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PROPERTIES OF THE RARE EARTH METALS AND COMPOUNDS

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GIFFORD S. HARVEY

BATTELLE MEMORIAL INSTITUTE

TECHNICAL REPORT AFML-TR-65-430

JANUARY 1966

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 OF THE RARE EARTH ELEMENTS
(Room Temperature)

Symbol	Atomic No.	Atomic Weight	Estimated Abundance, ppm	Density, g/cm^3	Atomic Volume, cm^3/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	19.032	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[a]	Lattice Constants a_o, A	Lattice Constants c_o, A	Metallic Radius, A
YTTRIUM	93	6.01	10.8	0.035	Hcp	3.6474	5.7306	1.801
					Bcc	4.11	--	1.83
LANTHANUM	96	6.65	4.9	0.033	Hcp	3.770	12.159	1.877
					Fcc	5.304	--	1.875
CERIUM	95	6.44	8.5	0.026	Fcc	5.1612	--	1.825
					Bcc	4.11	--	1.83
PRASEODYMIUM	79	6.48	4.8	0.028	Hcp	3.6725	11.8354	1.828
					Bcc	4.13	--	1.84
NEODYMIUM	69	6.57	6.7	0.031	Hcp	3.6579	11.7992	1.821
					Bcc	4.13	--	1.84
PROMETHIUM	(60)	(6.60)	--	--	Fcc	--	--	(1.810)
SAMARIUM	46	6.76	--	--	Rhombohedral	8.966	α=23°13'	1.802
					Bcc	4.07	--	1.81
EUROPIUM	42	6.4	32.0	--	Bcc	4.5820	--	2.042
GADOLINIUM	72	8.80	8.6	0.021	Hcp	3.6360	5.7826	1.802
					Bcc	4.06	--	--
TERBIUM	70	6.92	7.0	0.13	Hcp	3.6010	5.6936	1.782
DYSPROSIUM	67	6.73	8.6	0.024	Hcp	3.5903	5.6475	1.773
HOLMIUM	67	6.49	9.5	--	Hcp	3.5773	5.6158	1.766
ERBIUM	67	6.72	9.2	0.023	Hcp	3.5588	5.5874	1.757
THULIUM	59	6.45	11.6	--	Hcp	3.5375	5.5546	1.746
YTTERBIUM	38	(6.0)	25.0	--	Fcc	5.4862	--	1.940
					Bcc	4.45	--	1.93
LUTETIUM	90	(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	Thermal-Neutron Cross Section Cm^2/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^{11} dynes/cm^2	Shear Modulus, 10^{11} dynes/cm^2	Poisson's Ratio	Sonic Compressibility, 10^6 cm^2/kg
YTTRIUM	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

Tensile Strength, 1000 psi	Yield Strength, 1000 psi	Elongation, per cent	Izod Impact Strength, ft-lb	Resistivity, microhm-cm	Temperature Coefficient of Resistivity, 10^{-3}/C	
22.0	9.7	25	1.60	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	86	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[109]

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_3PO_4 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_3PO_4 30C	Eu	--	Sm, Gd, Tb, Dy, Ho, Tm, Y	Pr, Nd, Er, Yb	La, Ce	--	--
1N CrO_3, 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_2CrO_4 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 Hf-HNO_3, 25C	--	Sm	Nd	La, Ce, Pr	Eu	Tb, Ho, Yb	Gd, Dy, Er, Tm, Y

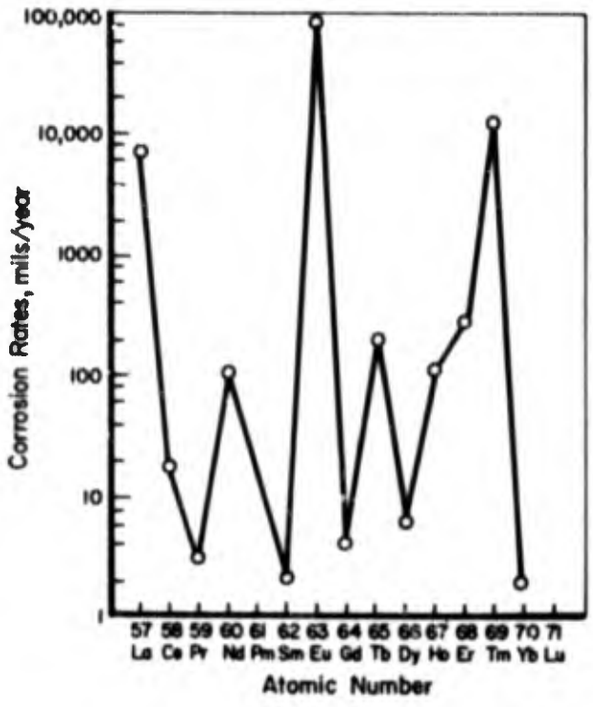
EXPLORATORY CORROSION TESTS OF GADOLINIUM, DYSPROSIUM, HOLMIUM, ERBIUM AND YTTRIUM AT 25 C

Medium	Corrosion Rate, mils/year
99% H_2SO_4	Dissolved[a]
37% HCl	Dissolved[a]
70% HNO_3	Dissolved[a]
70% $HClO_4$	Dissolved[a]
1N H_2SO_4	Over 10^6
1N HCl	Over 10^6
1N HNO_3	$1 - 9 \times 10^5$
1N $HClO_4$	$1 - 9 \times 10^5$
1N HCOOH	$1 - 9 \times 10^5$
0.1N H_2SO_4	$1 - 9 \times 10^4$
0.1N HCl	$1 - 9 \times 10^4$
1N KCl	$1 - 9 \times 10^4$
1N $CuCl_2$	$1 - 9 \times 10^4$
3.5% $Fe_2(SO_4)_3$	$1 - 9 \times 10^4$
99.9% CH_3COOH	$1 - 9 \times 10^3$
85% H_3PO_4	$1 - 9 \times 10^3$
48% HF	1 - 10

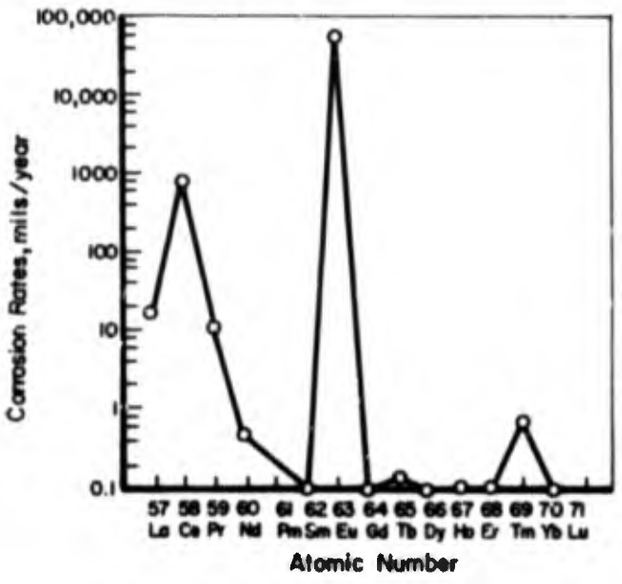
(a) Specimens had surface areas of approximately 3 sq cm and were completely dissolved within 10 minutes.

OXIDATION OF RARE EARTHS AND YTTRIUM

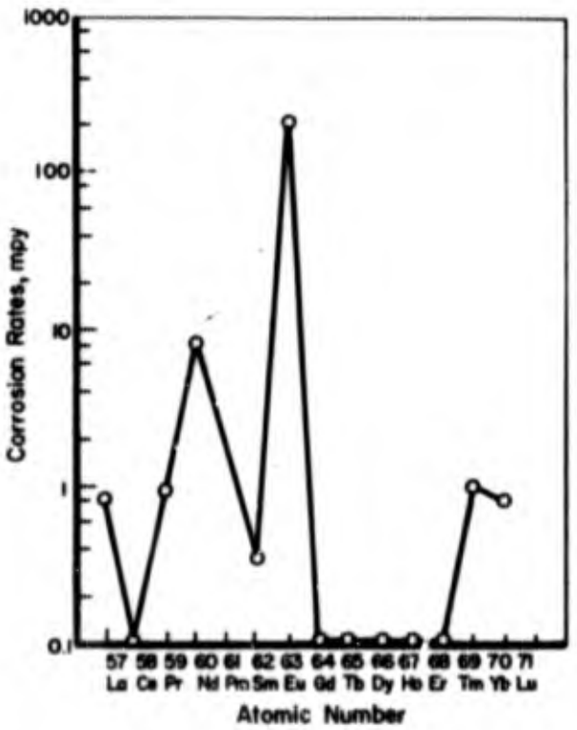
Metal	Weight Gain, milligrams per square decimeter per day				
	Air			Water-Saturated Air at 40C	Air in Equilibrium with 30% H_2O_2 at 40C
	25C	100C	200C		
La	2	48	<1	16	6
Ce	4	2020	870	37	25
Pr	<1	11	<1	13	25
Nd	0	3	<1	6	11
Sm	0	0	0	5	20
Eu	1550	230	560	3370	4560
Gd	0	0	0	<1	0
Tb	0	0	0	<1	2
Dy	0	0	0	<1	0
Ho	0	2	<1	<1	0
Er	0	0	0	<1	1
Tm	0	0	0	<1	<1
Yb	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_o, A	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_4Sb_3	Bcc	Th_3P_4	9.224	--	220	--	--
TbSb	Cubic	NaCl	6.180	--	--	36,232	9.57
DySb	Cubic	NaCl	6.160	--	--	45,556	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_o, A	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
YAs	Cubic	NaCl	5.808	--	--	--
LaAs	Cubic	NaCl	6.137	--	--	--
CeAs	Cubic	NaCl	6.072	--	--	--
PrAs	Cubic	NaCl	6.009	--	--	3.80
NdAs	Cubic	NaCl	5.970	150	--	--
SmAs	Cubic	NaCl	5.921	160	1,066	--
GdAs	Cubic	NaCl	5.862	--	27,548	8.18
TbAs	Cubic	NaCl	5.827	--	39,033	9.65
DyAs	Cubic	NaCl	5.803	--	46,948	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_o, A	Compound	a_o, A
YBe_{13}	10.238	$GdBe_{13}$	10.27
$LaBe_{13}$	10.450	$TbBe_{13}$	10.251
$CeBe_{13}$	10.378	$DyBe_{13}$	10.240
$PrBe_{13}$	10.367	$HoBe_{13}$	10.220
$NdBe_{13}$	10.356	$ErBe_{13}$	10.215
$PmBe_{13}$	10.33	$TmBe_{13}$	10.192
$SmBe_{13}$	10.28	$YbBe_{13}$	10.19
$EuBe_{13}$	10.288	$LuBe_{13}$	10.177

BISMUTHIDES

Compound	Structure	Lattice Type	a_o, 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_4Bi_3	--	--	9.383	190	--	--
TbBi	Cubic	NaCl	6.280	--	38,086	9.64
DyBi	Cubic	NaCl	6.251	--	44,053	10.97
HoBi	Cubic	NaCl	6.228	--	44,843	10.32
ErBi	Cubic	NaCl	6.202	--	35,714	9.32
TmBi	Cubic	NaCl	6.192	--	25,000	7.63

BORIDES

Compound	Structure	Lattice Constants, A		Density, g/cm^3	Melting Point, C
		a_o	c_o		
		MB_2			
YB_2	Hexagonal	3.298	3.843	2.91	2100
GdB_2	Hexagonal	3.31	3.94	--	--
TbB_2	Hexagonal	3.28	3.86	--	--
DyB_2	Hexagonal	3.285	3.835	--	--
HoB_2	Hexagonal	3.17	3.81	--	--
ErB_2	Hexagonal	3.28	3.79	--	--
LuB_2	Hexagonal	3.246	3.704	9.76	--

BORIDES (Continued)

Compound	Structure	Lattice Constants, A a_o	Lattice Constants, A c_o	Density, g/cm^3
		MB_3		
YB_3	Tetragonal	3.78	3.55	3.97
LaB_3	Tetragonal	3.82	3.96	4.92
PrB_3	Pseudocubic	3.81	--	5.20
GdB_3	Tetragonal	3.79	3.63	6.03
YbB_3	Tetragonal	3.77	3.562	6.74

Compound	Structure	Lattice Constants, A a_o	Lattice Constants, A c_o	Density, g/cm^3	Melting Point, C	Color
			MB_4			
YB_4	Tetragonal	7.111	4.017	4.36	2,800	--
LaB_4	Tetragonal	7.30	4.17	5.44	--	--
CeB_4	Tetragonal	7.205	4.090	5.74	--	Gray brown
PrB_4	Tetragonal	7.20	4.11	5.74	--	Gray brown
NdB_4	Tetragonal	7.219	4.1020	5.83	--	--
SmB_4	Tetragonal	7.174	4.070	6.19	--	Gray brown
GdB_4	Tetragonal	7.114	4.047	6.446	--	Gray brown
TbB_4	Tetragonal	7.118	4.0286	6.579	--	Gray brown
DyB_4	Tetragonal	7.101	4.0174	6.74	--	Gray brown
HoB_4	Tetragonal	7.064	4.000	6.88	--	Gray brown
ErB_4	Tetragonal	7.071	3.9972	7.261	--	Gray brown
TmB_4	Tetragonal	7.06	3.99	7.09	--	Gray brown
YbB_4	Tetragonal	7.01	4.00	7.31	--	Gray brown
LuB_4	Tetragonal	6.997	3.938	7.52	--	Gray brown

BORIDES (Continued)

Compound	Structure	a_o, A	Density, g/cm³	Melting Point, C	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons	Work Function, ev	Emissivity, λ = 0.655
				MB_6				
YB_6	Cubic	4.113	3.76	2,300	--	0.0	2.22	0.7
LaB_6	Cubic	4.154	4.721	2,100	--	9.0	2.66	0.7
CeB_6	Cubic	4.137	4.80	2,190	2,260	2.60	2.59	0.68
PrB_6	Cubic	4.130	4.851	--	4,800	3.37	3.12	0.67
NdB_6	Cubic	4.125	4.948	2,540	2,420	3.82	3.97	0.64
SmB_6	Cubic	4.131	5.08	1,810	1,810	2.52	4.4	0.66
EuB_6	Cubic	4.178	4.938	2,200	--	--	4.9	0.83
GdB_6	Cubic	4.112	5.30	>2,100	21,000	7.68	2.05	0.65
TbB_6	Cubic	4.1020	5.385	--	--	--	2.99	0.74
DyB_6	Cubic	4.0976	5.49	--	--	--	3.53	0.7
HoB_6	Cubic	4.096	5.53	--	--	--	3.42	0.7
ErB_6	Cubic	4.110	5.58	--	--	--	3.37	0.7
TmB_6	Cubic	4.11	5.59	--	--	--	3.34	--
YbB_6	Cubic	4.144	5.556	--	8,740	4.58	3.13	0.7
LuB_6	Cubic	4.11	5.74	--	--	--	3.0	0.7

Compound	Structure	a_o, A	Density, g/cm³
		MB_{12}	
YB_{12}	Cubic	7.500	3.44
TbB_{12}	Cubic	7.504	--
DyB_{12}	Cubic	7.501	4.60
HoB_{12}	Cubic	7.492	4.655
ErB_{12}	Cubic	7.484	4.706
TmB_{12}	Cubic	7.476	4.756
YbB_{12}	Cubic	7.476	--
LuB_{12}	Cubic	7.464	4.868

Compound	Structure	Lattice Constants, A		Melting Point, C
		a_o	c_o	
		MB_{70}		
YB_{70}	Tetragonal	11.15	12.62	(2,000)

CARBIDES

Compound	Melting Point, C	Resistivity, microhm-cm
	MC	
YC	1,950	4.54×10^4

Compound	Structure	Lattice Type	Lattice Constants, A a_o	c_o	Density, g/cm³	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
					MC_2				
YC_2	Body-centered tetragonal	CaC_2	3.664	6.169	4.528	2300	88.7	--	--
α-LaC_2	Body-centered tetragonal	CaC_2	3.92	6.56	5.35	--	68	--	--
β-LaC_2	Cubic	FeS_2	6.0	--	5.0	2438	--	--	--
CeC_2	Body-centered tetragonal	CaC_2	3.88	6.49	5.56	2540	58.8	1,640	2.19
PrC_2	Body-centered tetragonal	CaC_2	3.85	6.42	5.73	2535	25.7	4,500	(3.15)
NdC_2	Body-centered tetragonal	CaC_2	3.82	6.37	6.00	>2000	--	--	3.53
SmC_2	Body-centered tetragonal	CaC_2	3.76	6.29	6.50	>2200	--	~2,300	2.85
GdC_2	Body-centered tetragonal	CaC_2	3.718	6.275	6.939	>2200	--	--	7.92
TbC_2	Body-centered tetragonal	CaC_2	3.690	6.217	7.176	--	--	~2,850	9.57
DyC_2	Body-centered tetragonal	CaC_2	3.669	6.176	7.450	--	--	~38,500	10.53
HoC_2	Body-centered tetragonal	CaC_2	3.643	6.139	7.701	--	--	~43,500	10.57
ErC_2	Body-centered tetragonal	CaC_2	3.620	6.094	7.954	--	--	~33,300	8.75
TmC_2	Body-centered tetragonal	CaC_2	3.600	6.047	8.175	--	--	--	--
YbC_2	Body-centered tetragonal	CaC_2	2.673	6.109	8.097	--	--	~2,500	3.68
LuC_2	Body-centered tetragonal	CaC_2	3.563	5.964	8.728	--	--	--	--

Compound	Structure	Lattice Type	a_o, A	Density, g/cm³	Melting Point, C	Resistivity, microhm-cm
			M_2C_3			
Y_2C_3	--	--	--	--	1,800	350
La_2C_3	Bcc	Pu_2C_3	8.8185	6.079	2,080	144
Ce_2C_3	Bcc	Pu_2C_3	8.448	6.969	--	202
Pr_2C_3	Bcc	Pu_2C_3	8.7072	6.821	--	--
Nd_2C_3	Bcc	Pu_2C_3	8.6478	6.901	--	--
Sm_2C_3	Bcc	Pu_2C_3	8.4257	7.477	--	--
Gd_2C_3	Bcc	Pu_2C_3	8.3407	8.084	--	--
Tb_2C_3	Bcc	Pu_2C_3	8.2617	8.335	--	--

CARBIDES (Continued)

Component	Structure	Lattice Type	a_o, A	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm
			M_2C_3 (Continued)			
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_o, A	Density, g/cm^3
		M_3C		
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, A		
			a_o	b_o	c_o
		MGe			
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, A a_o	b_o	c_o	Density, g/cm^3
		MGe_2				
YGe_2	Imperfect	--	3.96	--	4.14	--
α-$LaGe_2$	--	α-$ThSi_2$	4.321	--	14.209	--
β-$LaGe_2$	--	α-$GdSi_2$	4.41	4.30	14.190	7.059
α-CeG_2	--	α-$ThSi_2$	4.27	--	14.08	--
β-CeG_2	--	α-$GdSi_2$	4.36	4.26	14.07	--
$PrGe_2$	--	α-$ThSi_2$	4.26	--	13.98	--
$NdGe_2$	--	α-$ThSi_2$	4.230	--	13.920	--
$SmGe_2$	--	α-$ThSi_2$	4.193	--	13.835	--
$EuGe_2$	--	AlB_2 defect	4.09	--	4.99	--
$GdGe_2$	--	α-$ThSi_2$	4.12	--	13.72	--

Compound	Lattice Type	Lattice Constants, A a_o	c_o
	M_2Ge_3		
Tb_2Ge_3	AlB_2 defect	3.95	4.16
Dy_2Ge_3	AlB_2 defect	3.92	4.13
Ho_2Ge_3	AlB_2 defect	3.90	4.11
Er_2Ge_3	AlB_2 defect	3.89	4.09
Tm_2Ge_3	AlB_2 defect	3.88	4.07
Yb_2Ge_3	AlB_2 defect	3.96	4.18
Lu_2Ge_3	AlB_2 defect	3.83	4.05

Compound	Structure	Lattice Constants, A a_o	c_o	Density, g/cm^3
		M_5Ge_3		
La_5Ge_3	Hcp	8.958	6.796	3.72
Ce_5Ge_3	Hcp	8.875	6.670	3.92

HALIDES

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Melting Point, C	Boiling Point, C
		MBr_3				
YBr_3	Hexagonal	4.102	--	6.399	904	1,463
$LaBr_3$	Hexagonal	--	--	--	788	1,580
$CeBr_3$	Hexagonal	--	--	--	732	1,560
$PrBr_3$	--	--	--	--	693	1,550
$NdBr_3$	--	--	--	--	684	1,540
$PmBr_3$	--	--	--	--	677	1,530
$SmBr_3$	--	--	--	--	664	Decomposes
$EuBr_3$	Orthorhombic	12.712	4.019	9.128	707	Decomposes
$GdBr_3$	Hexagonal	4.172	--	6.441	785	1,490
$TbBr_3$	Hexagonal	4.129	--	6.391	827	1,490
$DyBr_3$	Hexagonal	4.114	--	6.400	881	1,480
$HoBr_3$	Hexagonal	4.088	--	6.391	914	1,470
$ErBr_3$	Hexagonal	4.070	--	6.388	950	1,460
$TmBr_3$	Hexagonal	4.042	--	6.367	955	1,440
$YbBr_3$	Hexagonal	4.032	--	6.382	940	Decomposes
$LuBr_3$	Hexagonal	4.015	--	6.371	957	1,410

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Melting Point, C	Boiling Point, C
		MCl_2				
$SmCl_2$	Orthorhombic	8.973	7.532	4.497	740	2,030
$EuCl_2$	Orthorhombic	8.914	7.499	4.493	727	2,030
$YbCl_2$	Orthorhombic	6.53	6.68	6.91	727	1,930

HALIDES (Continued)

Compound	Structure	Lattice Constants, A			β, degrees	Melting Point, C	Boiling Point, C
		a_o	b_o	c_o			
			MCl_3				
YCl_3	Monoclinic	11.94	--	--	111.0	700	1,507
$LaCl_3$	Hexagonal	--	--	--	--	852	1,750
$CeCl_3$	Hexagonal	7.450	--	4.315	--	802	1,730
$PrCl_3$	Hexagonal	7.422	--	4.275	--	786	1,710
$NdCl_3$	Hexagonal	--	--	--	--	759	1,690
$PmCl_3$	Hexagonal	7.397	--	4.211	--	737	1,670
$SmCl_3$	Hexagonal	7.378	--	4.171	--	678	Decomposes
$EuCl_3$	Hexagonal	7.369	--	4.133	--	623	Decomposes
$GdCl_3$	Hexagonal	7.363	--	4.105	--	602	1,580
$TbCl_3$	Monoclinic	6.163	3.848	8.357	107.6	588	1,550
$DyCl_3$	Monoclinic	6.91	11.97	6.40	111.2	654	1,530
$HoCl_3$	Monoclinic	6.85	11.85	6.39	110.8	720	1,510
$ErCl_3$	Monoclinic	6.80	11.79	6.39	110.7	776	1,500
$TmCl_3$	Monoclinic	6.75	11.73	6.39	110.6	821	1,490
$YbCl_3$	Monoclinic	6.73	11.65	6.38	110.4	854	Decomposes
$LuCl_3$	Monoclinic	6.72	11.60	6.39	--	892	1,480

Compound	Structure	Lattice Constants, A			Density, g/cm^3	Melting Point, C	Boiling Point, C
		a_o	b_o	c_o			
			MF_3 and MF_4				
YF_3	Orthorhombic	6.353	6.850	4.393	5.069	1,148	(2,227)
YF_3	Cubic	5.644	--	--	--	--	--
LaF_3	Hcp	7.186	--	7.352	5.94	1,490	(2,327)
CeF_3	Hexagonal	7.114	--	7.273	5.99	1,437	(2,327)
PrF_3	Hexagonal	7.061	--	7.218	6.18	1,395	(2,327)
NdF_3	Hexagonal	7.030	--	7.200	6.37	1,374	(2,327)
PmF_3	Hexagonal	6.96	--	7.14	--	1,407	(2,327)
SmF_3	Orthorhombic	6.669	7.059	4.405	6.643	1,306	(2,327)
SmF_3	Hexagonal	6.956	--	7.120	6.925	--	--
EuF_3	Orthorhombic	6.622	7.019	4.396	6.793	1,276	(2,277)
EuF_3	Hexagonal	6.916	--	7.091	7.088	--	--
GdF_3	Orthorhombic	6.570	6.894	4.393	7.047	1,228	(2,277)
TbF_3	Orthorhombic	6.513	6.949	4.384	7.236	1,172	(2,277)
TbF_4	Monoclinic[a]	12.1	10.3	7.9	--	--	--
DyF_3	Orthorhombic	6.460	6.906	4.376	7.456	1,154	2,230
HoF_3	Orthorhombic	6.404	6.875	4.379	7.644	1,143	2,230
HoF_3	Hexagonal	6.833	--	6.984	7.829	--	--
ErF_3	Orthorhombic	6.354	6.846	4.380	7.814	1,140	2,230
TmF_3	Orthorhombic	6.283	6.811	4.408	7.971	--	--
TmF_3	Hexagonal	6.763	--	6.927	8.220	1,158	2,230
YbF_3	Orthorhombic	6.216	6.786	4.434	8.168	1,157	2,230
LuF_3	Orthorhombic	6.151	6.758	4.467	8.332	1,182	2,225

(a) β = 126 deg.

