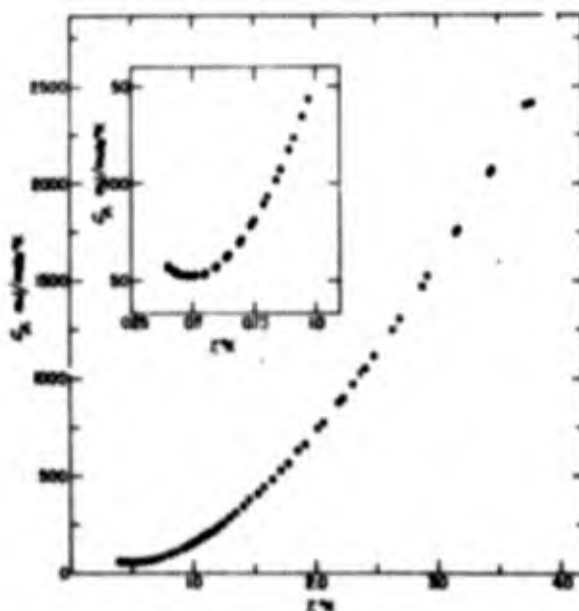
Authority

53, 97

## Specific Heat



0 to 150 K



○ - 1st experiment; ● - 2nd experiment. The inset shows results below 1 K on a larger scale. Only about 50 per cent of the points below 1 K have been plotted on the main graph.

Between 0.4 and 1 K the specific heat may be written with 1 per cent accuracy.

$$C_p = 125.7T^3 + 22.6T + 6.4T^{-2}. \quad (\text{Permission of Gordon and Breach Science Publishers, Inc.})$$

## NEODYMIUM COMPOUNDS

		<u>Authority</u>
<b>Antimonides</b>		169, 229
	<u>NdSb</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , Å	6.322	
Resistivity, microhm-cm	76	
<b>Arsenides</b>		169, 229
	<u>NdAs</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , Å	5.970	
Resistivity, microhm-cm	150	
<b>Beryllides</b>		179
	<u>NdBe<sub>13</sub></u>	
$a_0$ , Å	10.356	
<b>Bismuthides</b>		169
	<u>NdBi</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , Å	6.424	

	<u>Authority</u>	
Borides		153, 171
	<u>NdB<sub>4</sub></u>	<u>NdB<sub>6</sub></u>
Molecular Weight	187.55	209.19
Structure	Tetragonal	Cubic
a <sub>0</sub> , A	7.219	4.125
c <sub>0</sub> , A	4.1020	--
Density, g/cm <sup>3</sup>	5.83	4.948
Melting Point, C	--	2540
Heat Capacity, cal/(mole)(C)	--	23.69
Resistivity, microhm-cm	--	28.0
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	--	1.93
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	7.26
Thermal Conductivity, cal/(cm)(sec)(C)	--	0.113
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	--	2420
Effective Magnetic Moment, Bohr magnetons	--	3.82
Work Function, ev	--	3.97
Microhardness, kg/mm <sup>2</sup>	--	2530
Color	--	Dark blue
Emissivity, (λ = 0.655 μ)	--	0.64
Effective Metallic Radius, A	--	2.18

## Properties

			<u>Authority</u>
Carbides			153
	<u>NdC<sub>2</sub></u>	<u>Nd<sub>2</sub>C<sub>3</sub></u>	
Molecular Weight	168.29	324.54	
Structure	Body- centered tetragonal	Bcc	
Lattice Type	CaC <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>	
a <sub>0</sub> , A	3.82	8.5478	
c <sub>0</sub> , A	6.37	--	
Density, g/cm <sup>3</sup>	6.00	6.902	
Melting Point, (C)	>2000	--	
Effective Magnetic Moment, Bohr magnetons	3.53	--	
Curie Temperature, K	40	--	
Germanides			170, 183
	<u>NdGe<sub>2</sub></u>		
Lattice Type	α-ThSi <sub>2</sub>		
a <sub>0</sub> , A	4.230		
c <sub>0</sub> , A	13.920		
Volume of Unit Cell, A <sup>3</sup>	249.9		

Halides	<u>Authority</u>					
	93, 108, 157, 158, 181, 182, 184, 185, 186, 212, 215, 217, 235, 236, 211, 279					
	<u>NdBr<sub>3</sub></u>	<u>NdCl<sub>3</sub></u>	<u>NdF<sub>3</sub></u>	<u>NdI<sub>3</sub></u>	<u>NdOCl</u>	<u>NdOF</u>
Molecular Weight	--	--	201.27	--	--	--
Structure	--	Hexagonal	Hexagonal	Orthorhombic	Tetragonal	Rhombohedral
Lattice Type	PuBr <sub>3</sub>	UCl <sub>3</sub>	--	PuBr <sub>3</sub>	--	--
a <sub>0</sub> , Å	--	--	7.030	13.988	4.018	6.953
b <sub>c</sub> , Å	--	--	--	4.316	--	--
c <sub>0</sub> , Å	--	--	7.200	9.977	6.782	--
β, deg	--	--	--	--	--	33.04
Density, g/cm <sup>3</sup>	--	--	6.37	--	--	6.65
Heat of Formation, kcal/mole	--	245.71	--	152	237.1	--
Entropy of Formation, eu/mole	--	(63)	--	(8)	(45)	--
Melting Point, C	684	759	1374	787	--	--
Heat of Fusion, kcal/mole	10.8	12.0	(8)	9.7	--	--
Entropy of Fusion, eu/mole	11.3	11.6	(5)	9.2	--	--
Boiling Point, C	1540	1690	2327	1370	--	--
Heat of Vaporization, kcal/mole	46.8	51.8	62	41	--	--
Entropy of Vaporization, eu/mole	25	24	24	25	--	--
Vapor Pressure, log P <sub>mm Hg</sub>	$\left[ \begin{array}{c} 12.555 \\ -14829/T \end{array} \right]$	$\left[ \begin{array}{c} 12.014 \\ -15145/T \end{array} \right]$	--	$\left[ \begin{array}{c} 12.475 \\ -14495/T \end{array} \right]$	--	--
Heat of Sublimation, kcal/mole	67	68.8	--	--	--	--
Entropy of Sublimation, eu/mole	44	41.3	--	--	--	--

(Continued)

Authority

Halides (Continued)

	<u>NdBr<sub>3</sub></u>	<u>NdCl<sub>3</sub></u>	<u>NdF<sub>3</sub></u>	<u>NdI<sub>3</sub></u>	<u>NdOCl</u>	<u>NdOF</u>
Heat Capacity, cal/(mole)(C)	31.0	35.4	--	27.6	--	--
$\Delta H_{mp} - \Delta H_{298}$ , kcal/mole	17.6	20.3	--	24.3	--	--
Color	--	--	Violet	--	--	--
Refractive Index	--	--	--	--	--	1.82

Thermodynamic Data

Glaser has supplied in ANL-5750 the following equations for calculating thermodynamic quantities. The reactions concerned and the constants for use in these equations are tabulated.

$$\Delta C_p = \Delta a + (\Delta b \times 10^{-3})T + (\Delta c \times 10^{-6})T^2 + \frac{\Delta d \times 10^5}{T^2}$$

$$\Delta H - \Delta H_{P298} = (\Delta a)T + \frac{1}{2} (\Delta b \times 10^{-3})T^2 + \frac{1}{3} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} + \Delta A$$

$$\Delta S = (2.303 \Delta a) \log T + (\Delta b \times 10^{-3})T + \frac{1}{2} (\Delta c \times 10^{-6})T^2 - \frac{1/2(\Delta d \times 10^5)}{T^2} - \Delta B$$

$$\Delta F - \Delta H_{P298} = - (2.303 \Delta a) T \log T - \frac{1}{2} (\Delta b \times 10^{-3})T^2 - \frac{1}{6} (\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} - T\Delta(B - a) - \Delta A$$

Reaction	Temperature Range, K	$-\Delta H_{F298}$ , kcal/mole	$-\Delta F_{298}$ , kcal/mole	$\Delta a$	$\Delta b$	$\Delta c$	$\Delta d$	$\Delta A$ , kcal/mole	$-\Delta B$ , eu	$-\Delta(B-a)$
$Nd(s) + 3/2 F_2(g) = NdF_3(s)$	298 - 1297	410	392	2.6	2.4	--	1.2	-0.465	74.3	76.9
$Nd(l) + 3/2 F_2(g) = NdF_3(s)$	1297 - 1683	--	--	-0.9	7.7	--	1.2	-2.981	58.2	57.3
$Nd(l) + 3/2 F_2(g) = NdF_3(l)$	1683 - 2500	--	--	9.5	-0.7	--	1.2	-0.588	116.6	126.1
$Nd(s) + 3/2 Cl_2(g) = NdCl_3(s)$	298 1033	245.62	227.9	4.1	1.7	--	1.0	-0.949	82.2	86.2
$Nd(s) + 3/2 Cl_2(g) = NdCl_3(l)$	1033 1297	--	--	12.2	-5.7	--	1.0	2.528	123.7	135.9
$Nd(l) + 3/2 Cl_2(g) = NdCl_3(l)$	1297 1960	--	--	8.8	-0.4	--	1.0	0.012	107.6	116.4
$Nd(l) + 3/2 Cl_2(g) = NdCl_3(g)$	1960 2500	--	--	-2.2	-0.4	--	1.0	67.57	0.8	-1.4



			<u>Authority</u>
Hydrides			91, 165, 186, 187
	<u>NdH<sub>2</sub></u>	<u>NdH<sub>3</sub></u>	
Structure	Fluorite	Fluorite	
a <sub>0</sub> , Å	5.464	--	
Density, g/cm <sup>3</sup>	5.94	--	
Heat of Formation, kcal/mole H <sub>2</sub>	44.8	--	
Entropy of Formation, eu/mole H <sub>2</sub>	43	--	
Color	--	Indigo blue	
Dissociation Rate (log P)	[ 9.370 -9796/T ]	--	
Nitrides			149, 153, 223
	<u>NdN</u>		
Molecular Weight	158.28		
Structure	Cubic		
Lattice Type	NaCl		
a <sub>0</sub> , Å	5.151		
Density, g/cm <sup>3</sup>	7.691		
Resistivity, microhm-cm	75		
Temperature Coefficient of Resistivity (80-500 K), 10 <sup>-3</sup> /C	0.70		
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	5850		
Effective Magnetic Moment, Bohr magnetons	3.71		

(Continued)

Authority

Nitrides (Continued)

	<u>NdN</u>
Color	Black
Curie Temperature, K	19

Oxides

156, 172,  
173, 176,  
177

	<u>Nd<sub>2</sub>O<sub>3</sub></u>
Molecular Weight	336.48
Structure	Hexagonal
a <sub>0</sub> , Å	3.831
c <sub>0</sub> , Å	5.999
Density, g/cm <sup>3</sup>	7.24
Heat of Formation, kcal/mole of metal	216.08
Entropy of Formation, eu/mole of metal	(35.3)
Melting Point, C	2270
Effective Magnetic Moment, Bohr magneton	3.7

Thermodynamic Data

212

The equations given on page 171 may be used in calculating thermodynamic quantities for the following reactions:

Reaction	Temperature Range, K	-ΔH <sub>f</sub> <sup>298</sup> , kcal/mole	-ΔF <sub>f</sub> <sup>298</sup> , kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	-ΔB, eu	-Δ(B-a)
2Nd(s) + 3/2O <sub>2</sub> (g) = Nd <sub>2</sub> O <sub>3</sub> (s)	298 - 1297	428.6	409.5	4.12	-0.51	--	-1.3	-1.964	95.6	101.0
2Nd(l) + 3/2O <sub>2</sub> (g) = Nd <sub>2</sub> O <sub>3</sub> (s)	1297 - 2500	--	--	1.9	2.7	--	-1.3	-6.997	63.4	61.8

Authority

## Thermodynamic Functions for Neodymium Oxide

174

<u>T, K</u>	<u>C<sub>p</sub>, cal/(mole)(K)</u>	<u>S<sub>T</sub>-S<sub>16</sub>, cal/(mole)(K)</u>	<u>H<sub>T</sub>-H<sub>16</sub>, cal/mole</u>	<u>-(H<sub>T</sub>-H<sub>16</sub>)/T, cal/(mole)(K)</u>
16	1.938			
20	2.394	0.4863	8.748	0.04890
30	3.619	1.6785	38.563	0.3931
40	5.105	2.9186	82.024	0.8680
50	6.680	4.2271	140.95	1.4081
60	8.202	5.5805	215.42	1.9902
70	9.666	6.9556	304.82	2.6010
80	11.07	8.3382	408.51	3.2318
90	12.44	9.7216	526.09	3.8762
100	13.74	11.100	657.06	4.5294
120	16.10	13.819	955.99	5.8524
140	18.14	16.458	1298.9	7.1801
160	19.88	18.997	1679.6	8.4995
180	21.37	21.426	2092.4	9.8016
200	22.65	23.746	2533.0	11.081
220	23.72	25.957	2997.0	12.334
240	24.58	28.058	3480.3	13.557
260	25.32	30.056	3979.4	14.751
280	26.01	31.958	4492.8	15.912
298.16	26.50	33.607	4970.9	16.935
300	26.65	33.774	5019.4	17.043

186

<u>T, K</u>	<u>C<sub>p</sub>, cal/(K)(1/2 mole)</u>
298.15	13.0
400	14.3
500	15.1
600	15.6
700	16.1
800	16.5
900	16.8
1000	17.2
1100	17.5
1200	17.8

Authority

Heat Content and Entropy Increments (Hexagonal) (Smooth Values)  
Neodymium Oxide

175

<u>T, K</u>	<u>HT-H<sub>298, 15.</sub> cal/mole</u>	<u>S<sub>T</sub>-S<sub>298, 15.</sub> cal/(mole)(K)</u>
400	2,840	8.18
500	5,770	14.71
600	8,820	20.27
700	11,980	25.14
800	15,240	29.49
900	18,580	33.42
1000	22,000	37.03
1100	25,500	40.36
1200	29,070	43.47
1300	32,700	46.37
1395	36,210( $\alpha$ )	48.98( $\alpha$ )
1395	36,350( $\beta$ )	49.08( $\beta$ )
1400	36,540	49.22
1500	40,260	51.78
1600	43,980	54.18
1700	47,700	56.44
1800	51,420	58.56
1900	55,140	60.57
2000	58,860	62.48

Phosphides

169

	<u>NdP</u>
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , A	5.838

Selenides

189, 191,  
192, 193,  
194, 225,  
226, 227,  
232

	<u>NdSe</u>	<u>NdSe<sub>2</sub></u>	<u>Nd<sub>2</sub>Se<sub>3</sub></u>	<u>Nd<sub>3</sub>Se<sub>4</sub></u>	<u>Nd<sub>2</sub>O<sub>2</sub>Se</u>
Structure	Fcc	Tetragonal	Bcc	Bcc	Hcp
Lattice Type	NaCl	--	Th <sub>3</sub> P <sub>4</sub>	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , A	5.879	8.33	8.841	8.859	3.97
c <sub>0</sub> , A	--	8.41	--	--	6.97

(Continued)

Authority

## Selenides (Continued)

	<u>NdSe</u>	<u>NdSe<sub>2</sub></u>	<u>Nd<sub>2</sub>Se<sub>3</sub></u>	<u>Nd<sub>3</sub>Se<sub>4</sub></u>	<u>Nd<sub>2</sub>O<sub>2</sub>Se</u>
Density, g/cm <sup>3</sup>	6.93	6.83	6.69	7.15	6.99
Resistivity, microhm-cm	50	--	--	--	--
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	0.8	--	--	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.013	--	--	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	4780	4763	4685	--	--
Effective Magnetic Moment, Bohr magneton	3.4	3.4	3.58	--	--
Color	--	--	Violet	--	Bluish white

## Silicides

	<u><math>\alpha</math>-NdSi<sub>2</sub></u>	<u><math>\beta</math>-NdSi<sub>2</sub></u>
Molecular Weight	200.45	200.45
Structure	Ortho- rhombic	Tetrag- onal
Lattice Type	$\alpha$ -YSi <sub>2</sub>	$\alpha$ -ThSi <sub>2</sub>
a <sub>0</sub> , A	4.18	4.103
b <sub>0</sub> , A	4.15	--
c <sub>0</sub> , A	13.56	13.53
Density, g/cm <sup>3</sup>	5.62	5.84
Melting Point, C	--	1525

152, 153,  
160

(Continued)

	<u>Authority</u>				
<b>Silicides (Continued)</b>					
	<u><math>\alpha</math>-NdSi<sub>2</sub></u>	<u><math>\beta</math>-NdSi<sub>2</sub></u>			
Resistivity, microhm-cm	349	--			
Transition Temperature, C	$\alpha \rightarrow \beta$ at 20 to 150				
Transverse Rupture Strength, 10 <sup>3</sup> psi	8.5	--			
<b>Sulfides</b>					
	153, 186, 193, 198, 200, 230, 241				
	<u>NdS</u>	<u>NdS<sub>2</sub></u>	<u><math>\gamma</math>Nd<sub>2</sub>S<sub>3</sub></u>	<u>Nd<sub>3</sub>S<sub>4</sub></u>	<u>Nd<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	176.34	208.39	384.74	561.07	352.61
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal
a <sub>0</sub> , A	5.690	8.04	8.527	8.524	3.946
c <sub>0</sub> , A	--	--	--	--	6.790
Density, g/cm <sup>3</sup>	6.36	5.34	5.50	6.02	6.47
Heat of Formation, kcal/mole	--	--	138	--	--
Entropy of Formation, eu/mole	--	--	13	--	--
Melting Point, C	2200	1760	2200	2040	1990
Heat Capacity, cal/(mole)(C)	12.87	--	31.41	--	--
Resistivity, microhm-cm	242	--	7 x 10 <sup>13</sup>	1.2 x 10 <sup>6</sup>	--
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	1.4	--	--	--	--

(Continued)

## NEODYMIUM COMPOUNDS

## Sulfides (Continued)

	<u>Authority</u>				
	<u>NdS</u>	<u>NdS<sub>2</sub></u>	<u>γNd<sub>2</sub>S<sub>3</sub></u>	<u>Nd<sub>3</sub>S<sub>4</sub></u>	<u>Nd<sub>2</sub>O<sub>2</sub>S</u>
Coefficient of Thermal Expansion (20-1000 C), 10 <sup>-6</sup> /C	15.35	--	12.90	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.046	--	0.0092	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	4370	5082	4924	4849	--
Work Function, ev	3.39	--	3.93	--	--
Debye Temperature, K	633	--	840	--	--
Color	Gold	--	Yellow brown	Black	Blue
Emissivity, (λ = 0.655 μ)	0.80	--	--	--	--

## Tellurides

	<u>NdTe</u>	<u>NdTe<sub>2</sub></u>	<u>Nd<sub>2</sub>Te<sub>3</sub></u>	<u>Nd<sub>3</sub>Te<sub>4</sub></u>	<u>Nd<sub>2</sub>O<sub>2</sub>Te</u>
Structure	Fcc	Tetragonal	Orthorhombic	Bcc	Hexagonal
Lattice Type	NaCl	Fe <sub>2</sub> As	--	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , Å	6.249	4.41	12.12	9.438	4.03
b <sub>0</sub> , Å	--	--	11.93	--	--
c <sub>0</sub> , Å	--	9.04	4.37	--	12.77
Density, g/cm <sup>3</sup>	--	--	6.65	6.8	7.18

(Continued)

Authority

Tellurides (Continued)

	<u>NdTe</u>	<u>NdTe<sub>2</sub></u>	<u>Nd<sub>2</sub>Te<sub>3</sub></u>	<u>Nd<sub>3</sub>Te<sub>4</sub></u>	<u>Nd<sub>2</sub>O<sub>2</sub>Te</u>
Melting Point, C	--	--	1650	1685	--
Resistivity, microhm-cm	40	--	1.7 x 10 <sup>3</sup>	350	--
Color	--	--	--	--	Green

Miscellaneous

150

	<u>Structure</u>	<u>a<sub>0</sub>, A</u>	<u>c<sub>0</sub>, A</u>	<u>Curie Temperature, K</u>
NdIr <sub>2</sub>	Cubic	7.605	--	11.8
NdOs <sub>2</sub>	Hexagonal	5.368	8.945	27.5
NdPt <sub>2</sub>	Cubic	7.694	--	6.7
NdRh <sub>2</sub>	Cubic	7.564	--	8.1
NdRu <sub>2</sub>	Cubic	7.614	--	35



**PROMETHIUM**

Symbol Pm

Atomic Number 61

Atomic Weight 145

Promethium has no stable isotopes in nature; the few data found are presented below.

		<u>Authority</u>
<b>PHYSICAL PROPERTIES</b>		
Abundance	0.0	51
Melting Point	1080 C	102
Heat of Fusion	(3.0) kcal/mole	77
Boiling Point	(2727 C)	57
Heat of Vaporization (25 C)	(60) kcal/mole	57
Specific Heat (25 C)	(6.50) cal/(mole)(C)	76
Debye Temperature	162 K	97
<b>ALL OTHER PROPERTIES</b>		
Metallic Radius	(1.810) A	67
Stable Oxidation State	+3	67
Ionic Radius (Trivalent Ion)	0.979 A	55
Compressibility	$3.06 \times 10^{-6} \text{ cm}^2/\text{kg}$	89
Crystal Structure	Fcc	91
Preparation of Metallic Pm	(See reference)	102

Authority

Isotopes

58

<u>Whole Number Mass</u>	<u>Relative Abundance per cent</u>	<u>Half Life</u>	<u>Decay Mode</u>
144	0.0	200 days	K, $\gamma$
147	0.0	3.7 yr	$\beta^-$
148	0.0	5.3 days	$\beta^-$ , $\gamma$
149	0.0	47 hr	$\beta^-$ , $\gamma$
151	0.0	12 min	$\beta^-$
153	0.0	<5 min	$\beta^-$
156	0.0	<5 min	$\beta^-$

Room TemperatureMelting Point

76, 77

Entropy

$S_{298} = (17.2)$

$S_{1300} = (28.17) \text{ eu}$

Heat  
Capacity

$C_{p298} = (6.50)$

$C_{p1300} = (8.98) \text{ cal/(mole)(C)}$

## Heat Content and Entropy of Solid and Liquid Promethium

(Base: crystals at 298.15 K)

<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K) (mole)</u>	<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K) (mole)</u>
400	670	1.94	1300(l)	10,760	13.28
500	1,360	3.48	1400	11,560	13.87
600	2,070	4.77	1600	13,160	14.94
700	2,810	5.91	1800	14,760	15.88
800	3,570	6.93	2000	16,360	16.73
900	4,360	7.86	2200	17,960	17.49
1000	5,170	8.71	2400	19,560	18.19
1100	6,010	9.51	2600	21,160	18.83
1200	6,870	10.28	2800	22,760	19.42
1300(s)	7,760	10.97	3000	24,360	19.99

For solid promethium:

$H_T - H_{298.15} = 0.76T + 1.24 \times 10^{-3}T^2 - 1,828$   
(0.2 per cent; 298-1,300 K;)

$C_p = 5.76 + 2.48 \times 10^{-3}T$

$\Delta H_{1300}(\text{fusion}) = 3,000.$

For liquid promethium:

$H_T - H_{298.15} = 8.00T + 360$

(0.1 per cent; 1,300-3,000 K.);

$C_p = 8.00.$

PROMETHIUM COMPOUNDS

Authority

Antimonides

Arsenides

Beryllides



179

a<sub>0</sub>, A

10.33

Bismuthides

Borides

Carbides

Germanides

Halides

93, 236,  
276

	<u>PmBr<sub>3</sub></u>	<u>PmCl<sub>3</sub></u>	<u>PmF<sub>3</sub></u>	<u>PmI<sub>3</sub></u>	<u>α-PmOF</u>	<u>β-PmOF</u>
Structure	--	Hexagonal	Hexagonal	--	Fcc	Tetragonal
a <sub>0</sub> , A	--	7.397	6.96	--	5.56	3.95
c <sub>0</sub> , A	--	4.211	7.14	--	--	5.58
Melting Point, C	677	737	1407	797	--	--
Heat of Fusion, kcal/mole	(8)	(8)	(8)	(8)	--	--
Entropy of Fusion, eu/mole	(8)	(8)	(5)	(8)	--	--
Boiling Point, C	1530	1670	(2327)	1370	--	--
Heat of Vaporization, kcal/mole	(45)	(46)	(62)	(41)	--	--
Entropy of Vaporization, eu/mole	(25)	(24)	(24)	(25)	--	--
Color	--	Blue purple	Pink	--	Pink	Pink

Hydrides

Nitrides

Oxides	<u>Authority</u>		
	156, 172, 276		
	Type:	<u>Pm<sub>2</sub>O<sub>3</sub></u>	
	<u>A</u>	<u>B</u>	<u>C</u>
Structure	Hexagonal	Monoclinic	Cubic
a <sub>0</sub> , A	3.806	14.15	10.99
b <sub>0</sub> , A	--	3.69	--
c <sub>0</sub> , A	5.954	8.78	--
β, deg	--	98.5	--
Heat of Formation, kcal/mole	(216.5) Type not specified		
Entropy of Formation, eu/mole	(35.4) Type not specified		
Color	Blue purple	Pink purple	Coral red
Effective Magnetic Moment, Bohr magnetons	2.8 Type not specified		
Transition Temperature, C	B → C at 950		
Phosphides			
Selenides			
Silicides			
Sulfides			
Tellurides			

## SAMARIUM

Symbol Sm

Atomic Number 62

Atomic Weight 150.35

Authority

## PHYSICAL PROPERTIES

Abundance	4.5-7.0 ppm (approx. 6.5)	51
Density	7.536 g/cm <sup>3</sup>	67
Melting Point	1072 C	66
Heat of Fusion	2.061 kcal/mole	66
Boiling Point	1804 C	104
Heat of Vaporization (25 C)	46 kcal/mole	57
Vapor Pressure (885-1222 K)	$\text{Log } P_{\text{mmHg}} = 8.781 - \frac{10784}{T}$	60
Specific Heat (25 C)	6.76 cal/(mole)(C)	53
Heat of Combustion	216.94 kcal/g-atom	134
Coefficient of Linear Thermal Expansion		
Thermal Conductivity		
Heat of Sublimation (25 C)	49.3 kcal/mole	104
Cohesive Energy	50 kcal/mole	39
Work Function	3.2 ev	82
Debye Temperature	166 K	97
Expansion on Melting		
Surface Tension		

Authority

## CRYSTAL PROPERTIES

Structure	<u>Rhombohedral</u>	<u>BCC</u>	61
Lattice Constants	$a_0 = 8.966$ $\alpha = 23^\circ 13'$	$a_0 = 4.07 \text{ \AA}$ --	61
Density	7.536	-- g/cm <sup>3</sup>	66
Metallic Radius	1.802	1.81 \AA	67
Atomic Volume	19.0	-- cm <sup>3</sup> /mole	56
Transition Temperature	917 C		66
Heat of Transition	0.744 kcal/mole		61
Ionic Radius	+2 = 1.16, +3 = 0.964 \AA		53, 93
Closest Approach of Atoms			
Allotropic Modifications	(1) a durable hcp phase occurs at 300 C when metal is subjected to a static pressure of 40 kilobars		106

## CHEMICAL PROPERTIES

Stable Oxidation State	+2, +3	81
Electrode Potential	[Sm = Sm <sup>+3</sup> + 3e <sup>-</sup> ] + 2.2 volts (standard hydrogen electrode)	81
Ionization Potential	1st = 6.6, 2nd = 11.4 volts	82
Metallographic Polishing and Etching		
Corrosion Rates (In Air)	2.9 mil/year at 200 C 3.2 mil/year at 400 C 6.7 mil/year at 600 C Oxidation rate is 20 mil/year at 95 C with 75 per cent relative humidity.	68

## Corrosion Data

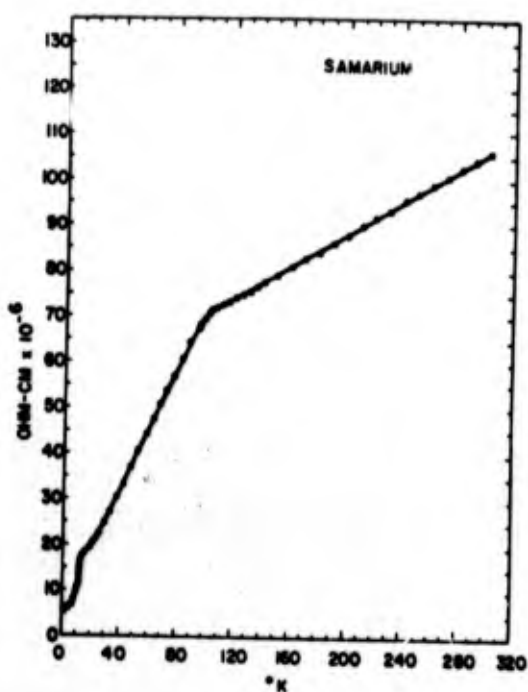
Authority

**ELECTRICAL PROPERTIES**

Resistivity (25 C) 88 microhm-cm 61

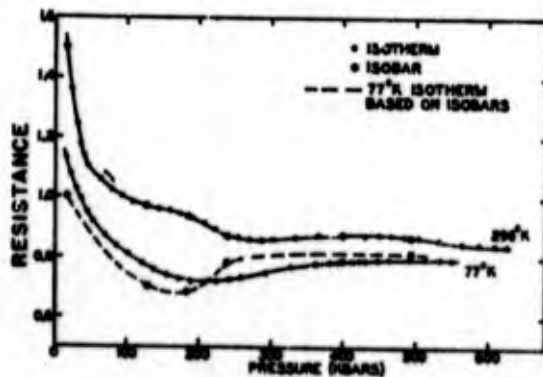
Temperature Coefficient of Resistivity  $1.48 \times 10^{-3}/C$  61

Resistivity Versus Temperature (Permission of the American Physical Society) 86



Resistance Versus Pressure (Permission of the American Physical Society)

96



		<u>Authority</u>
<b>MAGNETIC PROPERTIES</b>		
Susceptibility (25 C)	1275 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 1.6 Bohr magnetons Measured 1.74 Bohr magnetons	61
Curie Temperature		
Néel Temperature	15 K 27 K (double hcp structure)	61 106
<b>MECHANICAL PROPERTIES</b>		
Young's Modulus	3.41 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Shear Modulus	1.26 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Poisson's Ratio	0.352	61
Compressibility	2.56 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	57
Hardness (DPH)	45	57
	<u>70 F</u> <u>400 F</u> <u>800 F</u>	
Tensile Strength	18.0   21.0   12.0   10 <sup>3</sup> psi	88
Yield Strength	16.2   17.9   11.0   10 <sup>3</sup> psi	88
Elongation	3   10.4   5.6   per cent	88
Ultimate Compressive Strength	47.6 x 10 <sup>3</sup> psi	61
Impact Strength (Izod)	0.53 ft-lb	71
Workability		
General Fabrication	(See references)	70, 113



**NUCLEAR PROPERTIES**

Isotopes

58, 105

<u>Whole Number Mass</u>	<u>Relative Abundance, per cent</u>	<u>Half Life</u>	<u>Decay Mode</u>
144	3.16	Stable	--
145	--	70 days	K, $\gamma$ , $e^-$
147	15.07	Stable	--
148	11.27	Stable	--
149	13.84	Stable	--
150	7.47	Stable	--
151	--	20 yr	$\beta^-$
152	26.63	$2.5 \times 10^{11}$ yr	$\alpha$
153	--	47 hr	$\beta^-$ , $\gamma$ , $e^-$
154	22.53	Stable	--
155	--	25 min	$\beta^-$ , $\gamma$
156	--	10 hr	$\beta^-$

Thermal Neutron Cross Section

$5500 \pm 200$  barns/atom or  $22 \text{ cm}^2/\text{g}$

73

**SAFETY**

Samarium

Toxicity - Unknown.

Samarium Compounds

Details of toxicity unknown; the relative fire hazards, explosion hazards, and disaster controls depend on the nature of the anion.

**THERMODYNAMIC PROPERTIES**

	<u>Room Temperature</u>	<u>Melting Point</u>
Entropy	$S_{298} = 16.64$	$S_{1345} = 31.67 \text{ eu}$
Heat Capacity	$C_{p298} = 6.76$	$C_{p1345} = 11.22 \text{ cal}/(\text{mole})(\text{C})$

95

NUCLEAR PROPERTIES

Isotopes

58, 105

Whole Number Mass	Relative Abundance, per cent	Half Life	Decay Mode
144	3.16	Stable	--
145	--	70 days	K, $\gamma$ , e <sup>-</sup>
147	15.07	Stable	--
148	11.27	Stable	--
149	13.84	Stable	--
150	7.47	Stable	--
151	--	20 yr	$\beta^-$
152	26.63	2.5 x 10 <sup>11</sup> yr	$\alpha$
153	--	47 hr	$\beta^-$ , $\gamma$ , e <sup>-</sup>
154	22.53	Stable	--
155	--	25 min	$\beta^-$ , $\gamma$
156	--	10 hr	$\beta^-$

Thermal Neutron  
Cross Section

5500 ± 200 barns/atom or  
22 cm<sup>2</sup>/g

73

SAFETY

Samarium

Toxicity - Unknown.

Samarium Compounds

Details of toxicity unknown; the relative fire hazards, explosion hazards, and disaster controls depend on the nature of the anion.

THERMODYNAMIC PROPERTIES

	Room Temperature	Melting Point
Entropy	S <sub>298</sub> = 16.64	S <sub>1345</sub> = 31.67 eu
Heat Capacity	C <sub>p298</sub> = 6.76	C <sub>p1345</sub> = 11.22 cal/(mole)(C)

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Authority

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## Thermodynamic Functions

T, K	$C_p$ , joules/ mole-K	$S^\circ$ , joules/ mole-K	$H^\circ - H_0^\circ$	$F^\circ - H_0^\circ$	T, K	$C_p$ , joules/ mole-K	$S^\circ$ , joules/ mole-K	$H^\circ - H_0^\circ$	$F^\circ - H_0^\circ$
			T	T				T	T
			joules/ mole-K	joules/ mole-K				joules/ mole-K	joules/ mole-K
20.0	7.23	5.495	3.731	1.764	107.5	27.97	41.900	21.859	20.041
25.0	10.05	7.410	4.710	2.699	108.0	27.66	42.029	21.887	20.142
30.0	13.00	9.506	5.848	3.657	110.0	27.12	42.531	21.986	20.545
35.0	15.77	11.724	7.071	4.653	115.0	26.61	43.723	22.196	21.527
40.0	18.28	13.999	8.318	5.680	120.0	26.37	44.850	22.374	22.475
45.0	20.55	16.289	9.554	6.735	130.0	26.23	46.955	22.677	24.278
50.0	22.57	18.561	10.756	7.804	140.0	26.22	48.898	22.930	25.968
55.0	24.45	20.802	11.917	8.885	150.0	26.29	50.708	23.152	27.556
60.0	26.20	23.006	13.035	9.970	160.0	26.42	52.409	23.352	29.056
65.0	27.79	25.167	14.110	11.056	170.0	26.57	54.016	23.537	30.478
70.0	29.32	27.283	15.143	12.140	180.0	26.71	55.538	23.710	31.828
75.0	30.75	29.355	16.136	13.219	190.0	26.86	56.986	23.872	33.114
80.0	32.21	31.386	17.095	14.291	200.0	27.07	58.377	24.027	34.342
85.0	33.68	33.384	18.028	15.355	210.0	27.27	59.695	24.177	35.518
90.0	35.09	35.350	18.938	16.412	220.0	27.48	60.969	24.322	36.646
95.0	36.42	37.281	19.821	17.459	230.0	27.71	62.195	24.464	37.730
100.0	37.98	39.189	20.690	18.498	240.0	27.93	63.379	24.604	38.774
102.0	38.86	39.949	21.038	18.911	250.0	28.22	64.525	24.743	39.781
104.0	40.33	40.715	21.391	19.323	260.0	28.49	65.638	24.883	40.755
104.2	40.57	40.792	21.428	19.364	270.0	28.70	66.717	25.020	41.698
104.4	40.82	40.870	21.465	19.405	273.15	28.78	67.050	25.063	41.987
104.6	41.16	40.949	21.502	19.446	280.0	28.98	67.765	25.156	42.608
104.8	41.68	41.028	21.540	19.487	290.0	29.28	68.788	25.293	43.494
105.0	42.04	41.108	21.579	19.528	298.15	29.53	69.603	25.406	44.196
105.2	42.17	41.188	21.618	19.570	300.0	29.58	69.786	25.432	44.354
105.4	41.74	41.268	21.657	19.611	310.0	29.88	70.761	25.570	45.190
105.6	39.98	41.346	21.694	19.652	320.0	30.17	71.714	25.710	46.004
105.8	37.45	41.419	21.725	19.693	330.0	30.45	72.647	25.849	46.797
106.0	34.14	41.486	21.752	19.734	340.0	30.73	73.560	25.989	47.571
106.5	29.51	41.633	21.796	19.837	350.0	31.00	74.455	26.128	48.326
107.0	28.43	41.769	21.829	19.939	360.0	31.27	75.331	26.267	49.064

(Continued)

Thermodynamic Functions (Continued)

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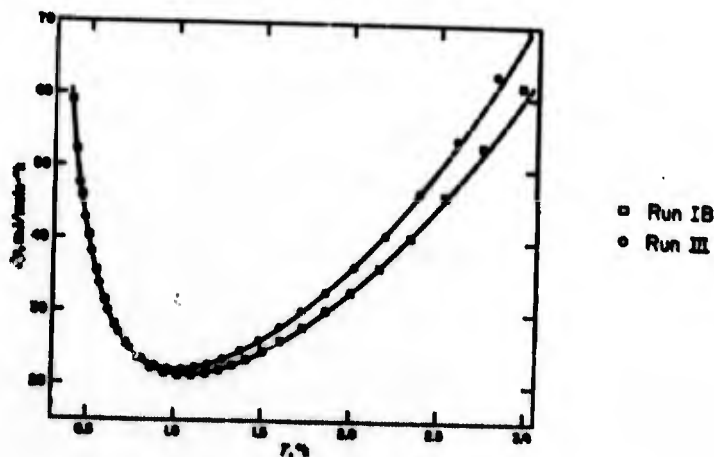
T, K	$C_p$ , cal/(K)(mole)	$S^0 - S^0_{298.15}$ , cal/(K)(mole)	$\frac{H^0 - H^0_{298.15(a)}}{T}$ , cal/(K)(mole)	$\frac{F^0 - H^0_{298.15}}{T}$ , cal/(K)(mole)
298.15	6.76	16.64	0.0	16.64
300	6.80	16.68	0.042	16.64
350	7.56	17.79	1.084	16.73
400	8.15	18.84	1.914	16.93
450	8.62	19.83	2.634	17.20
500	9.00	20.76	3.252	17.51
550	9.32	21.63	3.790	17.84
600	9.60	22.45	4.263	18.19
650	9.84	23.23	4.683	18.55
700	10.05	23.97	5.059	18.91
750	10.25	24.67	5.399	19.27
800	10.42	25.34	5.707	19.63
850	10.58	25.97	5.989	19.98
900	10.73	26.58	6.248	20.33
950	10.86	27.16	6.487	20.67
1000	10.99	27.72	6.709	21.01
1050	11.11	28.26	6.916	21.34
1100	11.22	28.78	7.109	21.67
1150	11.33	29.28	7.290	21.99
1190.15	11.41	29.67	7.428	22.24
1190.15	11.22	30.30	8.055	22.24
1200	11.22	30.39	8.079	22.31
1250	11.22	30.85	8.204	22.65
1300	11.22	31.29	8.320	22.97
1345.15(s)	11.22	31.67	8.417	23.25
1345.15(l)	14.04	33.20	9.950	23.25
1350	14.04	33.25	9.964	23.29
1398.15	14.04	33.74	10.105	23.63

(a)  $(H^0_{298.15} - H^0_{298.15})/T = 6.07 \text{ cal degree}^{-1} \text{ mole}^{-1}$ , unpublished value according to Jennings, Hill and Spedding.

Specific Heat

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## SAMARIUM COMPOUNDS

		<u>Authority</u>
Antimonides		169
	<u>SmSb</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	6.271	
Magnetic Susceptibility, $10^{-6}$ emu/mole	1000	
Arsenides		169, 229
	<u>SmAs</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	5.921	
Resistivity, microhm-cm	160	
Magnetic Susceptibility, $10^{-6}$ emu/mole	1086	
Beryllides		179
	<u>SmBe<sub>13</sub></u>	
$a_0$ , A	10.28	
Bismuthides		169
	<u>SmBi</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	6.362	
Magnetic Susceptibility, $10^{-6}$ emu/mole	1169	

Borides

153, 171

	<u>SmB<sub>4</sub></u>	<u>SmB<sub>6</sub></u>
Molecular Weight	193.71	215.35
Structure	Tetragonal	Cubic
a <sub>0</sub> , A	7.174	4.131
c <sub>0</sub> , A	4.070	--
Density, g/cm <sup>3</sup>	6.19	5.08
Melting Point, C	--	1810
Resistivity, microhm-cm	--	200
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	--	-4.2
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	6.5
Thermal Conductivity, cal/(cm)(sec)(C)	--	0.033
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	--	1810
Effective Magnetic Moment, Bohr magnetons	--	2.52
Work Function, ev	--	4.4
Microhardness, kg/mm <sup>2</sup>	--	2500
Color	Gray brown	Dark blue
Emissivity (λ = 0.655 μ)	--	0.68
Effective Metallic Radius, A	--	2.19

	<u>Authority</u>		
Carbides			153
	<u>SmC<sub>2</sub></u>	<u>Sm<sub>2</sub>C<sub>3</sub></u>	<u>Sm<sub>3</sub>C</u>
Molecular Weight	174.45	366.86	463.29
Structure	Body-centered tetragonal	Bcc	Cubic
Lattice Type	CaC <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>	Fe <sub>4</sub> N
a <sub>0</sub> , Å	3.76	8.4257	5.172
c <sub>0</sub> , Å	6.29	--	--
Density, g/cm <sup>3</sup>	6.50	7.477	8.139
Melting Point, C	>2200	--	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	~2300	--	--
Effective Magnetic Moment, Bohr magnetons	2.85	--	--

## Germanides

170, 183

	<u>SmGe<sub>2</sub></u>
Lattice Type	α-ThSi <sub>2</sub>
a <sub>0</sub> , Å	4.193
c <sub>0</sub> , Å	13.835
Volume of Unit Cell, Å <sup>3</sup>	241.4

Halides

Authority

58,93,158,  
181,186,  
210,212,  
215,235,  
236,250

	<u>SmBr<sub>2</sub></u>	<u>SmCl<sub>2</sub></u>	<u>SmF<sub>2</sub></u>	<u>SmI<sub>2</sub></u>	<u>SmBr<sub>3</sub></u>	<u>SmCl<sub>3</sub></u>	<u>SmF<sub>3</sub></u>	<u>SmI<sub>3</sub></u>
Molecular Weight	--	--	--	--	--	--	207.35	--
Structure	--	Ortho- rhombic	--	--	--	Hexagonal	Hexagonal, Orthorhombic	Hexagonal
a <sub>0</sub> , Å	--	8.973	--	--	--	7.378	Hex. 6.956 Ortho. 6.669	4.415
b <sub>0</sub> , Å	--	7.532	--	--	--	--	Ortho. 7.059	--
c <sub>0</sub> , Å	--	4.497	--	--	--	4.171	Hex. 7.120 Ortho. 4.405	6.976
Density, g/cm <sup>3</sup>	--	--	--	--	--	--	Hex. 6.925 Ortho. 6.643	--
Heat of Formation, kcal/mole	--	196.5	--	--	--	245	--	(149)
Entropy of Formation, eu/mole	--	39	--	--	--	61	--	(7)
Melting Point, C	700	740	(1377)	(527)	664	678	1306	820
Heat of Fusion, kcal/mole	(6)	(8)	(5)	(5)	(8)	(8)	(8)	(9)
Entropy of Fusion, eu/mole	(6)	(6)	(3)	(6)	(8)	(8)	(5)	(8)
Boiling Point, C	1880	2030	(2427)	1580	Decomposes	Decomposes	(2327)	Decomposes
Heat of Vaporization, kcal/mole	(50)	56.5	(78)	(40)	--	--	(82)	--
Entropy of Vaporization, eu/mole	(23)	25.4	(29)	(22)	--	--	(24)	--
Color	--	--	--	--	--	--	White	--
Volume of Unit Cell, Å <sup>3</sup>	--	--	--	--	--	--	Hex. 298.3 Ortho. 207.4	--

(Continued)



## Halides (Continued)

Authority

	SmOCl	SmOF	SmOI
Structure	Tetragonal	Rhombohedral	Tetragonal
Lattice Type	--	--	PbFC1
a <sub>0</sub> , Å	3.982	6.857	4.008
c <sub>0</sub> , Å	6.721	--	9.192
β, deg	--	33.07	--
Density, g/cm <sup>3</sup>	--	7.19	--
Heat of Formation, kcal/mole	(238)	--	--
Entropy of Formation, eu/mole	(43)	--	--
Refractive Index	--	1.84	--

## Thermodynamic Data

212

Glasner has supplied in ANL-5750 the following equations for calculating thermodynamic quantities. The reactions concerned and the constants for use in these equations are tabulated.

$$\Delta C_p = \Delta a + (\Delta b \times 10^{-3})T + (\Delta c \times 10^{-6})T^2 + \frac{\Delta d \times 10^5}{T^2}$$

$$\Delta H - \Delta H_{F298} = (\Delta a)T + \frac{1}{2}(\Delta b \times 10^{-3})T^2 + \frac{1}{3}(\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} + \Delta A$$

$$\Delta S = (2.303 \Delta a) \log T + (\Delta b \times 10^{-3})T + \frac{1}{2}(\Delta c \times 10^{-6})T^2 - \frac{1/2(\Delta d \times 10^5)}{T^2} - \Delta B$$

$$\Delta F - \Delta H_{F298} = - (2.303 \Delta a) T \log T - \frac{1}{2}(\Delta b \times 10^{-3})T^2 - \frac{1}{6}(\Delta c \times 10^{-6})T^3 - \frac{1/2(\Delta d \times 10^5)}{T} - T \Delta(B - a) - \Delta A$$

Reaction	Temperature Range, K	-ΔH <sub>F298</sub> , kcal/mole	-ΔF <sub>F298</sub> , kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	-ΔB, eu	-Δ(B-a)
Sm(s) + F <sub>2</sub> (g) = SmF <sub>2</sub> (s)	298-1621	237	225	0.7	3.0	--	0.8	-0.110	44.3	45.0
Sm(l) + F <sub>2</sub> (g) = SmF <sub>2</sub> (s)	1623-1650	--	--	-1.6	7.2	--	0.8	-4.555	35.1	33.5
Sm(l) + F <sub>2</sub> (g) = SmF <sub>2</sub> (l)	1750-2500	--	--	6.2	-0.4	--	0.8	-3.080	77.9	84.1
Sm(s) + 3/2 F <sub>2</sub> (g) = SmF <sub>3</sub> (s)	298-1623	405	307	1.1	5.3	--	1.2	-0.152	46.3	67.4
Sm(l) + 3/2 F <sub>2</sub> (g) = SmF <sub>3</sub> (s)	1623-1770	--	--	-1.2	0.7	--	1.2	-4.997	57.1	55.9
Sm(l) + 3/2 F <sub>2</sub> (g) = SmF <sub>3</sub> (l)	1670-2500	--	--	9.6	-0.7	--	1.2	-1.425	117.3	126.9
Sm(s) + Cl <sub>2</sub> (g) = SmCl <sub>2</sub> (s)	298-1013	193.6	187.1	0.8	5.1	--	0.6	-0.257	42.7	43.6
Sm(s) + Cl <sub>2</sub> (g) = SmCl <sub>2</sub> (l)	1013-1623	--	--	9.3	-3.7	--	0.6	1.446	88.1	97.7
Sm(l) + Cl <sub>2</sub> (g) = SmCl <sub>2</sub> (l)	1623-1700	--	--	7.2	-0.3	--	0.6	-2.999	78.9	86.2
Sm(l) + Cl <sub>2</sub> (g) = SmCl <sub>2</sub> (g)	1700-2500	--	--	-2.8	-0.3	--	0.6	59.00	-19.5	-22.2
Sm(s) + 3/2 Cl <sub>2</sub> (g) = SmCl <sub>3</sub> (g)	298-951	240	232	2.5	6.6	--	1.0	-0.694	69.4	71.9
Sm(s) + 3/2 Cl <sub>2</sub> (g) = SmCl <sub>3</sub> (l)	951-1623	--	--	11.7	-3.0	--	1.0	3.260	114.2	125.9
Sm(l) + 3/2 Cl <sub>2</sub> (g) = SmCl <sub>3</sub> (l)	1623-1830	--	--	9.4	-0.4	--	1.0	-1.185	105.0	119.4
Sm(l) + 3/2 Cl <sub>2</sub> (g) = SmCl <sub>3</sub> (g)	1830-2500	--	--	-2.1	-0.4	--	1.0	66.86	-7.1	-9.2

Properties

Hydrides

Authority

165, 187

	<u>SmH<sub>2</sub></u>	<u>SmH<sub>3</sub></u>
Structure	Fluorite	Hexagonal
a <sub>0</sub> , A	5.374	3.782
c <sub>0</sub> , A	--	6.779
Density, g/cm <sup>3</sup>	6.52	--

Nitrides

153, 223

	<u>SmN</u>
Molecular Weight	164.44
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	5.046
Density, g/cm <sup>3</sup>	8.495
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	1125

Oxides

172, 176,  
177, 186,  
247, 271

	<u>SmO</u>	<u>α-Sm<sub>2</sub>O<sub>3</sub></u>	<u>β-Sm<sub>2</sub>O<sub>3</sub></u>
Molecular Weight	--	348.70	348.70
Structure	Cubic	Monoclinic	Cubic
Lattice Type	NaCl	--	--
a <sub>0</sub> , A	4.988	--	10.90
b <sub>0</sub> , A	--	--	--
c <sub>0</sub> , A	--	--	--
β, deg	--	--	--

(Continued)

Authority

## Oxides (Continued)

	<u>SmO</u>	<u><math>\alpha</math>-Sm<sub>2</sub>O<sub>3</sub></u>	<u><math>\beta</math>-Sm<sub>2</sub>O<sub>3</sub></u>
Density, g/cm <sup>3</sup>	--	7.43	7.62
Heat of Formation, kcal/mole	159	--	--
Entropy of Formation, eu/mole	17.1	--	--
Melting Point, C	--	--	2350
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	9.9 (100-1000 C)	8.6 (100-950 C)
Effective Magnetic Moment, Bohr magnetons	--	1.6	--

## Thermodynamic Data

212

The equations given on page 196 may be used in calculating thermodynamic quantities for the following reactions:

<u>Reaction</u>	<u>Temper- ature Range, K</u>	<u><math>-\Delta H_f^{298}</math>, kcal/mole</u>	<u><math>-\Delta F^{298}</math>, kcal/mole</u>	<u><math>\Delta_a</math></u>	<u><math>\Delta_b</math></u>	<u><math>\Delta_c</math></u>	<u><math>\Delta_d</math></u>	<u><math>\Delta A</math>, kcal/mole</u>	<u><math>-\Delta B</math>, eu</u>	<u><math>-\Delta(B-a)</math></u>
$2Sm(s) + \frac{3}{2} O_2(g) = Sm_2O_3(s)$	298-1623	430	410	0.1	-0.2	--	2.8	0.775	65.9	66.0
$2Sm(l) + \frac{3}{2} O_2(g) = Sm_2O_3(g)$	1623-2150	--	--	-4.5	6.6	--	2.8	-8.115	47.5	43.0
$2Sm(l) + \frac{3}{2} O_2(g) = Sm_2O_3(l)$	2150-2500	--	--	5.6	-0.4	--	2.8	6.349	100.6	106.2

(Continued)

Oxides (Continued)

Heat Content and Entropy Increments  
for Samarium Oxide (Smooth Values)

175

T, K	Monoclinic Form (Sm <sub>2</sub> O <sub>3</sub> )		Cubic Form (Sm <sub>2</sub> O <sub>3</sub> )	
	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)
400	2,930	8.44	2,950	8.49
500	5,980	15.24	6,030	15.36
600	9,160	21.03	9,250	21.23
700	12,450	26.10	12,570	26.34
800	15,820	30.60	15,970	30.88
900	19,250	34.64	19,430	34.96
1000	22,730	38.31	22,930	38.65
1100	26,240	41.65	26,450	42.00
1150	--	--	28,210	43.57
1195	29,600	44.58	29,850	44.79
1200	--	--	30,030	44.94
1300	--	--	33,720	47.90
1400	--	--	37,410	50.63
1500	--	--	41,100	53.18
1600	--	--	44,790	55.56
1700	--	--	48,480	57.79
1800	--	--	52,170	59.90
1900	--	--	55,860	61.90
2000	--	--	59,550	63.79

Phosphides

169

	<u>SmP</u>
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , Å	5.760
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	1112

## Selenides

Authority168,189,  
191,192,  
194,225,  
226,227,  
228

	<u>SmSe</u>	<u>SmSe<sub>2</sub></u>	<u>Sm<sub>2</sub>Se<sub>3</sub></u>	<u>Sm<sub>3</sub>Se<sub>4</sub></u>	<u>Sm<sub>2</sub>O<sub>2</sub>Se</u>
Structure	Fcc	Tetragonal	Bcc	Bcc	Hcp
Lattice Type	NaCl	--	Th <sub>3</sub> P <sub>4</sub>	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , Å	6.159	8.16	8.76	8.84	3.93
c <sub>0</sub> , Å	--	8.36	--	--	6.93
Density, g/cm <sup>3</sup>	6.42	6.94	6.93	7.33	7.40
Melting Point, C	(2100)	--	(1540)	--	--
Resistivity, microhm-cm	1.38 x 10 <sup>9</sup>	--	1.7 x 10 <sup>3</sup>	--	--
Magnetic Suscep- tibility, 10 <sup>-6</sup> emu/mole	4440	1200	1049	--	--
Effective Magnetic Moment, Bohr magnetons	3.3	1.6	1.6	--	--
Color	--	--	Dark gray	--	Gray

## Silicides

153, 160

	<u>α-SmSi<sub>2</sub></u>	<u>β-SmSi<sub>2</sub></u>
Molecular Weight	206.61	206.61
Structure	Orthorhombic	Tetragonal
Lattice Type	α-YSi <sub>2</sub>	α-ThSi <sub>2</sub>
a <sub>0</sub> , Å	4.105	4.041
b <sub>0</sub> , Å	4.035	--
c <sub>0</sub> , Å	13.46	13.33
Density, g/cm <sup>3</sup>	6.13	6.26
Transition Temperature, C	α → β at 380	

Properties

Sulfides

Authority

153,169,  
240,248

	<u>SmS</u>	<u>Sm<sub>2</sub>S<sub>2</sub></u>	<u>γSm<sub>2</sub>S<sub>3</sub></u>	<u>Sm<sub>3</sub>S<sub>4</sub></u>	<u>Sm<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	182.50	214.55	397.06	579.55	364.93
Structure	Fcc	Cubic	Cubic	Cubic	Hexagonal
Lattice Type	NaCl	Unknown	Th <sub>3</sub> P <sub>4</sub>	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , Å	5.967	7.87	8.448	8.556	3.893
c <sub>0</sub> , Å	--	--	--	--	6.717
Density, g/cm <sup>3</sup>	5.67	5.66	5.87	6.14	6.90
Heat of Formation, kcal/mole	--	--	--	--	--
Melting Point, C	1500	1730	1780	1800	1980
Resistivity, microhm-cm	8.5 x 10 <sup>4</sup>	7.1 x 10 <sup>11</sup>	8.2 x 10 <sup>13</sup>	5.9 x 10 <sup>6</sup>	--
Thermal Conduc- tivity, 10 <sup>-3</sup> cal/ (cm)(sec)(C)	7.0	--	--	--	--
Magnetic Suscep- tibility, 10 <sup>-6</sup> emu/mole	5070	1238	1020	2350	1020
Effective Magnetic Moment, Bohr magnetons	4.34	--	--	--	--
Color	Black	Brown	Yellow	Black	Gray brown

Tellurides				<u>Authority</u>
	<u>SmTe</u>	<u>Sm<sub>2</sub>Te<sub>3</sub></u>	<u>Sm<sub>2</sub>O<sub>2</sub>Te</u>	169,202, 205,228
Structure	Fcc	Bcc	Hexagonal	
Lattice Type	NaCl	Th <sub>3</sub> P <sub>4</sub>	--	
a <sub>0</sub> , Å	6.58	9.480	4.00	
c <sub>0</sub> , Å	--	--	12.61	
Density, g/cm <sup>3</sup>	--	7.11	7.58	
Melting Point, C	1920	(1475)	--	
Resistivity, microhm-cm	1.64 x 10 <sup>9</sup>	--	--	
Magnetic Suscep- tibility, 10 <sup>-6</sup> emu/mole	4292	--	--	
Effective Magnetic Moment, Bohr magnetons	4.33	--	--	
Color	--	--	Dark green	

## Miscellaneous

150

	<u>Structure</u>	<u>a<sub>0</sub>, Å</u>	<u>c<sub>0</sub>, Å</u>
SmOs <sub>2</sub>	Hexagonal	5.336	8.879

## EUROPIUM

Symbol Eu

Atomic Number 63

Atomic Weight 152.0

Authority

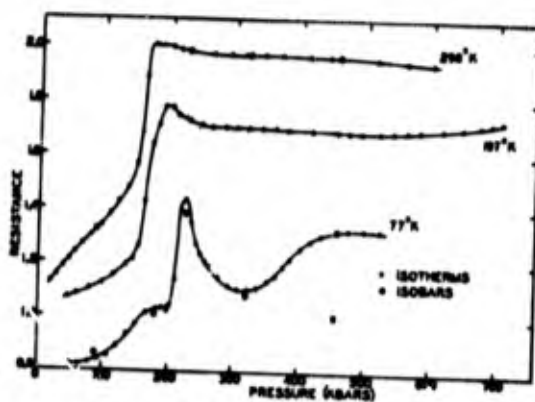
## PHYSICAL PROPERTIES

Abundance	0.14-1.1 ppm (approx. 0.5)	51
Density	5.245 g/cm <sup>3</sup>	67
Melting Point	826 C	66
Heat of Fusion	2.0 kcal/mole	61
Boiling Point	1439 C	57
Heat of Vaporization (25 C)	42 kcal/mole	57
Vapor Pressure (733-903 K)	$\text{Log } P_{\text{mm Hg}} = 8.160 - \frac{8982}{T}$	60
Specific Heat (25 C)	6.4 cal/(mole)(C)	76
Heat of Combustion (25 C)	217.0 kcal/g-atom	156
Coefficient of Linear Thermal Expansion (-200 - 780 C)	$32 \times 10^{-6}/\text{C}$	61
Thermal Conductivity		
Heat of Sublimation (25 C)	43.11 kcal/mole	130
Cohesion Energy	43.4 kcal/mole	130
Work Function		
Debye Temperature	70-120 K	112
Expansion on Melting	4.8 per cent	108
Surface Tension		



CRYSTAL PROPERTIES		<u>Authority</u>
Structure	Bcc	61
Lattice Constants	$a_0 = 4.5820 \text{ \AA}$	61
Density	$5.245 \text{ g/cm}^3$	67
Metallic Radius	$2.042 \text{ \AA}$	67
Atomic Volume	$28.91 \text{ cm}^3/\text{mole}$	66
Transition Temperature	None	66
Heat of Transition	None	66
Ionic Radius (Trivalent Ion)	$0.950 \text{ \AA}$	55
Closest Approach of Atoms	$3.960 \text{ \AA}$	56
Allotropic Modifications		
CHEMICAL PROPERTIES		
Stable Oxidation State	+2, +3	81
Electrode Potential	$[\text{Eu} = \text{Eu}^{+3} + 3\text{e}^-] + 2.2 \text{ volts (standard hydrogen electrode)}$	81
Ionization Potential	1st = 5.64, 2nd = 11.4 volts	82
Metallographic Polishing and Etching		
Corrosion Rates	Extremely rapid at all temperatures in air and acidic or basic media.	109
Corrosion Data		
ELECTRICAL PROPERTIES		
Resistivity (25 C)	$81.3 \text{ microhm-cm}$	61
Temperature Coefficient of Resistivity (25 C)	$4.80 \times 10^{-3}/\text{C}$	61

Resistance Versus Pressure  
(Permission of the American Physical Society)



**MAGNETIC PROPERTIES**

Susceptibility (25 C)	33,100 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 3.45 Bohr magnetons Measured 7.12 Bohr magnetons	61
Curie Temperature	108 K	61
Néel Temperature	91 K	112

**MECHANICAL PROPERTIES**

Youngs' Modulus		
Shear Modulus		
Poisson's Ratio		
Compressibility		
Hardness (DPH)	17 (not annealed)	57
Tensile Strength		
Yield Strength		
Elongation		
Ultimate Compressive Strength		

Authority

Impact Strength

Workability

General Fabrication (See references)

70, 113

## NUCLEAR PROPERTIES

Isotopes

110, 111

<u>Whole- Number Mass</u>	<u>Relative Abundance, per cent</u>	<u>Half Life</u>	<u>Decay Mode</u>
147	--	53 days	$\beta^+$
149	--	24 days	$\beta^+$
150	--	17 hr	$\beta^+$
151	47.77	Stable	--
152	--	5 yr	$\beta^-, e^-$
153	52.23	Stable	--
154	--	5.4 yr	$\beta^-, e^-, \gamma$
155	--	2 yr	$\beta^-, \gamma$
156	--	154 days	$\beta^-, \gamma$
157	--	15.4 hr	$\beta^-, \gamma$
158	--	60 min	$\beta^-$

Thermal Neutron  
Cross Section4600  $\pm$  200 barns/atom  
or 18 cm<sup>2</sup>/g

73

SAFETY

83

Details unknown.