HALIDES (Continued)

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Melting Point, C	Boiling Point, C
		MI_3				
YI_3	Hexagonal	4.340	--	6.960	1,000	1,307
LaI_3	--	--	--	--	761	1,405
CeI_3	Orthorhombic	14.0	4.4	10.1	752	1,400
PrI_3	Orthorhombic	13.9	4.3	10.0	738	1,380
NdI_3	Orthorhombic	13.988	4.316	9.977	787	1,370
PmI_3	--	--	--	--	797	1,370
SmI_3	Hexagonal	4.415	--	6.976	820	Decomposes
EuI_3	--	--	--	--	(877)	Decomposes
GdI_3	Hexagonal	4.383	--	6.968	926	1,340
TbI_3	Hexagonal	4.357	--	6.954	(952)	(1,330)
DyI_3	Hexagonal	4.335	--	6.958	955	1,320
HoI_3	Hexagonal	4.319	--	6.946	1,010	1,300
ErI_3	--	--	--	--	1,020	1,280
TmI_3	Hexagonal	4.288	--	6.934	1,015	1,260
YbI_3	Hexagonal	4.285	--	6.931	(1,027)	Decomposes
LuI_3	Hexagonal	4.271	--	6.930	1,045	1,210

Compound	Structure	Lattice Constants, A a_o	c_o
	MOBr		
LaOBr	Tetragonal	4.149	7.359

Compound	Structure	Lattice Constants, A a_o	c_o	Heat of Formation, kcal/mole
	MOCl			
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 a_o	c_o	β, degrees	Density, g/cm^3
		MOF			
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
α-PmOF	Fcc	5.56	--	--	--
β-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_o	c_o
		MOI		
LaOI	Tetragonal	PbFCl	4.144	9.126
SmOI	Tetragonal	PbFCl	4.008	9.192
TmOI	Tetragonal	PbFCl	3.887	9.166
YbOI	Tetragonal	PbFCl	3.870	9.161

HYDRIDES

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Density, g/cm^3	Heat of Formation, kcal/mole H_2	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
				MH_2-MD_2				
YH_2	--	5.205	--	--	--	--	--	--
LaH_2	--	5.667	--	--	5.14	49.7	--	--
CeH_2	Fluorite	5.581	--	--	5.43	33.9	--	--
PrH_2	Fluorite	5.517	--	--	5.65	47.8	--	--
NdH_2	Fluorite	5.464	--	--	5.94	44.8	--	--
SmH_2	Fluorite	5.374	--	--	6.52	--	--	--
EuD_2	Orthorhombic	6.21	3.77	7.16	--	--	--	--
GdH_2	Fluorite	5.303	--	--	7.08	46.9	--	--
TbH_2	Cubic	5.246	--	--	--	--	--	--
DyH_2	Cubic	5.201	--	--	--	--	46,700	10.8
HoH_2	Cubic	5.165	--	--	--	--	--	--
ErH_2	Cubic	5.123	--	--	--	--	36,200	9.75
TmH_2	Cubic	5.090	--	--	--	--	21,870	7.60
YbH_2	Orthorhombic	--	--	--	--	--	--	--
YbD_2	Orthorhombic	5.871	3.561	6.763	--	--	--	--
LuH2	Cubic	5.033	--	--	--	--	--	--

HYDRIDES (Continued)

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Density, g/cm^3	Heat of Formation, kcal/mole H_2	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
					MH_3-MD_3			
YH_3	Hcp	3.672	--	6.625	--	--	--	--
YD_3	Hcp	3.659	--	6.586	--	--	--	--
LaH_3	Amorphous	--	--	--	5.26	40.09	--	--
CeH_3	Fluorite	--	--	--	5.55	42.26	--	--
PrH_3	Fluorite	--	--	--	5.56	39.52	--	--
NdH_3	Fluorite	--	--	--	--	--	--	--
SmH_3	Hexagonal	3.782	--	6.779	--	--	--	--
GdH_3	Hexagonal	3.73	--	6.71	--	--	--	--
TbH_3	Hexagonal	3.700	--	6.658	--	--	--	--
DyH_3	Hexagonal	3.671	--	6.615	--	--	38,900	9.5
HoH_3	Hexagonal	3.642	--	6.560	--	--	--	--
ErH_3	Hexagonal	3.621	--	6.526	--	--	34,900	9.54
TmH_3	Hexagonal	3.599	--	6.489	--	--	21,140	7.47
LuH_3	Hexagonal	3.558	--	6.443	--	--	--	--

NITRIDES

Compound	Structure	Lattice Type	a_o, A	Density, g/cm^3	Heat of Formation, kcal/mole	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
YN	Fcc	NaCl	4.877	5.60	71.5	93	--	--
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	8.5
DyN	Fcc	NaCl	4.905	9.567	--	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_o, A	Density, g/cm^3	Heat of Formation, kcal/mole metal
			MO		
SmO	Fcc	NaCl	4.988	--	159
EuO	Fcc	--	5.142	8.16	145.2
YbO	--	--	--	--	158

Compound	Struct.	a_o, A	Density, g/cm^3	Melting Point, C	Magnetic Susceptibility, 10^{-6} emu/mole
			MO_2		
CeO_2	Fcc	5.41	7.2	1,950	--
PrO_2	--	--	--	--	1,910

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	β, degrees	Density, g/cm^3	Melting Point, C	Heat of Formation, kcal/mole of metal	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
						M_2O_3				
Y_2O_3	Bcc	10.60	--	--	--	5.03	2,410	227.73	--	--
La_2O_3	Hcp	3.94	--	6.15	--	6.51	2,300	214.29	--	0.0
Ce_2O_3	Hcp	3.880	--	6.057	--	--	~1,690	217.46	--	2.6
Pr_2O_3	Cubic	10.9	--	--	--	7.0	2,200	218.4	4,410	3.6
Pr_2O_3	Hexagonal	--	--	--	--	--	--	217.9	--	--
Nd_2O_3	Hexagonal	3.831	--	5.999	--	7.24	2,270	216.06	--	3.7
Pm_2O_3 (A)	Hexagonal	3.806	--	5.954	--	--	--	(216.5)	--	2.8
(B)	Monoclinic	14.15	3.69	8.78	98.5	--	--	--	--	--
(C)	Cubic	10.99	--	--	--	--	--	--	--	--
α-Sm_2O_3	Monoclinic	--	--	--	--	7.43	--	--	--	1.6
β-Sm_2O_3	Cubic	10.90	--	--	--	7.62	2,350	--	--	--
α-Eu_2O_3	Bcc	10.869	--	--	--	7.28	--	194.8	--	3.4
β-Eu_2O_3	Monoclinic	14.082	3.640	8.786	100	7.99	2,050	196.5	--	--
α-Gd_2O_3	Cubic	10.79	--	--	--	7.41	--	216.97	--	7.9
β-Gd_2O_3	Monoclinic	--	--	--	--	--	2,350	--	--	--
Tb_2O_3	Bcc	10.69	--	--	--	7.81	2,390	218.4	35,800	9.7
Dy_2O_3	Bcc	10.63	--	--	--	7.81	2,340	222.92	--	10.6
Ho_2O_3	Bcc	10.58	--	--	--	8.36	--	224.78	--	10.6
Er_2O_3	Bcc	10.51	--	--	--	8.640	--	226.80	--	9.6
Tm_2O_3	Bcc	10.52	--	--	--	8.6	--	225.7	--	7.6
Yb_2O_3	Bcc	10.41	--	--	--	9.2	2,350	216.84	--	4.5
Lu_2O_3	Bcc	10.38	--	--	--	--	--	224.5	--	0.0

OXIDES (Continued)

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Density, g/cm^3	Heat of Formation, kcal/mole of metal	Magnetic Susceptibility, 10^{-6} emu/mole
			Other Oxides				
Pr_6O_{11}	Cubic	5.4695	--	--	--	--	2,540
Eu_3O_4	Orthorhombic	10.085	12.054	3.502	8.07	--	--
Ortho I ($Eu_{16}O_{21}$)	Orthorhombic	9.75	49.5	5.63	6.74	--	--
Tb_4O_7	Cubic	10.70	--	--	--	224.8	30,100

PHOSPHIDES

Compound	Structure	Lattice Type	a_o, A	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
YP	Fcc	NaCl	5.662	--	--
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	39,586	9.56
DyP	Fcc	NaCl	5.654	46,729	10.34
HoP	Fcc	NaCl	5.626	46,083	10.34
ErP	Fcc	NaCl	5.606	37,583	9.92
TmP	Fcc	NaCl	5.573	25,316	7.93
YbP	Fcc	NaCl	5.554	1,813	4.5

SELENIDES

Compound	Structure	Lattice Type	a_o, A	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
					MSe			
YSe	Fcc	NaCl	5.703	--	--	--	--	--
LaSe	Fcc	NaCl	6.048	6.34	--	50	7.08	0.46
CeSe	Fcc	NaCl	5.992	6.55	1820	100	2,186	2.3
PrSe	Fcc	NaCl	5.940	6.80	--	--	4,611	3.3
NdSe	Fcc	NaCl	5.879	6.93	--	50	4,780	3.4
SmSe	Fcc	NaCl	6.159	6.42	2100	1.38×10^9	4,440	3.3
EuSe	Fcc	NaCl	6.178	6.42	2286	--	--	7.65
GdSe	Fcc	NaCl	5.758	8.2	1865	72	22,090	8.20
TbSe	Fcc	NaCl	5.740	--	--	--	33,755	9.82
DySe	Fcc	NaCl	5.711	--	--	--	40,984	10.37
HoSe	Fcc	NaCl	5.690	--	--	--	43,478	10.62
ErSe	Fcc	NaCl	5.662	--	(1800)	170	35,635	9.56
TmSe	Fcc	NaCl	5.640	--	--	--	18,180	6.89
YbSe	Fcc	NaCl	5.94	--	1945	1.0×10^8	--	0.84

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Density, g/cm^3	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
					MSe_2			
$LaSe_2$	Tetragonal	8.47	--	8.53	6.33	1.46×10^6	32	0
$CeSe_2$	Tetragonal	8.43	--	8.49	6.45	2.92×10^8	2,220	2.2
$PrSe_2$	Tetragonal	8.37	--	8.44	6.68	--	4,630	3.3
$NdSe_2$	Tetragonal	8.33	--	8.41	6.83	--	4,763	3.4
$SmSe_2$	Tetragonal	8.16	--	8.36	6.94	--	1,200	1.6
$GdSe_2$	Orthorhombic	7.27	4.03	8.30	--	--	--	--

Compound	Structure	Lattice Type	Lattice Constants, A a_o	b_o	c_o	Density, g/cm^3	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
						M_2Se_3			
Y_2Se_3	Fcc	NaCl	5.75	--	--	4.81	--	--	--
La_2Se_3	Bcc	Th_3P_4	9.037	--	--	6.15	2.4×10^4	69.77	0.0
Ce_2Se_3	Bcc	Th_3P_4	8.960	--	--	6.33	3.3×10^3	2,068	2.2
Pr_2Se_3	Bcc	Th_3P_4	8.909	--	--	--	--	4,465	3.38
Nd_2Se_3	Bcc	Th_3P_4	8.841	--	--	6.69	--	4,685	3.58

SELENIDES (Continued)

Compound	Structure	Lattice Type	Lattice Constants, Å a_0	b_0	c_0	Density, g/cm³	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
					M_2Se_3 (Continued)				
Sm_2Se_3	Bcc	Th_3P_4	8.76	--	--	6.93	1.7×10^3	1,040	1.6
Gd_2Se_3	Bcc	Th_3P_4	8.72	--	--	7.36	1.3×10^3	21,994	--
Dy_2Se_3	Orthorhombic	--	3.69	10.85	11.0	7.21	--	43,250	10.40
Er_2Se_3	Fcc	NaCl	5.71	--	--	6.59	7.9×10^5	38,600	9.63
Yb_2Se_3	Fcc	NaCl	5.66	--	--	7.33	--	7,890	4.75
Lu_2Se_3	Fcc	NaCl	5.62	--	--	--	--	--	--

Compound	Structure	Lattice Type	a_0, Å	Density, g/cm³	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole
				M_3Se_4		
La_3Se_4	Bcc	Th_3P_4	9.037	6.47	--	10.84
Ce_3Se_4	Bcc	Th_3P_4	8.973	6.76	8.0×10^3	--
Pr_3Se_4	Bcc	Th_3P_4	8.927	6.89	--	--
Nd_3Se_4	Bcc	Th_3P_4	8.859	7.15	--	--
Sm_3Se_4	Bcc	Th_3P_4	8.84	7.33	--	--
Gd_3Se_4	Bcc	Th_3P_4	8.718	--	1.1×10^3	--

Compound	Structure	Lattice Constants, Å a_0	c_0	Density, g/cm³	Color
			M_2O_2Se		
La_2O_2Se	Hcp	4.09	7.14	--	Beige
Ce_2O_2Se	Hcp	4.04	7.06	6.51	Maroon
Pr_2O_2Se	Hcp	4.01	7.04	6.65	Beige
Nd_2O_2Se	Hcp	3.97	6.97	6.99	Blue-white
Sm_2O_2Se	Hcp	3.93	6.93	7.40	Gray
Gd_2O_2Se	Hcp	3.90	6.87	7.80	Beige
Dy_2O_2Se	Hcp	3.83	6.79	8.39	Light gray
Er_2O_2Se	Hcp	3.81	7.68	8.68	Pink
Yb_2O_2Se	Hcp	3.76	6.69	9.26	Beige

SILICIDES

Compound	Structure	Lattice Type	Lattice Constants, A a_o	b_o	c_o	Density, g/cm^3	Heat of Formation, kcal/mole	Melting Point, C
			MSi					
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, A a_o	b_o	c_o	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm	$\alpha \cdot \beta$ Transition Temperature, C
			MSi_2-MSi_{2-n}						
α-YSi_2	Orthorhombic	α-YSi_2	4.04	3.95	13.23	4.5	--	--	--
β-YSi_2	Tetragonal	α-$ThSi_2$	4.04	--	13.14	4.39	1,520	--	540
$LaSi_2$	Tetragonal	α-$ThSi_2$	4.31	--	13.80	5.0	1,520	236	--
$CeSi_2$	Tetragonal	α-$ThSi_2$	4.175	--	13.848	5.45	--	408	--
α-$PrSi_2$	Orthorhombic	α-YSi_2	4.23	4.40	13.68	5.38	--	--	--
β-$PrSi_2$	Tetragonal	α-$ThSi_2$	4.140	--	13.65	5.64	--	202	-120
α-$NdSi_2$	Orthorhombic	α-YSi_2	4.18	4.15	13.56	5.62	--	349	--
β-$NdSi_2$	Tetragonal	α-$ThSi_2$	4.103	--	13.53	5.84	1,525	--	20-150
α-$SmSi_2$	Orthorhombic	α-YSi_2	4.105	4.035	13.46	6.13	--	--	--
β-$SmSi_2$	Tetragonal	α-$ThSi_2$	4.041	--	13.33	6.26	--	--	380
β-$EuSi_2$	Tetragonal	α-$ThSi_2$	4.29	--	13.66	5.50	1,500	--	-150
α-$GdSi_2$	Orthorhombic	α-YSi_2	4.09	4.01	13.44	6.43	1,540	263	--
β-$GdSi_2$	Tetragonal	α-$ThSi_2$	4.10	--	13.61	6.19	2,100	--	400
$TbSi_2$	Orthorhombic	α-YSi_2	4.045	3.96	13.38	--	--	--	--
$TbSi_{2-n}$	Hexagonal	Defect AlB_2	3.847	--	4.146	--	--	--	--
α-$DySi_2$	Orthorhombic	α-YSi_2	4.04	3.95	13.34	6.8	--	3,020	--
β-$DySi_2$	Tetragonal	α-$ThSi_2$	4.03	--	13.38	6.68	1,550	--	540
$DySi_{2-n}$	Hexagonal	Defect AlB_2	3.83	--	4.11	--	--	--	--
$HoSi_2$	Orthorhombic	α-YSi_2	4.03	3.97	13.40	--	--	--	--
$HoSi_{2-n}$	Hexagonal	Defect AlB_2	3.816	--	4.107	--	--	--	--
$ErSi_2$	Hexagonal	--	3.78	--	4.09	--	--	--	--
$TmSi_2$	Hexagonal	--	3.76	--	4.07	--	--	--	--
$YbSi_2$	Hexagonal	--	3.77	--	4.10	--	--	--	--
$LuSi_2$	Hexagonal	--	3.74	--	4.04	--	--	--	--

Compound	Structure	Lattice Constants, A a_o	c_o	Melting Point, C
		M_3Si_5		
Y_3Si_5	Hexagonal	3.842	4.104	1,635
Gd_3Si_5	Hexagonal	3.877	4.172	--

SILICIDES (Continued)

Compound	Structure	Lattice Type	Lattice Constants, A a_o	Lattice Constants, A c_o	Density, g/cm^3	Melting Point, C
			M_5Si_3			
Y_5Si_3	Hexagonal	Mn_5Si_3	8.403	6.303	4.556	1,850

SULFIDES

Compound	Structure	Lattice Type	a_o, A	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
					MS			
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	8.5×10^4	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
$ErS_{1.18}$	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, A a_o	Lattice Constants, A c_o	Density, g/cm^3	Melting Point, C	Magnetic Susceptibility, 10^{-6} emu/mole
			MS_2			
YS_2	Tetragonal	7.71	7.89	4.33	1,630	125
LaS_2	Cubic	8.20	--	4.90	1,650	36.3
CeS_2	Cubic	8.12	--	5.07	1,700	2,286
PrS_2	Cubic	8.08	--	4.90	1,780	4,800
NdS_2	Cubic	8.04	--	5.34	1,760	5,082
SmS_2	Cubic	7.87	--	5.66	1,730	1,238
GdS_2	Tetragonal	7.85	7.96	5.98	--	21,510
DyS_2	Tetragonal	7.69	7.85	6.11	--	--

SULFIDES (Continued)

Compound	Structure	Lattice Constants, A			β, degrees	Density, g/cm³	Melting Point, C	Magnetic Susceptibility, 10^{-6} emu/mole
		a_o	b_o	c_o				
				M_2S_3				
δ-Y_2S_3	Monoclinic	10.71	4.02	17.47	81.17	3.87	1,600	83.4
γ-La_2S_3	Cubic	8.723	--	--	--	4.99	2,150	27.1
γ-Ce_2S_3	Cubic	8.635	--	--	--	5.19	1,890	2,520
γ-Pr_2S_3	Cubic	8.611	--	--	--	5.27	1,795	4,640
γ-Nd_2S_3	Cubic	8.527	--	--	--	5.50	2,200	4,924
γ-Sm_2S_3	Cubic	8.448	--	--	--	5.87	1,780	1,020
Eu_2S_3	-	8.415	--	--	--	--	--	--
$Eu_2S_{3.81}$	Tetragonal	7.86	--	8.03	--	5.70	--	5,800
γ-Gd_2S_3	Cubic	8.387	--	--	--	6.15	1,885	27,800
γ-Dy_2S_3	Bcc	8.292	--	--	--	6.54	1,480	47,700
δ-Dy_2S_3	Monoclinic	10.17	4.02	17.57	--	5.75	--	--
δ-Er_2S_3	Monoclinic	10.07	4.00	17.33	--	6.07	1,730	38,600
Yb_2S_3	Hexagonal	6.784	--	18.29	--	6.04	--	7,130

Compound	Structure	Lattice Constants, A			Density, g/cm³	Melting Point, C	Magnetic Susceptibility, 10^{-6} emu/mole
		a_o	b_o	c_o			
				M_3S_4			
La_3S_4	Cubic	8.748	--	--	5.44	2,100	27.2
Ce_3S_4	Cubic	8.623	--	--	5.675	2,080	2,160
Pr_3S_4	Cubic	8.611	--	--	5.77	2,100	--
Nd_3S_4	Cubic	8.524	--	--	6.02	2,040	4,849
Sm_3S_4	Cubic	8.556	--	--	6.14	1,800	2,350
Eu_3S_4	Cubic	8.537	--	--	6.27	--	11,500
Yb_3S_4	Orthorhombic	12.81	12.97	3.84	6.71	--	4,740

Compound	Structure	Lattice Constants, A			β, degrees	Density, g/cm³	Melting Point, C	Magnetic Susceptibility, 10^{-6} emu/mole
		a_o	b_o	c_o				
				M_5S_7				
Y_5S_7	Monoclinic	12.67	3.81	11.45	74	4.18	1,630	39.3
Dy_5S_7	Monoclinic	12.84	3.81	11.61	74	6.14	1,540	--
Er_5S_7	Monoclinic	12.63	3.77	11.47	74	6.39	1,620	--

SULFIDES (Continued)

Compound	Structure	Lattice Constants, A a_o	Lattice Constants, A c_o	Density, g/cm^3	Melting Point, C	Magnetic Susceptibility, 10^{-6} emu/mole
			M_2O_2S			
Y_2O_2S	Hexagonal	3.78	6.56	4.95	2,120	0
La_2O_2S	Hexagonal	4.051	6.943	5.73	1,940	0
Ce_2O_2S	Hexagonal	4.00	6.82	5.99	1,950	2,139
Pr_2O_2S	Hexagonal	3.974	6.8[illegible]	6.16	--	--
Nd_2O_2S	Hexagonal	3.946	6.790	6.47	1,990	--
Sm_2O_2S	Hexagonal	3.893	6.717	6.90	1,980	1,020
Eu_2O_2S	Hexagonal	3.87	6.68	7.04	--	--
Gd_2O_2S	Hexagonal	3.851	6.667	7.34	--	--
Tb_2O_2S	Hexagonal	3.825	6.626	7.56	--	--
Dy_2O_2S	Hexagonal	3.803	6.603	7.84	--	--
Er_2O_2S	Hexagonal	3.760	6.552	7.92	--	--
Tm_2O_2S	Hexagonal	3.747	6.538	8.59	--	--
Yb_2O_2S	Hexagonal	3.723	6.503	8.72	--	--
Lu_2O_2S	Hexagonal	3.709	6.486	8.89	--	--

TELLURIDES

Compound	Structure	Lattice Type	a_o, A	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm	Magnetic Susceptibility, 10^{-6} emu/mole	Effective Magnetic Moment, Bohr magnetons
					MTe			
YTe	Fcc	NaCl	6.080	--	--	--	--	--
LaTe	Fcc	NaCl	6.422	6.682	1,725	1.5×10^{11}	--	--
CeTe	Fcc	NaCl	6.359	--	--	200	--	--
PrTe	Fcc	NaCl	6.322	--	--	--	--	--
NdTe	Fcc	NaCl	6.249	--	--	40	--	--
SmTe	Fcc	NaCl	6.58	--	1,920	1.64×10^{9}	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	7×10^{9}	--	--

TELLURIDES (Continued)

Compound	Structure	Lattice Type	Lattice Constants, A a_o	c_o	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm
			MTe_2				
$LaTe_2$	Tetragonal	Fe_2As	4.53	9.22	6.97	1,535	6.6×10^6
$CeTe_2$	Tetragonal	Fe_2As	4.51	9.10	7.06	--	--
$PrTe_2$	Tetragonal	Fe_2As	4.46	9.05	--	--	--
$NdTe_2$	Tetragonal	Fe_2As	4.41	9.04	--	--	--
$GdTe_2$	Tetragonal	Fe_2As	9.10	9.30	6.8	--	5.5×10^4
$DyTe_{2-n}$	Tetragonal	Fe_2As	4.29	8.91	--	--	--

Compound	Structure	Lattice Constants, A a_o	b_o	c_o	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm
			M_2Te_3				
Y_2Te_3	--	--	--	--	--	1,525	10^7
Ce_2Te_3	--	9.535	--	--	6.6	--	1.1×10^4
Pr_2Te_3	--	9.482	--	--	6.6	--	--
Nd_2Te_3	Orthorhombic	12.12	11.93	4.37	6.65	1,650	1.1×10^3
Sm_2Te_3	Bcc	9.480	--	--	7.11	(1,475)	--
Gd_2Te_3	Tetragonal	--	--	--	--	1,505	1.5×10^4
Er_2Te_3	--	--	--	--	--	--	1.1×10^3
Yb_2Te_3	--	--	--	--	--	--	10^7

Compound	Structure	Lattice Type	a_o, A	Density, g/cm^3	Melting Point, C	Resistivity, microhm-cm
			M_3Te_4			
La_3Te_4	Bcc	Ce_2S_3	9.619	6.65	1,595	--
Ce_3Te_4	Bcc	Th_3P_4	9.528	6.7	--	1.8×10^3
Nd_3Te_4	Bcc	Th_3P_4	9.438	6.8	1,685	350
Gd_3Te_4	--	--	--	--	1,410	460
Dy_3Te_4	--	--	--	--	--	3.1×10^3
Er_3Te_4	--	--	--	--	--	280

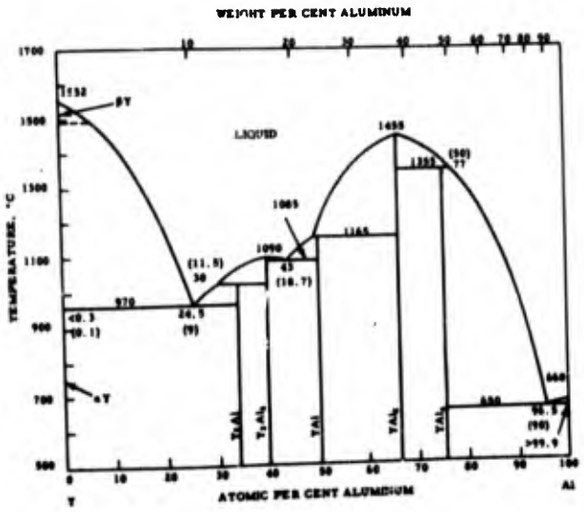
TELLURIDES (Continued)

Compound	Structure	Lattice Constants, A a_o	Lattice Constants, A c_o	Density, g/cm^3	Color
		M_2O_2Te			
La_2O_2Te	Hexagonal	4.12	13.10	6.36	Dark green
Ce_2O_2Te	Hexagonal	4.09	12.92	6.64	Maroon
Pr_2O_2Te	Hexagonal	4.06	12.83	--	Light green
Nd_2O_2Te	Hexagonal	4.03	12.77	7.18	Green
Sm_2O_2Te	Hexagonal	4.00	12.61	7.58	Dark green
Eu_2O_2Te	Hexagonal	3.98	12.57	7.74	Maroon
Gd_2O_2Te	Hexagonal	3.96	12.54	8.0	Brown
Dy_2O_2Te	Hexagonal	3.92	12.38	8.46	Maroon

Other Tellurides

Compound	Structure	Lattice Constants, A a_o	Lattice Constants, A b_o	Lattice Constants, A c_o	α, degrees	Density, g/cm^3	Melting Point, C
$LaTe_3$	Tetragonal	4.407	--	26.14	--	6.92	835
La_4Te_7	Orthorhombic	4.607	4.483	9.142	--	--	--
$GdTe_4$	Rhombohedral	13.0	--	--	25.5	--	--

YTTRIUM



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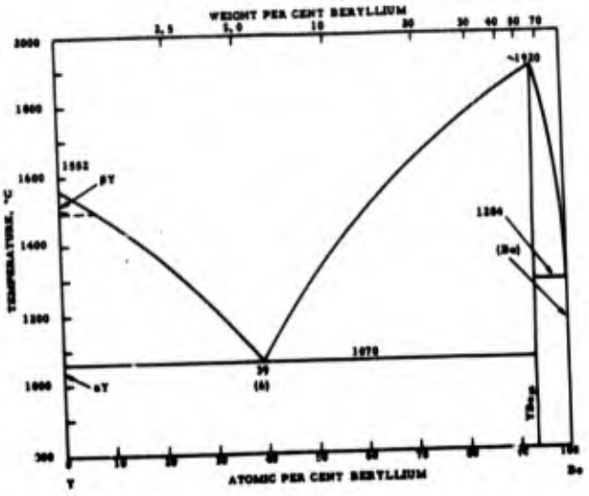
(Permission of U. S. AEC)



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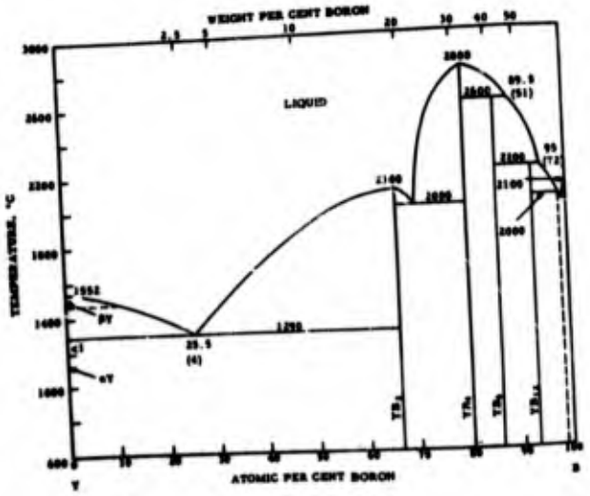

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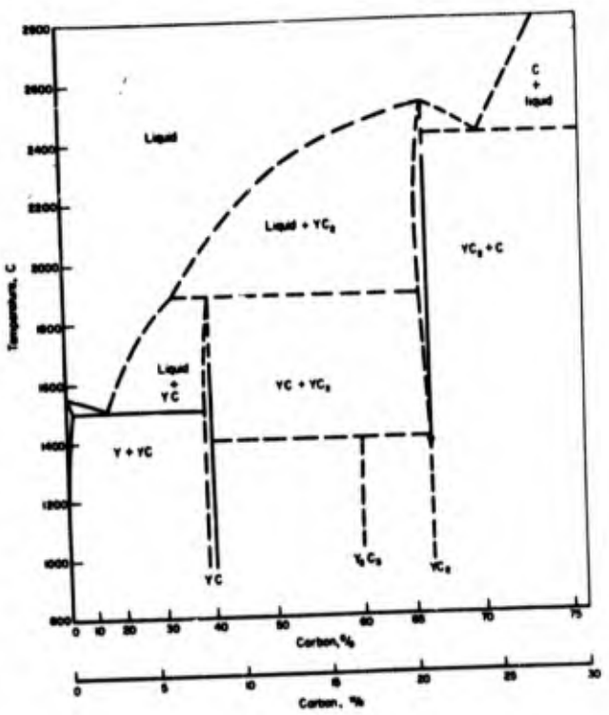

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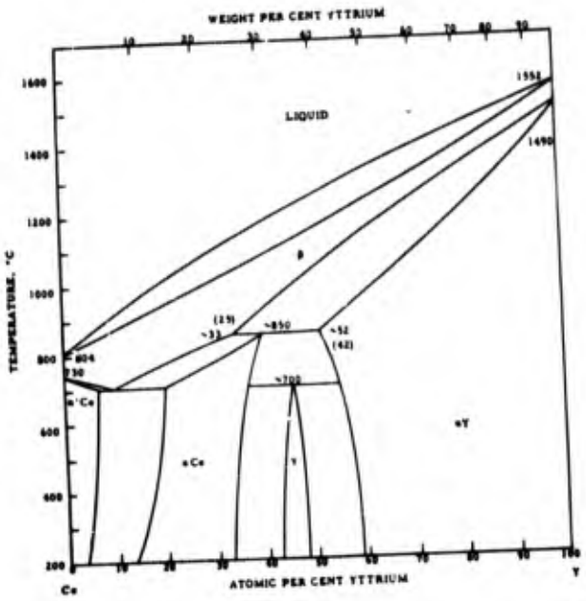

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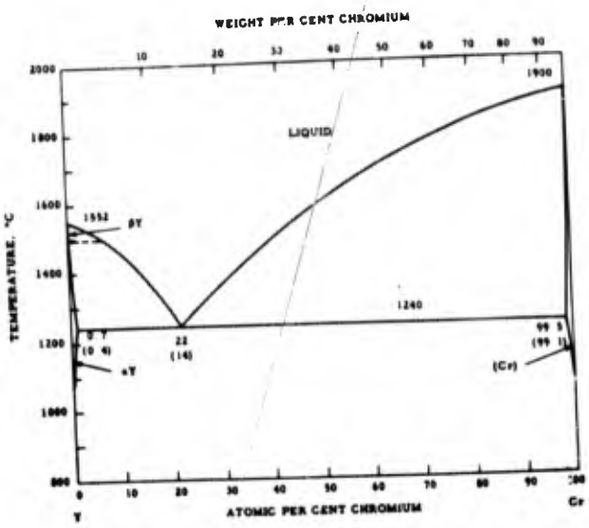

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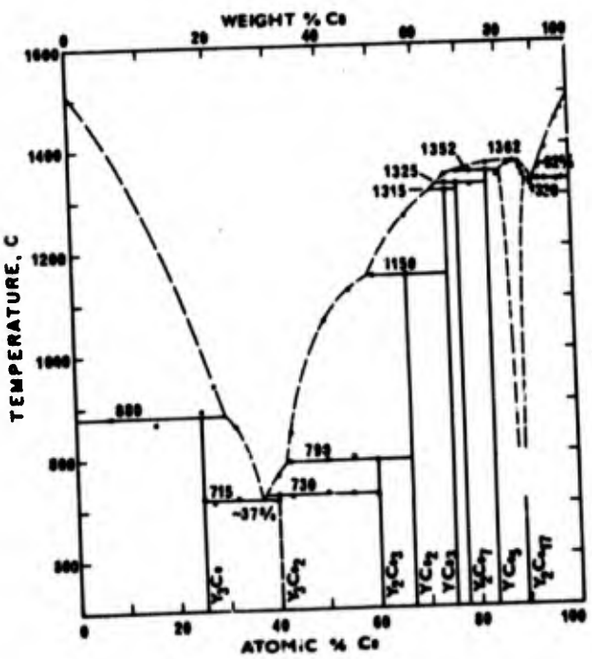

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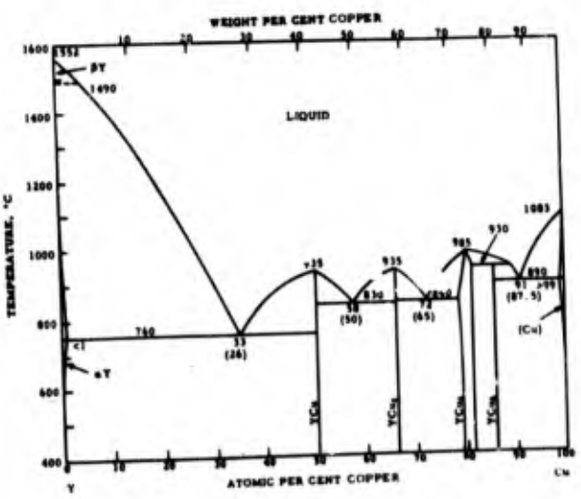

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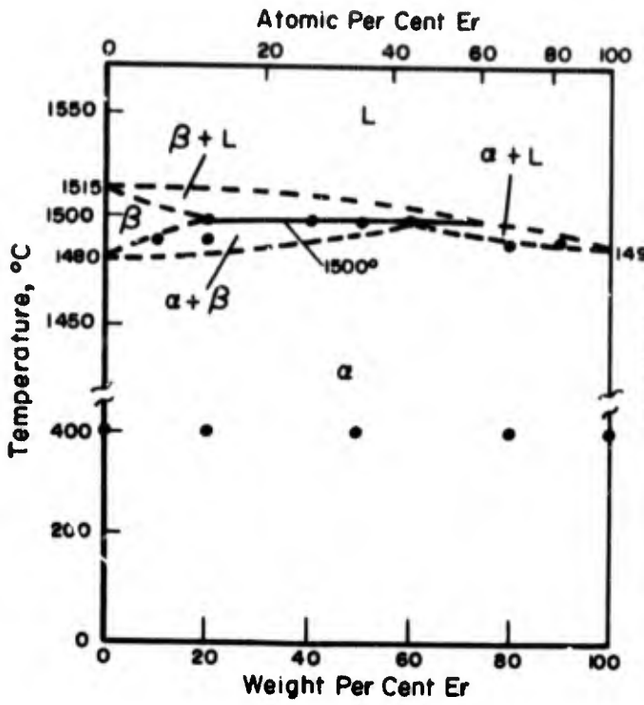

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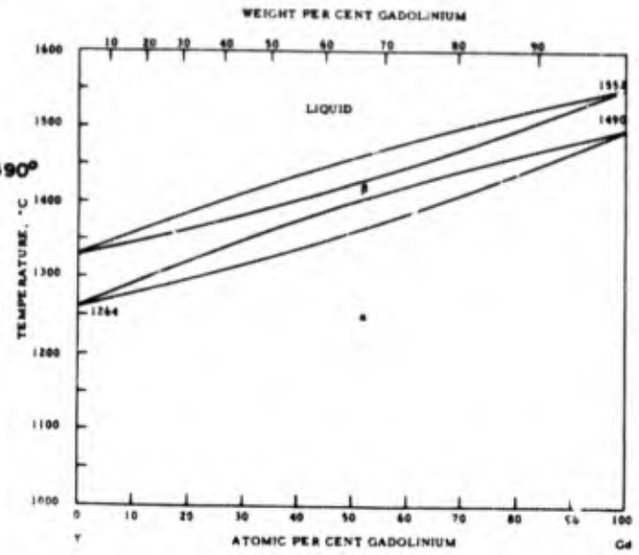

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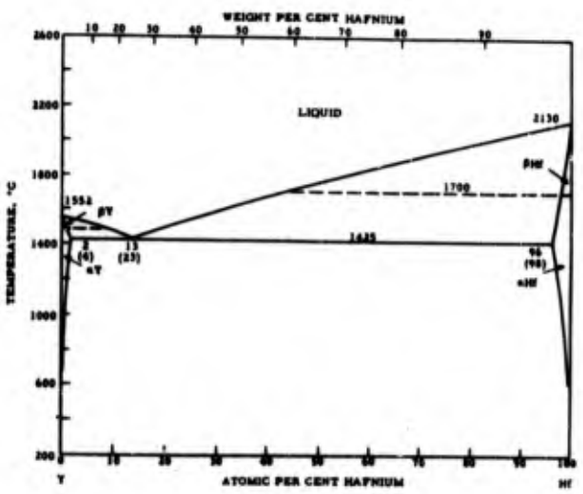

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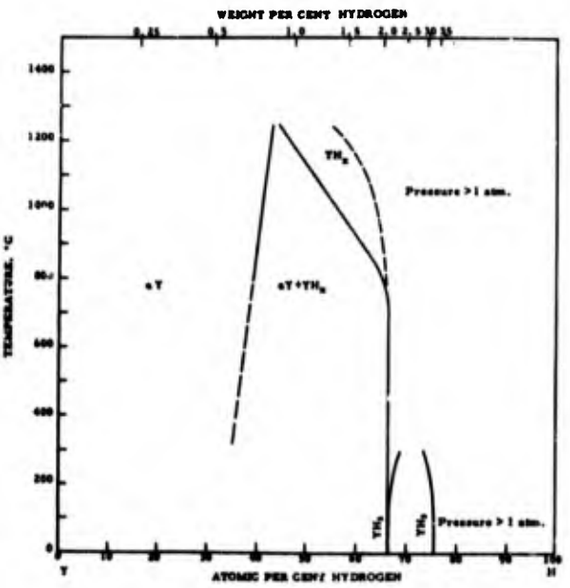

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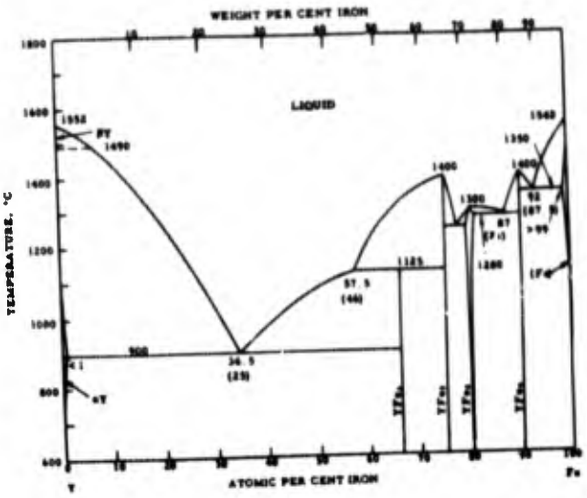

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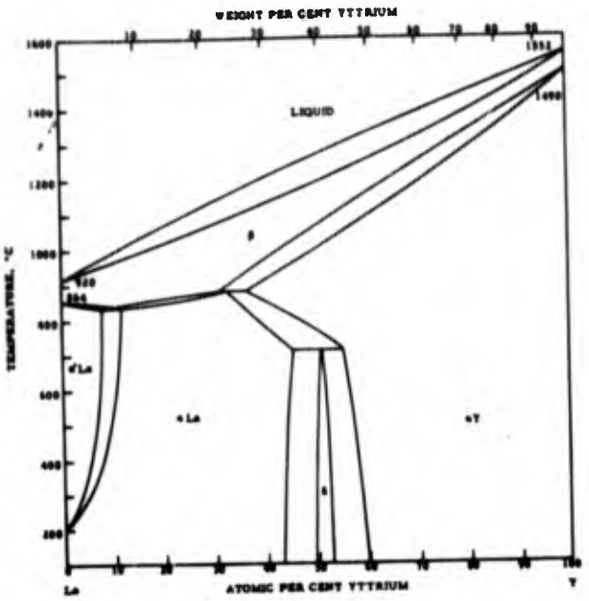

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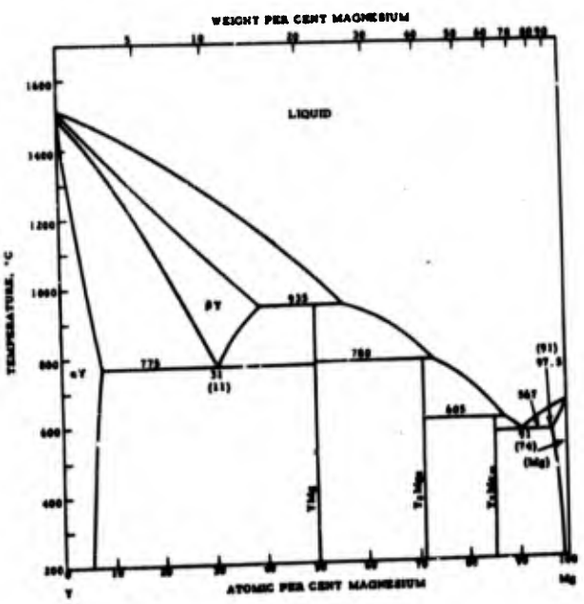

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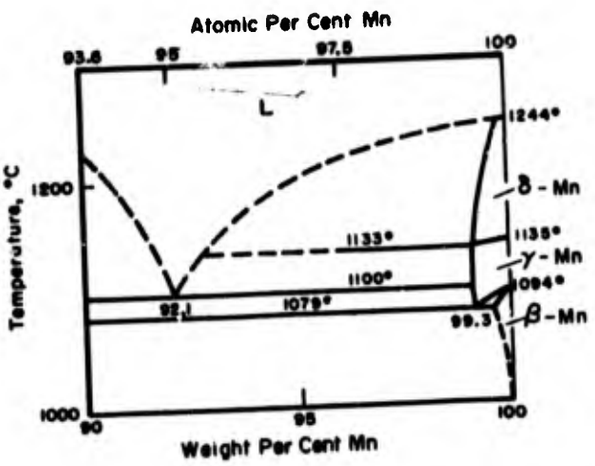

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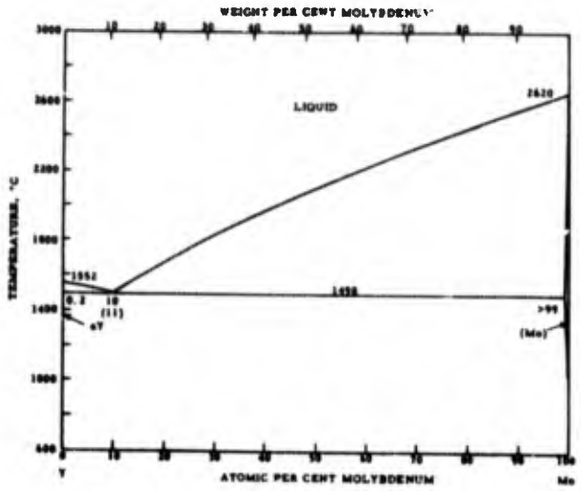

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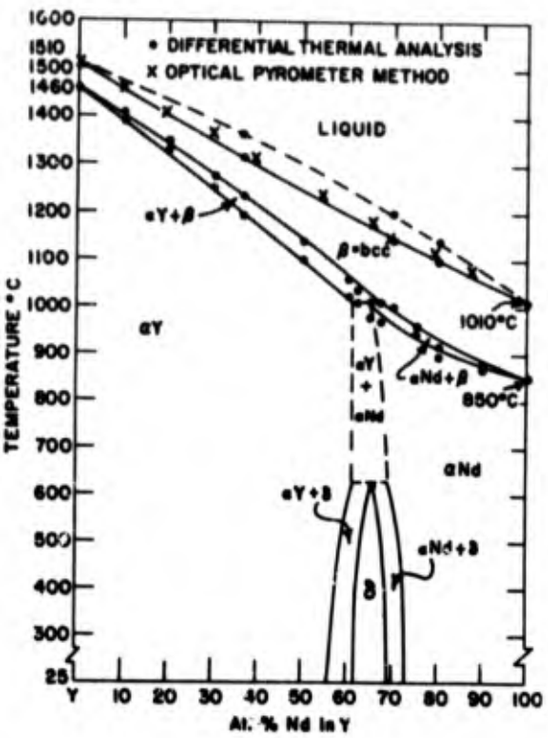

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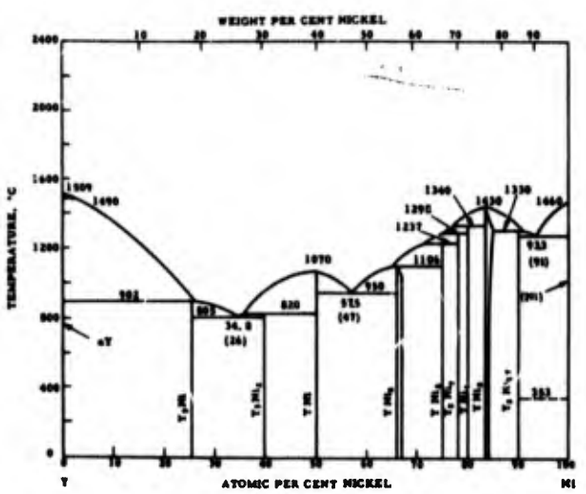

Nickel (1)
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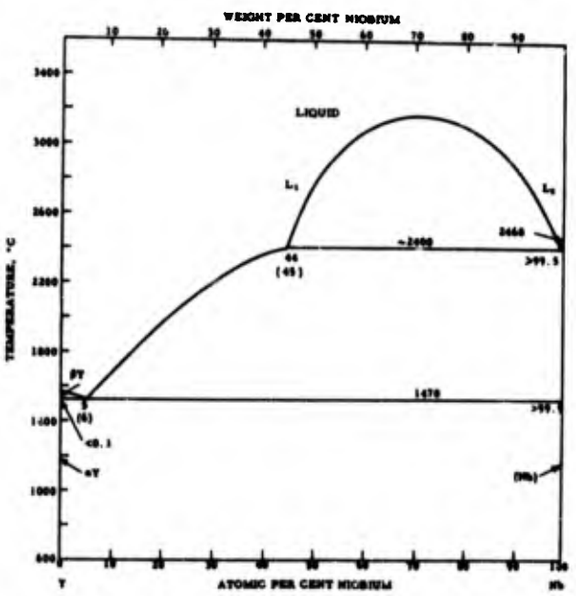

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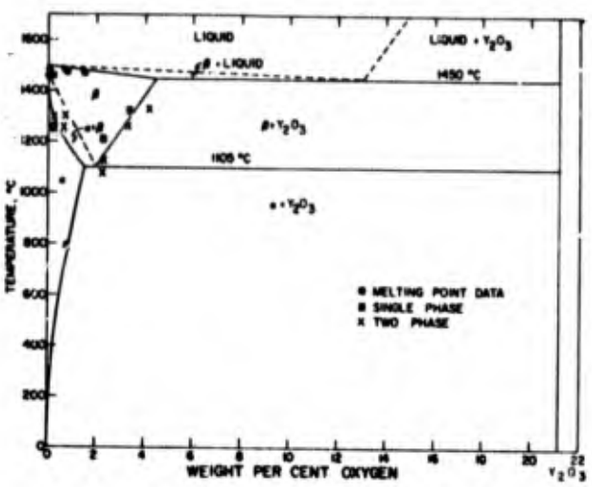
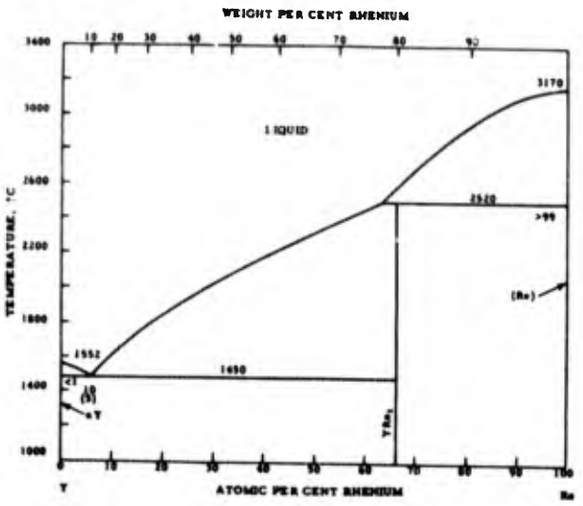


Oxygen (6)