THERMODYNAMIC PROPERTIES

	<u>Room Temperature</u>	<u>Melting Point</u>
Entropy	$S_{298} = 17.0$	$S_{1100} = 26.18 \text{ eu}$
Heat Capacity	$C_{p298} = 6.40$	$C_{p1100} = 8.99 \text{ cal/(mole)(C)}$

76, 77

Heat Content and Entropy of Solid and Liquid Europium  
(Base: crystals at 298.15 K)

77

T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(deg) (mole)	T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(deg) (mole)
400	660	1.91	1100(l)	8,270	11.45
500	1,330	3.40	1200	9,070	12.15
600	2,020	4.66	1300	9,870	12.79
700	2,730	5.76	1400	10,670	13.38
800	3,460	6.73	1500	11,470	13.93
900	4,210	7.62	1600	12,270	14.45
1000	4,980	8.43	1700	13,070	14.94
1100(s)	5,770	9.18			

For solid europium:

$$H_T - H_{298.15} = 5.81T + 0.99 \times 10^{-3}T^2 - 1,820$$

(0.2 per cent; 298-1100 K)

$$C_p = 5.81 + 1.98 \times 10^{-3}T;$$

$$H_{1100}(\text{fusion}) = 2,500.$$

For liquid europium:

$$H_T - H_{298.15} = 8.00T - 530$$

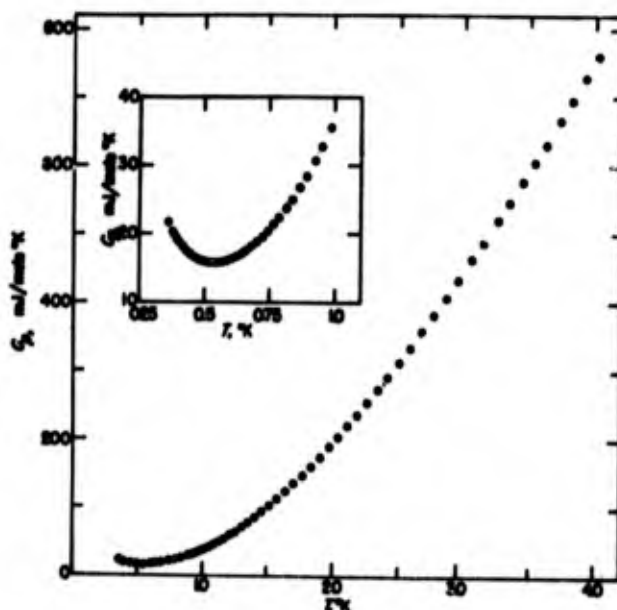
(0.1 per cent; 1100-1700 K);

$$C_p = 8.00.$$

Specific Heat

(Permission of Gordon and Breach, Science Publishers, Inc.)

97



## EUROPIUM COMPOUNDS

Authority

Antimonides

Arsenides

Beryllides

EuBe<sub>13</sub>

179

 $a_0, \text{A}$ 

10.288

Bismuthides

Borides

EuB<sub>6</sub>153, 171,  
249

Molecular Weight

216.92

Structure

Cubic

 $a_0, \text{A}$ 

4.178

Density, g/cm<sup>3</sup>

4.938

Melting Point, C

2200

Resistivity,  
microhm-cm

84.7

Temperature Coefficient  
of Resistivity, 10<sup>-4</sup>/C

9.0

Coefficient of Thermal  
Expansion, 10<sup>-6</sup>/C

6.86

Thermal Conductivity  
cal/(cm)(sec)(C)

0.055

Work Function, ev

4.9

Color

Blue black

Emissivity  
( $\lambda = 0.655 \mu$ )

0.83

Effective Metallic  
Radius, A

2.21

Carbides

Authority

Germanides

EuGe<sub>2</sub>

183

Lattice Type

AlB<sub>2</sub> defect

a<sub>0</sub>, Å

4.09

c<sub>0</sub>, Å

4.99

Volume of Unit Cell, Å<sup>3</sup>

72.79

Halides

55, 58, 93,  
158, 210, 235,  
236, 250, 277

	<u>EuBr<sub>2</sub></u>	<u>EuCl<sub>2</sub></u>	<u>EuF<sub>2</sub></u>	<u>EuI<sub>2</sub></u>	<u>EuBr<sub>3</sub></u>	<u>EuCl<sub>3</sub></u>	<u>EuF<sub>3</sub></u>	<u>EuI<sub>3</sub></u>
Structure	--	Orthorhombic	Cubic	--	Orthorhombic	Hexagonal	Hex, Ortho.	--
a <sub>0</sub> , Å	--	8.914	5.796	--	12.712	7.369	Hex. 6.916 Ortho 6.622	--
b <sub>0</sub> , Å	--	7.499	--	--	4.019	4.133	7.019	--
c <sub>0</sub> , Å	--	4.493	--	--	9.128	--	Hex. 7.091 Ortho 4.396	--
Density, cm <sup>3</sup>	--	--	--	--	--	--	Hex. 7.088 Ortho. 5.793	--
Melting Point, C	(677)	(727)	(1377)	(527)	(702)	623	1276	(877)
Heat of Fusion, kcal/mole	(6)	(6)	(5)	(5)	(8)	(7)	(5)	(9)
Entropy of Fusion, eu/mole	(6)	(6)	(3)	(6)	(8)	(8)	(5)	(8)
Boiling Point, C	1880	2030	(2427)	1580	Decomposes	Decomposes	2277	Decomposes
Heat of Vaporization, kcal/mole	(50)	55.3	(60)	(40)	--	--	(60)	--
Entropy of Vaporization, eu/mole	(23)	22.5	(29)	(22)	--	--	(24)	--
Color	--	--	--	--	--	--	White	--
Volume of Unit Cell, Å <sup>3</sup>	--	--	--	--	--	--	Hex. 293.7 Ortho. 204.3	--

(Continued)

Authority

211, 279

## Halides (Continued)

	<u>EuOCl</u>	<u>EuOF</u>
Structure	Tetragonal	Rhombohedral
$a_0$ , A	3.965	6.827
$c_0$ , A	6.695	--
$\beta$ , deg	--	33.05
Volume of Unit Cell, A <sup>3</sup>	105.25	--

## Hydrides

	<u>EuD<sub>2</sub></u>
Structure	Orthorhombic
$a_0$ , A	6.21
$b_0$ , A	3.77
$c_0$ , A	7.16

251

## Nitrides

	<u>EuN</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	5.014
Density, g/cm <sup>3</sup>	8.767
Color	Black

153, 169

Oxides

Authority

172, 177,  
252, 253,  
271

	<u>EuO</u>	<u><math>\alpha</math>-Eu<sub>2</sub>O<sub>3</sub></u>	<u><math>\beta</math>-Eu<sub>2</sub>O<sub>3</sub></u>	<u>Eu<sub>3</sub>O<sub>4</sub></u>	<u>Ortho I</u>
Molecular Weight	--	382.52	382.52	--	(Eu <sub>16</sub> O <sub>21</sub> ) --
Structure	Fcc	Bcc	Monoclinic	Orthorhombic	Orthorhombic
a <sub>0</sub> , Å	5.142	10.869	14.082	10.085	9.75
b <sub>0</sub> , Å	--	--	3.640	12.054	49.5
c <sub>0</sub> , Å	--	--	8.788	3.502	5.63
$\beta$ , deg	--	--	100.0	--	--
Density, g/cm <sup>3</sup>	8.16	7.28	7.99	8.07	6.74
Heat of Formation, kcal/mole	145.2	194.8	196.5	--	--
Entropy of Formation, eu/mole	--	--	(36)	--	--
Melting Point, C	--	--	2050	--	--
Coefficient of Thermal Expansion (25-1000 C), 10 <sup>-6</sup> /C	--	7.0	10.3	--	--
Effective Magnetic Moment, Bohr magnetons	--	3.4	--	--	--
Color	Dark brown	White	White	Black	Orange
Refractive Index	Opaque	1.92	2.09 at 20 C	2.12	1.91 at 25 C

(Continued)



Authority

Oxides (Continued)

Heat Content and Entropy Increments for Europium Oxide ( $\text{Eu}_2\text{O}_3$ )  
(Smooth Values)

T, K	Monoclinic Form		Cubic Form	
	$H_T - H_{298.15}$ , cal/mole	$S_T - S_{298.15}$ , cal/(K)(mole)	$H_T - H_{298.15}$ , cal/mole	$S_T - S_{298.15}$ , cal/(K)(mole)
400	3,070	8.85	3,150	9.07
500	6,210	15.85	6,370	16.25
600	9,460	21.77	9,690	22.30
700	12,800	26.92	13,100	27.56
800	16,210	31.47	16,580	32.21
895	19,510( $\alpha$ )	35.37( $\alpha$ )	--	--
895	19,640( $\beta$ )	35.51( $\beta$ )	--	--
900	19,810	35.70	20,110	36.36
1000	23,300	39.38	23,590	40.13
1100	26,840	42.75	27,320	43.59
1200	30,430	45.88	30,990	46.79
1300	34,070	48.79	34,690	49.75
1350	--	--	36,550	51.15
1400	37,750	51.52	--	--
1500	41,470	54.08	--	--
1600	45,220	56.50	--	--
1700	48,990	58.79	--	--
1800	52,780	60.96	--	--
1900	56,590	63.02	--	--
2000	60,410	64.98	--	--

Phosphides

Authority

Selenides	<u>EuSe</u>	189, 194, 254
Structure	Fcc	
Lattice Type	NaCl	
$a_0$ , A	6.178	
Density, g/cm <sup>3</sup>	6.42	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	2286	
Effective Magnetic Moment, Bohr magnetons	7.65	
Color	Dark brown	
Curie Temperature, K	6	
Silicides	<u><math>\beta</math>-EuSi<sub>2</sub></u>	153, 160
Molecular Weight	208.18	
Structure	Tetragonal	
Lattice Type	$\alpha$ -ThSi <sub>2</sub>	
$a_0$ , A	4.29	
$c_0$ , A	13.66	
Density, g/cm <sup>3</sup>	5.50	
Melting Point, C	1500	
Transition Temperature, C	$\alpha \rightarrow \beta$ at - 150	

	<u>Authority</u>				
Sulfides	254, 255				
	<u>EuS</u>	<u>Eu<sub>2</sub>S<sub>3</sub></u>	<u>Eu<sub>2</sub>S<sub>3.81</sub></u>	<u>Eu<sub>3</sub>S<sub>4</sub></u>	<u>Eu<sub>2</sub>O<sub>2</sub>S</u>
Structure	Fcc	--	Tetragonal	Cubic	Hexagonal
Lattice Type	NaCl	--	--	Th <sub>3</sub> P <sub>4</sub>	--
a <sub>0</sub> , Å	5.970	8.415	7.86	8.537	3.87
c <sub>0</sub> , Å	--	--	8.03	--	6.68
Density, g/cm <sup>3</sup>	5.745	--	5.70	6.27	7.04
Magnetic Susceptibility, 10 <sup>-6</sup> (emu/mole)	22600	--	5800	11500	--
Color	Black	--	--	Black	Pink
Curie Temperature, K	16	--	--	--	--
Tellurides	<u>EuTe</u>	<u>Eu<sub>2</sub>O<sub>2</sub>Te</u>			169, 202, 254, 280
Structure	Fcc	Hexagonal			
Lattice Type	NaCl	--			
a <sub>0</sub> , Å	6.585	3.98			
c <sub>0</sub> , Å	--	12.57			
Density, g/cm <sup>3</sup>	--	7.74			
Color	Black	Maroon			
Néel Temperature, K	6	--			

**GADOLINIUM**

Symbol Gd

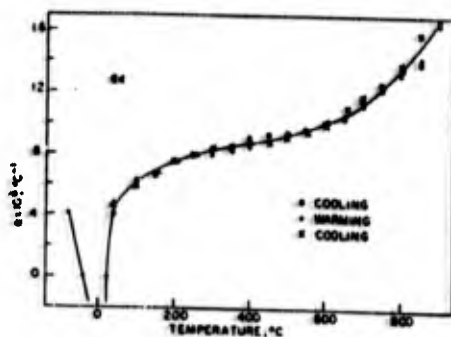
Atomic Number 64

Atomic Weight 157.26

Authority

**PHYSICAL PROPERTIES**

Abundance	4.5-6.4 ppm (approx. 6.4)	51
Density	7.886 g/cm <sup>3</sup>	67
Melting Point	1312 C	66
Heat of Fusion	2.1 kcal/mole	61
Boiling Point	3000 C	57
Heat of Vaporization (25 C)	72 kcal/mole	57
Vapor Pressure (1620-2097 K)	$\text{Log } P_{\text{mm Hg}} = 8.517 - \frac{19,600}{T}$	60
Specific Heat (25 C)	8.80 cal/mole C	76
Heat of Combustion	216.97 kcal/g-atom	134
Coefficient of Linear Thermal Expansion	$8.6 \times 10^{-6}/\text{C}$ (25-950 C)	61



53

Thermal Conductivity (28 C)	0.021 cal/(cm <sup>2</sup> )(sec)(C/cm)	115
Heat of Sublimation (25 C)	81.22 kcal/mole	130

		<u>Authority</u>
Cohesive Energy	81.9 kcal/mole	130
Work Function		
Debye Temperature	176 K	
Expansion on Melting		97
Surface Tension		

## CRYSTAL PROPERTIES

	<u>HCP</u>	<u>BCC</u>	
Structure			
Lattice Constants	$a_0 = 3.6360$ $c_0 = 5.7826$	$a_0 = 4.06 \text{ \AA}$ -- $\text{\AA}$	61
Density	7.856	-- $\text{g/cm}^3$	61
Metallic Radius	1.802	-- $\text{\AA}$	67
Atomic Volume	19.88	20.2 $\text{cm}^3/\text{mole}$	67
Transition Temperature	1262 C		66
Heat of Transition	1.03 kcal/mole		66
Ionic Radius			61
Closest Approach of Atoms	3.554 $\text{\AA}$		56
Allotropic Modifications			

## CHEMICAL PROPERTIES

Stable Oxidation State	+3	81
Electrode Potential	[Gd = Gd <sup>+3</sup> + 3e <sup>-</sup> ] + 2.2 volts	(standard hydrogen electrode) 81
Ionization Potential	1 <sup>st</sup> = 6.7 volts	82
Metallographic Polishing and Etching		62

Gadolinium may be cut, mounted and prepared in a manner similar to that for any metal. As a matter of practice the authors continue to carry out the preliminary grinding and polishing operations in kerosene. The final polish may be done using water and the structure is revealed after etching with 5% nital.

Corrosion Rates  
(In Air) 0 mil/year at 200 C  
38 mil/year at 400 C  
2900 mil/year at 600 C

Authority

68

Corrosion Data

Corrosive attack on crucible materials:

91

Material	Onset of Attack
MgO	None < 1300 C
Ta	None < 1300 C

ELECTRICAL PROPERTIES

Resistivity (25 C) 140.5 microhm-cm

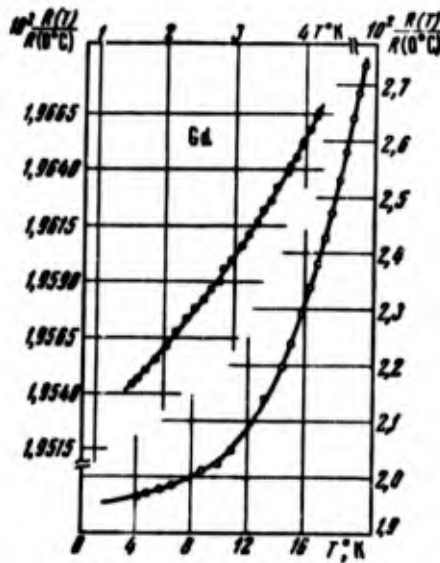
61

Temperature Coefficient of Resistivity  $1.76 \times 10^{-3}/C$

61

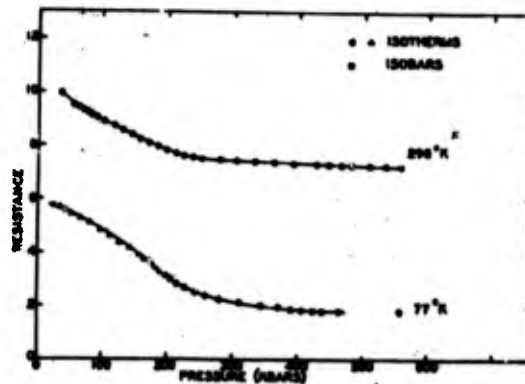
Resistance Versus Temperature

118



Resistance Versus Pressure  
(Permission of the American Physical Society)

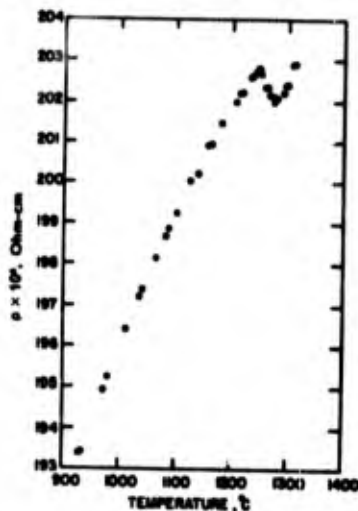
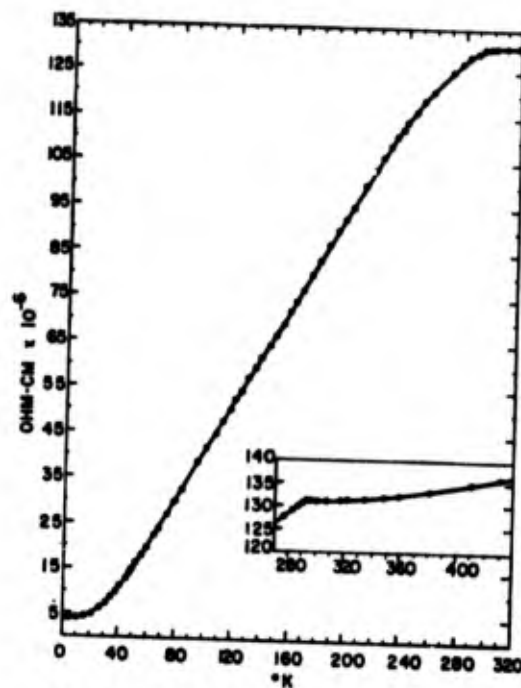
96



Authority

87,117

## Resistivity Versus Temperature

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## MAGNETIC PROPERTIES

Susceptibility (25 C)	356,000 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 7.94 Bohr magnetons Measured 7.95 Bohr magnetons	61
Curie Temperature	290 K	61
Néel Temperature		

## MECHANICAL PROPERTIES

Young's Modulus	5.62 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Shear Modulus	2.23 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Poisson's Ratio	0.259	61
Compressibility	2.52 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	57
Hardness (DPH)	57	57
Tensile Strength	$\frac{70 \text{ F}}{27.6}$ $\frac{400 \text{ F}}{18.0}$ $\frac{800 \text{ F}}{14.1} \times 10^3 \text{ psi}$	88
Yield Strength	25.1      15.6      13.0 x 10 <sup>3</sup> psi	88

	<u>70 F</u>	<u>400 F</u>	<u>800 F</u>	<u>Authority</u>
Elongation	8	6.8	11.3 per cent	88
Ultimate Compressive Strength				
Impact Strength (Izod)	1.3 ft-lb			71
Workability	Good just below red heat			88
General Fabrication	(See references)			70, 113

**NUCLEAR PROPERTIES**

Isotopes					58, 110, 116
	<u>Whole Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay Mode</u>	
	152	0.20	Stable	--	
	153	--	72 days	e <sup>-</sup> , γ	
	154	2.15	Stable	--	
	155	14.73	Stable	--	
	156	20.47	Stable	--	
	157	15.68	Stable	--	
	158	24.87	Stable	--	
	160	21.90	Stable	--	
Thermal Neutron Cross Section	46,000 ± 2000 barns/atom or 1.77 cm <sup>2</sup> /g				73

**SAFETY**

Gadolinium Toxicity - Unknown.

**Gadolinium Compounds**

Details unknown; the relative fire hazards, explosion hazards and disaster control depend on the nature of the anion present.

**THERMODYNAMIC PROPERTIES**

	<u>Room Temperature</u>	<u>Melting Point</u>	76, 77
Entropy	S <sub>298</sub> = 16.2	S <sub>1600</sub> = 29.23 eu	
Heat Capacity	C <sub>p298</sub> = 8.80	C <sub>p1600</sub> = 8.90 cal/(mole)(C)	



Heat Content and Entropy of Solid and Liquid Gadolinium

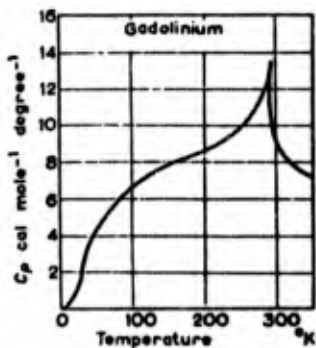
(Base: crystals at 298.15 K)

T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(deg)(mole)	T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(deg)(mole)
400	780	2.29	1500	9,480	12.46
500	1,480	3.83	1600(s)	10,370	13.03
600	2,200	5.15	1600(l)	14,070	15.34
700	2,940	6.30	1800	15,670	16.29
800	3,700	7.31	2000	17,270	17.13
900	4,480	8.22	2200	18,870	17.89
1000	5,270	9.06	2400	20,470	18.59
1100	6,080	9.83	2600	22,070	19.23
1200	6,900	10.54	2800	23,670	19.82
1300	7,740	11.22	3000	25,270	20.37
1400	8,600	11.85			

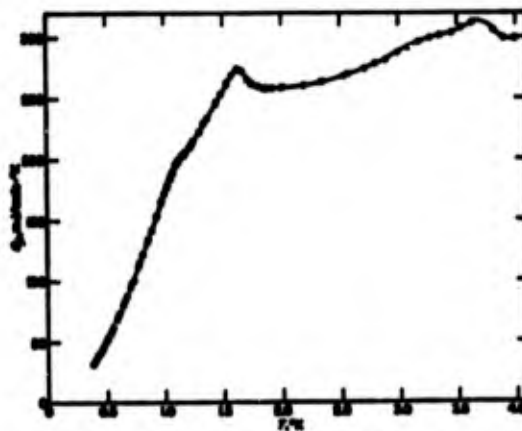
For solid gadolinium:  
 $H_T - H_{298.15} = 6.60 T + 0.72 \times 10^{-3} T^2 - 2,032$   
 (1.0 percent: 298° - 1,600° K):  
 $C_p = 6.60 + 1.44 \times 10^{-3} T$   
 $\Delta H_{1600}(\text{fusion}) = 3,700.$

For liquid gadolinium:  
 $H_T - H_{298.15} = 8.00 T + 1,270$   
 (0.1 percent: 1,600° - 3,000° K):  
 $C_p = 8.00.$

Specific Heat



0 to 350 K



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GADOLINIUM COMPOUNDS

Authority

Antimonides

169, 256

	<u>GdSb</u>	<u>Gd<sub>4</sub>Sb<sub>3</sub></u>
Structure	Cubic	Bcc
Lattice Type	NaCl	Th <sub>3</sub> P <sub>4</sub>
a <sub>0</sub> , A	6.217	9.224
Density, g/cm <sup>3</sup>	--	--
Resistivity, microhm-cm	--	220
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	25,575	--
Effective Magnetic Moment, Bohr magnetons	7.87	--

Arsenides

168, 169

	<u>GdAs</u>
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	5.862
Melting Point, C	>2270
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	27,548
Effective Magnetic Moment, Bohr magnetons	8.18

Beryllides

179

	<u>GdBe<sub>13</sub></u>
a <sub>0</sub> , A	10.27

Bismuthides		<u>Authority</u>			
		169, 256			
	<u>GdBi</u>	<u>Gd<sub>4</sub>Bi<sub>3</sub></u>			
Structure	Cubic	--			
Lattice Type	NaCl	--			
a <sub>0</sub> , A	6.316	9.383			
Density, g/cm <sup>3</sup>	--	10.09			
Resistivity, microhm-cm	--	190			
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	24,038	--			
Effective Magnetic Moment, Bohr magnetons	8.20	--			
Curie Temperature, K	--	340			
Borides		<u>Authority</u>			
	<u>GdB<sub>2</sub></u>	<u>GdB<sub>3</sub></u>	<u>GdB<sub>4</sub></u>	<u>GdB<sub>6</sub></u>	153, 155, 171
Molecular Weight	--	189.36	200.18	221.82	
Structure	Hexagonal	Tetragonal	Tetragonal	Cubic	
a <sub>0</sub> , A	3.31	3.79	7.114	4.112	
c <sub>0</sub> , A	3.94	3.63	4.047	--	
Density, g/cm <sup>3</sup>	--	6.03	6.446	5.30	
Melting Point, C	--	--	--	>2100	
Resistivity, microhm-cm	--	--	--	94.0	
Temperature Coefficient of Resistivity, 10 <sup>-3</sup> /C	--	--	--	1.40	

(Continued)

Borides (Continued)

	<u>GdB<sub>2</sub></u>	<u>GdB<sub>3</sub></u>	<u>GdB<sub>4</sub></u>	<u>GdB<sub>6</sub></u>
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	--	--	8.68
Thermal Conductivity, cal/(cm)(sec) (C)	--	--	--	0.049
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	--	--	--	21000
Effective Magnetic Moment, Bohr magnetons	--	--	--	7.68
Work Function, ev	--	--	--	2.05
Microhardness, kg/mm <sup>2</sup>	--	--	--	2340
Emissivity (λ = 0.655 μ)	--	--	--	0.65
Color	--	--	Gray brown	Blue
Effective Metallic Radius, A	--	--	--	2.18
Transverse Rupture Strength, 10 <sup>3</sup> psi	--	--	--	30

	<u>Authority</u>		
<b>Carbides</b>			153
	<u>GdC<sub>2</sub></u>	<u>Gd<sub>2</sub>C<sub>3</sub></u>	<u>Gd<sub>3</sub>C</u>
Molecular Weight	180.9	349.8	482.7
Structure	Body-centered tetragonal	Bcc	Cubic
Lattice Type	CaC <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>	Fe <sub>4</sub> N
a <sub>0</sub> , Å	3.718	8.3407	5.126
c <sub>0</sub> , Å	6.275	--	--
Density, g/cm <sup>3</sup>	6.939	8.024	8.701
Melting Point, C	>2200	--	--
Effective Magnetic Moment, Bohr magnetons	7.92	--	--
Curie Temperature, K	41.3	--	--
<b>Germanides</b>			183, 262
	<u>GdGe</u>	<u>GdGe<sub>2</sub></u>	
Structure	Orthorhombic	--	
Lattice Type	CrE	α-ThSi <sub>2</sub>	
a <sub>0</sub> , Å	4.175	4.12	
b <sub>0</sub> , Å	3.960	--	
c <sub>0</sub> , Å	10.61	13.72	
Volume of Unit Cell, Å <sup>3</sup>	175.4	232.9	