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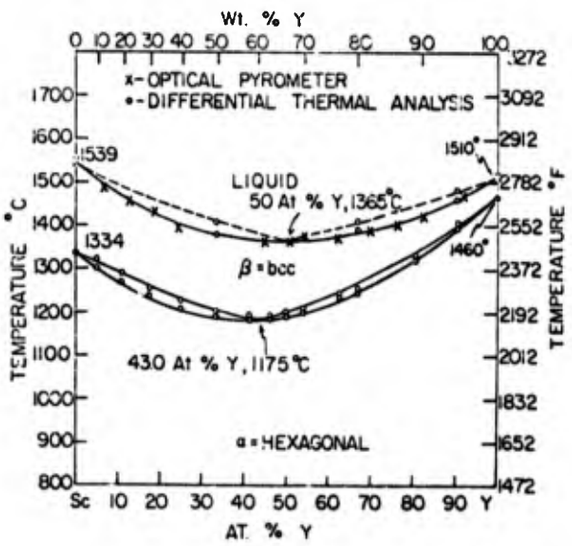
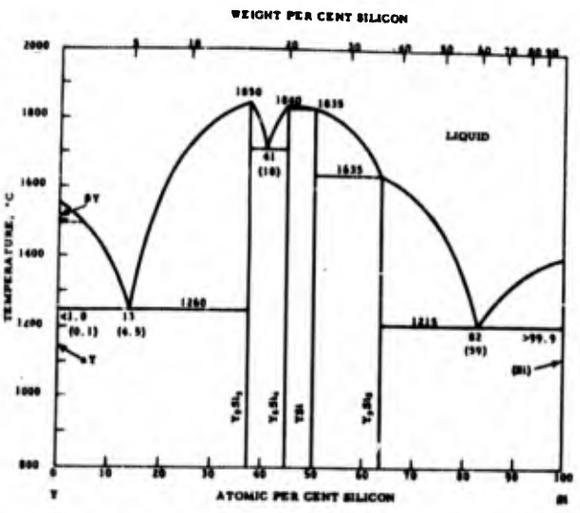


Scandium (28)
(Permission of Metallurgical Society AIME)



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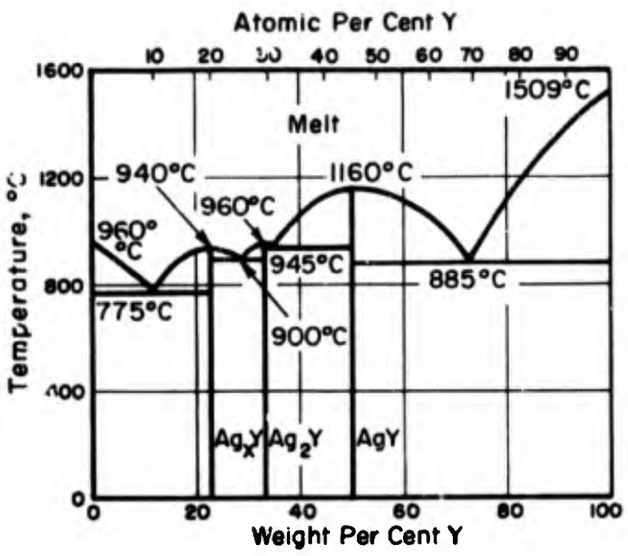
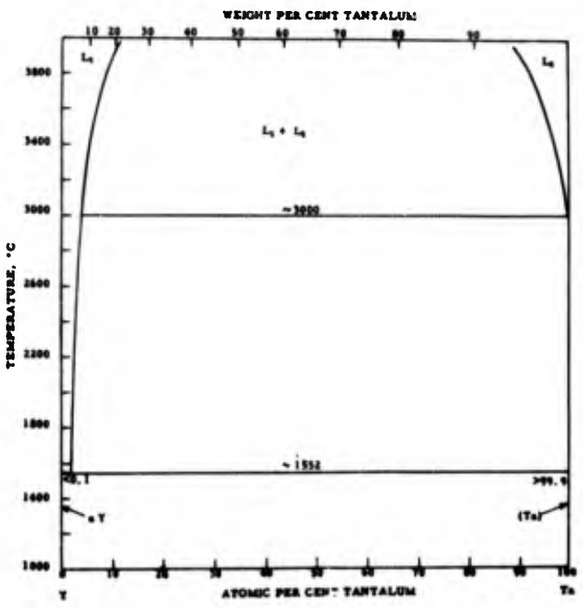


Silver (144)
(Permission of Metallurgical Society AIME)



Tantalum (1)
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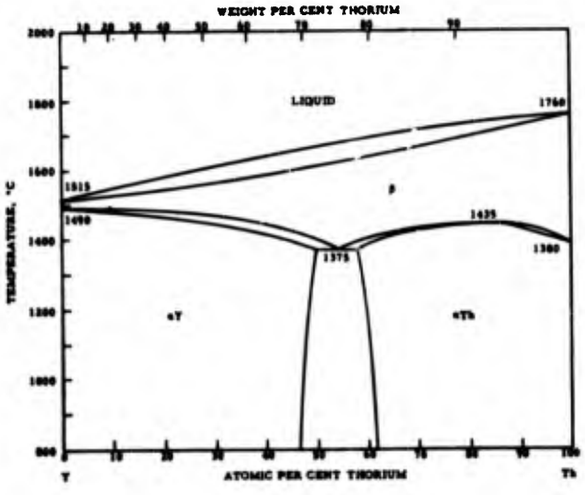

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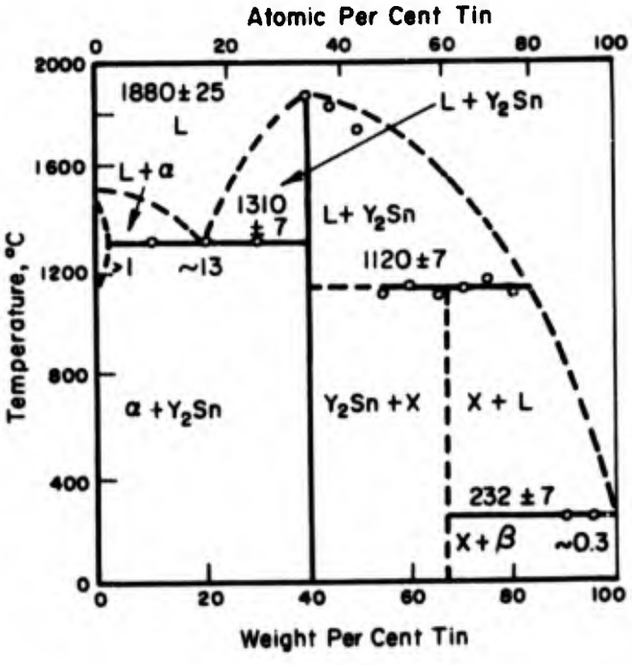

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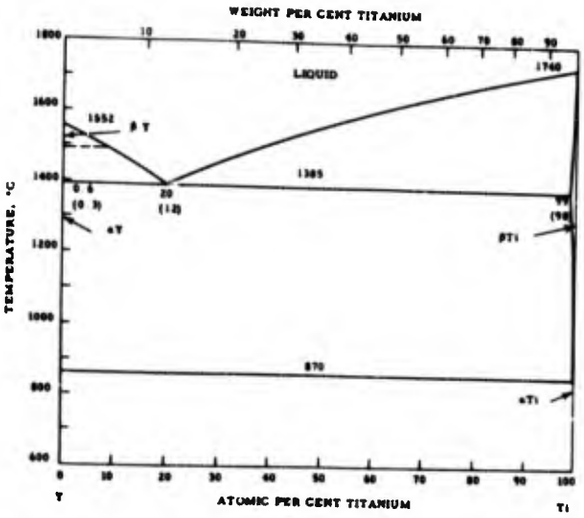

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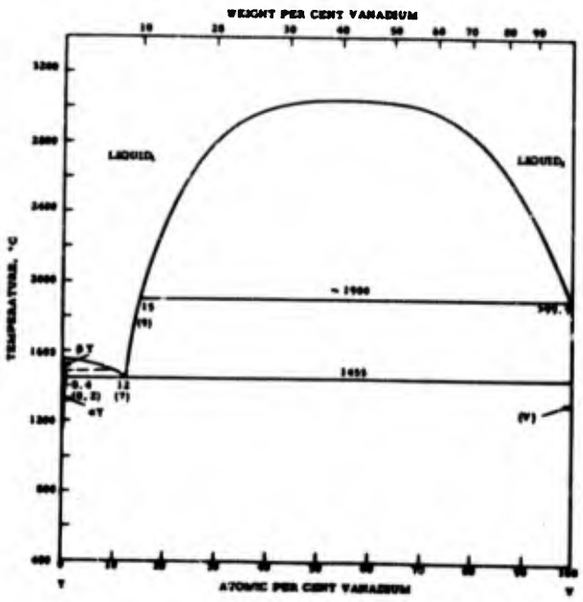

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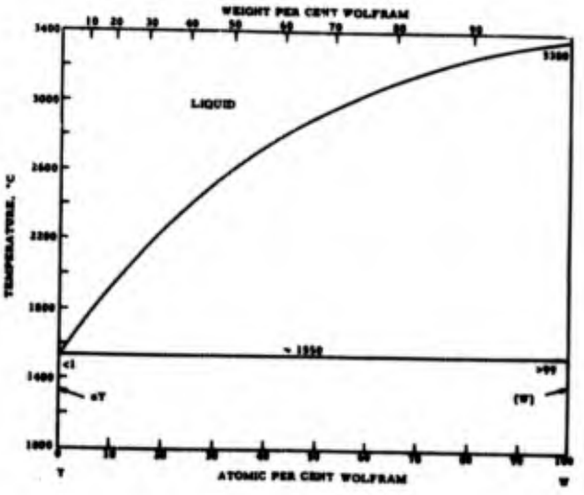

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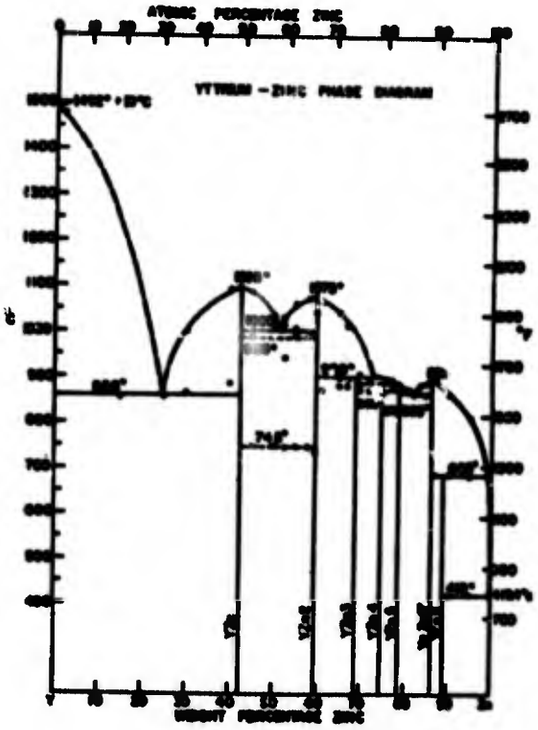
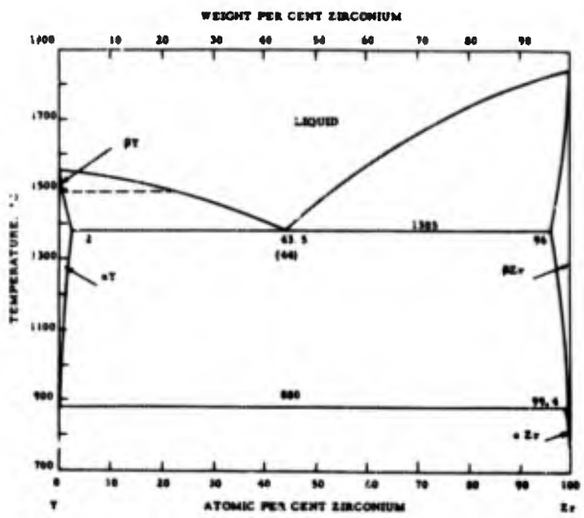


Zinc (8)



Zirconium (1)
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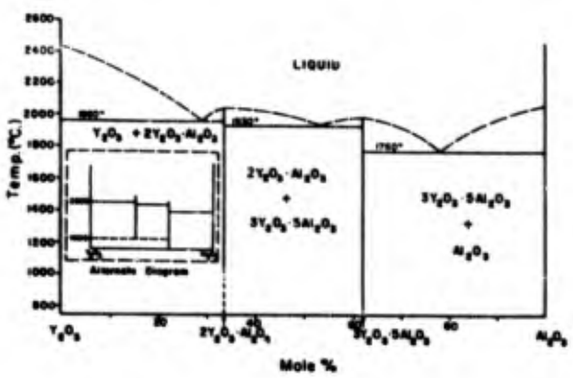

Y_2O_3-Al_2O_3
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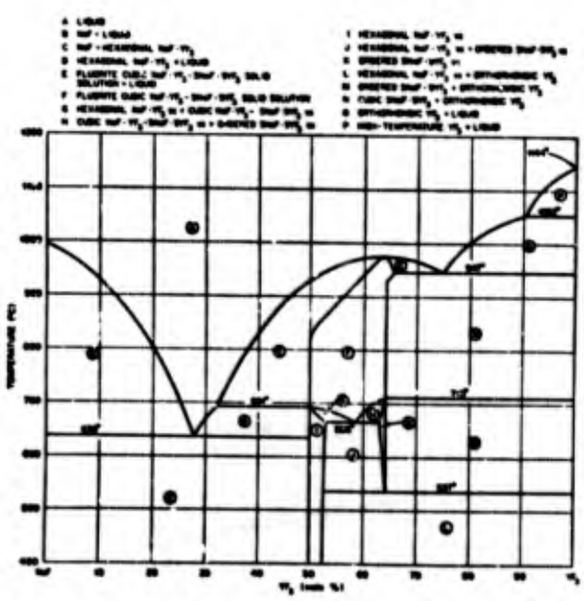

YF_3-NaF
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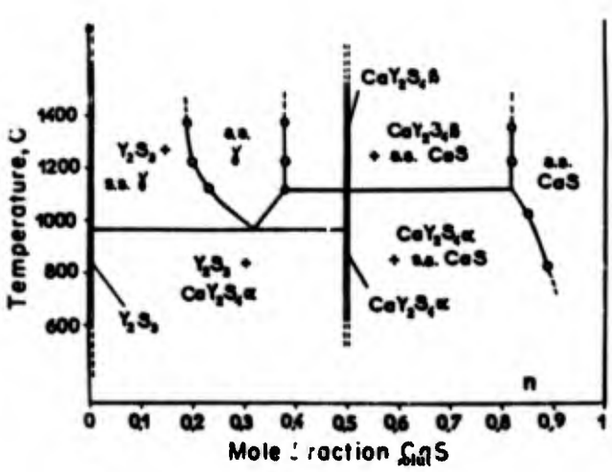
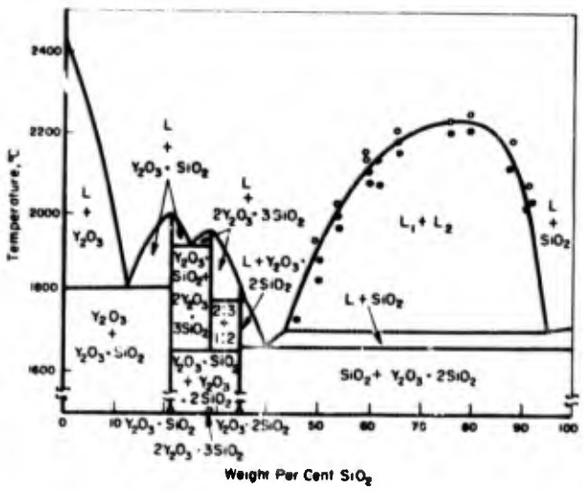
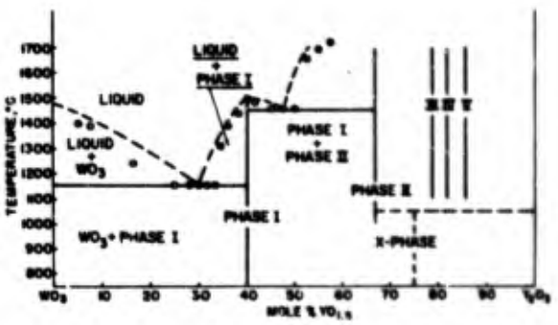


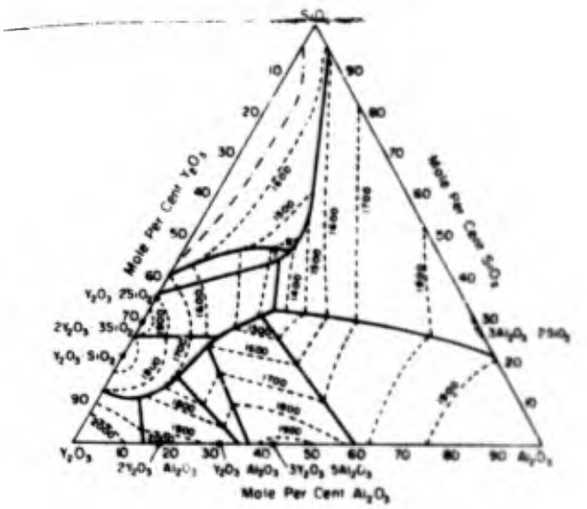
Yttrium-Sulfur-Calcium (12)



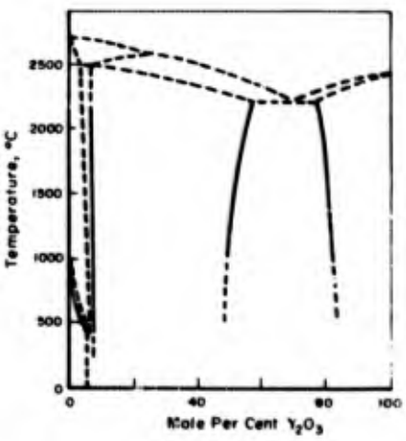
Y_2O_3-SiO_2 (13)



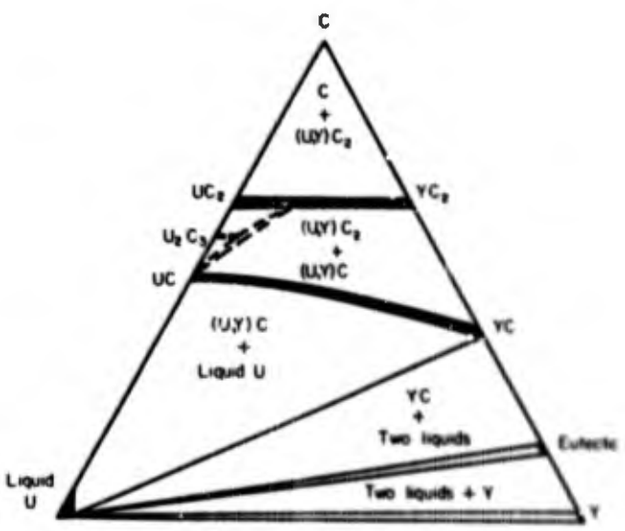
Y_2O_3-WO_3 (14)
(Reprinted from Inorganic Chemistry)



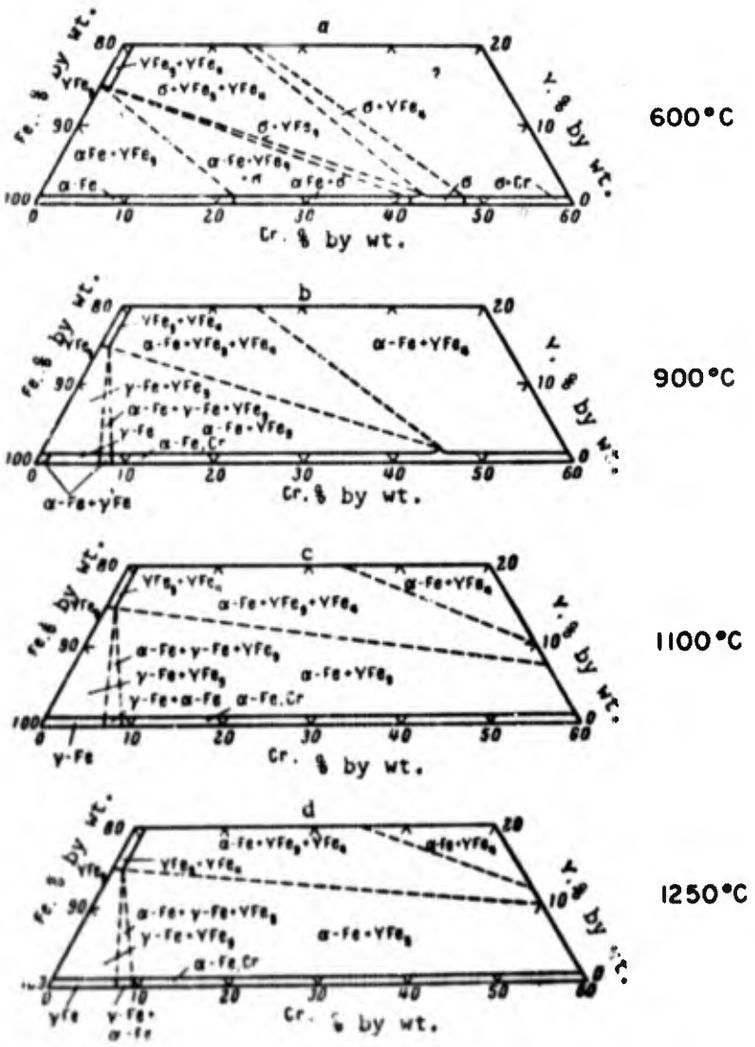
Y_2O_3-Al_2O_3-SiO_2 (9)



Y_2O_3-ZrO_2 (15)

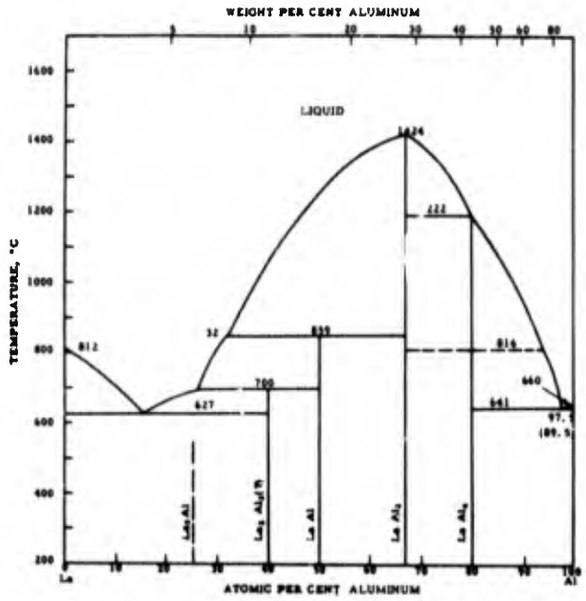


Yttrium-Uranium-Carbon at 1800 C (2)

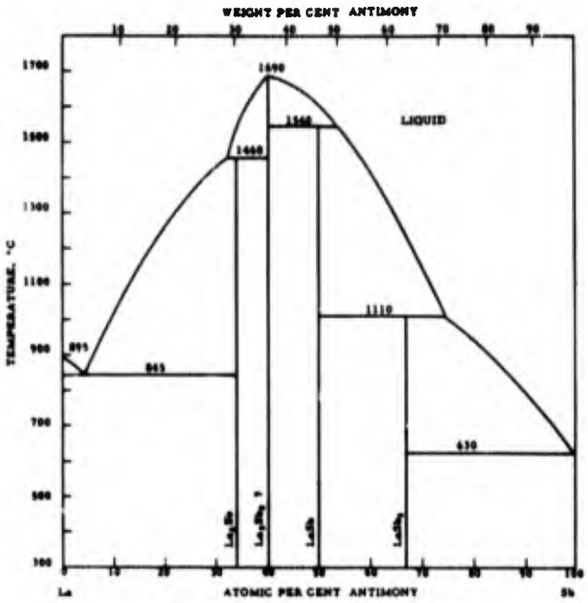


Yttrium-Iron-Chromium (4)

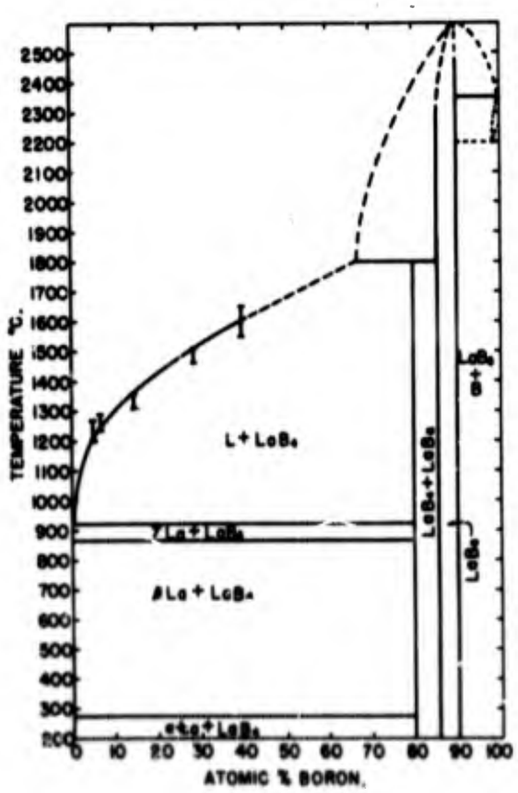
LANTHANUM



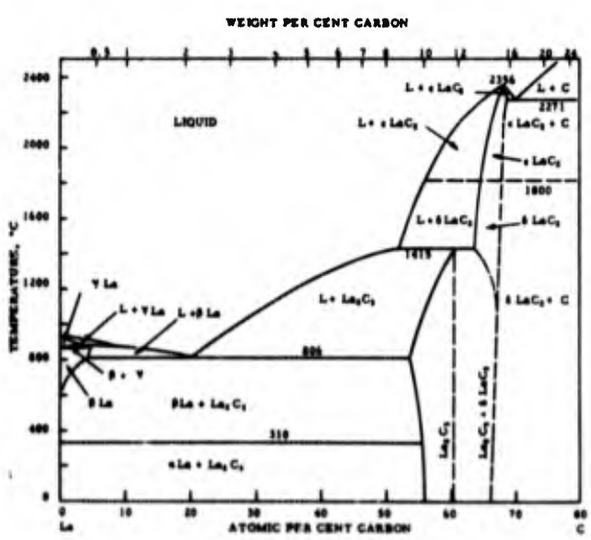
Aluminum (1)
(Permission of U. S. AEC)



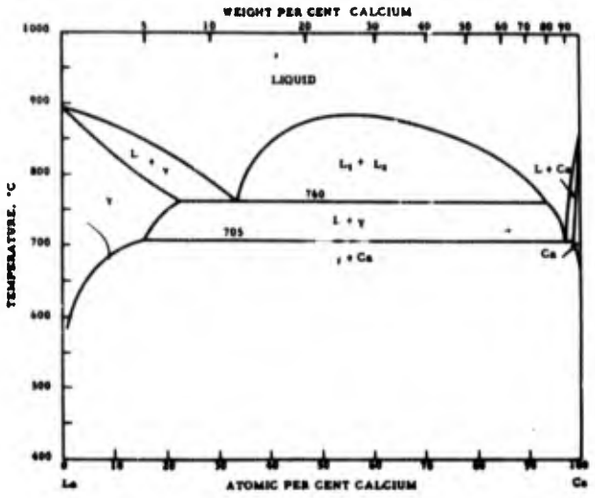
Antimony (1)
(Permission of U. S. AEC)



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



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



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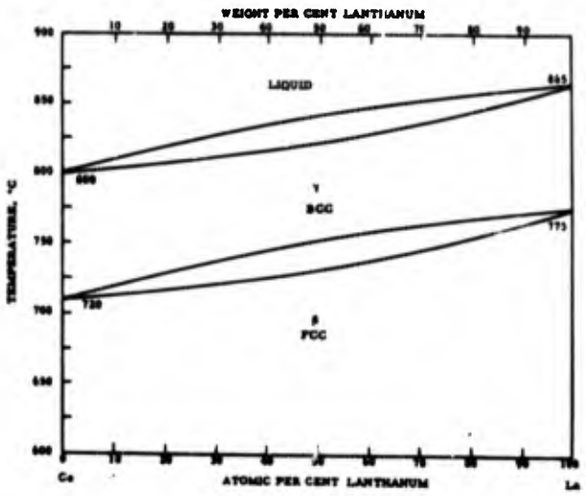
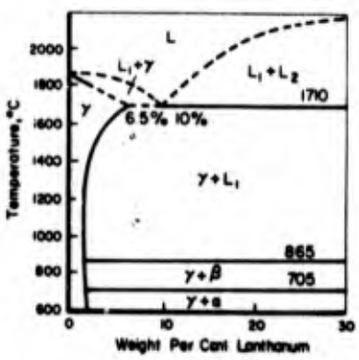
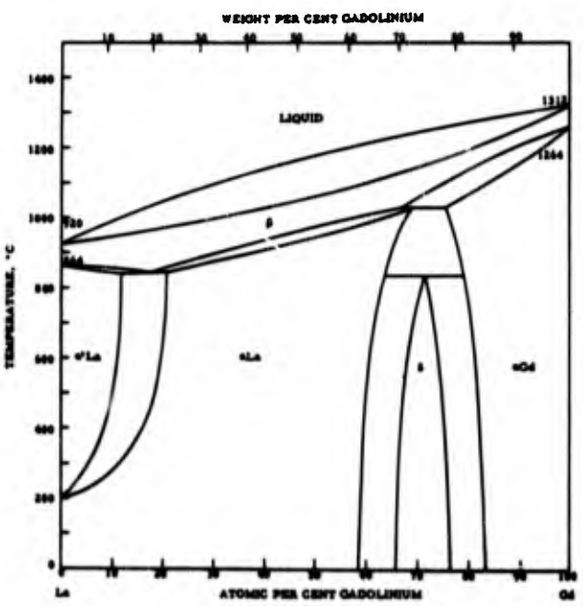
(Permission of U. S. AEC)



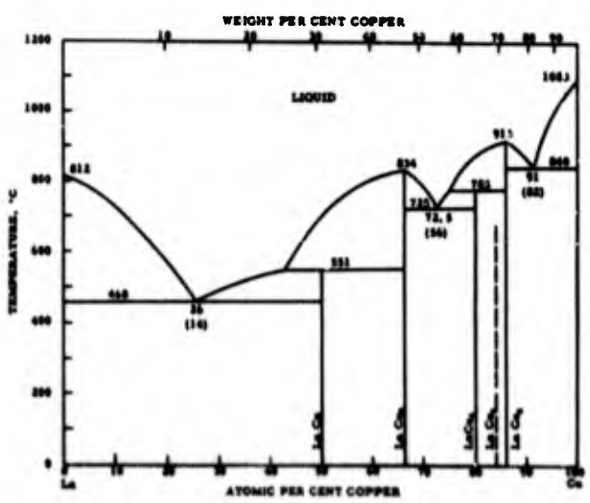
Cerium (1)
(Permission of U. S. AEC)



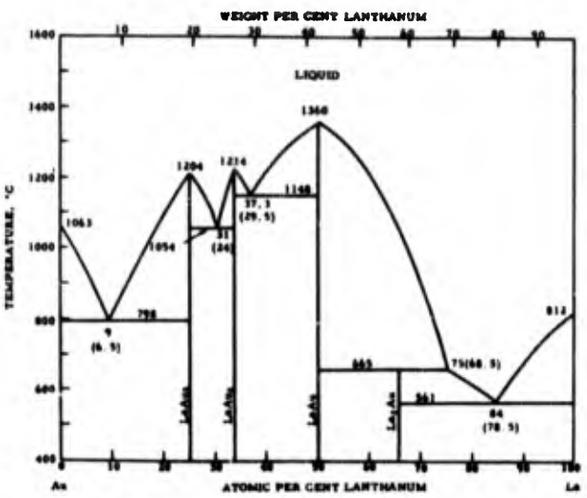
Chromium (16)



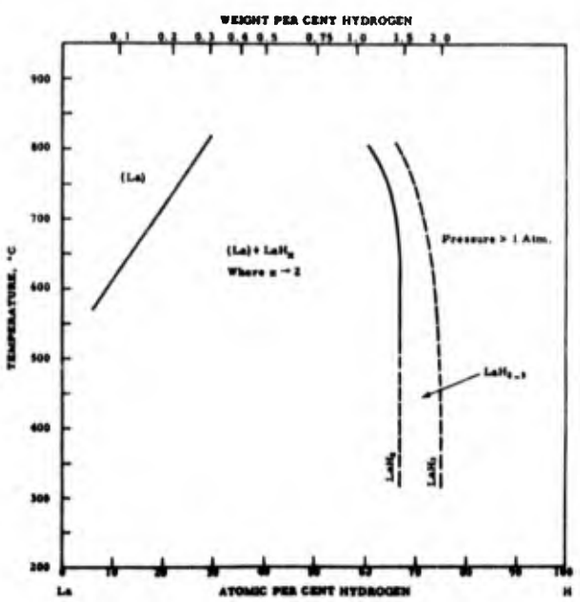
Gadolinium (1)
(Permission of U. S. AEC)



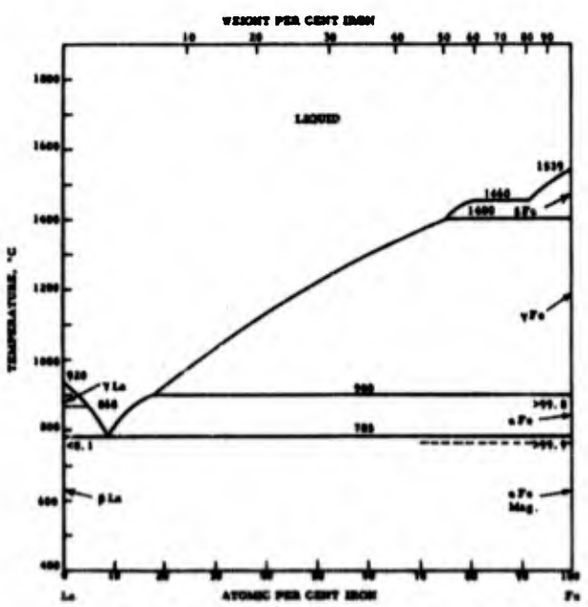
Copper (1)
(Permission of U. S. AEC)



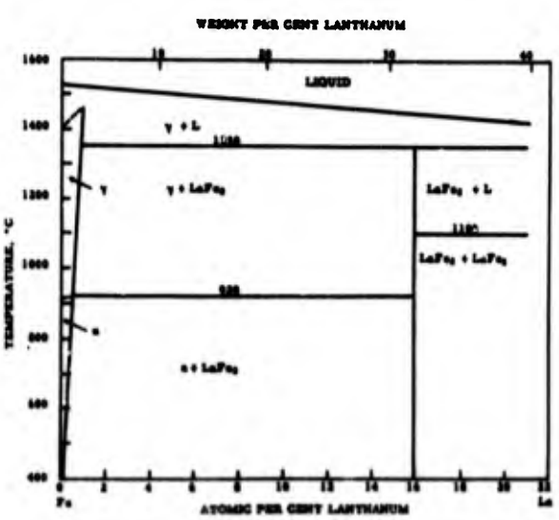
Gold (1)
(Permission of U. S. AEC)



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

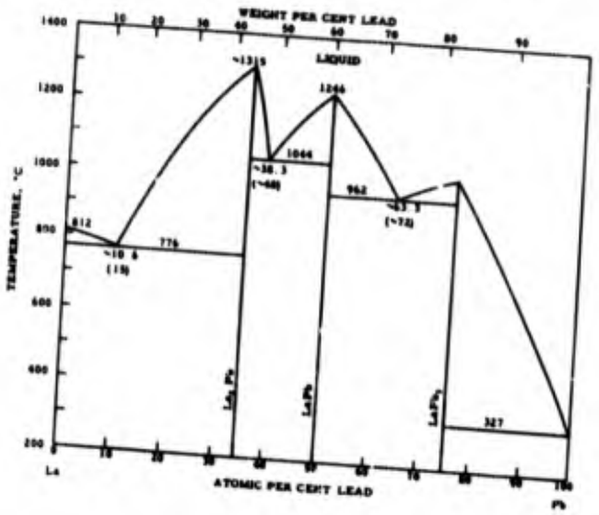


Complete Diagram

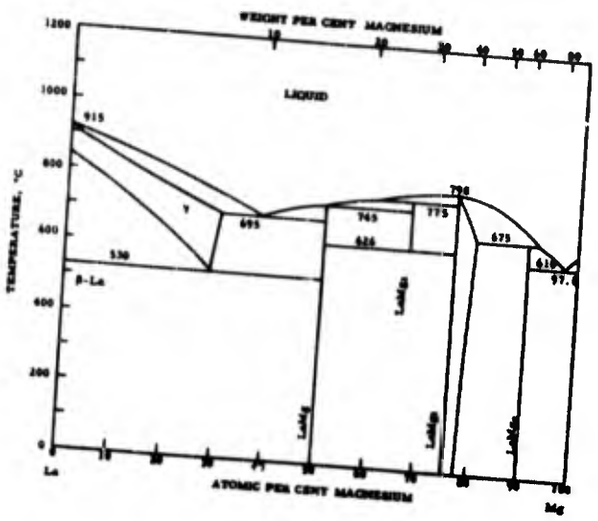


Partial Diagram – Iron-Rich Region

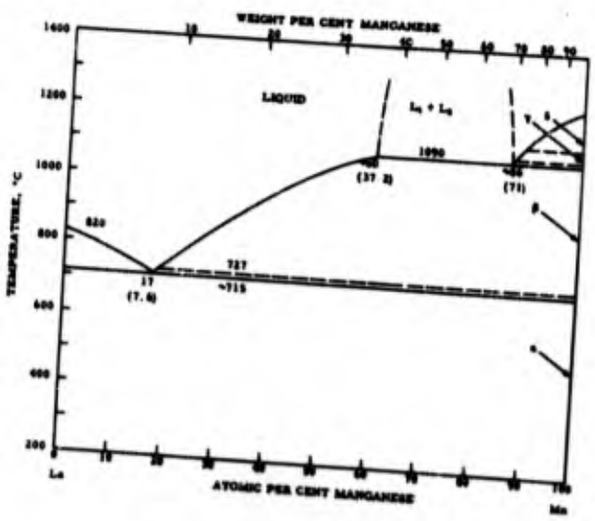
Iron (1)
(Permission of U. S. AEC)



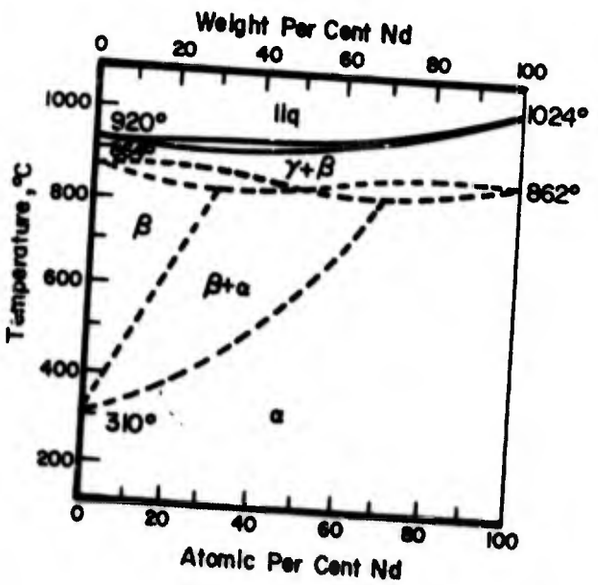
Lead (1)
(Permission of U. S. AEC)



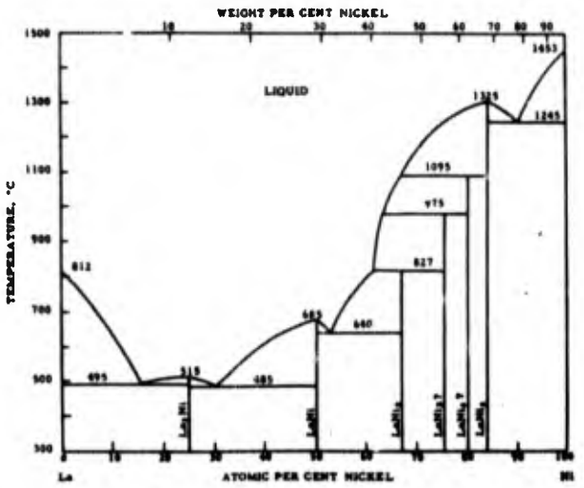
Magnesium (1)
(Permission of U. S. AEC)



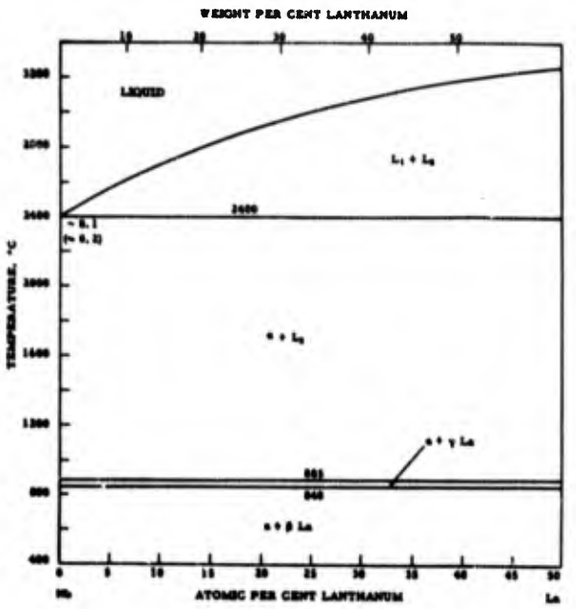
Manganese (1)
(Permission of U. S. AEC)



Neodymium (4)



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



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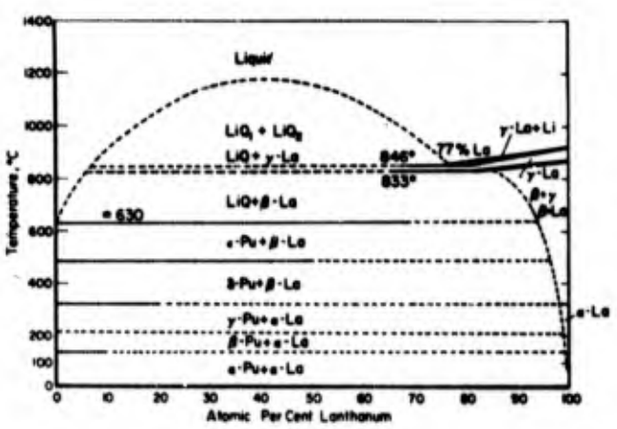
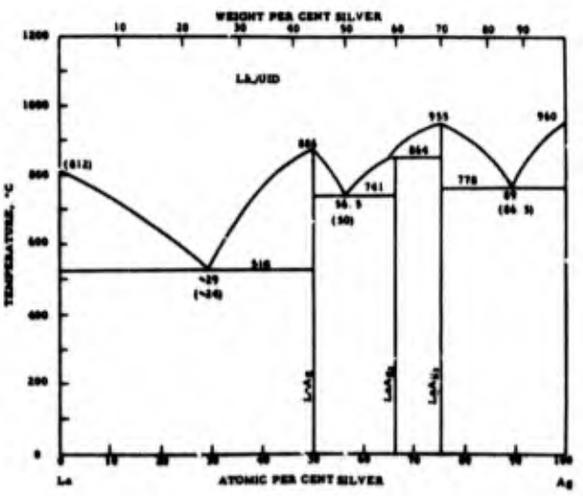
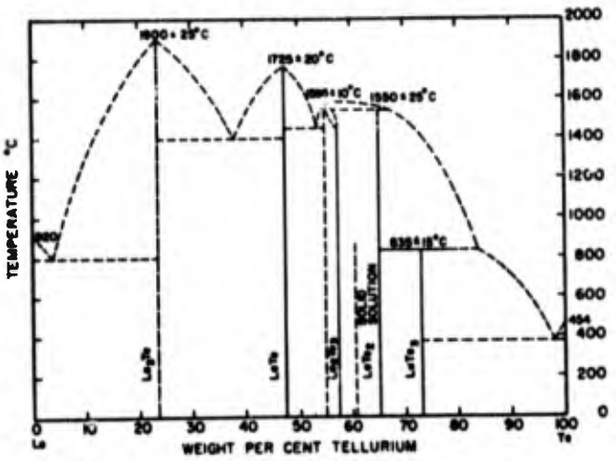


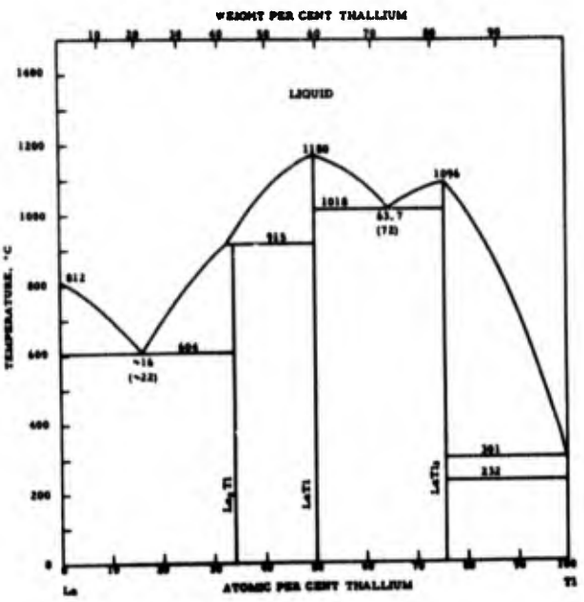
Plutonium (17)



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



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



Thallium (1)
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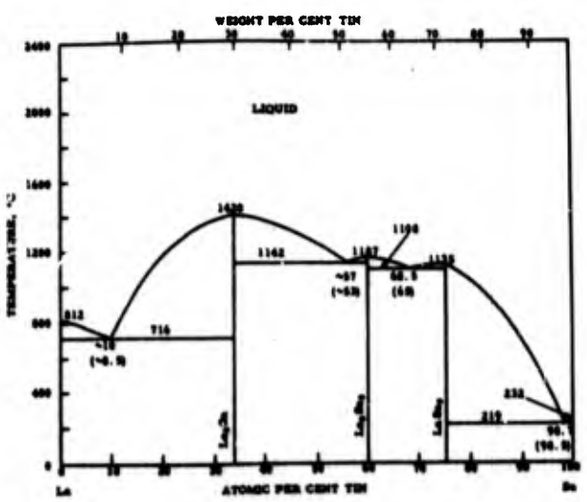

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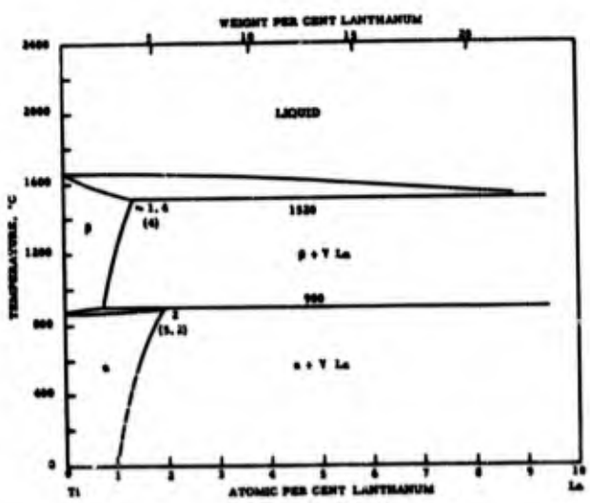
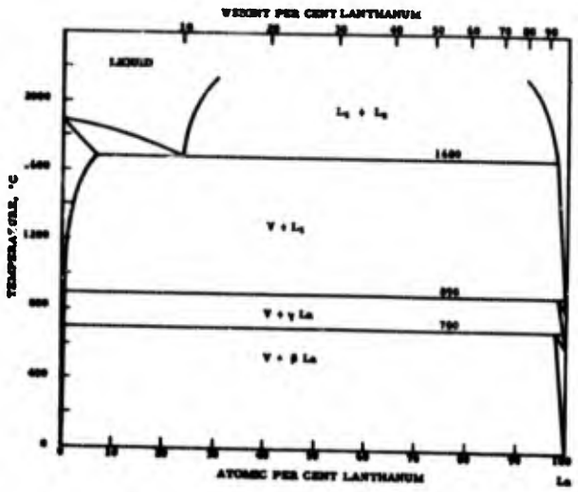
(Permission of U. S. AEC)



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



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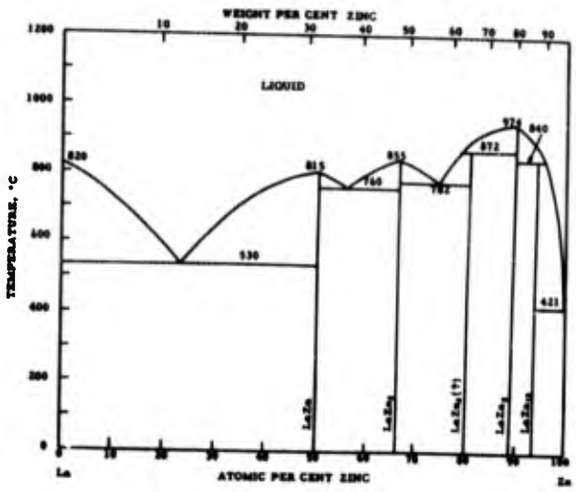
(Permission of U. S. AEC)