							<u>Authority</u>
Halides	<u>GdBr<sub>3</sub></u>	<u>BdCl<sub>3</sub></u>	<u>GdI<sub>3</sub></u>	<u>GdI<sub>3</sub></u>	<u>GdOCl</u>	<u>GdOF</u>	55, 58, 93, 108, 157, 158, 159, 182, 186, 210, 235, 236
Structure	Hexag- onal	Hexag- onal	Ortho- rhombic	Hexag- onal	Tetrag- onal	Rhombo- hedral	
a <sub>0</sub> , A	4.172	7.363	6.570	4.383	3.950	6.803	
b <sub>0</sub> , A	--	--	6.894	--	--	--	
c <sub>0</sub> , A	6.441	4.105	4.393	6.968	6.672	--	
β, deg	--	--	--	--	--	33.05	
Density, g/cm <sup>3</sup>	--	--	7.047	--	--	7.51	
Heat of Formation, kcal/mole	--	240.09	--	(142)	234.8	--	
Entropy of Formation, eu/mole	--	(61)	--	(6)	(43)	--	
Melting Point, C	785	602	1228	926	--	--	
Heat of Fusion, kcal/mole	8.7	9.6	(8)	(10)	--	--	
Entropy of Fusion, eu/mole	8.2	11.0	(5)	(8)	--	--	
Boiling Point, C	1490	1580	(2277)	1340	--	--	
Heat of Vaporization, kcal/mole	(44)	(45)	(60)	(40)	--	--	
Entropy of Vaporization, eu/mole	(25)	(24)	(24)	(25)	--	--	
Heat Capacity, cal/(mole) (C)	32.1	29.1	--	--	--	--	
Color	--	--	White	--	--	--	
Volume of Unit Cell, A <sup>3</sup>	--	--	201.6	--	104.10	--	

Hydrides			Authority
	<u>GdH<sub>2</sub></u>	<u>GdH<sub>3</sub></u>	186, 187, 251
Structure	Fluorite	Hexagonal	
a <sub>0</sub> , A	5.303	3.73	
c <sub>0</sub> , A	--	6.71	
Density, g/cm <sup>3</sup>	7.08	--	
Heat of Formation, kcal/mole H <sub>2</sub>	46.9	--	
Entropy of Formation, eu/mole H <sub>2</sub>	40	--	
Nitrides			153, 223
	<u>GdN</u>		
Molecular Weight	171.27		
Structure	Cubic		
Lattice Type	NaCl		
a <sub>0</sub> , A	4.999		
Density, g/cm <sup>3</sup>	9.105		
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	35,600		
Effective Magnetic Moment, Bohr magnetons	8.2		
Curie Temperature, K	60		
Oxides			
	<u>α-Gd<sub>2</sub>O<sub>3</sub></u>	<u>β-Gd<sub>2</sub>O<sub>3</sub></u>	156, 172, 173, 175, 176, 177, 247
Molecular Weight	362.50	362.50	
Structure	Cubic	Monoclinic	
a <sub>0</sub> , A	10.79	--	

(Continued)

Oxides (Continued)

	<u><math>\alpha</math>-Gd<sub>2</sub>O<sub>3</sub></u>	<u><math>\beta</math>-Gd<sub>2</sub>O<sub>3</sub></u>
Density, g/cm <sup>3</sup>	7.41	--
Melting Point, C	--	2350
Heat of Formation, kcal/mole	216.97	--
Entropy of Formation, eu/mole	(34.4)	--
Heat Capacity, cal/(mole)(C)	25.3	25.5
Coefficient of Thermal Expansion (100-1000 C), 10 <sup>-6</sup> /C	8.2	10.5
Effective Magnetic Moment, Bohr magnetons	7.9	--
Color	White	--
Transition Temperature, C	$\alpha \rightarrow \beta$ at 1280	

Heat Content and Entropy Increments for Gd<sub>2</sub>O<sub>3</sub> (Smooth Values)

T, K	Monoclinic Form		Cubic Form	
	<u>H<sub>T</sub>-H<sub>298.15</sub></u> cal/mole	<u>S<sub>T</sub>-S<sub>298.15</sub></u> cal/(deg)(mole)	<u>H<sub>T</sub>-H<sub>298.15</sub></u> cal/mole	<u>S<sub>T</sub>-S<sub>298.15</sub></u> cal/(deg)(mole)
400	2,680	7.72	2,700	7.77
500	5,440	13.88	5,490	13.99
600	8,290	19.07	8,380	19.26
700	11,200	23.55	11,340	23.82
800	14,150	27.49	14,360	27.85
900	17,140	31.01	17,430	31.47
1000	20,170	34.21	20,540	34.75
1100	23,240	37.13	23,690	37.75
1200	26,350	39.84	26,870	40.52
1300	29,500	42.58	30,080	43.09
1400	32,690	44.72	33,310	45.48
1500	35,920	46.95	36,550	47.71
1550	--	--	38,170	48.78
1600	39,190	49.06	--	--
1700	42,500	51.07	--	--
1800	45,850	52.98	--	--
1900	49,230	54.81	--	--
2000	52,640	56.56	--	--



						<u>Authority</u>
<b>Phosphides</b>						169
	<u>GdP</u>					
Structure	Fcc					
Lattice Type	NaCl					
$a_0$ , A	5.723					
Magnetic Susceptibility, $10^{-6}$ emu/mole	28,450					
Effective Magnetic Moment, Bohr magnetons	7.95					
<b>Selenides</b>						169, 189, 192, 227, 228, 260
	<u>GdSe</u>	<u>GdSe<sub>2</sub></u>	<u>Gd<sub>2</sub>Se<sub>3</sub></u>	<u>Gd<sub>3</sub>Se<sub>4</sub></u>	<u>Gd<sub>2</sub>O<sub>2</sub>Se</u>	
Structure	Cubic	Ortho- rhomboh	Bcc	Bcc	Hcp	
Lattice Type	NaCl	ThSe <sub>2</sub>	Th <sub>3</sub> P <sub>4</sub>	Th <sub>3</sub> P <sub>4</sub>	--	
$a_0$ , A	5.758	7.27	8.72	8.718	3.90	
$b_0$ , A	--	4.03	--	--	--	
$c_0$ , A	--	8.30	--	--	6.87	
Density, g/cm <sup>3</sup>	8.2	--	7.36	--	7.80	
Melting Point, C	1865	Decom- poses at >300 C	1750	(1500)	--	
Resistivity, microhm- cm	72	--	$1.3 \times 10^3$	$1.1 \times 10^3$	--	
Magnetic Suscepti- bility, $10^{-6}$ emu/mole	22,090	--	21,994	--	--	
Effective Magnetic Moment, Bohr magnetons	8.20	--	--	--	--	

(Continued)

Authority

Selenides (Continued)

	<u>GdSe</u>	<u>GdSe<sub>2</sub></u>	<u>Gd<sub>2</sub>Se<sub>3</sub></u>	<u>Gd<sub>3</sub>Se<sub>4</sub></u>	<u>Gd<sub>2</sub>O<sub>2</sub>Se</u>
Color	--	--	--	--	Beige
Volume of Unit Cell, A <sup>3</sup>	190.0	--	664.2	--	--

Silicides

	<u>α-GdSi<sub>2</sub></u>	<u>β-GdSi<sub>2</sub></u>	<u>Gd<sub>3</sub>Si<sub>5</sub></u>
Molecular Weight	213.08	213.08	--
Structure	Orthorhombic	Tetragonal	Hexagonal
Lattice Type	α-YSi <sub>2</sub>	α-ThSi <sub>2</sub>	--
a <sub>0</sub> , A	4.09	4.10	3.877
b <sub>0</sub> , A	4.01	--	--
c <sub>0</sub> , A	13.44	13.61	4.172
Density, g/cm <sup>3</sup>	6.43	6.19	--
Melting Point, C	1540	2100	--
Resistivity, microhm-cm	263	--	--
Transition Temperature, C		α → β at 400	
Transverse Rupture Strength, 10 <sup>3</sup> psi	6.1	--	--

152, 153,  
160, 261

Sulfides

	<u>GdS</u>	<u>GdS<sub>2</sub></u>	<u>γ-Gd<sub>2</sub>S<sub>3</sub></u>	<u>Gd<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	189.33	221.39	410.72	378.59
Structure	Cubic	Tetragonal	Cubic	Hexagonal
a <sub>0</sub> , A	5.574	7.85	8.387	3.851
c <sub>0</sub> , A	--	7.96	--	6.667

153, 169

(Continued)

							<u>Authority</u>
Sulfides (Continued)							
	<u>GdS</u>	<u>GdS<sub>2</sub></u>	<u>γ-Gd<sub>2</sub>S<sub>3</sub></u>	<u>Gd<sub>2</sub>O<sub>2</sub>S</u>			
Density, g/cm <sup>3</sup>	7.26	5.98	6.15	7.34			
Melting Point, C	--	--	1885	--			
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	30,300	21,510	27,800	--			
Effective Magnetic Moment, Bohr magnetons	8.01	--	--	--			
Tellurides							
	<u>GdTe</u>	<u>GdTe<sub>2</sub></u>	<u>GdTe<sub>4</sub></u>	<u>Gd<sub>2</sub>Te<sub>3</sub></u>	<u>Gd<sub>3</sub>Te<sub>4</sub></u>	<u>Gd<sub>2</sub>O<sub>2</sub>Te</u>	168, 169, 202, 228, 229, 232
Structure	Fcc	Tetragonal	Rhombohedral	Tetragonal	--	Hexagonal	
Lattice Type	NaCl	--	--	--	--	--	
a <sub>0</sub> , Å	6.139	9.10	13.0	--	--	3.96	
c <sub>0</sub> , Å	--	9.30	--	--	--	12.54	
α, deg	--	--	25.5	--	--	--	
Density, g/cm <sup>3</sup>	--	6.8	--	--	--	8.0	
Melting Point, C	1870	--	--	1505	1410	--	
Resistivity, microhm-cm	700	5.5 x 10 <sup>4</sup>	--	1.5 x 10 <sup>4</sup>	460	--	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	26,042	--	--	--	--	--	
Effective Magnetic Moment, Bohr magnetons	7.63	--	--	--	--	--	
Color	--	--	--	--	--	Brown	

Miscellaneous	Structure	Lattice Type	Lattice Parameters			Volume of Unit Cell, A <sup>3</sup>	Curie Temperature, K	Authority
			a <sub>0</sub> , A	b <sub>0</sub> , A	c <sub>0</sub> , A			
GdAg	--	CsCl	3.6478	--	--	48.53	--	150, 256, 262
GdAg <sub>2</sub>	Tetragonal	MoSi <sub>2</sub>	3.728	--	9.296	129.2	--	
GdAu <sub>2</sub>	Tetragonal	MoSi <sub>2</sub>	3.7320	--	9.014	125.5	--	
GdGa	Ortho-rhombic	CrB	4.314	4.006	11.02	194.5	--	
GdGa <sub>2</sub>	Hexagonal	AlB <sub>2</sub>	4.22.	--	4.141	63.89	--	
GdIn	--	CsCl	3.830	--	--	56.18	--	
GdIn <sub>3</sub>	--	AuCu <sub>3</sub>	4.6103	--	--	97.99	--	
GdIr <sub>2</sub>	Cubic	--	7.550	--	--	--	88	
GdMn	--	MgCu <sub>2</sub>	7.732	--	--	462.2	--	
GdOs <sub>2</sub>	Hexagonal	--	5.319	--	8.838	--	>77	
GdPt	Ortho-rhombic	FeB	5.574	4.458	7.164	178.0	--	
GdPt <sub>2</sub>	--	MgCu <sub>2</sub>	7.6349	--	--	445.05	>77	
GdRh <sub>2</sub>	Cubic	--	7.514	--	--	--	>77	
GdRu <sub>2</sub>	Hexagonal	--	5.271	--	8.904	--	>77	
GdTl	--	CsCl	3.7797	--	--	54.00	--	
GdTl <sub>3</sub>	--	AuCu <sub>3</sub>	4.696	--	--	103.6	--	

**TERBIUM**

Symbol Tb

Atomic Number 65

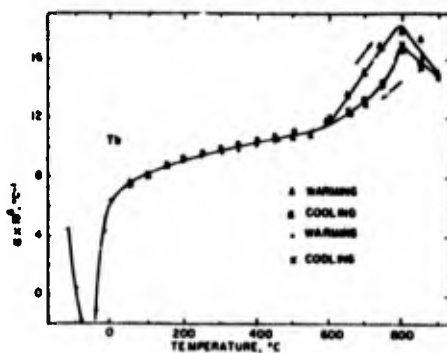
Atomic Weight 158.93

Authority

**PHYSICAL PROPERTIES**

Abundance	0.7-1.0 ppm (approx. 0.9)	51
Density	8.253 g/cm <sup>3</sup>	67
Melting Point	1356 C	66
Heat of Fusion	2.2 kcal/mole	61
Boiling Point	2800 C	57
Heat of Vaporization (25 C)	70 kcal/mole	57
Vapor Pressure (1625-2043 K)	$\text{Log } P_{\text{mm Hg}} = 8.657 - \frac{19,147}{T}$	60
Specific Heat (25 C)	6.92 cal/(mole)(C)	53
Heat of Combustion (25 C)	218.4 kcal/g-atom	57
Coefficient of Linear Thermal Expansion	$7.0 \times 10^{-6}/C$ (25-950 C)	61

90



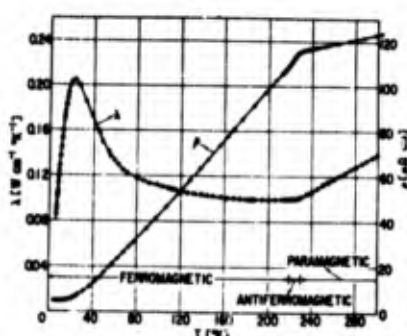
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Thermal Conductivity 0.031 cal/(cm<sup>2</sup>)(sec)(C/cm)

121

Thermal Conductivity and  
Electrical Resistivity  
Versus Temperature

121



(Permission of the American Physical Society)

Heat of Sublimation

Cohesive Energy

Work Function

Debye Temperature 181 K

97

Expansion on Melting

Surface Tension

#### CRYSTAL PROPERTIES

Structure Hcp 67

Lattice Constants  $a_0 = 3.6010 \text{ \AA}$  67

$c_0 = 5.6936 \text{ \AA}$

Density 8.253 g/cm<sup>3</sup> 67

Metallic Radius 1.782 \AA 67

Atomic Volume 19.245 cm<sup>3</sup>/mole 66

Transition Temperature 1317 C 66

Heat of Transition 1.06 kcal/mole 61

Ionic Radius (+3) = 0.923 \AA, (+4) = 0.91 \AA 55,93

Closest Approach of Atoms

3.508 Å

Authority

56

Allotropic Modifications

**CHEMICAL PROPERTIES**

Stable Oxidation State

+3, +4

81

Electrode Potential

[Tb = Tb<sup>+3</sup> + 3e<sup>-</sup>] +2.2 volts (standard hydrogen electrode)

81

Ionization Potential

1st = 6.7 volts

82

Metallurgical Polishing and Etching

62

Terbium, like gadolinium, requires no special precautions to prevent oxidation during sample preparation; however, a hydrofluoric acid etch is needed to show the grain structure.

Corrosion Rates (In Air)

0 mil/year at 200 C  
110 mil/year at 400 C  
6,960 mil/year at 600 C

68

Corrosion Data

**ELECTRICAL PROPERTIES**

Resistivity (18 C)

135.5 microhm-cm (18 C)

61

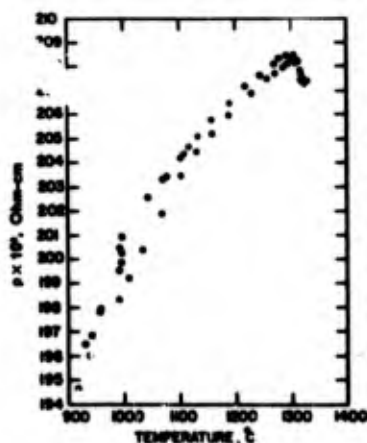
Temperature Coefficient of Resistivity

$0.91 \times 10^{-3} \text{ C}^{-1}$

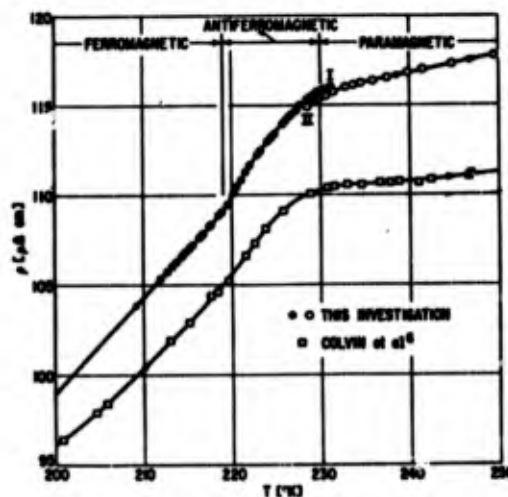
61

Resistivity Versus Temperature

87,121

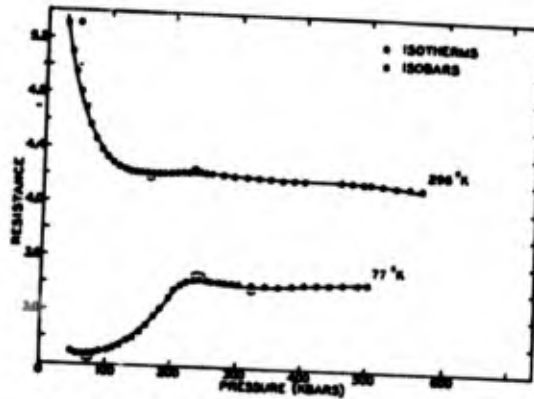


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Resistance Versus Pressure



(Permission of the American Physical Society)

MAGNETIC PROPERTIES

Susceptibility (25 C)	193,000 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 9.72 Bohr magnetons	61
	Measured 9.7 Bohr magnetons	
Curie Temperature	237 K	61
Néel Temperature	230 K	61

MECHANICAL PROPERTIES

Young's Modulus	5.75 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Shear Modulus	2.28 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Poisson's Ratio	0.261	61
Compressibility	2.45 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	57
Hardness (DPH)	46	57
Tensile Strength		
Yield Strength		
Elongation		
Ultimate Compressive Strength	101 x 10 <sup>3</sup> psi	61
Impact Strength (Izod)	3.2 ft-lb	71



Authority

Workability

General Fabrication (See references)

70,113

**NUCLEAR PROPERTIES**

Isotopes

58,110

<u>Whole-Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay Mode</u>
152	--	4.5 hr	K, X, e <sup>-</sup>
153	--	5.1 days	K, X, e <sup>-</sup>
154	--	17.5 hr	K, X, e <sup>-</sup> , γ, B <sup>+</sup>
155	--	1 yr	K, X, e <sup>-</sup>
159	100	Stable	
160	--	77 days	e <sup>-</sup> , γ, B <sup>-</sup>

Thermal Neutron Cross Section 44 ± 4 barns/atom or 0.166 cm<sup>2</sup>/g

73

**SAFETY**

83

Terbium

Toxicity - Unknown.

Fire hazard - Moderate in powder form.

Terbium Compounds

Details unknown. In general precautions should be taken appropriate to the anion present.

**THERMODYNAMIC PROPERTIES**

76,77

	<u>Room Temperature</u>	<u>Melting Point</u>
Entropy	S <sub>298</sub> = 17.5	S <sub>1700</sub> = 30.47 eu
Heat Capacity	C <sub>p298</sub> = 6.92	C <sub>p1700</sub> = 8.88 cal/(mole)(C)

Heat Capacities, cal/(K)(mole)

76

<u>10 K</u>	<u>25 K</u>	<u>50 K</u>	<u>100 K</u>	<u>150 K</u>	<u>200 K</u>	<u>208.15 K</u>
(.12)	1.82	5.10	7.56	8.90	11.20	6.92

Heat Content and Entropy of Solid  
and Liquid Terbium  
(Base: crystals at 298.15 K)

$T, K$	$H_T - H_{298.15},$ cal/mole	$S_T - S_{298.15},$ cal/(K)(mole)	$T, K$	$H_T - H_{298.15},$ cal/mole	$S_T - S_{298.15},$ cal/(K)(mole)
400	675	1.95	1500	9,160	11.86
500	1,360	3.46	1600	10,040	12.42
600	2,055	4.74	1700(s)	10,930	12.97
700	2,770	5.84	1700(l)	14,830	15.26
800	3,510	6.82	1800	15,630	15.71
900	4,260	7.71	1900	16,430	16.15
1000	5,030	8.52	2000	17,230	16.56
1100	5,820	9.28	2200	18,830	17.32
1200	6,630	9.98	2400	20,430	18.02
1300	7,450	10.64	2600	22,030	18.06
1400	8,300	11.26	2800	23,630	19.25

For solid terbium:

$$H_T - H_{298.15} = 6.00T + 0.90 \times 10^{-3}T^2 - 1,869$$

(0.1 percent; 298°-1,700°K);

$$C_p = 6.00 + 1.80 \times 10^{-3}T;$$

$$\Delta H_{1700}(\text{fusion}) = 3,900.$$

For liquid terbium:

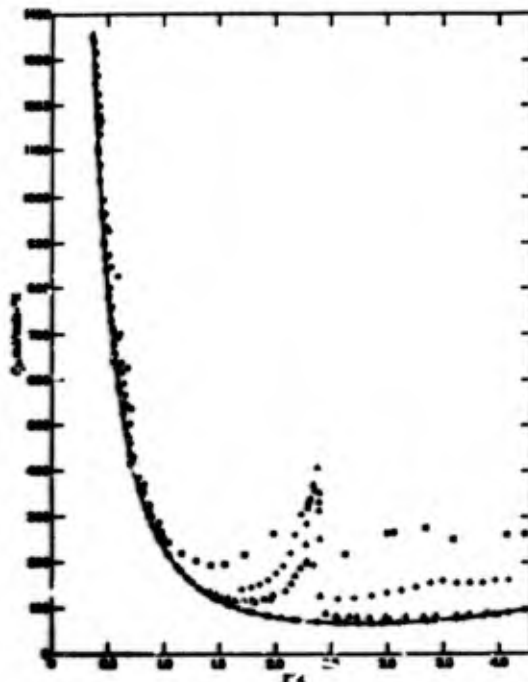
$$H_T - H_{298.15} = 8.00T + 1,230$$

(0.1 percent; 1,700°-2,800°K);

$$C_p = 8.00.$$

Specific Heat

(Permission of the American  
Physical Society)



(Results of several  
investigators)

$$\text{Solid curve: } C_p = 0.58T^3 + 9.05T + 238T^{-2} - 11.9T^{-3} - 4.5T^{-4} + 0.38T^{-5} + 0.06T^{-6}$$

## TERBIUM COMPOUNDS

		<u>Authority</u>
<b>Antimonides</b>		169
	<u>TbSb</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	6.180	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	36232	
Effective Magnetic Moment, Bohr magnetons	9.57	
<b>Arsenides</b>		169
	<u>TbAs</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	5.827	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	39033	
Effective Magnetic Moment, Bohr magnetons	9.65	
<b>Beryllides</b>		179
	<u>TbBe<sub>13</sub></u>	
$a_0$ , A	10.251	

	<u>Authority</u>			
<b>Bismuthides</b>	169			
	<u>TbBi</u>			
Structure	Cubic			
Lattice Type	NaCl			
$a_0$ , A	6.280			
Magnetic Susceptibility, $10^{-6}$ emu/mole	38086			
Effective Magnetic Moment, Bohr magneton	9.64			
<b>Borides</b>	153, 155			
	<u>TbB<sub>2</sub></u>	<u>TbB<sub>4</sub></u>	<u>TbB<sub>6</sub></u>	<u>TbB<sub>12</sub></u>
Molecular Weight	--	202.48	224.12	289.04
Structure	Hexagonal	Tetragonal	Cubic	Cubic
$a_0$ , A	3.28	7.118	4.1020	7.504
$c_0$ , A	3.86	4.0286	--	--
Density, g/cm <sup>3</sup>	--	6.579	5.385	--
Resistivity, microhm-cm	--	--	88.0	--
Temperature Coefficient of Resistivity, $10^{-3}/C$	--	--	1.31	--
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	0.048	--
Work Function, ev	--	--	2.99	--
Microhardness, kg/mm <sup>2</sup>	--	--	3500	--
Color	--	Gray brown	Blue	--
Emissivity ( $\lambda = 0.655 \mu$ )	--	--	0.74	--
Effective Metallic Radius, A	--	--	2.18	--

**Properties**

**Carbides**

Authority

153

	<u>TbC<sub>2</sub></u>	<u>Tb<sub>2</sub>C<sub>3</sub></u>	<u>Tb<sub>3</sub>C</u>
Molecular Weight	182.93	355.86	489.6
Structure	Body-centered tetragonal	Bcc	Cubic
Lattice Type	CaC <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>	Fe <sub>4</sub> N
a <sub>0</sub> , A	3.690	8.2617	5.107
c <sub>0</sub> , A	6.217	--	--
Density, g/cm <sup>3</sup>	7.176	8.335	8.882
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	~28500	--	--
Effective Magnetic Moment, Bohr magnetons	9.57	--	--

**Germanides**

183

	<u>Tb<sub>2</sub>Ge<sub>3</sub></u>
Lattice Type	AlB <sub>2</sub> defect
a <sub>0</sub> , A	3.95
c <sub>0</sub> , A	4.16
Volume of Unit Cell, A <sup>3</sup>	56.21

Halides								Authority
	<u>TbBr<sub>3</sub></u>	<u>TbCl<sub>3</sub></u>	<u>TbF<sub>3</sub></u>	<u>TbI<sub>3</sub></u>	<u>TbF<sub>4</sub></u>	<u>TbOCl</u>	<u>TbOF</u>	158,211, 235,236, 279,281
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Monoclinic	Tetragonal	Rhombohedral	
a <sub>0</sub> , Å	4.129	6.163	6.513	4.357	12.1	3.927	6.758	
b <sub>0</sub> , Å	--	3.848	6.949	--	10.3	--	--	
c <sub>0</sub> , Å	6.391	8.357	4.384	6.954	7.9	6.645	--	
β, deg	--	107.59	--	--	126	--	33.02	
Density, g/cm <sup>3</sup>	--	--	7.236	--	--	--	--	
Melting Point	(827)	588	1172	(952)	--	--	--	
Heat of Fusion, kcal/mole	(9)	(7)	(8)	(10)	--	--	--	
Entropy of Fusion, eu/mole	(8)	(8)	(5)	(8)	--	--	--	
Boiling Point, C	1490	1550	(2277)	1330	--	--	--	
Heat of Vaporization, kcal/mole	(44)	(45)	(60)	(40)	--	--	--	
Entropy of Vaporization, eu/mole	(25)	(25)	(24)	(25)	--	--	--	
Color	--	--	White	--	--	--	--	
Volume of Unit Cell, Å <sup>3</sup>	--	--	198.4	--	--	102.47	--	

## Hydrides

165

Structure	<u>TbH<sub>2</sub></u>	<u>TbH<sub>3</sub></u>
	Cubic	Hexagonal
a <sub>0</sub> , Å	5.246	3.700
c <sub>0</sub> , Å	--	6.658

**Properties**

Authority

Nitrides

153,223

	<u>TbN</u>
Molecular Weight	172.94
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	4.933
Density, g/cm <sup>3</sup>	9.567
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	42900
Effective Magnetic Moment, Bohr magnetons	9.5
Curie Temperature, K	38

Oxides

172,176,  
186,218,  
238

	<u>TbO<sub>2</sub></u>	<u>Tb<sub>2</sub>O<sub>3</sub></u>	<u>Tb<sub>4</sub>O<sub>7</sub></u>
Structure	--	Bcc	Cubic
$a_0$ , A	--	10.69	10.70
Density, g/cm <sup>3</sup>	--	7.81	--
Heat of Formation, kcal/mole metal	(231)	218.4	224.8
Entropy of Formation, eu/mole metal	(50)	(35.8)	(45)
Melting Point, C	--	2390	--
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	--	35800	30100
Effective Magnetic Moment, Bohr magnetons	--	9.7	--
Color	--	--	Dark brown

	<u>Authority</u>	
<b>Phosphides</b>	169	
	<u>TbP</u>	
Structure	Fcc	
Lattice Type	NaCl	
$a_0$ , A	5.686	
Magnetic Susceptibility, $10^{-6}$ emu/mole	39526	
Effective Magnetic Moment, Bohr magnetons	9.56	
<b>Selenides</b>	169	
	<u>TbSe</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	5.740	
Magnetic Susceptibility, $10^{-6}$ emu/mole	33755	
Effective Magnetic Moment, Bohr magnetons	9.82	
<b>Silicides</b>	263,264	
	<u>TbSi<sub>2</sub></u>	<u>TbSi<sub>2-n</sub></u>
Structure	Ortho- rhombic	Hexagonal
Lattice Type	$\alpha$ -YSi <sub>2</sub>	AlB <sub>2</sub> defect
$a_0$ , A	4.045	3.847
$b_0$ , A	3.96	--
$c_0$ , A	13.38	4.146
Volume of Unit Cell, A <sup>3</sup>		53.1



Authority

Sulfides

153,169

	<u>TbS</u>	<u>Tb<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	--	381.93
Structure	Fcc	Hexagonal
Lattice Type	NaCl	--
a <sub>0</sub> , A	5.517	3.825
c <sub>0</sub> , A	--	6.626
Density, g/cm <sup>3</sup>	--	7.56
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	35088	--
Effective Magnetic Moment, Bohr magnetons	9.63	--