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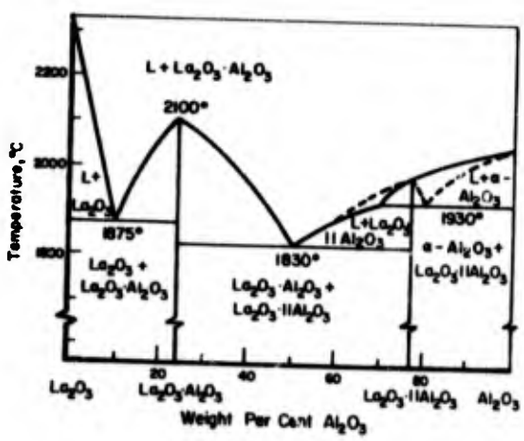
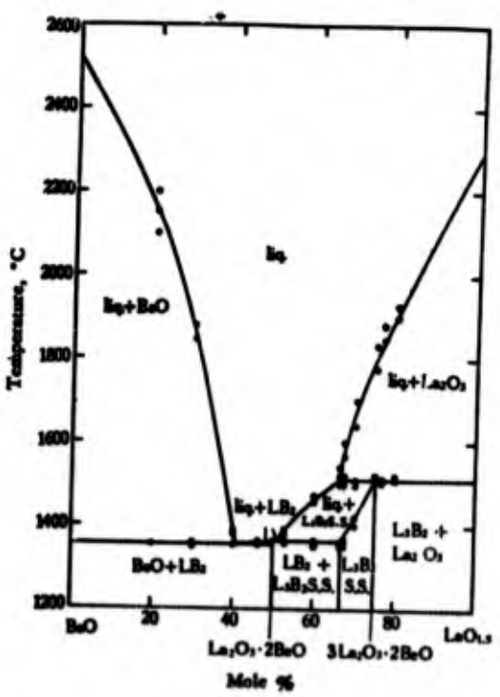
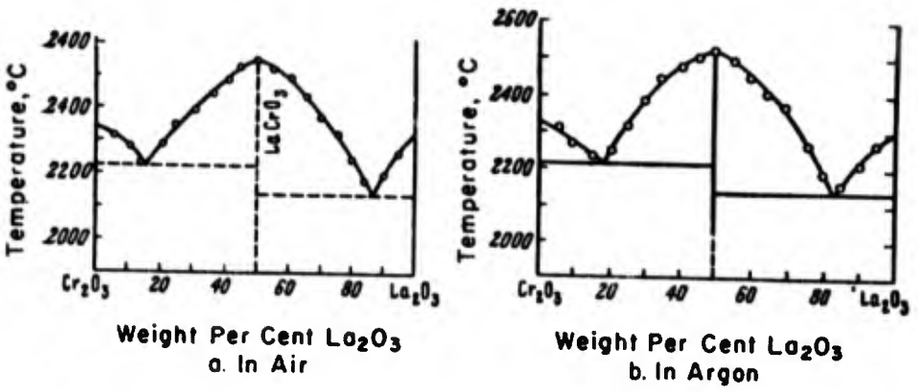
(Permission of U. S. AEC)



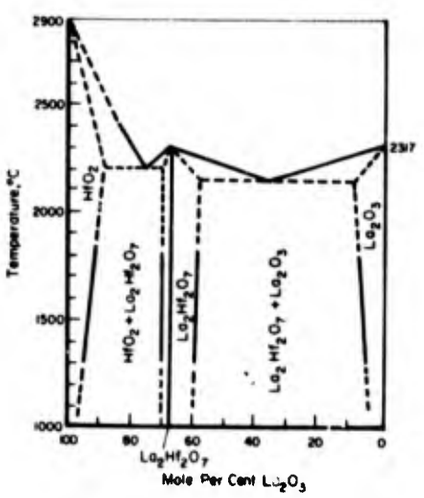
La_2O_3-Al_2O_3 (19)



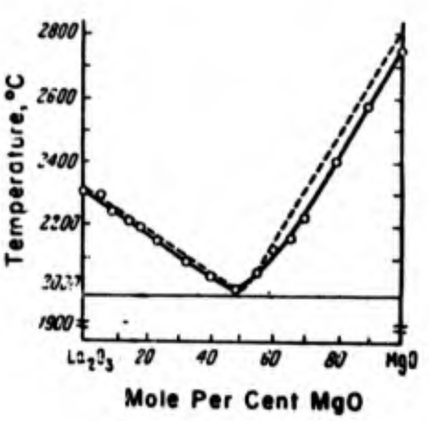
La_2O_3-BeO (20)



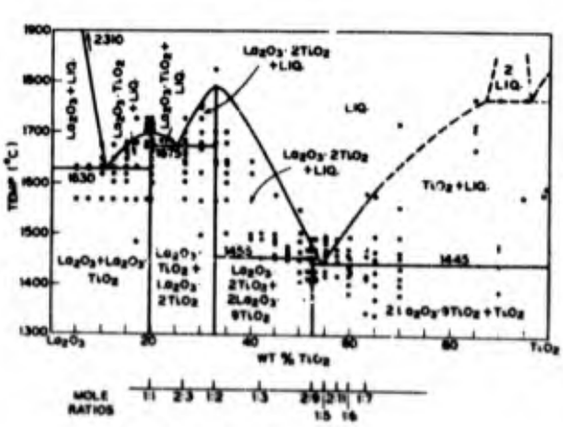
La_2O_3-Cr_2O_3 (21)

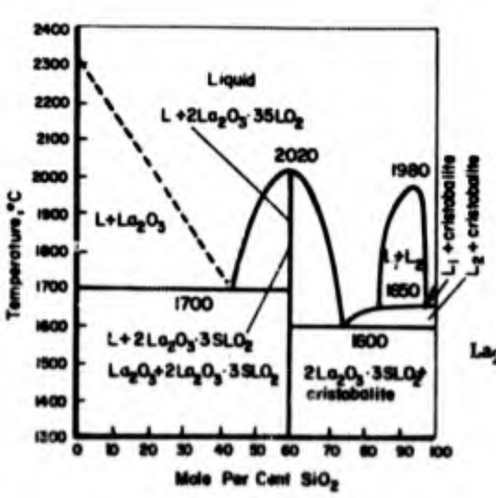


La_2O_3-HfO_2 (22)



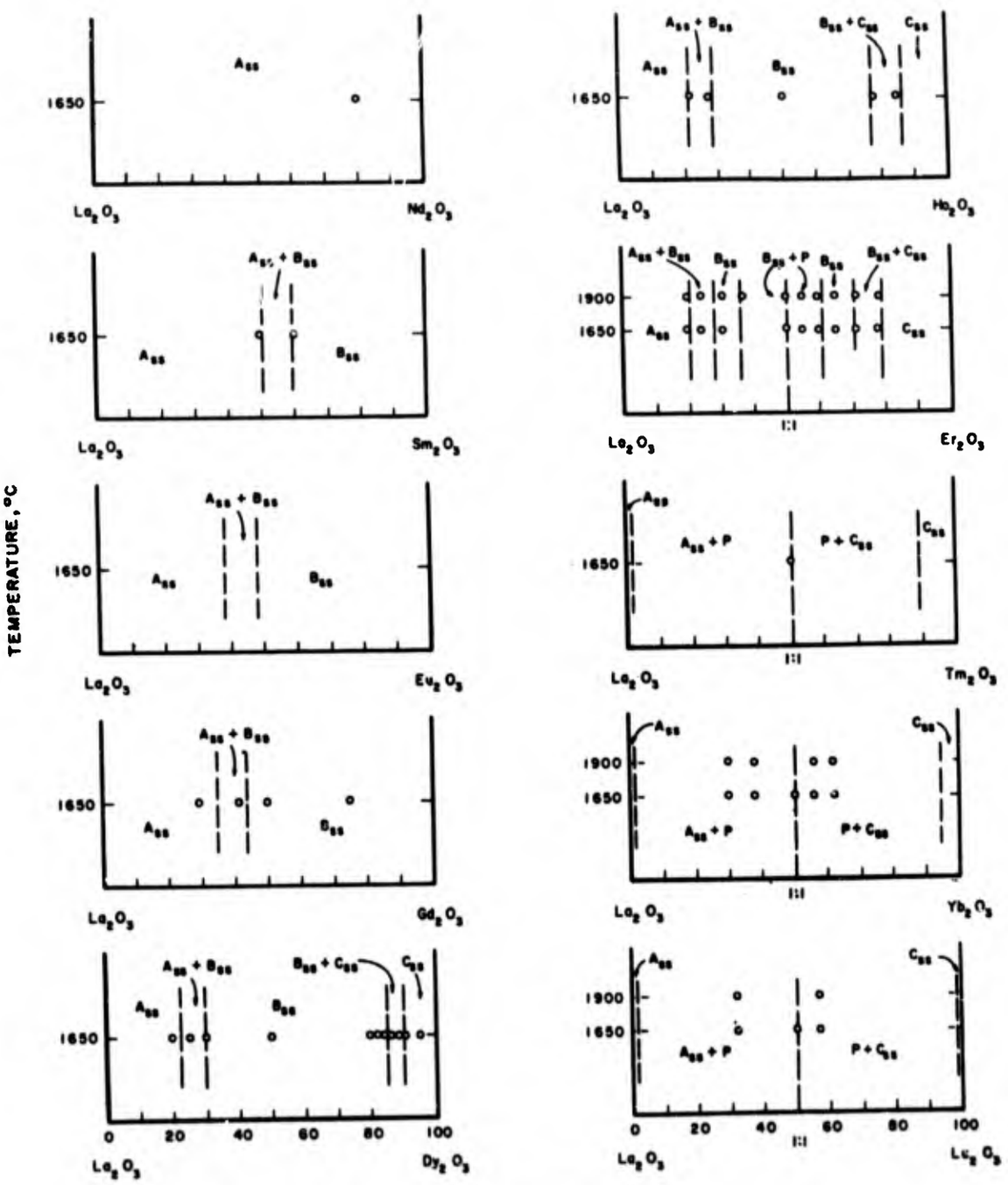
La_2O_3-MgO (23)



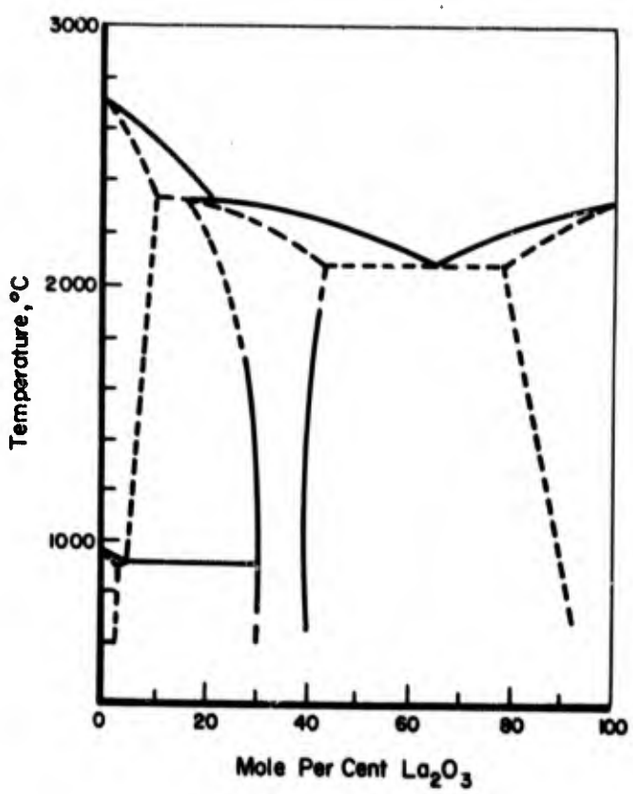


La_2O_3-SiO_2 (24)

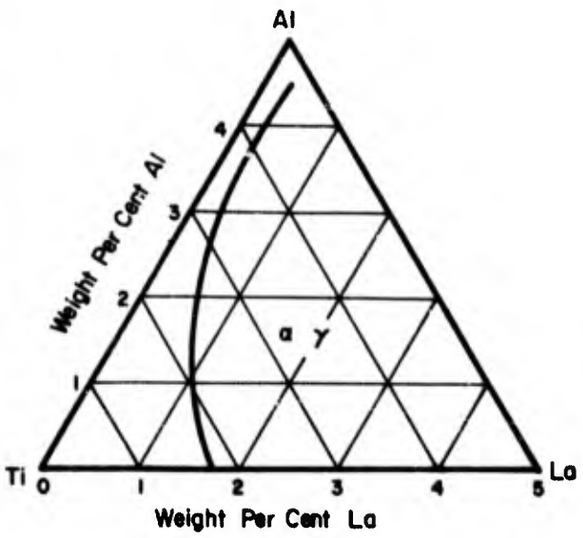
La_2O_3-TiO_2 (25)
(Permission of American Ceramic Society)



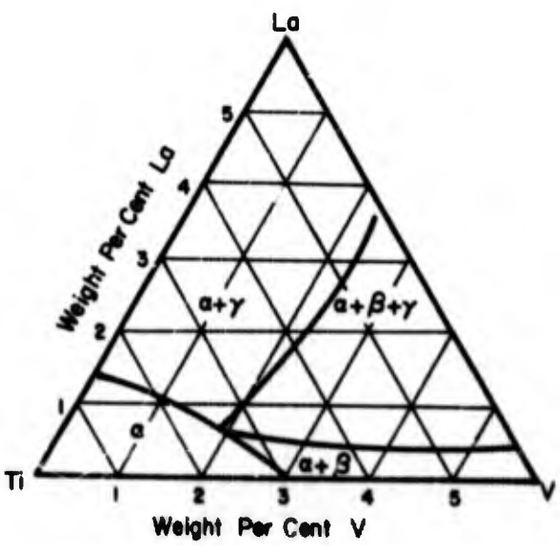
La_2O_3 – Rare-Earth Oxides (26)



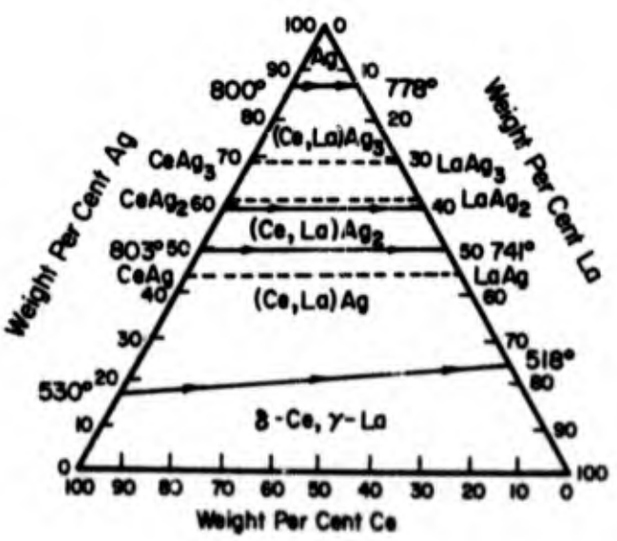
La_2O_3-ZrO_2 (3)



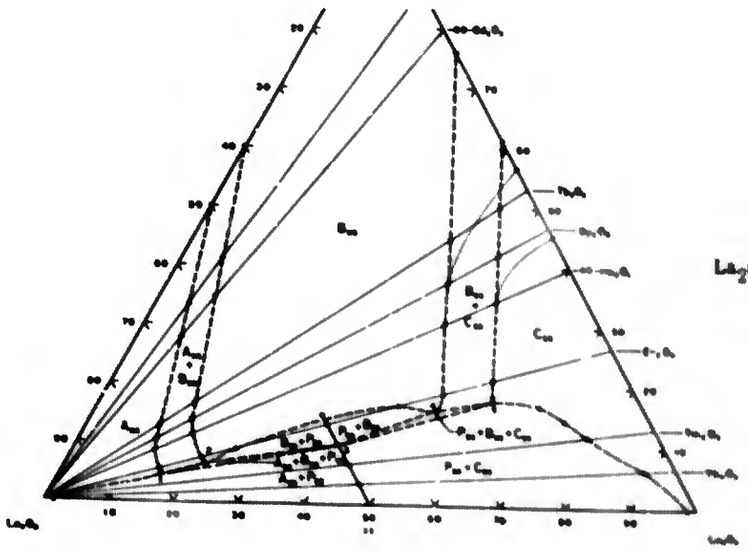
Lanthanum-Aluminum-Titanium at 600 C (4)



Lanthanum-Vanadium-Titanium at 600 C (4)

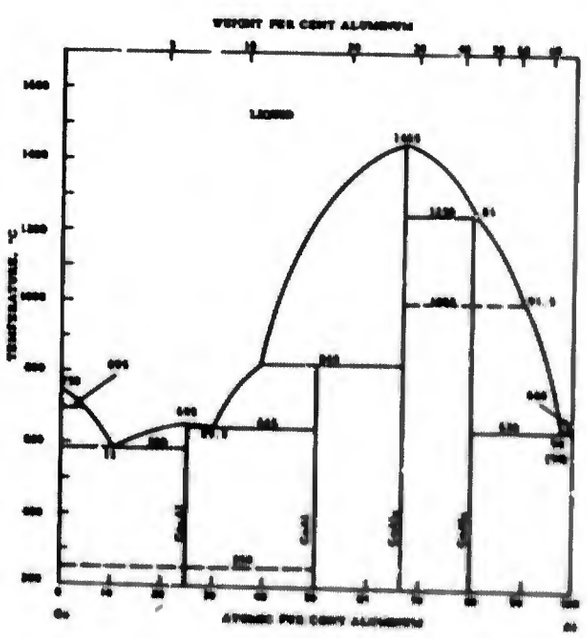


Lanthanum-Cerium-Silver (4)

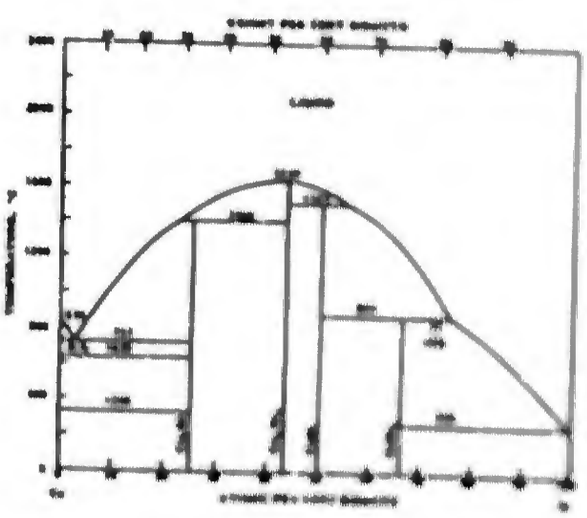


La_2O_3-Sm_2O_3-Lu_2O_3 (1/3)

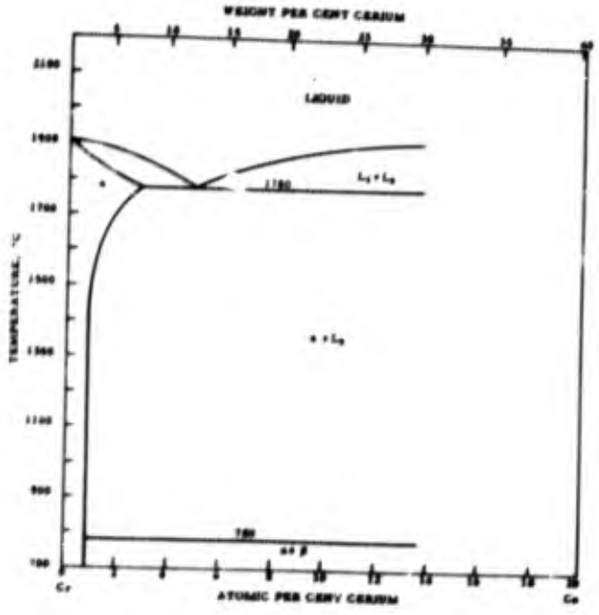
CERIUM



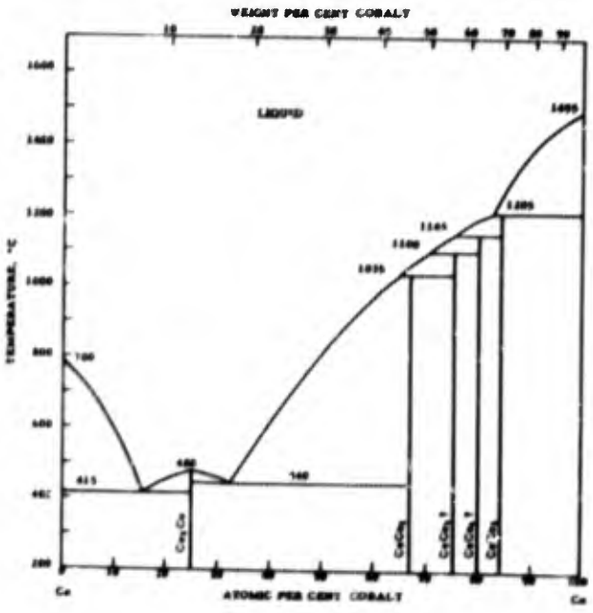
Aluminum (1)
(Permission of U. S. AEC)



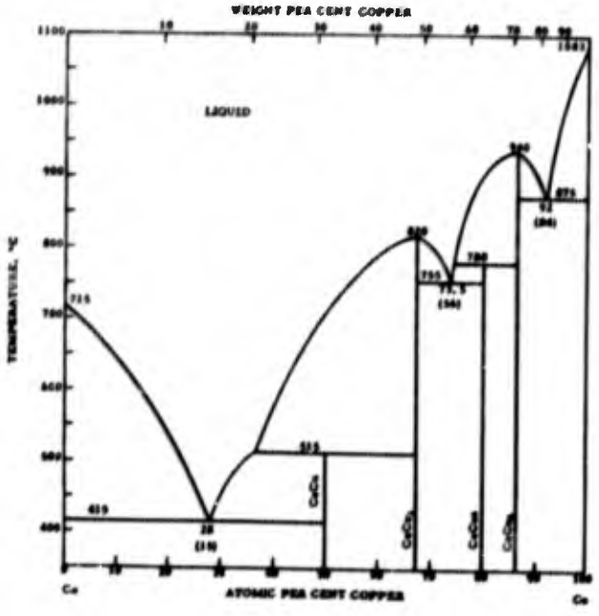
Bismuth (1)
(Permission of U. S. AEC)



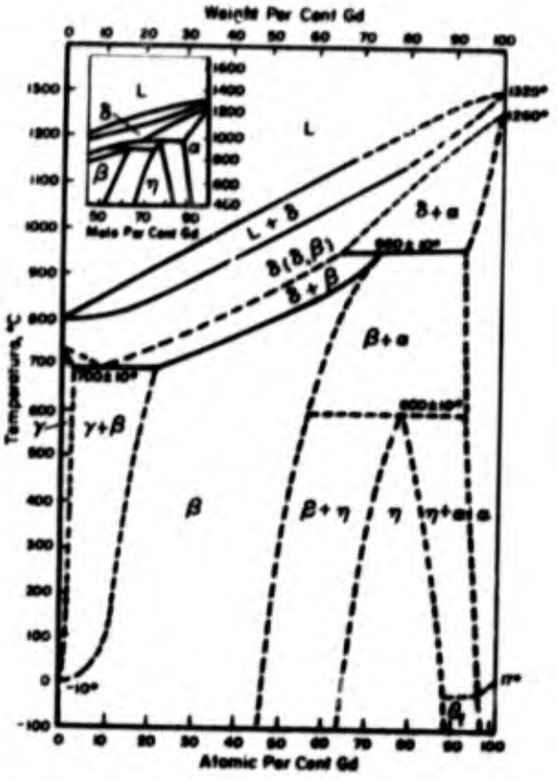
Chromium (1)
(Permission of U. S. AEC)



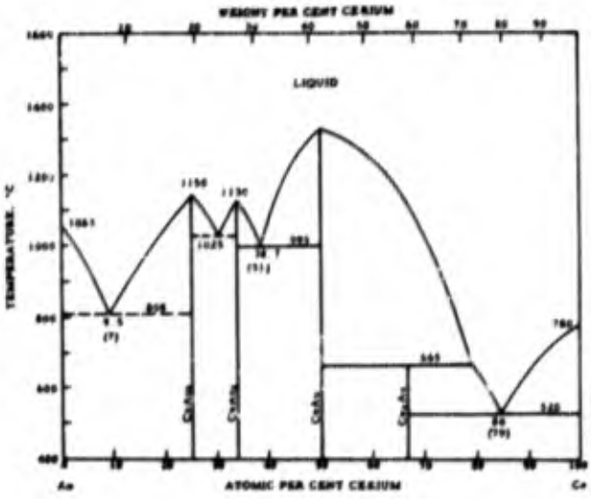
Cobalt (1)
(Permission of U. S. AEC)



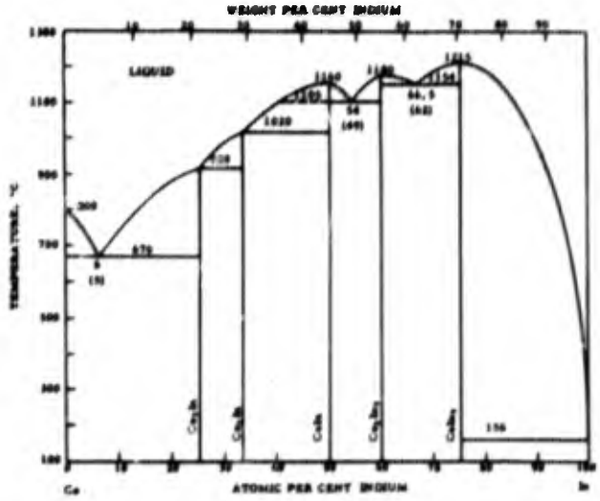
Copper (1)
(Permission of U. S. AEC)



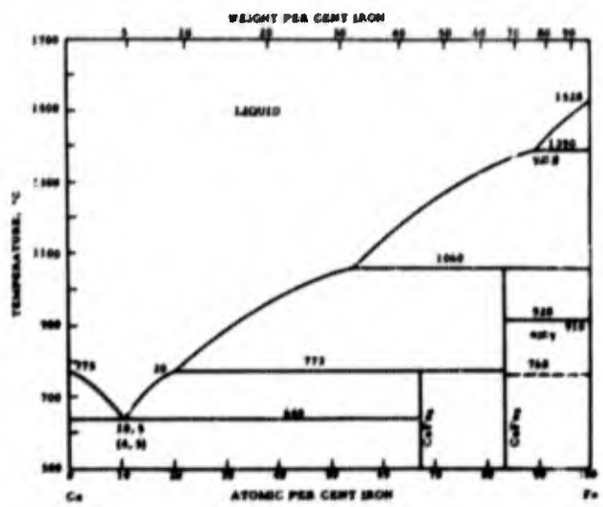
Gadolinium (29)



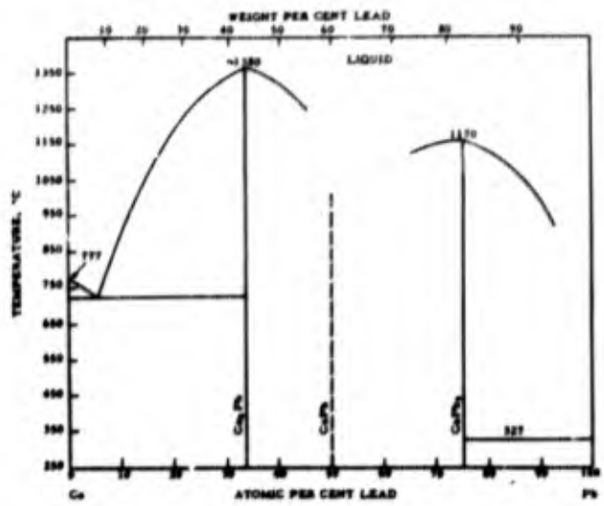
Gold (1)
(Permission of U. S. AEC)



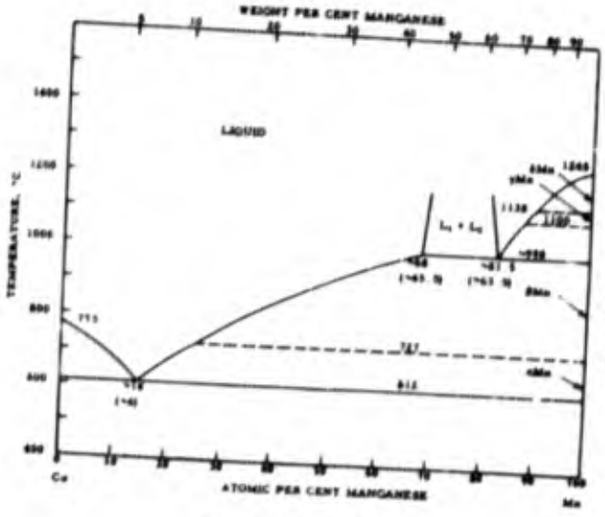
Indium (1)
(Permission of U. S. AEC)



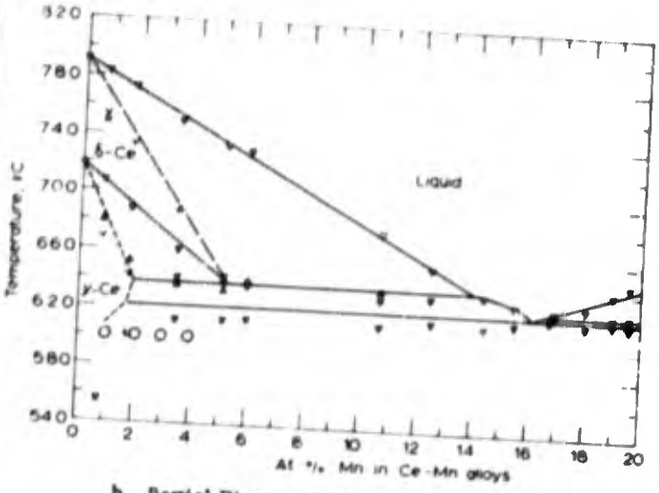
Iron (1)
(Permission of U. S. AEC)



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

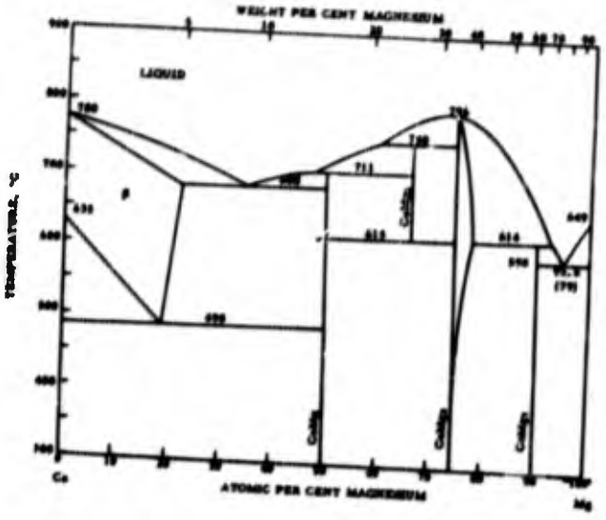


a. Full Diagram (1)
(Permission of U. S. AEC)

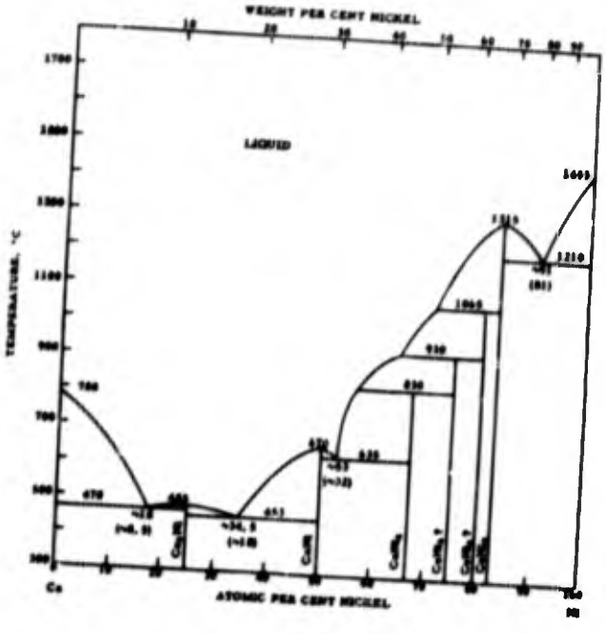


b. Partial Diagram – Cerium-Rich Region (30)
(Permission of Elsevier Publishing Co.)

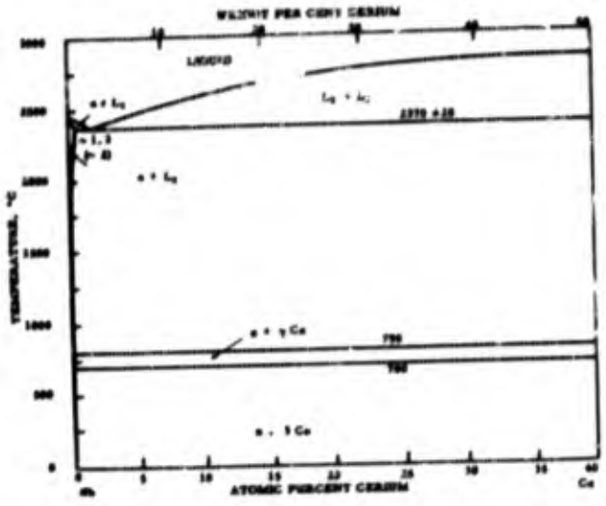
Manganese



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



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



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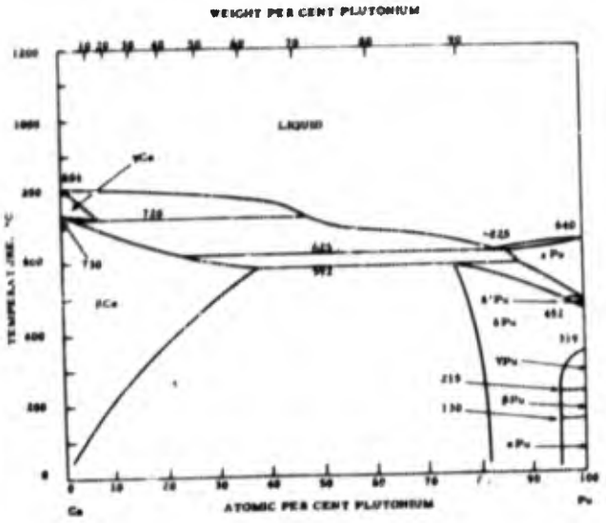

Plutonium (1)
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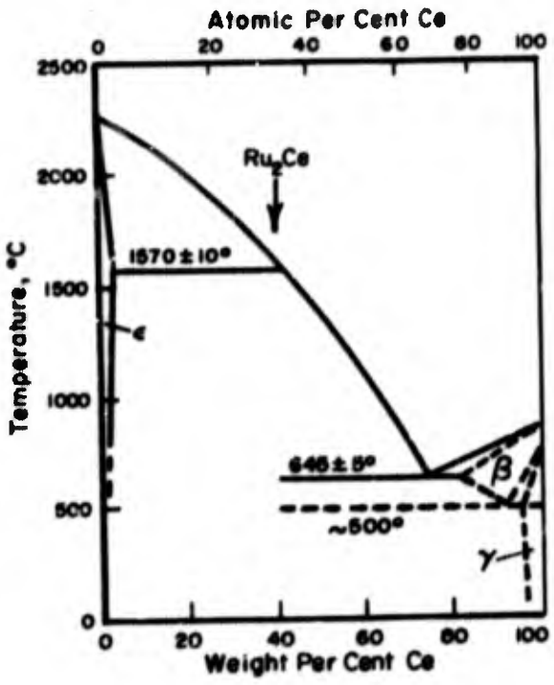
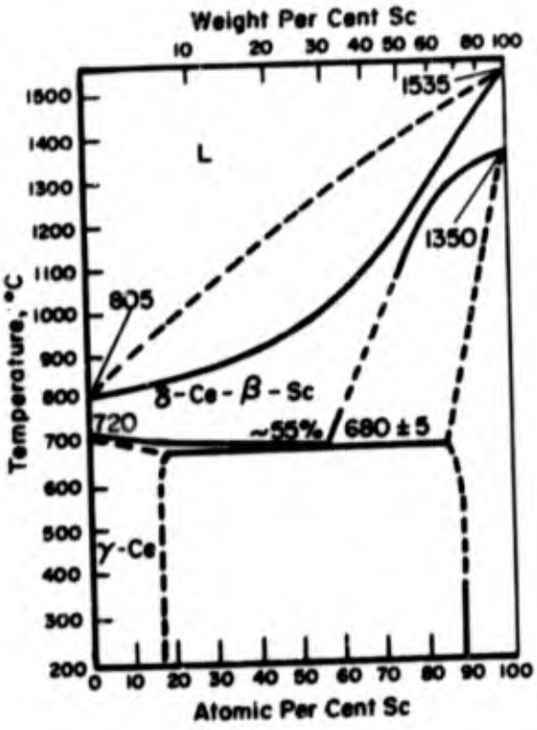
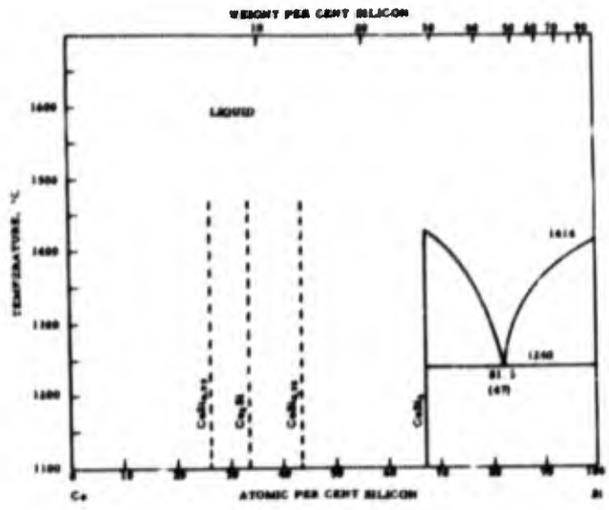


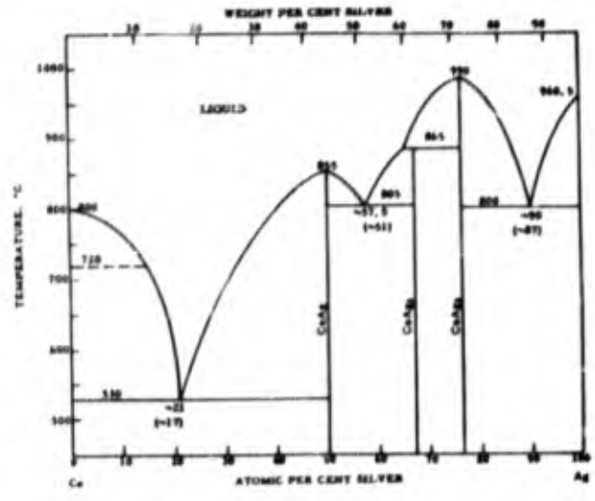
Ruthenium (31)



Scandium (32)



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



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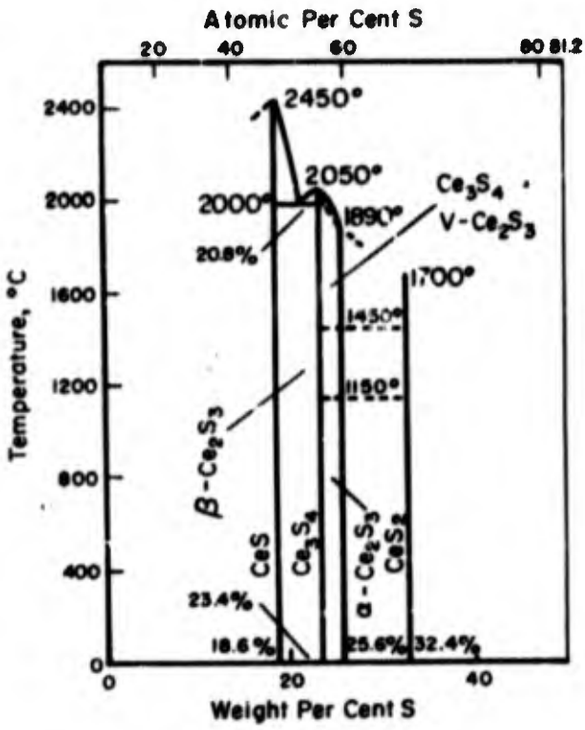
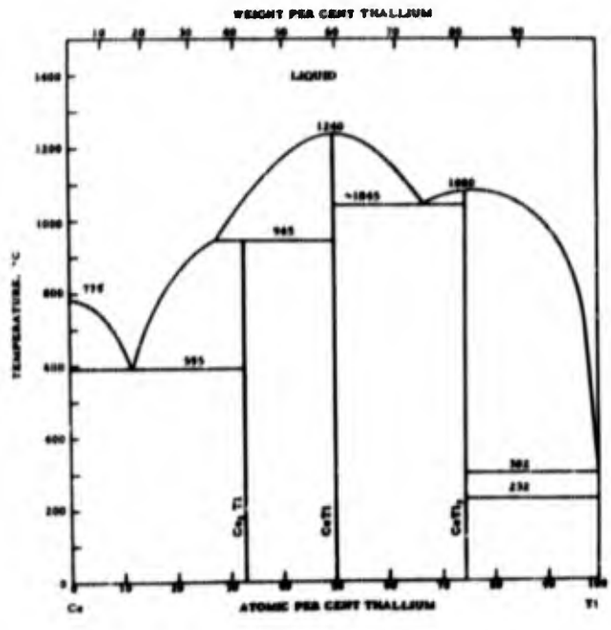
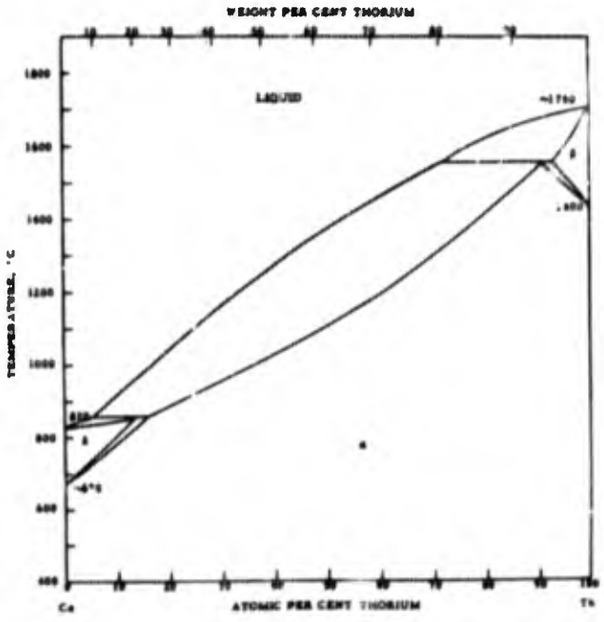


Sulfur (4)



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



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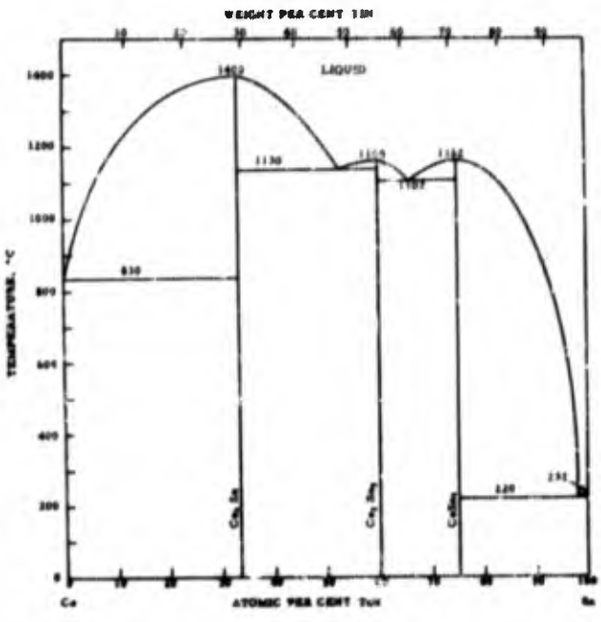
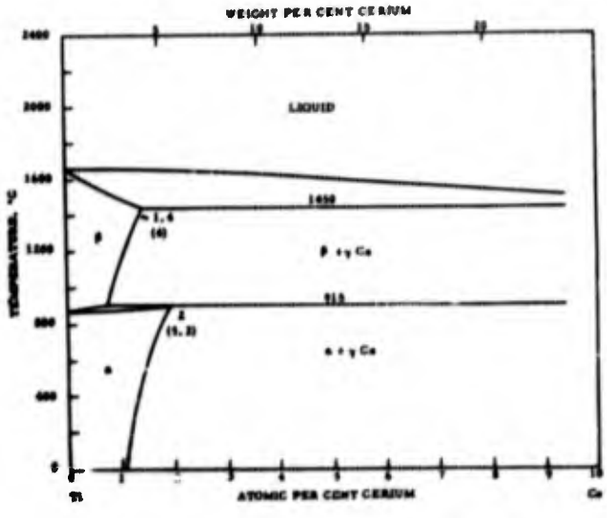


Tin (1)
(Permission of U. S. AEC)



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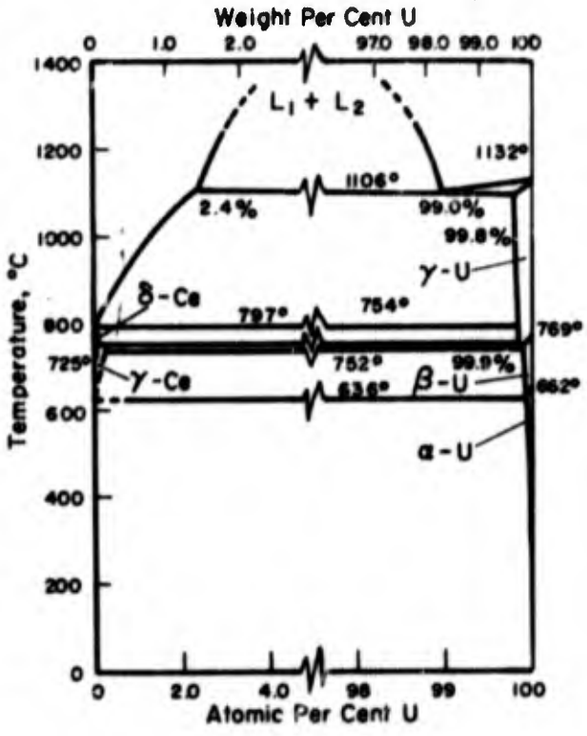

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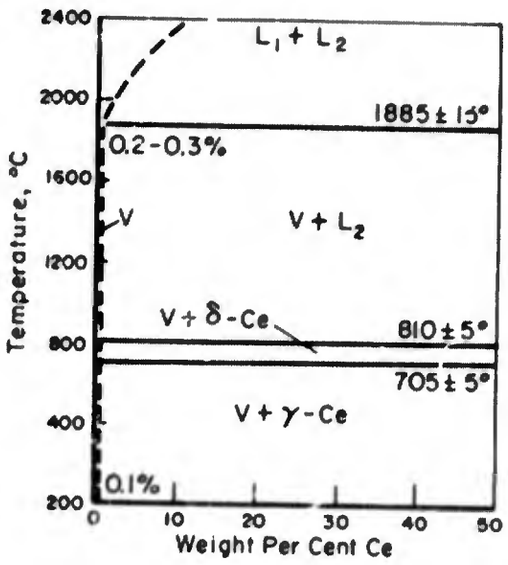
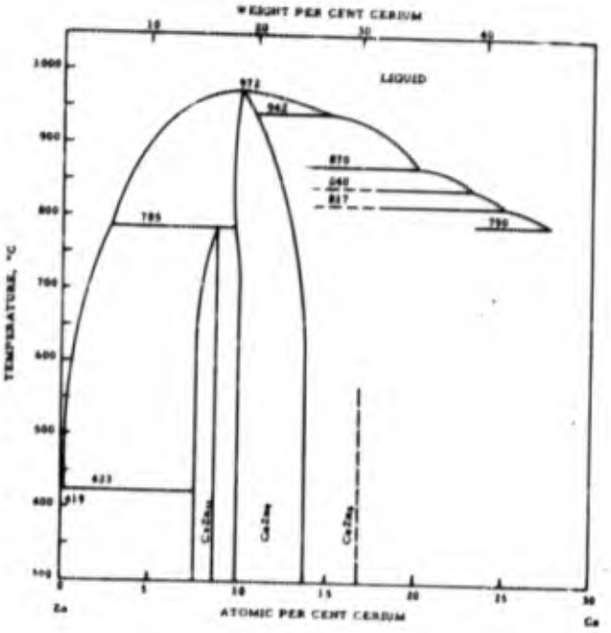
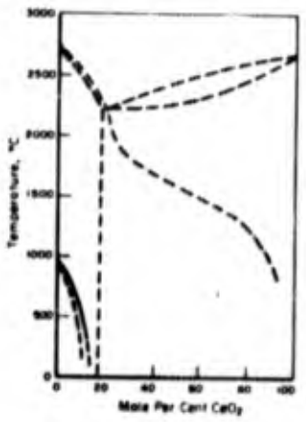


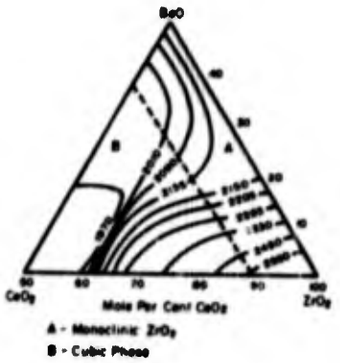
Vanadium (33)



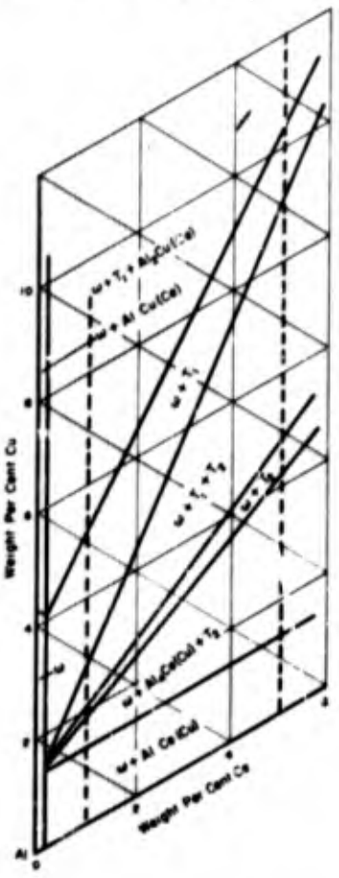
Zinc (1)
(Permission of U. S. AEC)



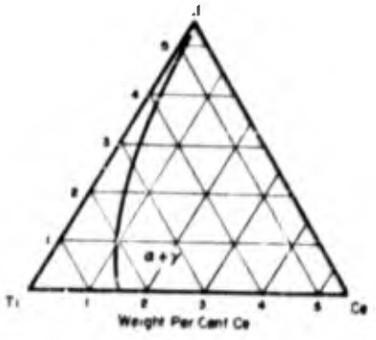
CeO_2-ZrO_2 (37)