Tellurides

169

	<u>TbTe</u>
Structure	Fcc
Lattice Type	NaCl
a <sub>0</sub> , A	6.101
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	38760
Effective Magnetic Moment, Bohr magnetons	9.57

**DYSPROSIUM**

Symbol Dy

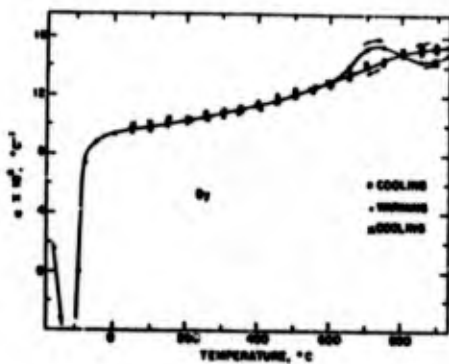
Atomic Number 66

Atomic Weight 162.51

Authority

**PHYSICAL PROPERTIES**

Abundance	4.5-7.5 ppm (approx. 5)	51
Density	8.559 g/cm <sup>3</sup>	67
Melting Point	1407 C	66
Heat of Fusion	3.8 kcal/mole	61
Boiling Point	2600 C	57
Heat of Vaporization (25 C)	67 kcal/mole	57
Vapor Pressure (1257-1690 K)	$\text{Log } P_{\text{mm Hg}} = 8.882 - \frac{15,090}{T}$	60
Specific Heat (25 C)	6.73 cal/(mole)(C)	76
Heat of Combustion	222.92 kcal/g-atom	134
Coefficient of Linear Thermal Expansion	$8.6 \times 10^{-6}/\text{C}$	61



90

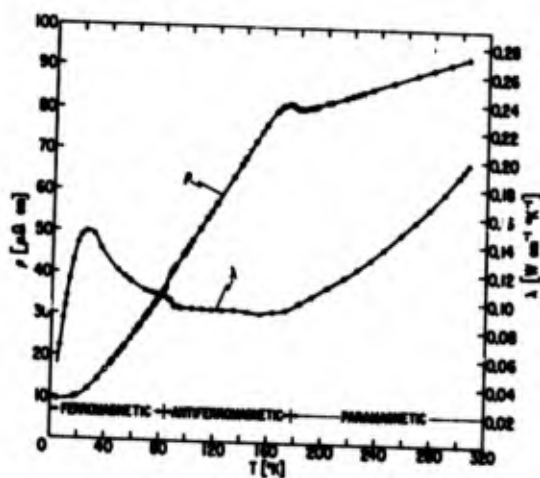
Thermal Conductivity (28 C) 0.024 cal/(cm<sup>2</sup>)(sec)(C/cm)

115

Authority

128

Thermal Conductivity and Electrical Resistivity  
Versus Temperature



Heat of Sublimation

Cohesive Energy

72 kcal/mole

89

Work Function

Debye Temperature

186 K

97

Expansion on Melting

Surface Tension

## CRYSTAL PROPERTIES

Structure

Hcp

61

Lattice Constants

 $a_0 = 3.5903 \text{ \AA}$ 

61

 $c_0 = 5.6475 \text{ \AA}$ 

61

Density

8.559 g/cm<sup>3</sup>

67

Metallic Radius

1.773 \AA

67

Atomic Volume

19.032 cm<sup>3</sup>/mole

66

Transition Temperature

Heat of Transition

**Properties**

249

		<u>Authority</u>
Ionic Radius (Trivalent Ion)	0.908 A	55
Closest Approach of Atoms	3.499 A	56
Allotropic Modifications	(1) Resistivity measurements indicate a structural change at high temperature	66
	(2) Hcp transforms to orthorhombic when temperature is lowered to 86 K. $b/a = 1.732$	124

**CHEMICAL PROPERTIES**

Stable Oxidation State	+3	81			
Electrode Potential	$[Dy = Dy^{+3} + 3e^{-}] + 2.2$ volts (standard hydrogen electrode)	81			
Ionization Potential	1st = 6.8 volts	82			
Metallographic Polishing and Etching	Dysprosium exhibits considerable resistance to oxidation and to etching. The most satisfactory etch is based on hydrofluoric acid.	62			
Corrosion Rates (In Air)	59 mil/year at 400 C 1110 mil/year at 600 C	68			
Corrosion Data	Corrosive attack on crucible materials:	91			
	<table border="0" style="margin-left: 2em;"> <thead> <tr> <th style="text-align: center;"><u>Material</u></th> <th style="text-align: center;"><u>Onset of Attack</u></th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">Ta</td> <td style="text-align: center;">None &lt;1400 C</td> </tr> </tbody> </table>	<u>Material</u>	<u>Onset of Attack</u>	Ta	None <1400 C
<u>Material</u>	<u>Onset of Attack</u>				
Ta	None <1400 C				

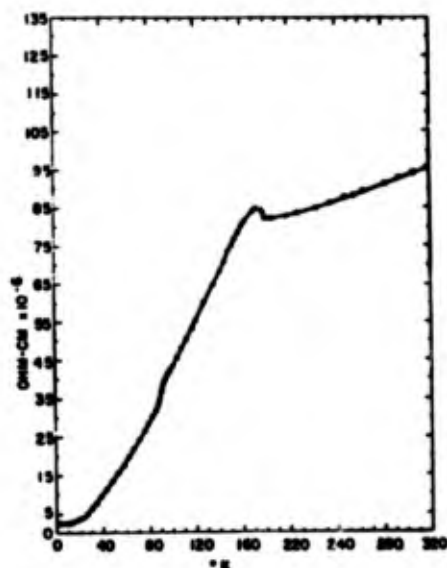
**ELECTRICAL PROPERTIES**

Resistivity (25 C)	56 microhm-cm	61
Temperature Coefficient of Resistivity	$1.19 \times 10^{-3}/C$	61

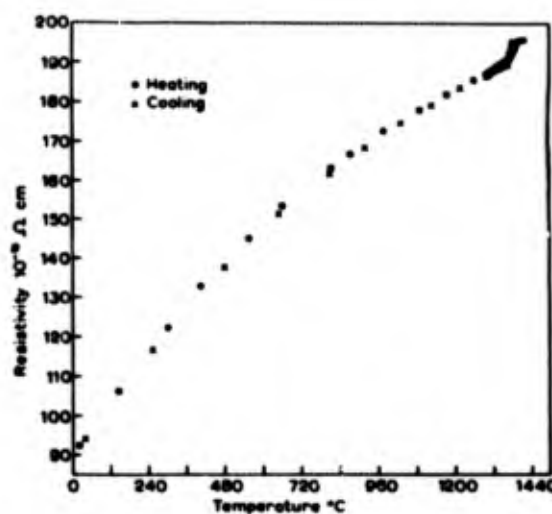
Authority

## Resistivity Versus Temperature

117, 127



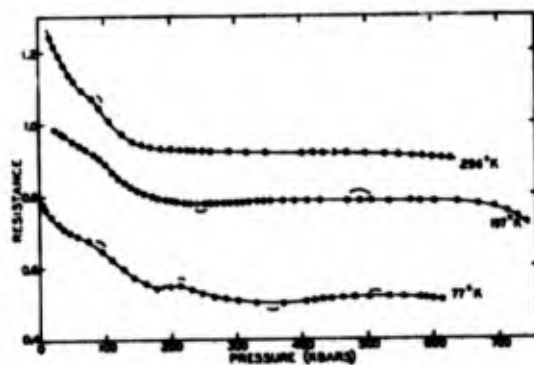
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## Resistance Versus Pressure

96



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## MAGNETIC PROPERTIES

Susceptibility (25 C)	$99,800 \times 10^{-6}$ emu/mole	61
Effective Magnetic Moment	Theoretical 10.6 Bohr magnetons Measured 10.64 Bohr magnetons	61
Curie Temperature	85 K	61
Néel Temperature	178.5 K	61

Authority**MECHANICAL PROPERTIES**

Young's Modulus	6.31 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Shear Modulus	2.54 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Poisson's Ratio	0.243	61
Compressibility	2.39 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	57
Hardness (DPH)	42	57
	<u>70 F</u> <u>400 F</u>	
Tensile Strength	35.7      30.8      10 <sup>3</sup> psi	88
Yield Strength	32.6      20.8      10 <sup>3</sup> psi	88
Elongation	6      8.3      per cent	88
Ultimate Compressive Strength	73.8      10 <sup>3</sup> psi	61
Impact Strength (Izod)	1.6 ft-lb	71
Workability	Fair	88
General Fabrication	(See references)	70, 113

**NUCLEAR PROPERTIES**

Isotopes 58, 123

<u>Whole- Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay Mode</u>
156	0.0524	Stable	--
158	0.0902	Stable	--
160	2.294	Stable	--
161	18.88	Stable	--
162	25.53	Stable	--
163	24.97	Stable	--
164	28.18	Stable	--
165	--	2.4 hr	β <sup>-</sup> , e <sup>-</sup> , γ

Thermal Neutron Cross Section 1100 ± 150 barns/atom or 4.1 cm<sup>2</sup>/g 73

Authority

## SAFETY

Dysprosium and its compounds - Toxicity unknown. The hazards are unknown except where precautions are required because of the anion present.

## THERMODYNAMIC PROPERTIES

	<u>Room Temperature</u>	<u>Melting Point</u>	76, 77
Entropy	$S_{298} = 17.9$	$S_{1773} = 31.1$ eu	
Heat Capacity	$C_{p298} = 6.73$	$C_{p1173} = 9.02$ cal/mole C	
Heat Capacities, cal/(K)(mole)			76
	<u>10 K</u>	<u>25 K</u>	<u>50 K</u>
	<u>100 K</u>	<u>150 K</u>	<u>200 K</u>
	<u>298.15 K</u>		
	(0.18)	2.20	5.52
	8.32	10.88	6.97
			6.73

Heat Content and Entropy of Solid and Liquid Dysprosium 77  
(Base: crystals at 298.15 K)

<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K)(mole)</u>	<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K)(mole)</u>
400	670	1.93	1500	9,050	11.74
500	1,350	3.45	1600	9,910	12.29
600	2,040	4.70	1700	10,790	12.82
700	2,750	5.80	1773(s)	11,440	13.20
800	3,480	6.77	1773(l)	15,540	15.51
900	4,220	7.65	1800	15,760	15.63
1000	4,980	8.45	1900	16,560	16.07
1100	5,760	9.19	2000	17,350	16.48
1200	6,560	9.88	2200	18,360	17.24
1300	7,370	10.53	2400	20,560	17.93
1400	8,200	11.15	2600	21,160	18.57

$$H_T - H_{298.15} = 6.00T + 0.85 \times 10^{-3}T^2 - 1,864$$

(0.1 percent; 298-1773 K);

$$C_p = 6.00 + 1.70 \times 10^{-3}T;$$

$$H_{1773}(\text{fusion}) = 4,100.$$

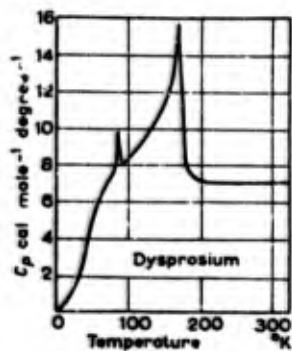
$$H_T - H_{298.15} = 8.00T + 1,360$$

(0.1 percent; 1773-2600 K);

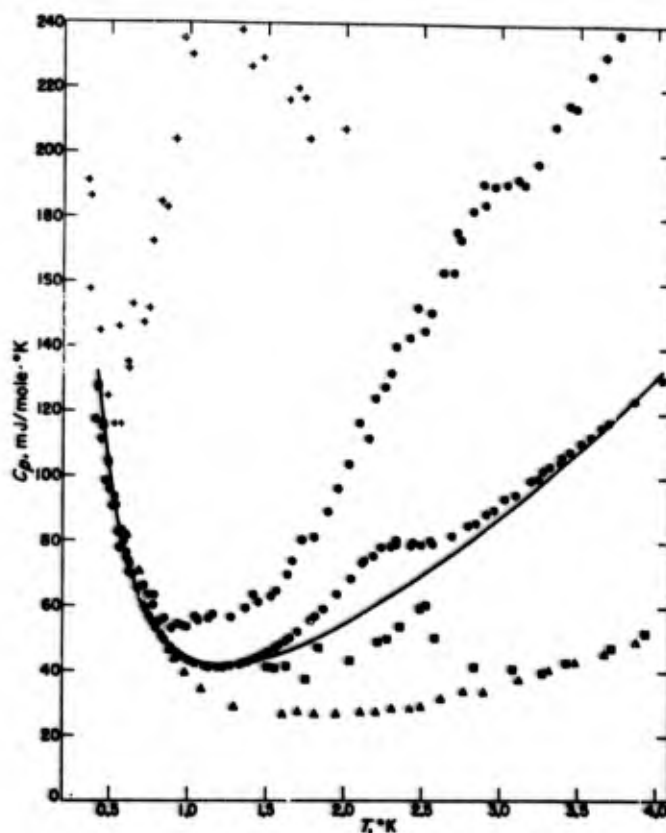
$$C_p = 8.00.$$

Specific Heat

53, 125



0 - 300 K



(Permission of the American Physical Society; results of several investigators are reported.)

DYSPROSIUM COMPOUNDS

Antimonides

169

	<u>DySb</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	6.160
Magnetic Susceptibility $10^{-6}$ emu/mole	4558
Magnetic Moment, Bohr magnetons	10.62



		<u>Authority</u>
<b>Arsenides</b>		169
	<u>DyAs</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	5.803	
Magnetic Susceptibility, $10^{-6}$ emu/mole	46948	
Magnetic Moment, Bohr magnetons	10.51	
<b>Beryllides</b>		179
	<u>DyBe<sub>13</sub></u>	
$a_0$ , A	10.240	
<b>Bismuthides</b>		169
	<u>DyBi</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	6.251	
Magnetic Susceptibility, $10^{-6}$ emu/mole	44,053	
Magnetic Moment, Bohr magnetons	10.97	

Authority

Borides

153,154,  
155,171

	<u>DyB<sub>2</sub></u>	<u>DyB<sub>4</sub></u>	<u>DyB<sub>6</sub></u>	<u>DyB<sub>12</sub></u>
Molecular Weight	184. 10	205. 74	227. 38	292. 30
Structure	Hexagonal	Tetragonal	Cubic	Cubic
a <sub>0</sub> , A	3. 285	7. 101	4. 0976	7. 501
c <sub>0</sub> , A	3. 835	4. 0174	--	--
Density, g/cm <sup>3</sup>	--	6. 74	5. 49	4. 60
Work Function, ev	--	--	3. 53	--
Color	--	Gray brown	Blue	--
Emissivity (λ = 0. 655 μ)	--	--	0. 7	--
Effective Metallic Radius, A	--	--	2. 18	--

Carbides

153

	<u>Dy<sub>3</sub>C</u>	<u>Dy<sub>2</sub>C<sub>3</sub></u>	<u>DyC<sub>2</sub></u>
Molecular Weight	499. 38	360. 92	186. 46
Structure	Cubic	Bcc	Body-centered tetragonal
Lattice Type	Fe <sub>4</sub> N	Pu <sub>2</sub> C <sub>3</sub>	CaC <sub>2</sub>
a <sub>0</sub> , A	5. 079	8. 198	3. 669
c <sub>0</sub> , A	--	--	6. 176
Density, g/cm <sup>3</sup>	9. 211	--	7. 450
Magnetic Suscep- tibility, 10 <sup>-6</sup> emu/mole	--	--	~38500
Magnetic Moment, Bohr magnetons	--	--	10. 53

Germanides	<u>Authority</u>	
	183,262	
	<u>DyGe</u>	<u>Dy<sub>2</sub>Ge<sub>3</sub></u>
Structure	Orthorhombic	--
Lattice Type	CrB	Defective AlB <sub>2</sub>
a <sub>0</sub> , Å	4.112	3.92
b <sub>0</sub> , Å	3.924	--
c <sub>0</sub> , Å	10.81	4.13
Volume of Unit Cell, Å <sup>3</sup>	174.4	54.96

## Halides

	93,108, 157,158, 209,210, 211,235, 236					
	<u>DyBr<sub>3</sub></u>	<u>DyCl<sub>3</sub></u>	<u>DyF<sub>3</sub></u>	<u>DyI<sub>3</sub></u>	<u>DyOCl</u>	<u>DyOF</u>
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Tetragonal	Rhombohedral
a <sub>0</sub> , Å	4.114	6.91	6.460	4.335	3.911	--
b <sub>0</sub> , Å	--	11.97	6.906	--	--	--
c <sub>0</sub> , Å	6.400	6.40	4.376	6.958	6.620	--
β, deg	--	111.2	--	--	--	--
Density, g/cm <sup>3</sup>	--	--	7.456	--	--	--
Melting Point, C	881	654	1154	955	--	--
Heat of Fusion, kcal/mole	9	7	8	10	--	--
Boiling Point, C	1480	1530	2230	1320	--	--
Heat of Vaporization, kcal/mole	44	45	60	41	--	--
Entropy of Fusion, eu/mole	8	8	5	8	--	--
Entropy of Vaporization, eu/mole	25	25	24	25	--	--
Color	--	--	Light green	--	--	--
Volume of Unit Cell, Å <sup>3</sup>	--	--	195.2	--	101.26	--

**Properties**

**257**

Authority

**Hydrides**

165, 265

	<u>DyH<sub>2</sub></u>	<u>DyH<sub>3</sub></u>
Structure	Cubic	Hexagonal
a <sub>0</sub> , A	5.201	3.671
c <sub>0</sub> , A	--	6.615
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	46,700	38,900
Magnetic Moment, Bohr magnetons	10.8	9.5
Néel Temperature, K	8	--

**Nitrides**

149,153,  
223

	<u>DyN</u>
Molecular Weight	176.52
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	4.905
Density, g/cm <sup>3</sup>	9.567
Resistivity, microhm-cm	100
Temperature Coefficient of Resistivity (300-750 K), 10 <sup>-3</sup> /C	0.75 x 10 <sup>-3</sup>
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	48,900
Magnetic Moment, Bohr magnetons	10.6
Curie Temperature, K	22

## Oxides

Authority156,172  
173,176,  
177,245

	<u>Dy<sub>2</sub>O<sub>3</sub></u>
Molecular Weight	373.0
Structure	Bcc
a <sub>0</sub> , A	10.63
Density, g/cm <sup>3</sup>	7.81
Melting Point, C	2340
Heat of Formation, kcal/mole metal	222.92
Entropy of Formation, eu/mole metal	(35.7)
Heat Capacity, cal/(mole)(C)	28.05 (300 K) 3450 (2300 C)
Coefficient of Thermal Expansion (20-1300 C), 10 <sup>-6</sup> /C	7.7
Magnetic Moment, Bohr magnetons	10.6
Color	White

Heat-Content and Entropy Values for Dysprosium Oxide  
(Smooth Values)

245

T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)	T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)
400	2,920	8.42	1400	34,720	47.77
500	5,900	15.06	1500	38,120	50.11
600	8,960	20.64	1590(α)	41,220	52.12
700	12,070	25.43	1590(β)	41,440	52.26
800	15,210	29.63	1600	41,780	52.47
900	18,380	33.36	1700	45,230	54.57
1000	21,580	36.73	1800	48,680	56.54
1100	24,810	39.81	1900	52,130	58.40
1200	28,070	42.65	2000	55,580	60.17
1300	31,370	45.29			

**Properties**

**259**

**Phosphides**

Authority

169

	<u>DyP</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	5.654
Magnetic Susceptibility $10^{-6}$ emu/mole	46729
Magnetic Moment, Bohr magnetons	10.34

**Selenides**

166, 168,  
169, 192,  
194, 213

	<u>DySe</u>	<u>Dy<sub>2</sub>Se<sub>3</sub></u>	<u>Dy<sub>2</sub>O<sub>2</sub>Se</u>
Structure	Cubic	Orthorhombic	Hcp
Lattice Type	NaCl	--	--
$a_0$ , A	5.711	3.69	3.83
$b_0$ , A	--	10.85	--
$c_0$ , A	--	11.0	6.79
Density, g/cm <sup>3</sup>	--	7.21	8.39
Magnetic Susceptibility $10^{-6}$ emu/mole	40984	43250	--
Magnetic Moment, Bohr Magnetons	10.37	10.40	--
Color	--	Blue black	Light gray

## Silicides

Authority

	<u><math>\alpha</math>-DySi<sub>2</sub></u>	<u><math>\beta</math>-DySi<sub>2</sub></u>	<u>DySi<sub>2-n</sub></u>
Molecular Weight	218.62	218.62	--
Structure	Orthorhombic	Tetragonal	Hexagonal
Lattice Type	$\alpha$ -YSi <sub>2</sub>	$\alpha$ -ThSi <sub>2</sub>	AlB <sub>2</sub> defect
a <sub>0</sub> , Å	4.04	4.03	3.83
b <sub>0</sub> , Å	3.95		
c <sub>0</sub> , Å	13.34	13.38	4.11
Density, g/cm <sup>3</sup>	6.8	6.68	--
Melting Point, C	--	1550	--
Transition Temperature, C	$\alpha \rightarrow \beta \rightarrow 540$	--	--
Resistivity, microhm-cm	3020	--	--
Superficial Hardness, Rockwell A	80	--	--
Transverse Rupture Strength, 10 <sup>3</sup> psi	9.5	--	--
Volume of Unit Cell, Å <sup>3</sup>	--	--	52.2

152,153,  
160,264

Sulfides							<u>Authority</u>
	<u>DyS</u>	<u>Dy<sub>5</sub>S<sub>7</sub></u>	<u>γ-Dy<sub>2</sub>S<sub>3</sub></u>	<u>δ-Dy<sub>2</sub>S<sub>3</sub></u>	<u>DyS<sub>2</sub></u>	<u>Dy<sub>2</sub>O<sub>2</sub>S</u>	153,169, 227
Molecular Weight	194.51	1037.01	421.22	421.22	226.64	389.09	
Structure	Fcc	Monoclinic	Bcc	Monoclinic	Tetragonal	Hexagonal	
Lattice Type	NaCl	--	Th <sub>3</sub> P <sub>4</sub>	--	--	--	
a <sub>0</sub> , Å	5.490	12.84	8.292	10.17	7.69	3.803	
b <sub>0</sub> , Å	--	3.81	--	4.01	--	--	
c <sub>0</sub> , Å	--	11.61	--	17.57	7.85	6.603	
β, deg	--	74	--	--	--	--	
Density, g/cm <sup>3</sup>	--	6.14	6.54	5.75	6.11	7.84	
Melting Point, C	--	1540	1480	--	--	--	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	40000	--	47700	--	--	--	
Magnetic Moment, Bohr magnetons	10.39						

Tellurides					169,202, 205,242
	<u>DyTe</u>	<u>DyTe<sub>2-n</sub></u>	<u>Dy<sub>3</sub>Te<sub>4</sub></u>	<u>Dy<sub>2</sub>O<sub>2</sub>Te</u>	
Structure	Fcc	--	--	Hexagonal	
Lattice Type	NaCl	--	--	--	
a <sub>0</sub> , Å	6.075	4.29	--	3.92	
c <sub>0</sub> , Å		8.91		12.38	
Density, g/cm <sup>3</sup>	--	--	--	8.46	
Resistivity, microhm-cm	--	--	3.1 x 10 <sup>3</sup>	--	
Magnetic Suscep- tibility, 10 <sup>-6</sup> emu/ mole	45977	--	--	--	
Magnetic Moment, Bohr magnetons	10.47	--	--	--	
Color	--	--	--	Maroon	



Authority

## Miscellaneous

262

<u>Compound</u>	<u>Structure</u>	<u>Lattice Type</u>	<u>a<sub>0</sub>, Å</u>	<u>b<sub>0</sub>, Å</u>	<u>c<sub>0</sub>, Å</u>	<u>Volume of Unit Cell, Å<sup>3</sup></u>
DyAg <sub>2</sub>	Tetragonal	MoSi <sub>2</sub>	3.6957	--	9.213	125.8
DyAu <sub>2</sub>	Tetragonal	MoSi <sub>2</sub>	3.6940	--	8.956	122.2
DyGa	Orthorhombic	CrB	4.300	4.067	10.89	190.4
DyGa <sub>2</sub>	Hexagonal	AlB <sub>2</sub>	4.2011	--	4.0655	62.14
DyIn	--	CsCl	3.7866	--	--	54.29
DyIn <sub>3</sub>	--	AuCu <sub>3</sub>	4.5762	--	--	95.83
Dy <sub>3</sub> In	Tetragonal	CuTl <sub>3</sub>	4.602	--	4.495	104.7
DyMn <sub>2</sub>	--	MgCu <sub>2</sub>	7.5731	--	--	434.33
DyPt	Orthorhombic	FeB	5.466	4.453	7.118	173.3
DyPt <sub>2</sub>	--	MgCu <sub>2</sub>	7.5966	--	--	438.39
DyPt <sub>3</sub>	--	AuCu <sub>3</sub>	4.072	--	--	67.52
DyTl	--	CsCl	3.7866	--	--	54.29
DyTl <sub>3</sub>	--	AuCu <sub>3</sub>	4.6720	--	--	101.98

**HOLMIUM**

Symbol Ho

Atomic Number 67

Atomic Weight 164.94

**PHYSICAL PROPERTIES**

		<u>Authority</u>
Abundance	0.7-1.2 ppm	51
Density	8.799 g/cm <sup>3</sup>	67
Melting Point	1461 C	66
Heat of Fusion	4.1 kcal/mole	61
Boiling Point	2600 C	57
Heat of Vaporization (25 C)	67 kcal/mole	57
Vapor Pressure		
Specific Heat (25 C)	6.49 cal/(mole)(C)	76
Heat of Combustion	224.78 kcal/g-atom	134
Coefficient of Linear Thermal Expansion (20-708 C)	9.5 x 10 <sup>-6</sup> /C	61
Thermal Conductivity		
Heat of Sublimation (25 C)	75.04 kcal/mole	130
Cohesive Energy	75.5 kcal/mole	130
Work Function		
Debye Temperature	191 K	97
Expansion on Melting		
Surface Tension		

## CRYSTAL PROPERTIES

Authority

Structure	Hcp	61
Lattice Constants	$a_0 = 3.5773 \text{ \AA}$ $c_0 = 5.6158 \text{ \AA}$	61
Density	$8.799 \text{ g/cm}^3$	67
Metallic Radius	1.766 $\text{\AA}$	67
Atomic Volume	$18.742 \text{ cm}^3/\text{mole}$	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ion)	0.894 $\text{\AA}$	55
Closest Approach of Atoms	3.480 $\text{\AA}$	56
Allotropic Modifications	(1) Resistivity measurements indicate a structural change at high temperature.	

## CHEMICAL PROPERTIES

Stable Oxidation State	+3	81
Electrode Potential	$[\text{Ho} = \text{Ho}^{+3} + 3e^-] + 2.1 \text{ volts}$ (standard hydrogen electrode)	81
Ionization Potential		
Metallographic Polishing and Etching	Holmium exhibits considerable resistance to oxidation and to etching. The most satisfactory etch is based on hydrofluoric acid.	62
Corrosion Rates (In Air)	2 mil/year up to 200 C 18 mil/year at 400 C 880 mil/year at 600 C	68
Corrosion Data		

**Properties**

**ELECTRICAL PROPERTIES**

Authority

Resistivity (25 C) 87 microhm-cm

61

Temperature Coefficient of Resistivity  $1.71 \times 10^{-3}/C$

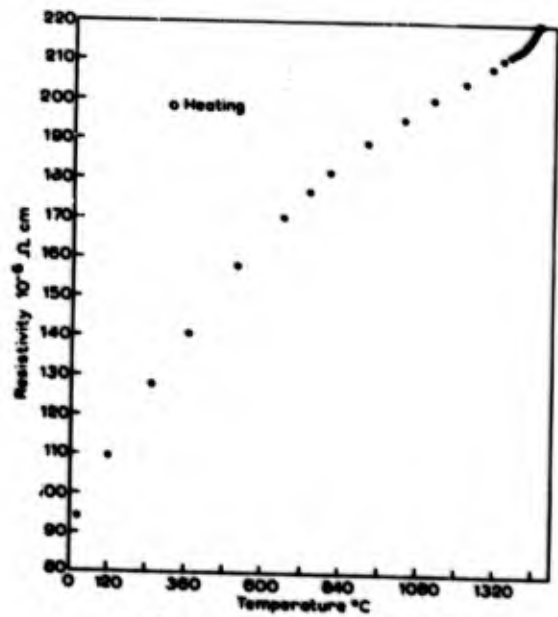
61

Resistivity Versus Temperature

117,127



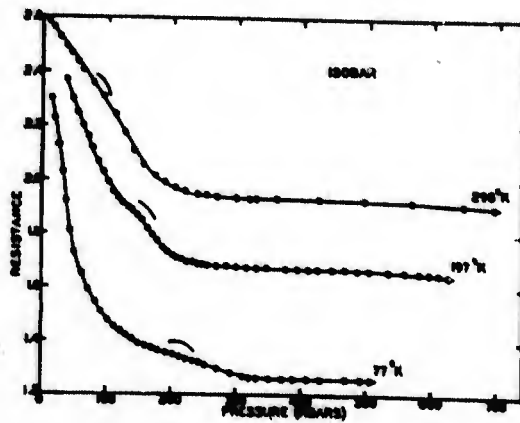
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Resistance Versus Pressure  
(Permission of the American Physical Society)

96



## MAGNETIC PROPERTIES

		<u>Authority</u>
Susceptibility (25 C)	70,200 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 10.6 Bohr magnetons Measured 10.89 Bohr magnetons	61
Curie Temperature	<20 K	61
Néel Temperature	133 K	61
<b>MECHANICAL PROPERTIES</b>		
Young's Modulus (Y)	6.71 dynes/cm <sup>2</sup>	57
Shear Modulus	2.67 dynes/cm <sup>2</sup>	57
Poisson's Ratio ( $\nu$ )	0.266	
Compressibility ( $\beta$ )	2.14 x 10 <sup>-6</sup> cm <sup>2</sup> /kg (calculated from $\beta = \frac{3(1-2\nu)}{Y}$ )	57
Hardness (DPH)	42	57
Tensile Strength	<u>70 F</u>	
	37.5	88
Yield Strength	<u>400 F</u>	
	30.8 10 <sup>3</sup> psi	88
Elongation	32.1	88
	24.6 10 <sup>3</sup> psi	88
Ultimate Compressive Strength	5	88
	6 per cent	88
Impact Strength (Izod)	72.4 10 <sup>3</sup> psi	61
	7 ft-lb	71
Workability		
General Fabrication	(See references)	70, 113

NUCLEAR PROPERTIES

Authority

Isotopes

111, 116

Whole-Number Mass	Relative Abundance, percent	Half Life	Decay Mode
160	--	20 min	K, X
161	--	60 days	K, X, $\gamma$ , $e^-$
162	--	4.5 hr	K, X, $\gamma$ , $e^-$ , $\beta^+$
163	--	7 days	K, X, $\gamma$ , $e^-$
164	--	35 min	$\beta^-$
165	100	Stable	--
166	--	27.5 hr	$\beta^-$ , $\gamma$

Thermal Neutron Cross Section

64 ± 3 barns/atom or 0.23 cm<sup>2</sup>/g

73

SAFETY

Details unknown.

83

THERMODYNAMIC PROPERTIES

	Room Temperature	Melting Point					
Entropy	S <sub>298</sub> = 18.0	S <sub>1773</sub> = 31.2 eu	76, 77				
Heat Capacity	C <sub>p298</sub> = 6.49	C <sub>p1773</sub> = 9.02 cal/(mole)(C)					
Heat Capacities, cal/(K)(mole)			76				
	<u>10 K</u>	<u>25 K</u>	<u>50 K</u>	<u>100 K</u>	<u>150 K</u>	<u>200 K</u>	<u>298.15 K</u>
	(.52)	3.03	5.86	9.36	6.35	6.33	6.49

Heat Content and Entropy of Solid and Liquid Holmium

77

(Base: crystals at 298.15 K)

T, K	H <sub>T</sub> -H <sub>298.15</sub> <sup>o</sup> cal/mole	S <sub>T</sub> -S <sub>298.15</sub> <sup>o</sup> cal/(K)(mole)	T, K	H <sub>T</sub> -H <sub>298.15</sub> <sup>o</sup> cal/mole	S <sub>T</sub> -S <sub>298.15</sub> <sup>o</sup> cal/(K)(mole)
400	670	1.94	1600	9,050	11.74
500	1,350	3.44	1670	9,910	12.29
600	2,040	4.71	1700	10,790	12.83
700	2,750	5.80	1773(s)	11,440	13.20
800	3,480	6.77	1773(l)	15,540	15.52
900	4,420	7.65	1800	15,760	15.64
1000	4,985	8.45	2000	17,360	16.49
1100	5,760	9.19	2200	18,960	17.25
1200	6,560	9.89	2400	20,560	17.94
1300	7,370	10.54	2600	22,160	18.58
1400	8,200	11.15			

(Continued)

## Heat Content and Entropy of Solid and Liquid Holmium (Continued)

77

For solid holmium:

$$H_T - H_{298.15} = 6.00 T + 0.85 \times 10^{-3} T^2 - 1,864$$

(0.1 percent; 298-1773 K);

$$C_p = 6.00 + 1.70 \times 10^{-3} T;$$

$$H_{1773}(\text{fusion}) = 4,100.$$

For liquid holmium:

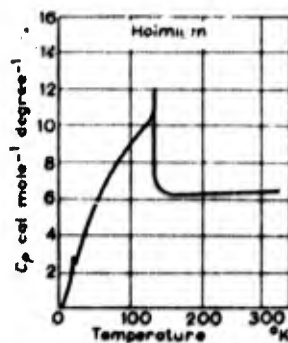
$$H_T - H_{298.15} = 8.00 T + 1,360$$

(0.1 percent; 1773-2600 K);

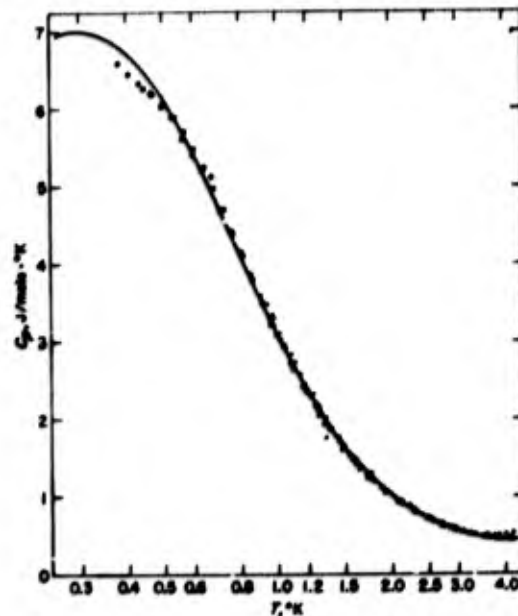
$$C_p = 8.00.$$

## Specific Heat

53,129



0 to 300 K



## HOLMIUM COMPOUNDS

## Antimonides

169

	<u>HoSb</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , Å	6.130
Magnetic Susceptibility, $10^{-6}$ emu/mole	44,743
Magnetic Moment, Bohr magnetons	10.35

Authority

Arsenides

169

	<u>HoAs</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	5.771
Magnetic Susceptibility, $10^{-6}$ emu/mole	46,080
Magnetic Moment, Bohr magnetons	10.47

Beryllides

179

	<u>HoBe<sub>13</sub></u>
$a_0$ , A	10.220

Bismuthides

169

	<u>HoBi</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	6.228
Magnetic Susceptibility, $10^{-6}$ emu/mole	44,543
Magnetic Moment, Bohr magnetons	10.32

Borides

153, 155

	<u>HoB<sub>2</sub></u>	<u>HoB<sub>4</sub></u>	<u>HoB<sub>6</sub></u>	<u>HoB<sub>12</sub></u>
Molecular Weight	175.26	206.78	228.42	294.78
Structure	Hexag- onal	Tetrag- onal	Cubic	Cubic
$a_0$ , A	3.17	7.064	4.096	7.492
$c_0$ , A	3.81	4.000	--	--
Density, g/cm <sup>3</sup>	--	6.88	5.53	4.655
Coefficient of Thermal Expansion, $10^{-6}/C$	--	--	3.0	--

(Continued)



Authority

## Borides (Continued)

	<u>HoB<sub>2</sub></u>	<u>HoB<sub>4</sub></u>	<u>HoB<sub>6</sub></u>	<u>HoB<sub>12</sub></u>
Work Function, ev	--	--	3.42	--
Color	--	Gray brown	Blue	--
Emissivity ( $\lambda = 0.665 \mu$ )	--	--	--	0.7
Effective Metallic Radius, $\text{\AA}$	--	--	2.17	--

153

## Carbides

	<u>HoC<sub>2</sub></u>	<u>Ho<sub>2</sub>C<sub>3</sub></u>	<u>Ho<sub>3</sub>C</u>
Molecular Weight	188.94	365.88	506.82
Structure	Body-centered tetragonal	Bcc	Cubic
Lattice Type	CaC <sub>2</sub>	Pu <sub>2</sub> C <sub>3</sub>	Fe <sub>4</sub> N
$a_0$ , A	3.643	8.176	5.061
$c_0$ , A	6.139	--	--
Density, g/cm <sup>3</sup>	7.701	8.892	9.434
Magnetic Susceptibility, $10^{-6}$ emu/mole	~43,500	--	--
Magnetic Moment, Bohr magnetons	10.57	--	--

183

## Germanides

	<u>Ho<sub>2</sub>Ge<sub>3</sub></u>
Lattice Type	Defective AlB <sub>2</sub>
$a_0$ , A	3.90
$c_0$ , A	4.11
Volume of Unit Cell, A <sup>3</sup>	54.14

Authority

Halides

	<u>HoBr<sub>3</sub></u>	<u>HoCl<sub>3</sub></u>	<u>HoF<sub>3</sub></u>		<u>HoI<sub>3</sub></u>	<u>HoOCl</u>	93, 108, 158, 182, 209, 210, 235, 236
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Hexagonal	Tetragonal	
a <sub>0</sub> , A	4.088	6.85	6.404	6.833	4.319	3.893	
b <sub>0</sub> , A	--	11.85	6.875	--	--	--	
c <sub>0</sub> , A	6.391	6.39	4.379	6.984	6.946	6.602	
β, deg	--	110.8	--	--	--	--	
Density, g/cm <sup>3</sup>	--	--	7.644	7.829	--	--	
Melting Point, C	914	720		1143	1010	--	
Heat of Fusion, kcal/mole	10	7.0		8	10	--	
Boiling Point, C	1470	1510		2230	1300	--	
Heat of Vaporization, kcal/mole	43	44		60	41	--	
Entropy of Fusion, eu/mole	8	7.1		5	8	--	
Entropy of Vaporization, eu/mole	25	25		24	26	--	
Heat Capacity, cal/(mole)(C)	--	29.0		--	--	--	
Volume of Unit Cell, A <sup>3</sup>	--	485	192.8	282.4	--	100.06	
Color	--	--	Brown pink	--	--	--	

Authority

## Hydrides

165

	<u>HoH<sub>2</sub></u>	<u>HoH<sub>3</sub></u>
Structure	Cubic	Hexagonal
a <sub>0</sub> , A	5.165	3.642
c <sub>0</sub> , A	--	6.560

## Nitrides

149, 153,  
223

	<u>HoN</u>
Molecular Weight	178.95
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	4.87
Density, g/cm <sup>3</sup>	10.26
Resistivity, microhm-cm	110
Temperature Coefficient of Resistivity (300-1500 K), 10 <sup>-3</sup> /C	1
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	47,800
Magnetic Moment, Bohr magnetons	10.3
Curie Temperature, K	19

## Oxides

156, 172,  
177, 259,  
266

	<u>Ho<sub>2</sub>O<sub>3</sub></u>
Structure	Bcc
a <sub>0</sub> , A	10.58
Density, g/cm <sup>3</sup>	8.36
Heat of Formation, kcal/mole	224.78
Entropy of Formation, eu/mole	(35.7)

(Continued)

Oxides (Continued)

	<u>Ho<sub>2</sub>O<sub>3</sub></u>
Heat Capacity at 300 K, cal/(mole)(C)	27.05
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	7.9
Magnetic Moment, Bohr magnetons	10.6
Color	Light yellow

Heat Content and Entropy Increments for Holmium Oxide  
(Smooth Values)

<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15°</sub> cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15°</sub> cal/(K)(mole)</u>	<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15°</sub> cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15°</sub> cal/(K)(mole)</u>
400	2,820	8.13	1300	30,420	43.90
500	5,710	14.57	1400	33,640	46.29
600	8,680	19.98	1500	36,900	48.54
700	11,700	24.64	1600	40,200	50.67
800	14,760	28.72	1700	43,540	52.69
900	17,840	32.35	1800	46,920	54.53
1000	20,940	35.62	1900	50,330	56.47
1100	24,070	38.60	2000	53,770	58.23
1200	27,230	41.35			

Phosphides

	<u>HoP</u>
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	5.626
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	46,083
Magnetic Moment, Bohr magnetons	10.34

		<u>Authority</u>
<b>Selenides</b>		169
	<u>HoSe</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , A	5.680	
Magnetic Susceptibility, $10^{-6}$ emu/mole	43,478	
Magnetic Moment, Bohr magnetons	10.62	
		263, 264
<b>Silicides</b>		
	<u>HoSi<sub>2</sub></u>	<u>HoSi<sub>2-n</sub></u>
Structure	Orthorhombic	Hexagonal
Lattice Type	$\alpha$ -YSi <sub>2</sub>	Defect AlB <sub>2</sub>
$a_0$ , A	4.03	3.816
$b_0$ , A	3.97	--
$c_0$ , A	13.40	4.107
Volume of Unit Cell, A <sup>3</sup>	--	51.5
		169
<b>Sulfides</b>		
	<u>HoS</u>	
Structure	Fcc	
Lattice Type	NaCl	
$a_0$ , A	5.465	
Magnetic Susceptibility, $10^{-6}$ emu/mole	41,464	
Magnetic Moment, Bohr magnetons	10.50	

**Properties****275**Authority**Tellurides**

169

	<u>HoTe</u>
Structure	Fcc
Lattice Type	NaCl
$a_0$ , A	6.049
Magnetic Susceptibility, $10^{-6}$ emu/mole	48,780
Magnetic Moment, Bohr magnetons	10.50

**Miscellaneous**

267

<u>Compound</u>	<u>Lattice Type</u>	<u><math>a_0</math>, A</u>
HoGa <sub>3</sub>	AuCu <sub>3</sub>	4.226

**ERBIUM**

Symbol Er

Atomic Number 68

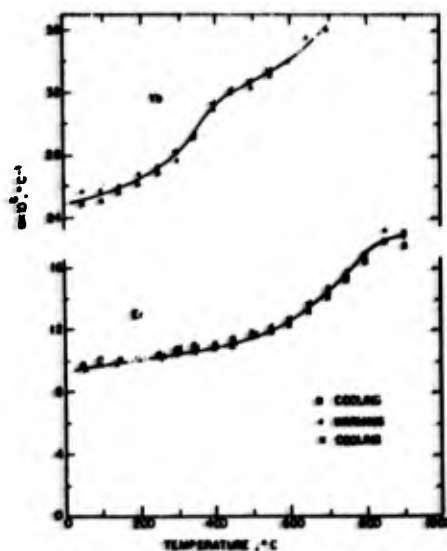
Atomic Weight 167.27

Authority

**PHYSICAL PROPERTIES**

Abundance	2.5-6.5 ppm	51
Density	9.062 g/cm <sup>3</sup>	67
Melting Point	1550 C	257
Heat of Fusion	4.1 kcal/mole	61
Boiling Point	2650 C	257
Heat of Vaporization (25 C)	64.75 kcal/mole	257
Vapor Pressure (1392-1780 K)	$\text{Log } P_{\text{mm Hg}} = 9.222 - \frac{17,324}{T}$	60
Specific Heat (25 C)	6.72 cal/(mole)(C)	76
Heat of Combustion	226.80 kcal/g-atom	134
Coefficient of Linear Thermal Expansion	$9.2 \times 10^{-6}/\text{C} (-178 - 950 \text{ C})$	61

90



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		<u>Authority</u>
Thermal Conductivity (28 C)	0.023 cal/(cm <sup>2</sup> )(sec)(C/cm)	115
Heat of Sublimation (25 C)	75.39 kcal/mole	130
Cohesive Energy	75.7 kcal/mole	130
Work Function		
Debye Temperature	195 K	97
Expansion on Melting		
Surface Tension		

**CRYSTAL PROPERTIES**

Structure	Hcp	61
Lattice Constants	$a_0 = 3.5588 \text{ \AA}$ $c_0 = 5.5874 \text{ \AA}$	61
Density	9.062 g/cm <sup>3</sup>	67
Metallic Radius	1.757 \AA	67
Atomic Volume	18.473 cm <sup>3</sup> /mole	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ions)	0.881	55
Closest Approach of Atoms	3.459 \AA	56
Allotropic Modifications		

**CHEMICAL PROPERTIES**

Stable Oxidation State	+3	81
Electrode Potential	$[\text{Er} = \text{Er}^{+3} + 3\text{e}^-] + 2.1 \text{ volts (standard hydrogen electrode)}$	81
Ionization Potential		



Authority

Metallographic Polishing  
and Etching

62

Erbium exhibits considerable resistance to oxidation and to etching. The most satisfactory etch is based on hydrofluoric acid.

Corrosion Rates  
(In Air)

<1 mil/year up to 200 C  
14 mil/year at 400 C  
114 mil/year at 600 C

68

Corrosion Data

91

Corrosive attack on crucible materials:

<u>Material</u>	<u>Onset of Attack</u>
Ta	None < 1400 C

**ELECTRICAL PROPERTIES**

Resistivity (25 C)

107 microhm-cm

61

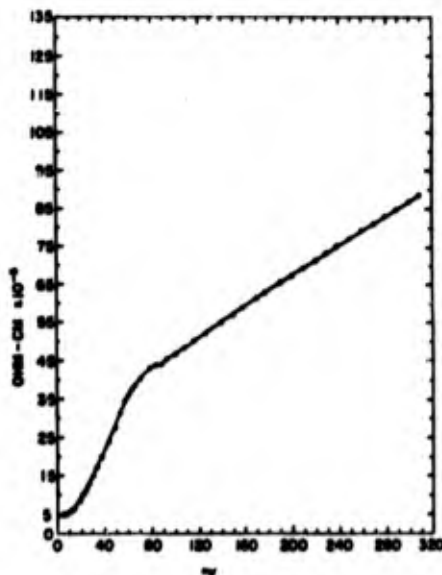
Temperature Coefficient  
of Resistivity

$2.01 \times 10^{-3}/C$

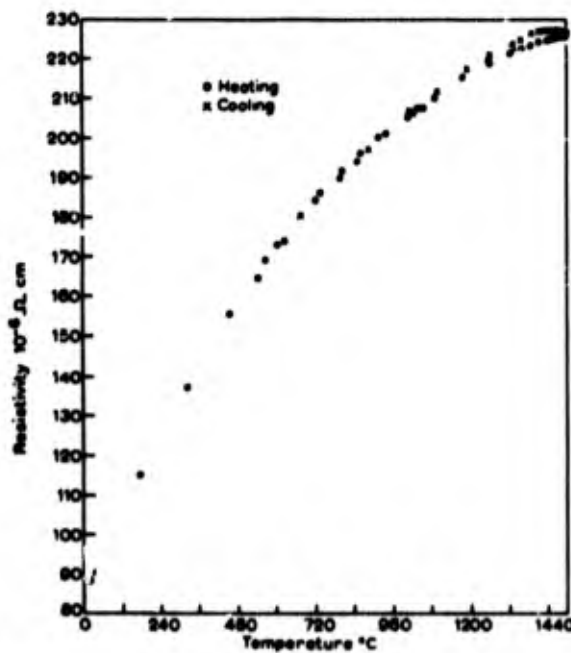
61

Resistivity Versus Temperature

117,127

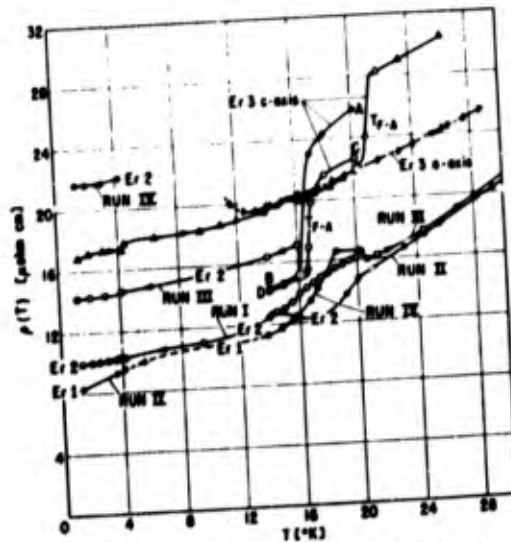


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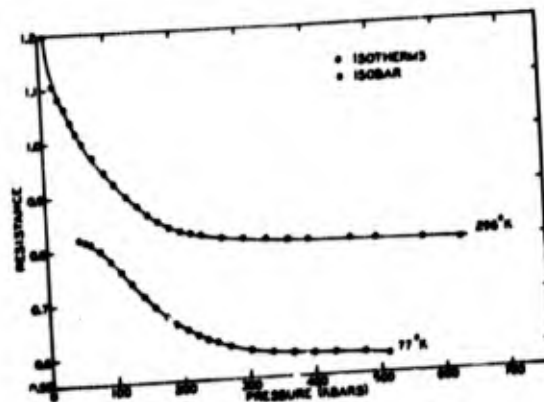
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Resistivity Versus Temperature



(Permission of Elsevier Publishing Co.)

Resistance Versus Pressure  
(Permission of the American Physical Society)



MAGNETIC PROPERTIES

Susceptibility (25 C)	44,100 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 9.6 Bohr magnetons	61
	Measured 9.5 Bohr magnetons	
Curie Temperature	20 K	61
Néel Temperature	84 K	61

Authority

**MECHANICAL PROPERTIES**

Young's Modulus	7.33 x 10 <sup>11</sup> dynes/cm <sup>2</sup>			57	
Shear Modulus	2.96 x 10 <sup>11</sup> dynes/cm <sup>2</sup>			57	
Poisson's Ratio	0.238			61	
Compressibility	2.11 x 10 <sup>-6</sup> cm <sup>2</sup> /kg			57	
Hardness (DPH)	44			57	
	<u>70 F</u>	<u>400 F</u>	<u>800 F</u>		
Tensile Strength	42.4	34.7	25.1	10 <sup>3</sup> psi	88
Yield Strength	38.7	29.6	21.8	10 <sup>3</sup> psi	88
Elongation	4	5.5	6.8	per cent	88
Ultimate Compressive Strength	110.1	10 <sup>3</sup> psi		61	
Impact Strength (Izod)	1.2 ft-lb			71	
Workability	Poor			88	
General Fabrication	(See references)			70, 113	

**NUCLEAR PROPERTIES**

Isotopes 58, 133

<u>Whole- Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay Mode</u>
162	0.136	Stable	--
164	1.56	Stable	--
165	--	1.1 min	β <sup>+</sup>
166	33.41	Stable	--
167	22.94	Stable	--
168	27.07	Stable	--
169	--	9.4 days	β <sup>-</sup>
170	14.88	Stable	--
171	--	7.5 (?)	β <sup>-</sup> , γ

Thermal Neutron Cross Section 166 ± 16 barns/atom or 0.60 cm<sup>2</sup>/g 73

Authority

## SAFETY

Details unknown.

83

## THERMODYNAMIC PROPERTIES

	<u>Room Temperature</u>	<u>Melting Point</u>	76,77
Entropy	$S_{298} = 17.5$	$S_{1800} = 31.03$ eu	
Heat Capacity	$C_{p298} = 6.72$	$C_{p1800} = 8.95$ cal/ (mole)(C)	

Heat Capacities,  
cal/(K)(mole)

76

<u>10 K</u>	<u>25 K</u>	<u>50 K</u>	<u>100 K</u>	<u>150 K</u>	<u>200 K</u>	<u>298.15 K</u>
(.47)	3.73	6.78	5.88	6.21	6.46	6.72

Heat Content and Entropy  
of Solid and Liquid  
Erbium

77

(Base: crystals at 298.15 K)

<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K)(mole)</u>	<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K)(mole)</u>
400	690	1.99	1600	10,020	12.49
500	1,390	3.54	1700	10,890	13.02
600	2,095	4.84	1800(s)	11,780	13.53
700	2,820	5.95	1800(l)	15,880	15.81
800	3,560	6.94	1900	16,680	16.24
900	4,310	7.83	2000	17,480	16.65
1000	5,060	8.64	2200	19,080	17.41
1100	5,870	9.39	2400	20,680	18.11
1200	6,670	10.08	2600	22,280	18.75
1300	7,480	10.73	2800	23,880	19.34
1400	8,310	11.35	2900	24,680	19.62
1500	9,160	11.93			

For solid erbium:

$$H_T - H_{298.15} = 6.29T + 0.74 \times 10^{-3}T^2 - 1.941$$

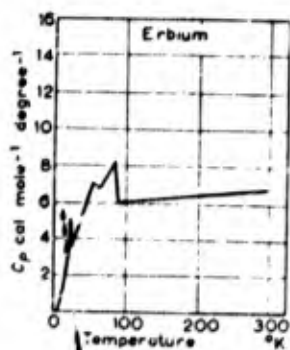
(0.2 percent; 298 - 1,800 K);

$$C_p = 6.29 + 1.48 \times 10^{-3}T;$$

$$\Delta H_{1800}(\text{fusion}) = 4,100.$$

Specific Heat

53



0 to 300 K

**ERBIUM COMPOUNDS**

Antimonides

168,169

	<u>ErSb</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	6.107
Melting Point, C	<1900
Resistivity, microhm-cm	47
Magnetic Susceptibility, $10^{-6}$ emu/mole	36,232
Magnetic Moment, Bohr magnetons	9.36

		<u>Authority</u>
<b>Arsenides</b>		169
	<u>ErAs</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , Å	5.745	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	37,453	
Magnetic Moment, Bohr magnetons	9.34	
<b>Beryllides</b>		179
	<u>ErBe<sub>13</sub></u>	
$a_0$ , Å	10.215	
<b>Bismuthides</b>		169
	<u>ErBi</u>	
Structure	Cubic	
Lattice Type	NaCl	
$a_0$ , Å	6.202	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	35,714	
Magnetic Moment, Bohr magnetons	9.32	

Authority

Borides

153, 155,  
171

	<u>ErB<sub>2</sub></u>	<u>ErB<sub>4</sub></u>	<u>ErB<sub>6</sub></u>	<u>ErB<sub>12</sub></u>
Molecular Weight	188.91	210.48	232.12	297.04
Structure	Hexagonal	Tetragonal	Cubic	Cubic
a <sub>0</sub> , A	3.28	7.071	4.110	7.464
c <sub>0</sub> , A	3.79	3.9972	--	--
Density, g/cm <sup>3</sup>	--	7.261	5.58	4.706
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	--	--	3.0
Work Function, ev	--	--	3.37	--
Emissivity (λ = 0.655 μ)	--	--	0.7	--
Color	--	Gray brown	Blue	--
Effective Metallic Radius, A	--	--	2.18	--

Carbides

153

	<u>ErC<sub>2</sub></u>	<u>Er<sub>2</sub>C<sub>3</sub></u>	<u>Er<sub>3</sub>C</u>
Molecular Weight	191.2	370.4	513.6
Structure	Body-centered tetragonal	--	Cubic
Lattice Type	CaC <sub>2</sub>	Y <sub>2</sub> C <sub>3</sub>	Fe <sub>4</sub> N
a <sub>0</sub> , A	3.620	--	5.034
c <sub>0</sub> , A	6.094	--	--
Density, g/cm <sup>3</sup>	7.954	--	4.708
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	~33,300	--	--
Magnetic Moment, Bohr magnetons	8.	--	--
Curie Temperature, K	14.7	--	--

Authority

## Germanides

183

	<u>Er<sub>2</sub>Ge<sub>3</sub></u>
Lattice Type	Defective AlB <sub>2</sub>
a <sub>0</sub> , Å	3.89
c <sub>0</sub> , Å	4.09
Volume of Unit Cell, Å <sup>3</sup>	53.60

## Halides

93, 108, 158,  
182, 186,  
209, 210,  
235, 236

	<u>ErBr<sub>3</sub></u>	<u>ErCl<sub>3</sub></u>	<u>ErF<sub>3</sub></u>	<u>ErI<sub>3</sub></u>	<u>ErOCl</u>
Structure	Hexagonal	Monoclinic	Orthorhombic	--	Tetragonal
a <sub>0</sub> , Å	4.070	6.80	6.354	--	3.88
b <sub>0</sub> , Å	--	11.79	6.846	--	--
c <sub>0</sub> , Å	6.388	6.39	4.380	--	6.58
β, deg	--	110.7	--	--	--
Density, g/cm <sup>3</sup>	--	--	7.814	--	--
Heat of Formation, kcal/mole	--	229.07	--	137	--
Entropy of Formation, eu/mole	--	(62)	--	(7)	--
Melting Point, C	950	776	1140	1020	--
Heat of Fusion, kcal/mole	10	7.8	8	10	--
Boiling Point, C	1460	1500	2230	1280	--
Heat of Vaporization, kcal/mole	43	44	60	40	--
Entropy of Fusion, eu/mole	8	7.4	5	8	--
Entropy of Vaporization, eu/mole	25	25	24	26	--
Heat Capacity, cal/(mole)(C)	--	32.0	--	--	--
Volume of Unit Cell, Å <sup>3</sup>	--	479	190.5	--	99.1
Color	--	--	Pink	--	--



**Properties**

**287**

**Hydrides**

Authority

165,265

	<u>ErH<sub>2</sub></u>	<u>ErH<sub>3</sub></u>
Structure	Cubic	Hexagonal
a <sub>0</sub> , A	5.123	3.621
c <sub>0</sub> , A	--	6.526
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	36,200	34,900
Magnetic Moment, Bohr magnetons	9.75	9.54

**Nitrides**

149,153,  
223

	<u>ErN</u>
Molecular Weight	181.28
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	4.831
Density, g/cm <sup>3</sup>	10.26
Resistivity, microhm-cm	79
Temperature Coefficient of Resistivity (80-800 K), 10 <sup>-3</sup> /C	1.3
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	36,300
Magnetic Moment, Bohr magnetons	9.2
Curie Temperature, K	5

		<u>Authority</u>
Oxides	<u>Er<sub>2</sub>O<sub>3</sub></u>	156, 172, 173, 177, 266
Molecular Weight	328.52	
Structure	Bcc	
a <sub>0</sub> , Å	10.51	
Density, g/cm <sup>3</sup>	8.640	
Heat of Formation, kcal/mole	226.80	
Entropy of Formation, eu/mole	(35.5)	
Coefficient of Thermal Expansion (20-1300 C), 10 <sup>-6</sup> /C	7.3	
Heat Capacity at 300 K, cal/(mole)(C)	25.26	
Magnetic Moment, Bohr magnetons	9.6	
Color	Pink	

**Heat Content and Entropy Increments  
for Erbium Oxide (Smooth Values)**

<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K)mole</u>	<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K)mole</u>
400	2,710	7.80	1300	30,140	43.27
500	5,540	14.11	1400	33,360	45.66
600	8,470	19.45	1500	36,600	47.99
700	11,460	24.06	1600	39,860	50.00
800	14,490	28.11	1700	43,140	51.99
900	17,560	31.72	1800	46,440	53.87
1000	20,660	34.99	1900	49,750	55.66
1100	23,790	37.97	2000	53,070	57.36
1200	26,950	40.72			

Authority

Phosphides

169

	<u>ErP</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	5.606
Magnetic Susceptibility, $10^{-6}$ emu/mole	37,523
Magnetic Moment, Bohr magnetons	9.32

Selenides

166,169,  
192,194,  
213

	<u>ErSe</u>	<u>Er<sub>2</sub>Se<sub>3</sub></u>	<u>Er<sub>2</sub>O<sub>2</sub>Se</u>
Structure	Cubic	Fcc	Hcp
Lattice Type	NaCl	NaCl	--
$a_0$ , A	5.662	5.71	3.81
$c_0$ , A	--	--	7.68
Density, g/cm <sup>3</sup>	--	6.59	8.68
Melting Point, C	(1800)	1520	--
Resistivity, microhm-cm	170	$7.9 \times 10^6$	--
Magnetic Susceptibility, $10^{-6}$ emu/mole	35,635	38,600	--
Magnetic Moment, Bohr magnetons	9.56	9.63	--
Color	--	Yellow brown	Pink

Silicides

263,264

	<u>ErSi<sub>2</sub></u>
Structure	Hexagonal
$a_0$ , A	3.78
$c_0$ , A	4.09
Volume of Unit Cell, A <sup>3</sup>	51.1

Authority

153,169

## Sulfides

	<u>ErS</u>	<u>ErS<sub>1.18</sub></u>	<u>Er<sub>5</sub>S<sub>7</sub></u>	<u>δ-Er<sub>2</sub>S<sub>3</sub></u>	<u>Er<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	199.27	204.8	1060.80	430.74	398.61
Structure	Cubic	Cubic	Mono- clinic	Mono- clinic	Hexago- nal
a <sub>0</sub> , Å	5.424	5.452	12.63	10.07	3.760
b <sub>0</sub> , Å	--	--	3.77	4.00	--
c <sub>0</sub> , Å	--	--	11.47	17.33	6.552
β, deg	--	--	74	--	--
Density, g/cm <sup>3</sup>	--	6.75	6.39	6.07	7.92
Melting Point, C	--	--	1620	1730	--
Magnetic Suscepti- bility, 10 <sup>-6</sup> emu/ mole	35,088	--	--	38,600	--
Magnetic Moment, Bohr magnetons	9.50	--	--	--	--
Color	--	--	--	Bright ochre	--

## Tellurides

	<u>ErTe</u>	<u>Er<sub>2</sub>Te<sub>3</sub></u>	<u>Er<sub>3</sub>Te<sub>4</sub></u>
Structure	Fcc	--	--
Lattice Type	NaCl	--	--
a <sub>0</sub> , Å	6.021	--	--
Resistivity, microhm-cm	140	1.1 x 10 <sup>3</sup>	280
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	34965	--	--
Magnetic Moment, Bohr magnetons	9.30	9.63	--

168,169,  
194,229,  
232

**Properties**

291

Authority**Miscellaneous**

150,267

<u>Compound</u>	<u>Structure</u>	<u>Lattice Type</u>	<u>a<sub>0</sub>, A</u>	<u>c<sub>0</sub>, A</u>	<u>Curie Temperature, K</u>
ErGa <sub>3</sub>	--	AuCu <sub>3</sub>	4.206	--	--
ErRu <sub>2</sub>	Hexagonal	--	5.227	8.780	13

**THULIUM**

Symbol Tm

Atomic Number 69

Atomic Weight 168.94

**PHYSICAL PROPERTIES**

Authority

Abundance	0.2-1.0 ppm	51
Density	9.318 g/cm <sup>3</sup>	67
Melting Point	1545 C	66
Heat of Fusion	4.2 kcal/mole	61
Boiling Point	1727 C	57
Heat of Vaporization (25 C)	59 kcal/mole	57
Vapor Pressure	$\text{Log } P_{\text{mm Hg}} = \frac{1.2552(10^4)}{T} - 9.1761$	135
Specific Heat (25 C)	6.45 cal/(mole)(C)	137
Heat of Combustion	225.7 kcal/g-atom	136
Coefficient of Linear Thermal Expansion (20-923 C)	$11.6 \times 10^{-6}/C$	61
Thermal Conductivity		
Heat of Sublimation		
Cohesive Energy	58 kcal/mole	89
Work Function		
Debye Temperature	200 K	97
Expansion on Melting		
Surface Tension		

**CRYSTAL PROPERTIES**

Structure	Hcp	61
Lattice Constants	$a_0 = 3.5375 \text{ \AA}$ $c_0 = 5.5546 \text{ \AA}$	61
Density	9.318 g/cm <sup>3</sup>	67

## THULIUM

Authority

Metallic Radius	1.746 A	67
Atomic Volume	18.151 cm <sup>3</sup> /mole	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ion)	0.869 A	55
Closest Approach of Atoms	3.446 A	56
Allotropic Modifications		

## CHEMICAL PROPERTIES

Stable Oxidation State	+3	81
Electrode Potential	[ Tm = Tm <sup>+3</sup> + 3e <sup>-</sup> ] + 2.1 volts (standard hydrogen electrode)	81
Ionization Potential		
Metallographic Polishing and Etching		
Corrosion Rates (In Air)	<1 mil/year up to 200 C	109
Corrosion Data		

## ELECTRICAL PROPERTIES

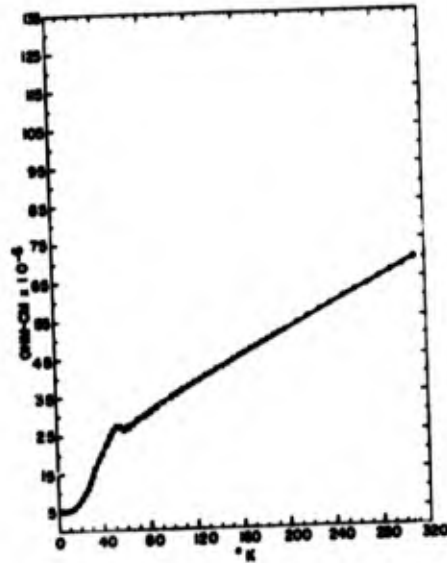
Resistivity (25 C)	79 microhm-cm	61
Temperature Coefficient of Resistivity	1.95 x 10 <sup>-3</sup> /C	61

Properties

Authority

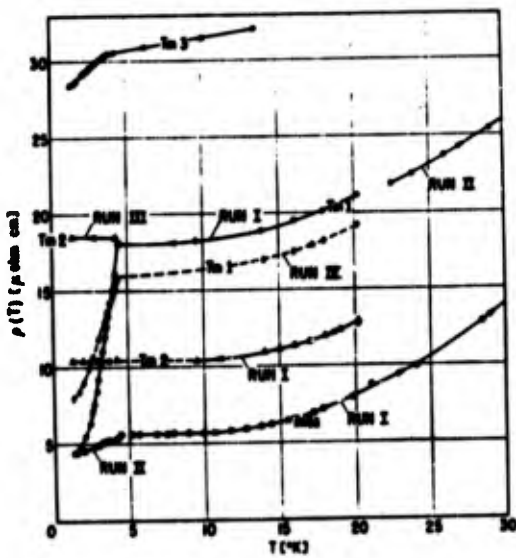
117

Resistivity Versus Temperature

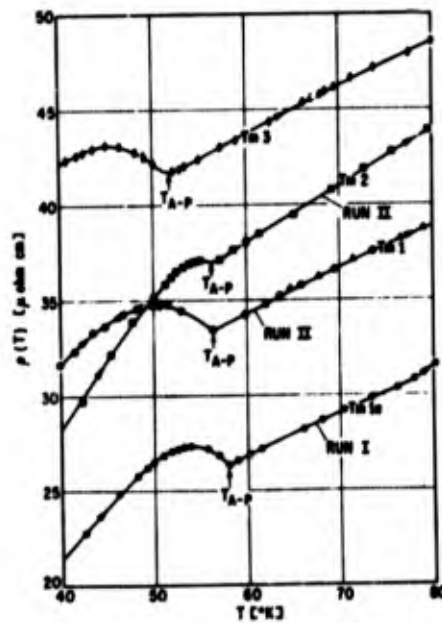


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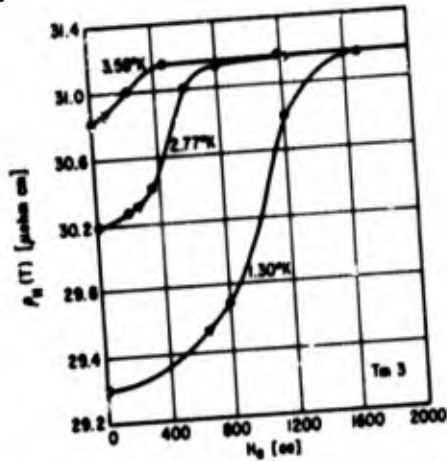
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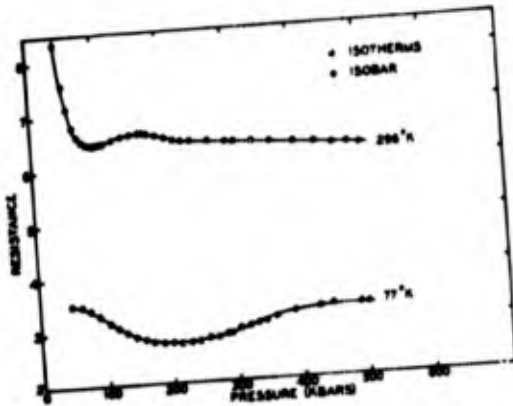


Magneto-resistivity



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Resistance Versus Pressure  
(Permission of the American Physical Society)



MAGNETIC PROPERTIES

Susceptibility (25 C)	26, 200 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 7.6 Bohr magnetons	61
	Measured 7.62 Bohr magnetons	138
Curie Temperature	22 K	138
Néel Temperature	60 K	

# Properties

297

## MECHANICAL PROPERTIES

### Authority

Young's Modulus		
Shear Modulus		
Poisson's Ratio		
Compressibility	$2.6 \times 10^{-6} \text{ cm}^2/\text{kg}$	64
Hardness (DPH)	48	57
Tensile Strength		
Yield Strength		
Elongation		
Ultimate Compressive Strength	$78.1 \times 10^3 \text{ psi}$	61
Impact Strength (Izod)		
Workability		
General Fabrication	(See references)	70, 113

## NUCLEAR PROPERTIES

Isotopes		58, 139
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<u>Whole-Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay Mode</u>
166	--	7.7 hr	K, X, $\gamma$ , $\beta^+$ , $e^-$
167	--	9 days	K, X, $\gamma$ , $\beta^-$
168	--	100 days	K, X, $e^-$
169	100	Stable	--
170	--	127 days	$\beta$
171	--	2 yr	$\beta^-$

Thermal Neutron Cross Section	$118 \pm 6 \text{ barns/atom or } 0.42 \text{ cm}^2/\text{g}$	73
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## SAFETY

Details unknown.	83
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## THERMODYNAMIC PROPERTIES

Authority

	<u>Room Temperature</u>	<u>Melting Point</u>	76, 77
Entropy	$S_{298} = 17.1$	$S_{1900} = 30.62 \text{ eu}$	
Heat Capacity	$C_{p298} = 6.45$	$C_{p1900} = 8.85 \text{ cal/}$ (mole)(C)	

## Heat Content and Entropy of Solid and Liquid Thulium

77

(Base: crystals at 298.15 K)

<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K)(mole)</u>	<u>T, K</u>	<u><math>H_T - H_{298.15}</math> cal/mole</u>	<u><math>S_T - S_{298.15}</math> cal/(K)(mole)</u>
400	660	1.91	1400	8,010	10.93
500	1,330	3.40	1500	8,830	11.50
600	2,010	4.65	1600	9,660	12.05
700	2,710	5.72	1700	10,510	12.55
800	3,420	6.67	1800	11,370	13.04
900	4,150	7.53	1900(s)	12,250	13.52
1000	4,890	8.31	1900(l)	16,650	15.83
1100	5,650	9.03	2000	17,450	16.24
1200	6,420	9.71	2200	19,050	17.01
1300	7,210	10.34	2400	20,650	17.71

For solid thulium:

$$H_T - H_{298.15} = 6.00 T + 0.75 \times 10^{-3} T^2 - 1,856$$

(0.1 percent; 298 - 1900 K);

$$C_p = 6.00 + 1.50 \times 10^{-3} T;$$

$$H_{1900}(\text{fusion}) = 4,400.$$

For liquid thulium:

$$H_T - H_{298.15} = 8.00 T + 1,450$$

(0.1 percent; 1900 - 2400 K);

$$C_p = 8.00.$$

## THULIUM COMPOUNDS

## Antimonides

169

	<u>TmSb</u>
Structure	Cubic
Lattice Type	NaCl
$a_0, \text{ \AA}$	6.091
Magnetic Susceptibility, $\times 10^{-6} \text{ emu/mole}$	26,667
Effective Magnetic Moment, Bohr magnetons	8.14

Authority

Arsenides

169

	<u>TmAs</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	5.721
Magnetic Susceptibility, $10^{-6}$ emu/mole	24,390
Effective Magnetic Moment, Bohr magneton	7.77

Beryllides

179

	<u>TmBe<sub>13</sub></u>
$a_0$ , A	10.192

Bismuthides

169

	<u>TmBi</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	6.192
Magnetic Susceptibility, $10^{-6}$ emu/mole	25,000
Effective Magnetic Moment, Bohr magneton	7.63

Borides

153, 171

	<u>TmB<sub>4</sub></u>	<u>TmB<sub>6</sub></u>	<u>TmB<sub>12</sub></u>
Molecular Weight	212.22	233.86	299.24
Structure	Tetragonal	Cubic	Cubic
$a_0$ , A	7.06	4.11	7.476
$c_0$ , A	3.99	--	--

(Continued)

Authority

## Borides (Continued)

	<u>TmB<sub>4</sub></u>	<u>TmB<sub>6</sub></u>	<u>TmB<sub>12</sub></u>
Density, g/cm <sup>3</sup>	7.09	5.59	4.756
Work Function, ev	--	3.34	--
Color	Gray brown	Blue	--
Effective Metallic Radius, A	--	2.19	--

## Carbides

153

	<u>TmC<sub>2</sub></u>	<u>Tm<sub>2</sub>C<sub>3</sub></u>	<u>Tm<sub>3</sub>C</u>
Molecular Weight	192.94	374.8	520.2
Structure	Body-centered tetragonal	--	Cubic
Lattice Type	CaC <sub>2</sub>	Y <sub>2</sub> C <sub>3</sub>	Fe <sub>4</sub> N
a <sub>0</sub> , A	3.600	--	5.016
c <sub>0</sub> , A	6.047	--	--
Density, g/cm <sup>3</sup>	8.175	--	9.901

## Germanides

183

	<u>Tm<sub>2</sub>Ge<sub>3</sub></u>
Lattice Type	Defective AlB <sub>2</sub>
a <sub>0</sub> , A	3.88
c <sub>0</sub> , A	4.07
Volume of Unit Cell, A <sup>3</sup>	53.06

## Halides

93, 108, 158, 209,  
210, 222, 235, 236

	<u>TmBr<sub>3</sub></u>	<u>TmCl<sub>3</sub></u>	<u>TmF<sub>3</sub></u>		<u>TmI<sub>3</sub></u>	<u>TmOI</u>
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Hexagonal	Tetragonal
Lattice Type	--	--	--	--	--	PbFCl
a <sub>0</sub> , A	4.042	6.75	6.283	6.763	4.288	3.887
b <sub>0</sub> , A	--	11.73	6.811	--	--	--
c <sub>0</sub> , A	6.357	6.39	4.408	6.927	6.934	9.166
β, deg	--	110.6	--	--	--	--

(Continued)

Halides (Continued)

	<u>TmBr<sub>3</sub></u>	<u>TmCl<sub>3</sub></u>	<u>TmF<sub>3</sub></u>		<u>TmI<sub>3</sub></u>	<u>TmOI</u>
Density, g/cm <sup>3</sup>	--	--	7.971	8.220	--	--
Melting Point, C	955	821	--	1158	1015	--
Transition Temperature, C	--	--	1043	Ortho. → Hex.	--	--
Heat of Fusion, kcal/mole	10	9		8	10	--
Boiling Point, C (est.)	1440	1490		2230	1260	--
Heat of Vaporization, kcal/mole	43	44		60	40	--
Entropy of Fusion, eu/mole	8	8		5	8	--
Entropy of Vaporization, eu/mole	25	25		24	26	--
Color	--	--	White		--	--
Volume of Unit Cell, A <sup>3</sup>	--	474	188.6	274.4	--	--

Hydrides

165, 265

	<u>TmH<sub>2</sub></u>	<u>TmH<sub>3</sub></u>
Structure	Cubic	Hexagonal
a <sub>0</sub> , A	5.090	3.599
c <sub>0</sub> , A	--	6.489
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	21,870	21,140
Effective Magnetic Moment, Bohr magnetons	7.60	7.47

Authority

153

## Nitrides

	<u>TmN</u>
Molecular Weight	182.95
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	4.809
Density, g/cm <sup>3</sup>	10.84
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	23,600
Magnetic Moment, Bohr magnetons	7.5
Curie Temperature, K	0

## Oxides

	<u>Tm<sub>2</sub>O<sub>3</sub></u>
Molecular Weight	385.87
Structure	Bcc
$a_0$ , A	10.52
Density, g/cm <sup>3</sup>	8.6
Heat of Formation, kcal/mole	225.7
Entropy of Formation, eu/mole	35.7
Heat Capacity, cal/(K)(mole)	27.43 (300 K) 32.0 (1700 K)
Coefficient of Thermal Expansion (20-1300 C), 10 <sup>-6</sup> /C	7.7
Color	Light green
Effective Magnetic Moment, Bohr magnetons	7.6

172, 173,  
177, 251,  
259, 266

(Continued)

Oxides (Continued)

<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K)(mole)</u>	<u>T, K</u>	<u>H<sub>T</sub>-H<sub>298.15</sub>, cal/mole</u>	<u>S<sub>T</sub>-S<sub>298.15</sub>, cal/(K)(mole)</u>
400	2,890	8.32	1400	34,00J	46.95
500	5,840	14.90	1500	37,200	49.15
600	8,860	20.41	1600	40,400	51.22
700	11,930	25.14	1680	42,960 (α)	52.78 (α)
800	15,040	29.29	1680	43,270 (β)	52.96 (β)
900	18,170	32.97	1700	43,910	53.34
1000	21,310	36.28	1800	47,110	55.17
1100	24,460	39.28	1900	50,310	56.90
1200	27,630	42.04	2000	53,510	58.54
1300	30,180	44.58			

Phosphides

169

	<u>TmP</u>
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	5.573
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	25,316
Effective Magnetic Moment, Bohr magnetons	7.93

Selenides

169

	<u>TmSe</u>
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , A	5.640
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	18,180
Effective Magnetic Moment, Bohr magnetons	6.89



		<u>Authority</u>
<b>Silicides</b>		263, 264
	<u>TmSi<sub>2</sub></u>	
Structure	Hexagonal	
a <sub>0</sub> , A	3.76	
c <sub>0</sub> , A	4.07	
Volume of Unit Cell, A <sup>3</sup>	50.52	
<b>Sulfides</b>		169, 153
	<u>TmS</u>	<u>Tm<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	--	401.95
Structure	Fcc	Hexagonal
Lattice Type	NaCl	--
a <sub>0</sub> , A	5.412	3.747
c <sub>0</sub> , A	--	6.538
Density, g/cm <sup>3</sup>	--	8.59
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	21,505	--
Effective Magnetic Moment, Bohr magnetons	7.42	--
<b>Tellurides</b>		169
	<u>TmTe</u>	
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	25,641	
Effective Magnetic Moment, Bohr magnetons	7.63	
<b>Miscellaneous</b>		267
<u>Compound</u>	<u>Lattice Type</u>	<u>a<sub>0</sub>, A</u>
TmGa <sub>3</sub>	AuCu <sub>3</sub>	4.188

Properties

YTTERBIUM

Symbol Yb

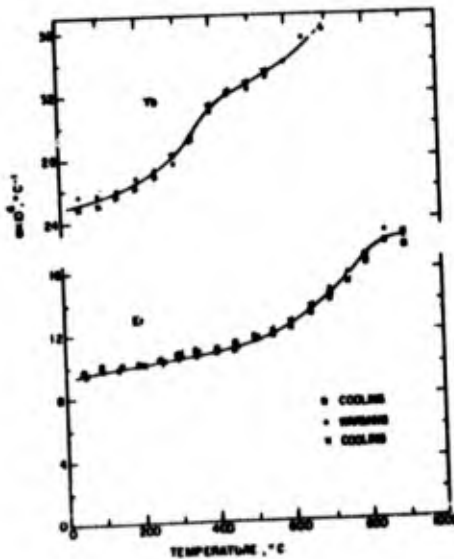
Atomic Number 70

Atomic Weight 173.04

Authority

PHYSICAL PROPERTIES

Abundance	2.7-8.0 (approx. 2.7)	51
Density	6.959 g/cm <sup>3</sup>	67
Melting Point	824 C	66
Heat of Fusion	1.8 kcal/mole	61
Boiling Point	1427 C	57
Heat of Vaporization (25 C)	38 kcal/mole	57
Vapor Pressure (623-931 K)	$\text{Log } P_{\text{mm Hg}} = 8.295 - \frac{7696}{T}$	60
Specific Heat (25 C)	(6.0) cal/(mole)(C)	53
Heat of Combustion (25 C)	216.8 kcal/g-atom	57
Coefficient of Linear Thermal Expansion	$25.0 \times 10^{-6}/C$ (25-700 C)	61



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Authority

Thermal Conductivity

Heat of Sublimation

Cohesive Energy            40 kcal/mole            89

Work Function

Debye Temperature        118 K            97

Expansion on Melting

Surface Tension

## CRYSTAL PROPERTIES

Structure                    FCC                    BCC            61Lattice Constants         $a_0 = 5.4862$          $a_0 = 4.45 \text{ \AA}$         61Density                    6.959            6.52 g/cm<sup>3</sup>        67

Metallic Radius        1.940            1.98 \AA            67

Atomic Volume        24.80            26.5 cm<sup>3</sup>/mole        66

Transition Temperature    798 C            66

Heat of Transition        0.425 kcal/mole        61

Ionic Radius            (+2) 1.06 \AA, (+3) 0.858 \AA        55, 93

Closest Approach of Atoms    3.866 \AA            56

Allotropic Modifications

**Atomic Volume Versus Temperature**  
(Permission of Elsevier Publishing Co.)

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**CHEMICAL PROPERTIES**

Stable Oxidation State	+2, +3	81
Electrode Potential	[ $\text{Yb} = \text{Yb}^{+3} + 3\text{e}^-$ ] + 2.1 volts (standard hydrogen electrode)	81
Ionization Potential	1st = 7.1 volts	82
Metallographic Polishing and Etching		
Corrosion Rates (In Air)	<1 mil/year up to 200 C	109
Corrosion Data		

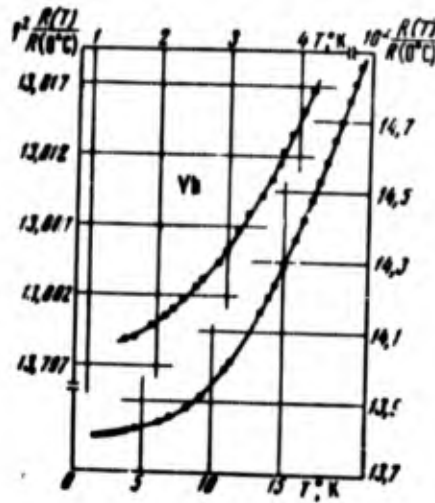
**ELECTRICAL PROPERTIES**

Resistivity (25 C)	27.0 microhm-cm	61
Temperature Coefficient of Resistivity (25 C)	$1.30 \times 10^{-3}/\text{C}$	61

Authority

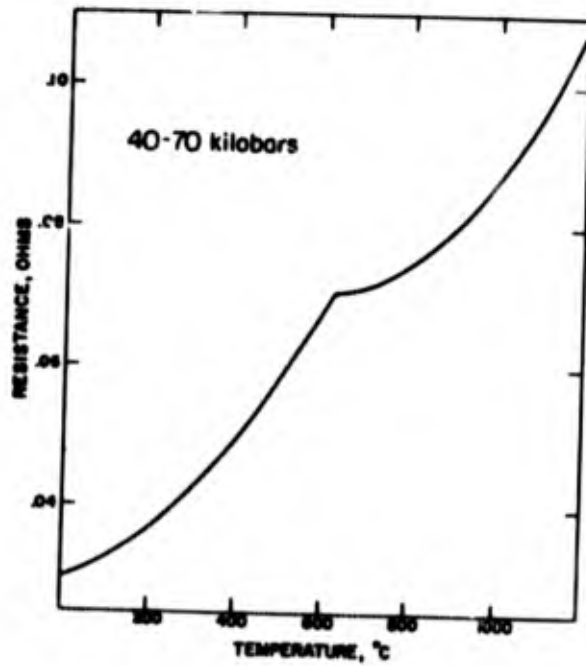
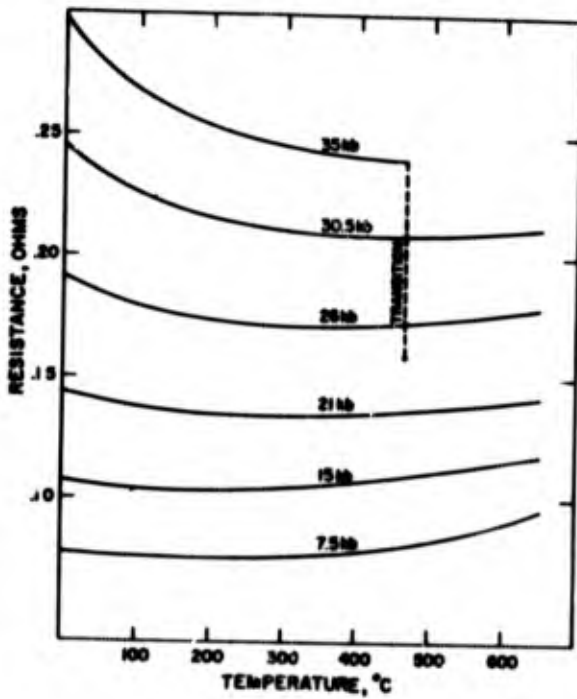
118

Resistivity Versus Temperature



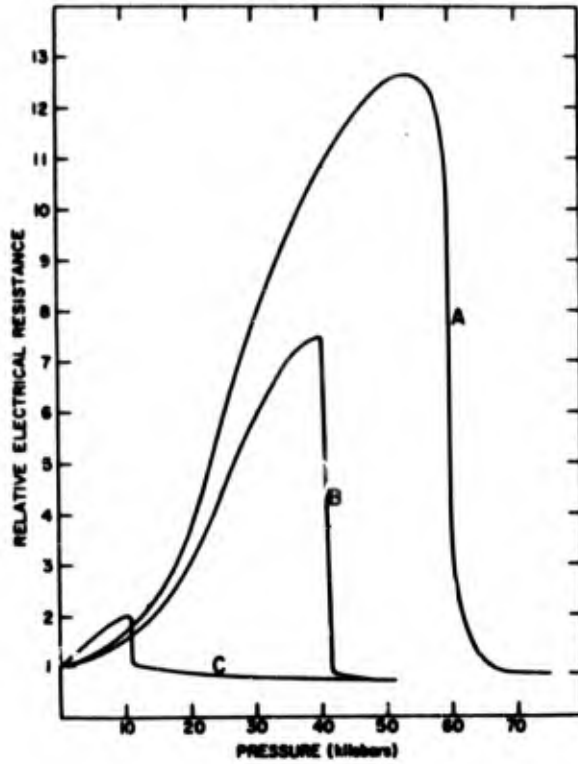
Resistance Versus Temperature  
(Reprinted from Inorganic Chemistry)

141



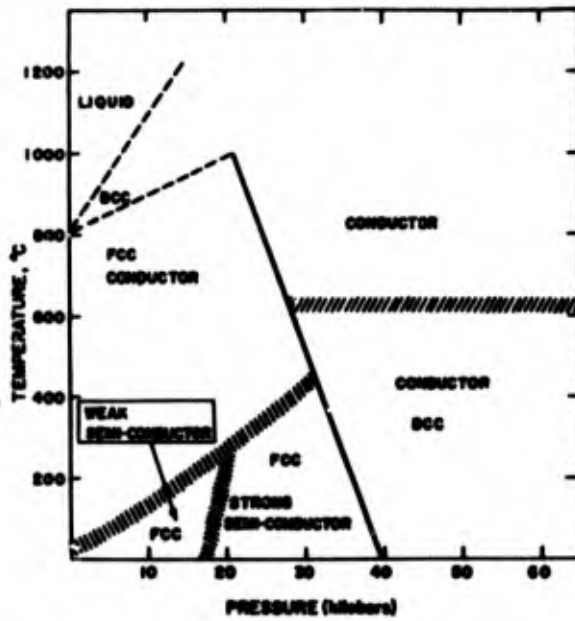
Resistance Versus Pressure  
(Reprinted from Inorganic Chemistry)

141



Partial Pressure-Temperature Phase Diagram  
(Reprinted from Inorganic Chemistry)

141



Authority**MAGNETIC PROPERTIES**

Susceptibility (25 C)	71 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 4.5 Bohr magnetons Measured 0.41 Bohr magnetons	61
Curie Temperature	None	61
Néel Temperature	None	61

**MECHANICAL PROPERTIES**

Young's Modulus	1.78 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Shear Modulus	0.70 x 10 <sup>11</sup> dynes/cm <sup>2</sup>	57
Poisson's Ratio	0.284	61
Compressibility	7.12 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	57
Hardness (DPH)	21 (not annealed)	57
	<u>70 F</u> <u>400 F</u>	
Tensile Strength	10.4      10.2    10 <sup>3</sup> psi	88
Yield Strength	9.5      7.8    10 <sup>3</sup> psi	88
Elongation	6      10.8    percent	88
Ultimate Compressive Strength		
Impact Strength (Izod)	5.3 ft-lb	71
Workability		
General Fabrication	(See references)	70, 113

Authority

NUCLEAR PROPERTIES

Isotopes

58, 116,  
140

<u>Whole- Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay Mode</u>
168	0.140	Stable	--
169	--	33 days	K, X, $\gamma$
170	3.03	Stable	--
171	14.31	Stable	--
172	21.82	Stable	--
173	16.13	Stable	--
174	31.82	Stable	--
175	--	99 hr	X, $\gamma$ , $\beta^-$
176	12.73	Stable	--
177	--	2.1 hr	$\beta^-$

Thermal Neutron  
Cross Section

$36 \pm 4$  barns/atom  
or  $125 \text{ cm}^2/\text{g}$

73

SAFETY

Details unknown.

83

THERMODYNAMIC PROPERTIES

	<u>Room Temperature</u>	<u>Melting Point</u>
Entropy	$S_{298} = 15.0$	$S_{1097} = 23.92 \text{ eu}$
Heat Capacity	$C_{p298} = 6.00$	$C_{p1097} = 7.58 \text{ cal}/(\text{mole})(\text{C})$



Authority

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## Specific Heat

<u>T, K</u>	<u>C<sub>p</sub>, mj/(mole)(K)</u>	<u>T, K</u>	<u>C<sub>p</sub>, mj/(mole)(K)</u>
	Run I		Run II
0.4275	1.418	0.3697	1.305
0.4428	1.451	0.3864	1.341
0.4651	1.510	0.4051	1.368
0.4959	1.603	0.4288	1.412
0.5355	1.734	0.4514	1.476
0.5823	1.907	0.4781	1.554
0.6350	2.123	0.5058	1.638
0.6615	2.376	0.5360	1.746
0.7494	2.654	0.5688	1.860
0.8090	2.966	0.6043	2.012
0.8727	3.311	0.6422	2.171
0.9403	3.711	0.6811	2.328
1.0109	4.170	0.7217	2.528
1.0848	4.665	0.7652	2.736
1.1615	5.236	0.8123	2.977
1.2422	5.877	0.8645	3.260
1.3283	6.629	0.9226	3.607
1.4200	7.468	0.9850	3.990
1.5201	8.542	1.0518	4.431
1.6343	9.871	1.1238	4.941
1.7626	11.586	1.2044	5.563
1.9097	13.724	1.2924	6.296
2.0682	16.407	1.3909	7.188
2.2351	19.622	1.4957	8.277
2.4120	23.460	1.6309	9.827
2.6012	28.000	1.7562	11.387
2.7992	34.028	1.9045	13.635
3.0023	40.886	2.0815	16.621
3.2097	48.643	2.2782	20.498
3.4197	57.253	2.4883	25.335
3.6341	67.595	2.7076	31.218
3.8576	78.375	2.9215	38.017
		3.1315	45.610
		3.3404	53.958
		3.5487	63.249
		3.7656	73.805
		3.9956	86.267

Heat Content and Entropy of Solid and Liquid Ytterbium  
(Base:  $\alpha$ -crystals at 298.15 K)

77

T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)	T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)
400	620	1.79	1097(1)	7,930	10.92
500	1,250	3.19	1100	7,950	10.94
600	1,900	4.38	1200	8,700	11.59
700	2,570	5.41	1300	9,450	12.19
800	3,260	6.33	1400	10,200	12.75
900	3,970	7.17	1500	10,950	13.27
1000	4,700	7.94	1600	11,700	13.75
1071( $\alpha$ )	5,230	8.45	1700	12,450	14.20
1071( $\beta$ )	5,530	8.73	1800	13,200	14.64
1097(s)	5,730	8.92			

For  $\alpha$ -ytterbium:  $H_T - H_{298.15} = 5.41T + 0.99 \times 10^{-3}T^2 - 1,701$   
(0.1 percent; 298-1,071 K);  
 $C_p = 5.41 + 1.98 \times 10^{-3}T$ ;  
 $\Delta H_{1071}(\text{transition}) = 300$ .

For  $\beta$ -ytterbium:  $H_T - H_{298.15} = 7.70T - 2,717$   
(0.1 percent; 1071-1097 K);  
 $C_p = 7.70$ ;  
 $\Delta H_{1097}(\text{fusion}) = 2,200$ .

For liquid ytterbium:  $H_T - H_{298.15} = 7.50T - 300$   
(0.1 percent; 1097-1800 K);  
 $C_p = 7.50$ .

YTTERBIUM COMPOUNDS

Antimonides

169

	<u>YbSb</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	6.079
Magnetic Susceptibility, $10^{-6}$ emu/mole	5,450
Effective Magnetic Moment, Bohr Magnetons	3.74

Authority

169

## Arsenides

	<u>YbAs</u>
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	5.702
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	7,825
Magnetic Moment, Bohr magnetons	4.61

179

## Beryllides

	<u>YbBe<sub>13</sub></u>
$a_0$ , A	10.19

## Bismuthides

## Properties

	<u>Authority</u>			
Borides	153,155, 171			
	<u>YbB<sub>3</sub></u>	<u>YbB<sub>4</sub></u>	<u>YbB<sub>6</sub></u>	<u>YbB<sub>12</sub></u>
Molecular Weight	205.50	216.32	237.96	--
Structure	Tetragonal	Tetragonal	Cubic	Cubic
a <sub>0</sub> , A	3.77	7.01	4.144	7.476
c <sub>0</sub> , A	3.562	4.00	--	--
Density, g/cm <sup>3</sup>	6.74	7.31	5.556	
Resistivity, microhm-cm	--	--	36.5	--
Temperature Coef- ficient of Resis- tivity, 10 <sup>-3</sup> /C	--	--	2.34	--
Coefficient of Thermal Expansion, 10 <sup>-6</sup> /C	--	--	5.85	--
Thermal Conduc- tivity, cal/ (cm)(sec)(C)	--	--	0.60	--
Magnetic Suscep- tibility, 10 <sup>-6</sup> emu/mole	--	--	8,740	--
Magnetic Moment, Bohr magnetons	--	--	4.58	--
Work Function, ev	--	--	3.13	--
Microhardness, kg/mm <sup>2</sup>	--	--	3080	--
Color	--	--	Black	--
Emissivity (λ = 0.655μ)	--	--	0.7	--
Effective Metallic Radius, A	--	--	2.20	--

Authority

153

## Carbides

	<u>YbC<sub>2</sub></u>	<u>Yb<sub>3</sub>C</u>
Molecular Weight	197.04	531.12
Structure	Body-centered tetragonal	Cubic
Lattice Type	CaC <sub>2</sub>	Fe <sub>4</sub> N
a <sub>0</sub> , Å	2.673	4.993
c <sub>0</sub> , Å	6.109	--
Density, g/cm <sup>3</sup>	8.097	10.26
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	~2,500	--
Effective Magnetic Moment, Bohr magnetons	3.69	--

183

## Germanides

	<u>Yb<sub>2</sub>Ge<sub>3</sub></u>
Structure	Defective AlB <sub>2</sub>
a <sub>0</sub> , Å	3.96
c <sub>0</sub> , Å	4.18
Volume of Unit Cell, Å <sup>3</sup>	56.77

Halides

Authority

93,108,  
109,158,  
186,209,  
210,235,  
236,250,  
277

	<u>YbBr<sub>2</sub></u>	<u>YbCl<sub>2</sub></u>	<u>YbF<sub>2</sub></u>	<u>YbI<sub>2</sub></u>	<u>YbBr<sub>3</sub></u>	<u>YbCl<sub>3</sub></u>	<u>YbF<sub>3</sub></u>	<u>YbI<sub>3</sub></u>	<u>YbOI</u>
Structure	--	Ortho- rhombic	--	--	Hexa- gonal	Mono- clinic	Ortho- rhombic	Hexagonal	Tetragonal
Lattice Type	--	--	--	--	--	--	--	--	PbFCl
a <sub>0</sub> , A	--	6.53	--	--	4.032	6.73	6.216	4.285	3.870
b <sub>0</sub> , A	--	6.68	--	--	--	11.65	6.786	--	--
c <sub>0</sub> , A	--	6.91	--	--	6.382	6.38	4.434	6.931	9.181
β, deg	--	--	--	--	--	110.4	--	--	--
Density, g/cm <sup>3</sup>	--	--	--	--	--	--	8.168	--	--
Heat of Formation, kcal/mole	--	185.5	--	--	--	(224)	--	--	--
Entropy of Formation, eu/mole	--	(39)	--	--	--	(82)	--	--	--
Melting Point, C	677	727	1377	527	940	854	1157	1027	--
Heat of Fusion, kcal/mole	6	6	5	5	10	9	8	10	--
Boiling Point, C	1830	1930	2380	1330	Decom- poses	Decom- poses	2230	Decom- poses	--
Heat of Vaporization, kcal/mole	48	55.7	75	37	--	--	60	--	--
Entropy of Fusion, eu/mole	6	6	3	6	8	8	5	8	--
Entropy of Vaporization, eu/mole	23	23.4	28	23	Decom- poses	Decom- poses	24	Decom- poses	--
Color	--	--	--	--	--	--	White	--	--

Authority

251

## Hydrides

	<u>YbH<sub>2</sub></u>	<u>YbD<sub>2</sub></u>
Structure	Orthorhombic	Orthorhombic
a <sub>0</sub> , Å	--	5.871
b <sub>0</sub> , Å	--	3.561
c <sub>0</sub> , Å	--	6.763

153, 223

## Nitrides

	<u>YbN</u>
Molecular Weight	187.05
Structure	Cubic
Lattice Type	NaCl
a <sub>0</sub> , Å	4.78
Density, g/cm <sup>3</sup>	11.33
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	7,250
Effective Magnetic Moment, Bohr magnetons	4.8
Color	Black

Oxides

Authority

	<u>YbO</u>	<u>Yb<sub>2</sub>O<sub>3</sub></u>
Molecular Weight	--	394.08
Structure	--	Bcc
a <sub>0</sub> , Å	--	10.41
Density, g/cm <sup>3</sup>	--	9.2
Heat of Formation, kcal/mole	158	216.84
Entropy of Formation, eu/mole	--	(34.5)
Melting Point, C	--	2350
Heat Capacity at 300 K, cal/(K)(mole)	--	27.64
Coefficient of Thermal Expansion (20-1100 C), 10 <sup>-6</sup> /C	--	7.5
Effective Magnetic Moment, Bohr magnetons	--	4.5
Color	--	White

156,172,  
153,176,  
177,259,  
266,271

Heat Content and Entropy Increments for Ytterbium Oxide (Yb<sub>2</sub>O<sub>3</sub>)  
(Smooth values)

T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)	T, K	H <sub>T</sub> -H <sub>298.15</sub> , cal/mole	S <sub>T</sub> -S <sub>298.15</sub> , cal/(K)(mole)
400	2,910	8.38	1365	33,000(α)	49.42(α)
500	5,890	15.03	1365	33,150(β)	46.53(β)
600	8,950	20.61	1400	34,280	47.35
700	12,030	25.40	1500	37,500	49.57
800	15,200	29.59	1600	40,720	51.65
900	18,350	33.30	1700	43,940	53.60
1000	21,500	36.62	1800	47,160	55.44
1100	24,650	39.62	1900	50,380	57.18
1200	27,800	42.36	2000	53,600	58.83
1300	30,950	44.88			



		<u>Authority</u>			
<b>Phosphides</b>		169			
	<u>YbP</u>				
Structure	Cubic				
Lattice Type	NaCl				
$a_0$ , A	5.554				
Magnetic Susceptibility, $10^{-6}$ emu/mole	7813				
Magnetic Moment, Bohr magnetons	4.5				
<b>Selenides</b>		192,194, 213,228, 232,268, 278			
	<u>YbSe</u>	<u>Yb<sub>2</sub>Se<sub>3</sub></u>	<u>Yb<sub>4</sub>Se<sub>3</sub></u>	<u>Yb<sub>2</sub>O<sub>2</sub>Se</u>	
Structure	Fcc	Fcc	--	Hcp	
Lattice Type	NaCl	NaCl	--	--	
$a_0$ , A	5.94	5.66	--	3.76	
$c_0$ , A	--	--	--	6.69	
Density, g/cm <sup>3</sup>	--	7.33	--	9.26	
Melting Point, C	1945	>1665	--	--	
Resistivity, microhm-cm	$1 \times 10^8$	--	$6.6 \times 10^5$	--	
Magnetic Susceptibility, $10^{-6}$ emu/mole	--	7,890	--	--	
Magnetic Moment, Bohr magnetons	0.84	4.75	--	--	
Color	--	Violet black	--	Beige	

**Properties**

**321**

Authority

**Silicides**

264

	<u>YbSi<sub>2</sub></u>
Structure	Hexagonal
a <sub>0</sub> , Å	3.77
c <sub>0</sub> , Å	4.10
Volume of Unit Cell, Å <sup>3</sup>	50.5

**Sulfides**

153

	<u>YbS</u>	<u>Yb<sub>3</sub>S<sub>4</sub></u>	<u>Yb<sub>2</sub>S<sub>3</sub></u>	<u>Yb<sub>2</sub>O<sub>2</sub>S</u>
Molecular Weight	205.10	647.36	442.28	410.15
Structure	Cubic	Orthorhombic	Hexagonal	Hexagonal
a <sub>0</sub> , Å	5.673	12.81	6.784	3.723
b <sub>0</sub> , Å	--	12.97	--	--
c <sub>0</sub> , Å	--	3.84	18.29	6.503
Density, g/cm <sup>3</sup>	6.75	6.71	6.04	8.72
Magnetic Susceptibility, 10 <sup>-6</sup> emu/mole	1,450	4,740	7,130	--
Color	--	--	Yellow	--

**Tellurides**

168,228,  
232

	<u>YbTe</u>	<u>Yb<sub>2</sub>Te<sub>3</sub></u>
Structure	Fcc	--
Lattice Type	NaCl	--
a <sub>0</sub> , Å	6.39	--
Melting Point, C	1740	--
Resistivity, microhm-cm	7 x 10 <sup>9</sup>	1 x 10 <sup>7</sup>

LUTETIUM

Symbol Lu

Atomic Number 71

Atomic Weight 174.99

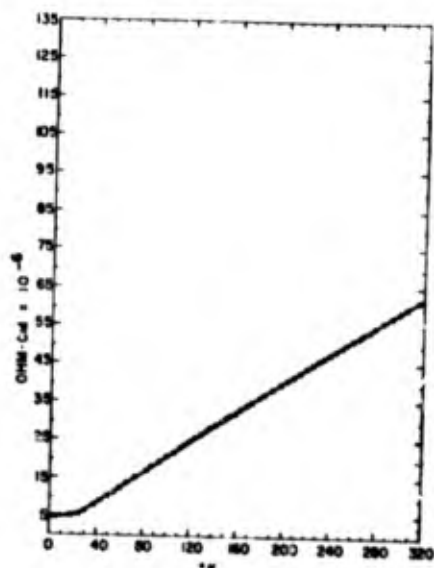
Authority

PHYSICAL PROPERTIES

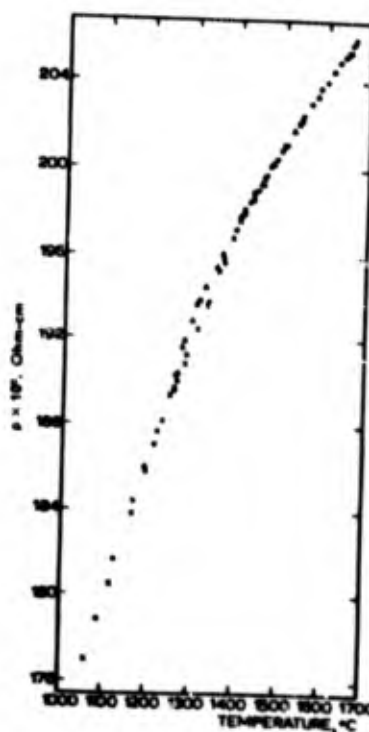
Abundance	0.8-1.7 ppm (approx. 0.8)	51
Density	9.849 g/cm <sup>3</sup> (20 C)	67
Melting Point	1652 C	66
Heat of Fusion	4.5 kcal/mole	61
Boiling Point	3327 C	57
Heat of Vaporization (25 C)	90 kcal/mole	57
Vapor Pressure (1651-1932 K)	$\text{Log } P_{\text{mm Hg}} = 9.247 - \frac{21719}{T}$	60
Specific Heat (25 C)	(6.45) cal/(mole)(C)	53
Heat of Combustion	221.0 kcal/g-atom	142
Coefficient of Linear Thermal Expansion (20-956 C)	12.5 x 10 <sup>-6</sup> /C	61
Thermal Conductivity		
Heat of Sublimation		
Cohesive Energy	94 kcal/mole	89
Work Function		
Debye Temperature	210 K	97
Expansion on Melting		
Surface Tension		

		<u>Authority</u>
<b>CRYSTAL PROPERTIES</b>		
Structure	Hcp	61
Lattice Constants	$a_0 = 3.5031 \text{ \AA}$ $c_0 = 5.5509 \text{ \AA}$	61
Density	9.849 g/cm <sup>3</sup>	67
Metallic Radius	1.734 \AA	67
Atomic Volume	17.779 cm <sup>3</sup> /mole	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ion)	0.848 \AA	55
Closest Approach of Atoms	3.439 \AA	56
Allotropic Modifications	Resistivity measurements indicate a structural change at high temperature.	66
<b>CHEMICAL PROPERTIES</b>		
Stable Oxidation State	+3	81
Electrode Potential	$[\text{Lu} = \text{Lu}^{+3} + 3e^-] + 2.1 \text{ volts}$ (standard hydrogen electrode)	81
Ionization Potential		
Metallographic Polishing and Etching		
Corrosion Rates		
Corrosion Data		
<b>ELECTRICAL PROPERTIES</b>		
Resistivity (25 C)	79 microhm-cm (25 C)	61
Temperature Coefficient of Resistivity	$1.4 \times 10^{-3}/\text{C}$	61

Resistivity Versus Temperature



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(Permission of the Elsevier Publishing Co.)

Values were taken during both heating and cooling.

MAGNETIC PROPERTIES

Magnetic Susceptibility (25 C)	17.9 x 10 <sup>-6</sup> emu/mole	61
Effective Magnetic Moment	Theoretical 0.00 Bohr magnetons Measured 0.21 Bohr magnetons	61
Curie Temperature	None	61
Néel Temperature	None	61

MECHANICAL PROPERTIES

Young's Modulus		
Shear Modulus		
Poisson's Ratio		
Compressibility	2.3 x 10 <sup>-6</sup> cm <sup>2</sup> /kg	64
Hardness (DPH)	77	57

Authority

Tensile Strength

Yield Strength

Elongation

Ultimate Compressive Strength      144.8  $10^3$  psi

61

Impact Strength (Izod)

Workability

General Fabrication      (See references)

70, 113

## NUCLEAR PROPERTIES

Isotopes

56, 133

<u>Whole- Number Mass</u>	<u>Relative Abundance, percent</u>	<u>Half Life</u>	<u>Decay Mode</u>
170	--	2.15 days	K, e <sup>-</sup> , $\gamma$ , X, $\beta^+$
171	--	9 days	K, e <sup>-</sup> , $\gamma$ , X
172	--	100 days	K, e <sup>-</sup> , $\gamma$ , X
175	97.4	Stable	--
176	2.6	$2.4 \times 10^{10}$ years	K, $\gamma$ , $\beta^-$ , X
177	--	6.6 days	$\beta^-$

Thermal Neutron  
Cross Section108  $\pm$  5 barns/atom  
or 0.37 cm<sup>2</sup>/g

73

## SAFETY

83

Details unknown.

## THERMODYNAMIC PROPERTIES

76, 77

	<u>Room Temperature</u>	<u>Melting Point</u>
Entropy	S <sub>298</sub> = 11.8	S <sub>2000</sub> = 25.77 eu
Heat Capacity	C <sub>p298</sub> = 6.45	C <sub>p2000</sub> = 9.00 cal/(mole)(C)

## Properties

## Authority

77

Heat Content and Entropy of Solid and  
Liquid Lutetium  
(Base: crystals at 298.15 K)

T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(K)(mole)	T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(K)(mole)
400	665	1.91	1400	8,010	10.93
500	1,330	3.40	1500	8,830	11.50
600	2,015	4.65	1600	9,660	12.03
700	2,710	5.72	1700	10,510	12.55
800	3,425	6.67	1800	11,370	13.04
900	4,150	7.53	1900	12,250	13.51
1000	4,890	8.31	2000(s)	13,140	13.97
1100	5,650	9.03	2000(l)	17,740	16.27
1200	6,420	9.71	2100	18,540	16.66
1300	7,210	10.34	2200	19,340	17.03

For solid lutetium:  $H_T - H_{298.15} = 6.00T + 0.75 \times 10^{-3} T^2 - 1,856$   
(0.1 percent; 298-2000 K);  
 $C_p = 6.00 + 1.50 \times 10^{-3} T$ ;  
 $\Delta H_{2,000}(\text{fusion}) = 4,600$ .

For liquid lutetium:  $H_T - H_{298.15} = 8.00T + 1,740$   
(0.1 percent; 2000-2200 K);  
 $C_p = 8.00$ .

79

## Thermodynamic Functions

T, K	$C_p$ j/(g-atom)(K)	$S^\circ$ j/(g-atom)(K)	$\frac{H^\circ - H_0^\circ}{T}$ j/(g-atom)(K)	$\frac{(-F^\circ - H_0^\circ)}{T}$ j/(g-atom)(K)
5	0.10	0.063	0.036	0.027
10	0.49	0.225	0.145	0.080
15	1.67	0.607	0.425	0.182
20	3.66	1.346	0.977	0.369
30	8.47	3.746	2.673	1.073
40	12.71	6.793	4.677	2.116
50	15.84	9.973	6.613	3.360
60	18.10	13.072	8.309	4.723
70	19.74	15.993	9.865	6.127
80	20.98	18.712	11.179	7.533
90	21.93	21.241	12.323	8.918
100	22.59	23.587	13.318	10.269
120	23.64	27.802	14.954	12.848
140	24.40	31.506	16.252	15.254
160	24.97	34.802	17.307	17.495
180	25.42	37.769	18.184	19.585
200	25.78	40.457	18.926	21.531
220	26.03	42.936	19.561	23.375
240	26.25	45.210	20.109	25.101
260	26.50	47.322	20.591	26.731
273.15	26.63	48.633	20.979	27.754
280	26.69	49.293	21.020	28.273
298.15	26.85	50.975	21.369	29.606
300	26.88	51.141	21.404	29.737
320	27.04	52.881	21.751	31.130
340	27.17	54.523	22.066	32.457

## LUTETIUM COMPOUNDS

		<u>Authority</u>			
Antimonides	<u>LuSb</u>	275			
Structure	Cubic				
Lattice Type	NaCl				
$a_0$ , A	6.0555				
Arsenides	--				
Beryllides	<u>LuBe<sub>13</sub></u>	179			
$a_0$ , A	10.177				
Bismuthides	--				
Borides		153, 171			
	<u>LuB<sub>2</sub></u>	<u>LuB<sub>4</sub></u>	<u>LuB<sub>6</sub></u>	<u>LuB<sub>12</sub></u>	
Molecular weight	196.63	218.27	239.91	304.83	
Structure	Hexagonal	Tetragonal	Cubic	Cubic	
$a_0$ , A	3.246	6.997	4.11	7.464	
$c_0$ , A	3.704	3.938	--	--	
Density, g/cm <sup>3</sup>	9.76	7.52	5.74	4.868	
Work Function, ev	--	--	3.0	--	
Color	--	--	Blue	--	
Emissivity ( $\lambda = 0.655\mu$ )	--	--	0.7	--	
Effective Metallic Radius, A	--	--	2.19	--	



**Properties**

**329**

Authority

**Carbides**

153

	<u>Lu<sub>3</sub>C</u>	<u>LuC<sub>2</sub></u>
Molecular Weight	536.97	198.99
Structure	Cubic	Body-centered tetragonal
Lattice Type	Fe <sub>4</sub> N	CaC <sub>2</sub>
a <sub>0</sub> , Å	4.965	3.563
c <sub>0</sub> , Å	--	5.964
Density, g/cm <sup>3</sup>	10.54	8.728

**Germanides**

183

	<u>Lu<sub>2</sub>Ge<sub>3</sub></u>
Lattice Type	Defective AlB <sub>2</sub>
a <sub>0</sub> , Å	3.83
c <sub>0</sub> , Å	4.05
Volume of Unit Cell, Å <sup>3</sup>	51.45

Halides	<u>Authority</u>			
	93, 108, 158, 165, 209, 210, 235, 236			
	<u>LuBr<sub>3</sub></u>	<u>LuCl<sub>3</sub></u>	<u>LuF<sub>3</sub></u>	<u>LuI<sub>3</sub></u>
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal
a <sub>0</sub> , A	4.015	6.72	6.151	4.271
b <sub>0</sub> , A	--	11.60	6.758	--
c <sub>0</sub> , A	6.371	6.39	4.467	6.930
Density, g/cm <sup>3</sup>	--	--	8.332	--
Melting Point, C	957	892	1182	1045
Heat of Fusion, kcal/mole	10	9	8	11
Entropy of Fusion, eu/mole	8	8	5	8
Boiling Point, C	1410	1490	2225	1210
Heat of Vaporization, kcal/mole	42	43	60	38
Entropy of Vaporization, eu/mole	25	25	24	25
Color	--	--	White	--
Volume of Unit Cell, A <sup>3</sup>	--	467	185.7	--

## Hydrides

165

	<u>LuH<sub>2</sub></u>	<u>LuH<sub>3</sub></u>
Structure	Cubic	Hexagonal
a <sub>0</sub> , A	5.033	3.558
c <sub>0</sub> , A		6.443

Nitrides

Authority

153

LuN

Molecular Weight	189.00
Structure	Cubic
Lattice Type	NaCl
$a_0$ , A	4.766
Density, g/cm <sup>3</sup>	11.59

Oxides

156, 172,  
173, 177,  
245

Lu<sub>2</sub>O<sub>3</sub>

Molecular Weight	397.94
Structure	Bcc
$a_0$ , A	10.38
Heat of Formation, kcal/mole metal	224.5
Entropy of Formation, eu/mole	(35.6)
Heat Capacity, cal/(mole)(C)	23.40
Coefficient of Thermal Expansion (20-1300 C), 10 <sup>-6</sup> /C	7.4
Effective Magnetic Moment, Bohr magnetons	0.0

(Continued)

Authority

## Oxides (Continued)

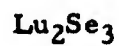
Heat Content and Entropy Values for  
Lutetium Oxide (Smooth Values)

T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(K)(mole)	T, K	$H_T - H_{298.15}$ cal/mole	$S_T - S_{298.15}$ cal/(K)(mole)
400	2,550	7.33	1300	29,340	41.89
500	5,260	13.38	1400	32,490	44.23
600	8,100	18.55	1500	35,660	46.41
700	11,020	23.05	1600	38,840	48.46
800	13,990	27.02	1700	42,030	50.40
900	17,000	30.56	1800	45,230	52.23
1000	20,040	33.76	1900	48,440	53.97
1100	23,110	36.69	2000	51,660	55.62
1200	26,210	39.39			

## Phosphides

## Selenides

268



Structure

Fcc

a<sub>0</sub>, A

5.62

## Silicides

263, 264



Structure

Hexagonal

a<sub>0</sub>, A

3.74

c<sub>0</sub>, A

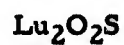
4.04

Volume of Unit  
Cell, A<sup>3</sup>

49.2

## Sulfides

153



Molecular Weight

414.05

Structure

Hexagonal

a<sub>0</sub>, A

3.709

c<sub>0</sub>, A

6.486

Density, g/cm<sup>3</sup>

8.89

Tellurides

Miscellaneous

150, 267

<u>Compound</u>	<u>Structure</u>	<u>Lattice Type</u>	<u>a<sub>0</sub>, A</u>	<u>c<sub>0</sub>, A</u>	<u>Superconducting Transition Temperature, K</u>
LuCa <sub>3</sub>	--	AuCu <sub>3</sub>	4.169	--	--
LuRu <sub>2</sub>	Hexagonal	--	5.204	8.725	--
LuOs <sub>2</sub>	Hexagonal	--	5.254	8.661	3.49

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The unclassified literature, both U. S. and foreign, relating to yttrium and the lanthanide rare-earth elements Numbers 57 through 71 has been reviewed. The best available data on properties have been compiled and are presented in tabular form by property and by element. Included are the physical, chemical, magnetic, electrical, mechanical, and nuclear properties of the elements and their compounds. Over 200 phase diagrams are presented. A supplemental list of publications containing data on optical properties has been included.

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