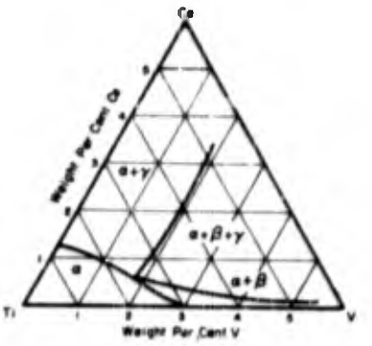
CeO_2-BeO-ZrO_2 (37)



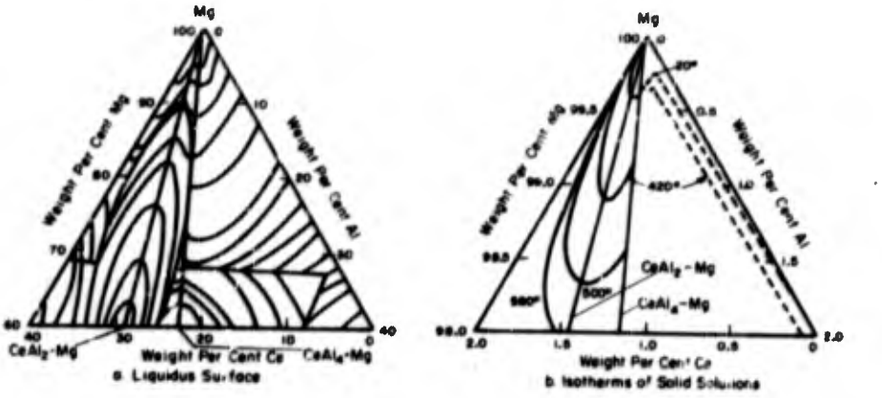
Cerium-Aluminum-Copper (34)
Isothermal Section at 500°C



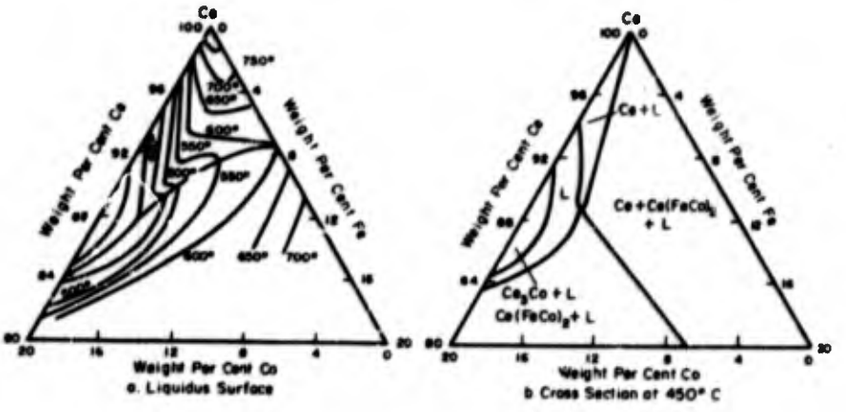
Cerium-Aluminum-Titanium (4)



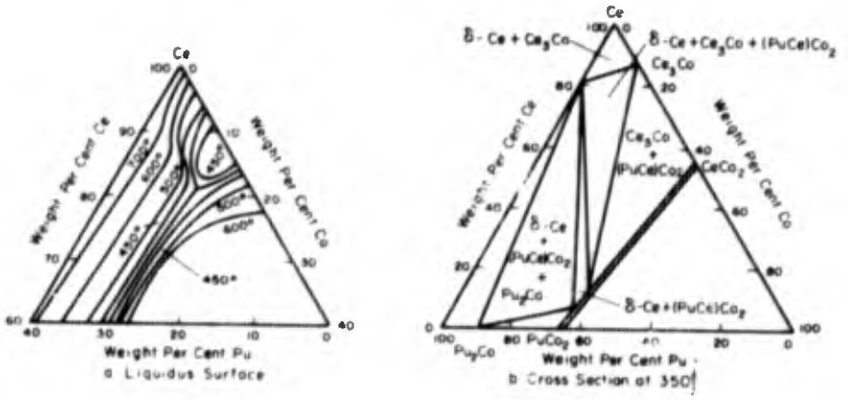
Cerium-Vanadium-Titanium (4)



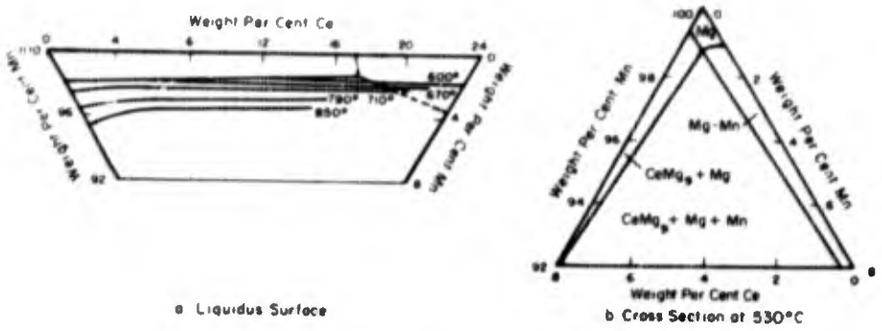
Cerium-Magnesium-Aluminum (4)



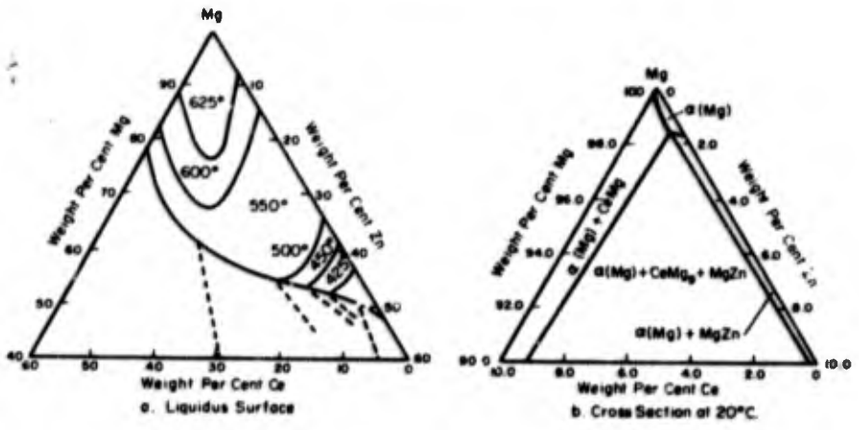
Cerium-Cobalt-Iron (4)



Cerium-Cobalt-Plutonium (4)

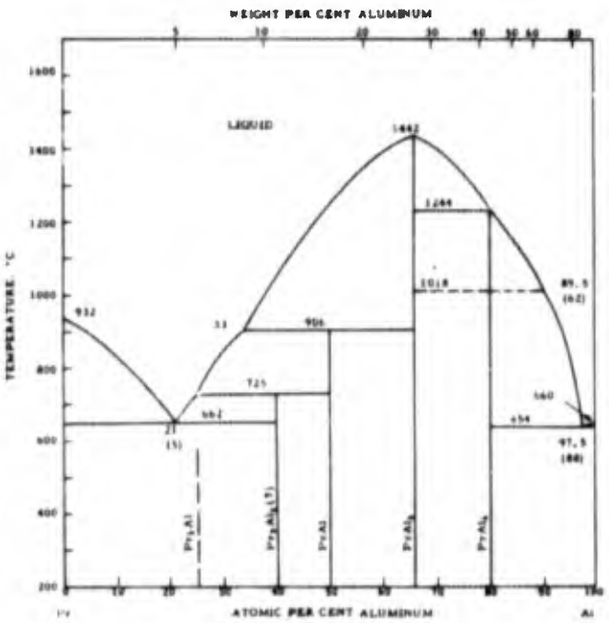


Cerium-Magnesium-Manganese (4)

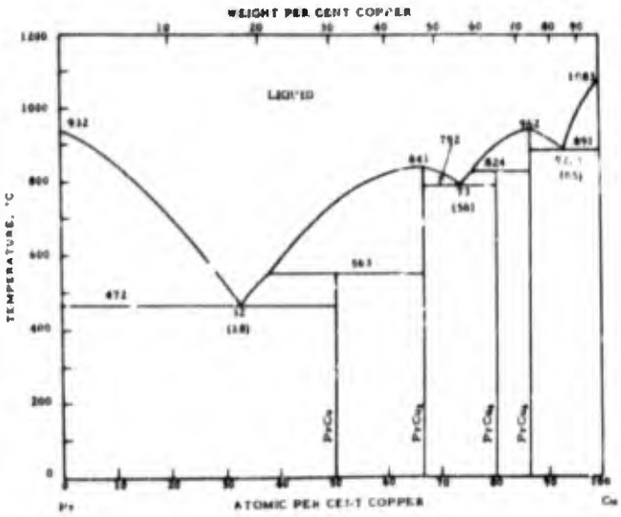


Cerium-Magnesium-Zinc (4)

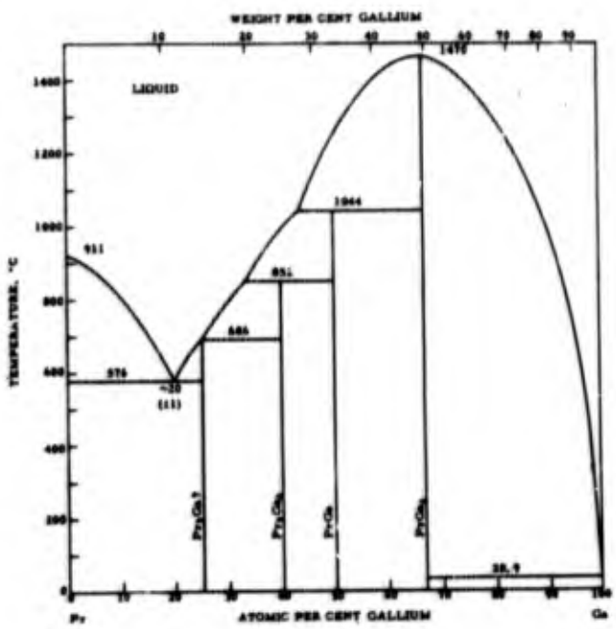
PRASEODYMIUM



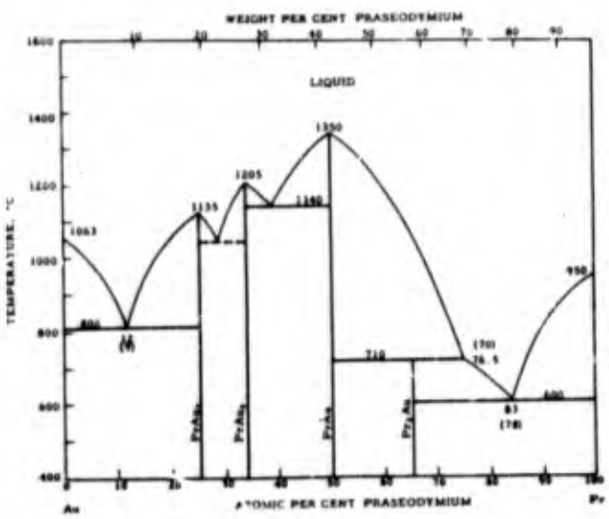
Aluminum (1)
(Permission of U. S. AEC)



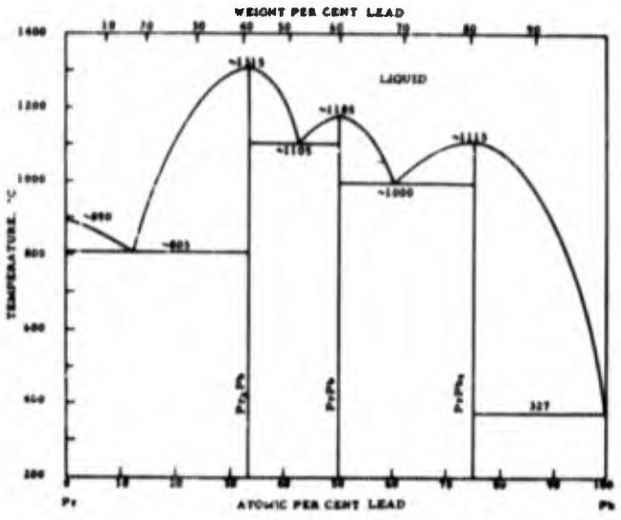
Copper (1)
(Permission of U. S. AEC)



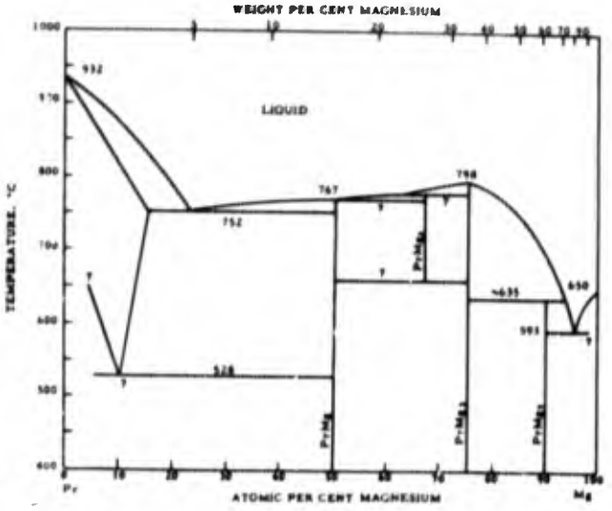
Gallium (1)
(Permission of U. S. AEC)



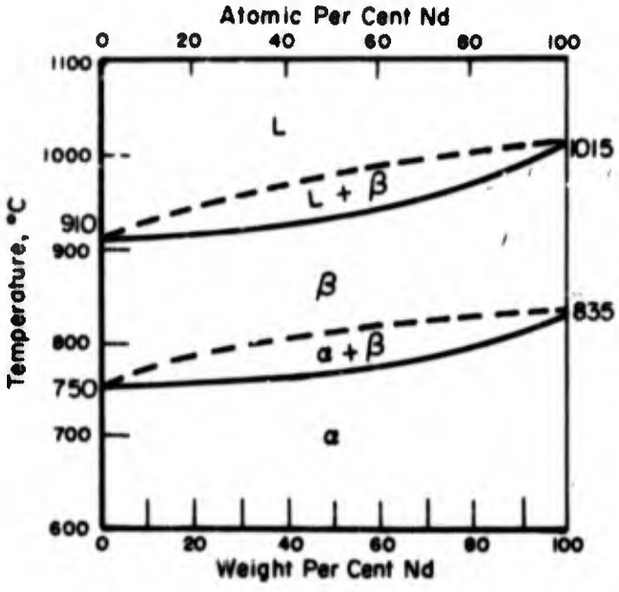
Gold (1)
(Permission of U. S. AEC)



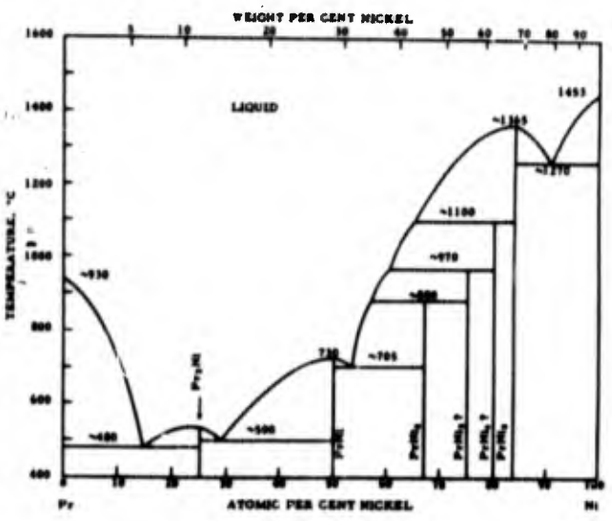
Lead (1)
(Permission of U. S. AEC)



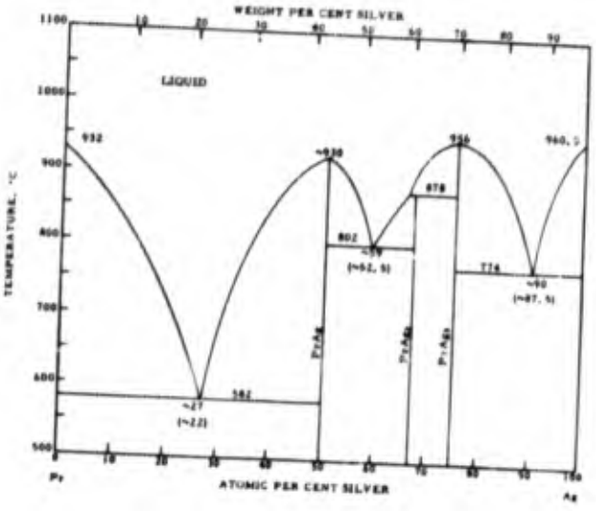
Magnesium (1)
(Permission of U. S. AEC)



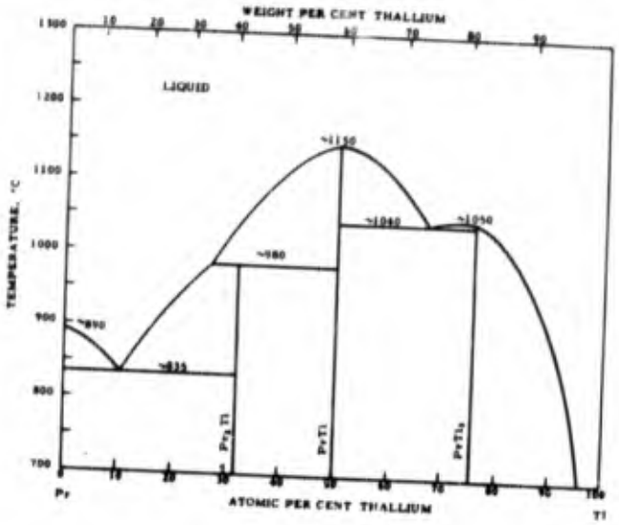
Neodymium (35)



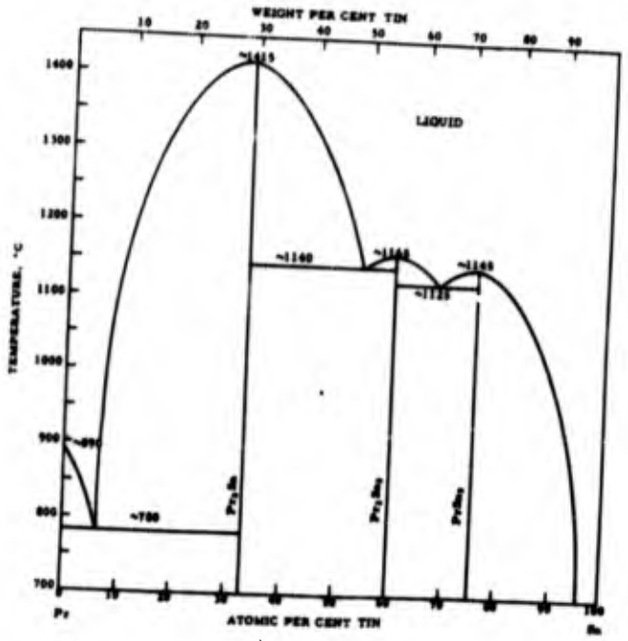
Nickel (1)
(Permission of U. S. AEC)



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

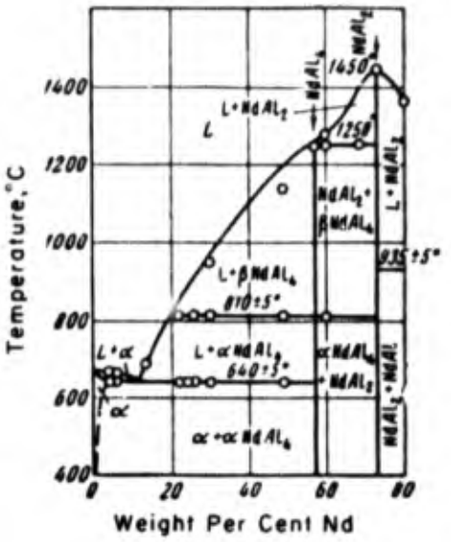


Thallium (1)
(Permission of U. S. AEC)

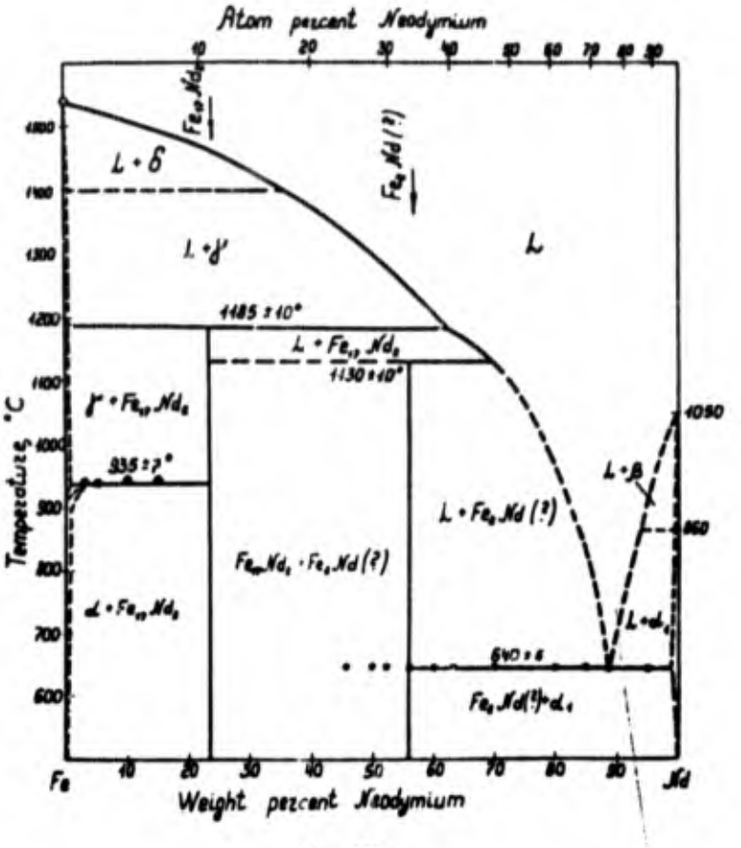


Tin (1)
(Permission of U. S. AEC)

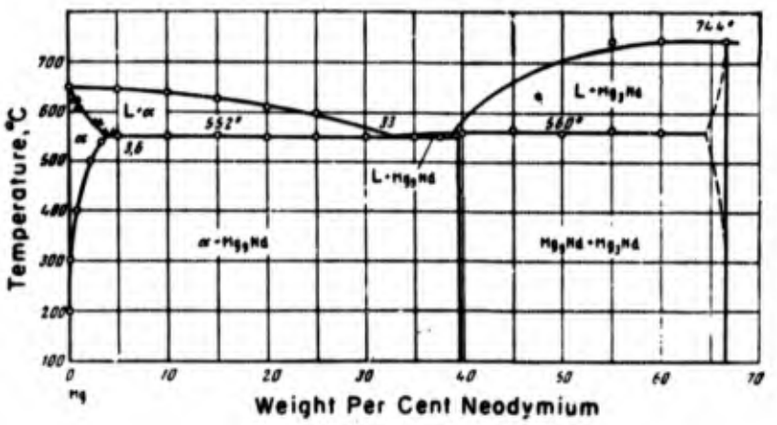
NEODYMIUM



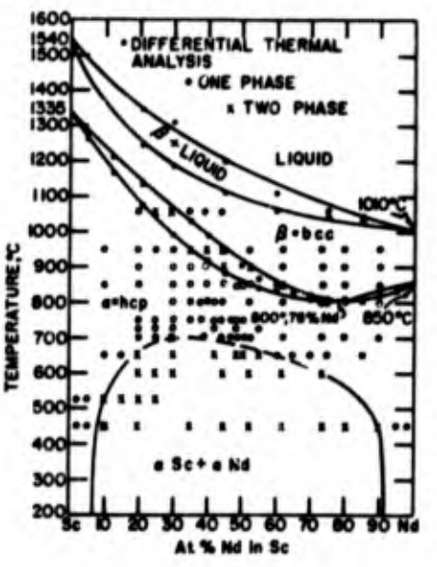
Aluminum (36)



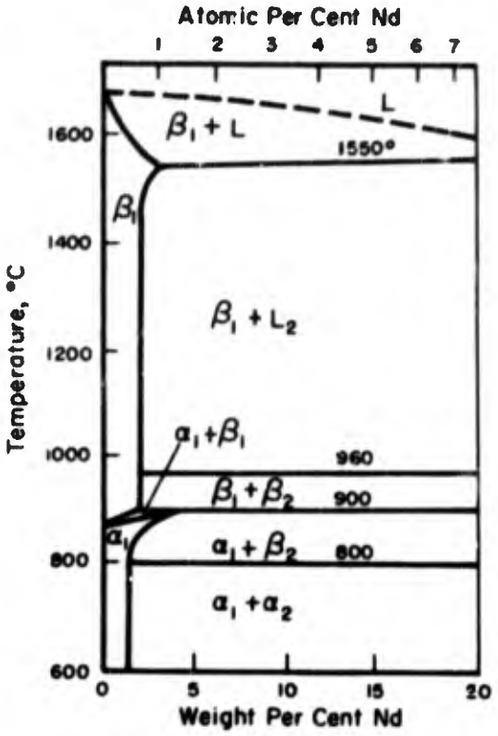
Iron (38)



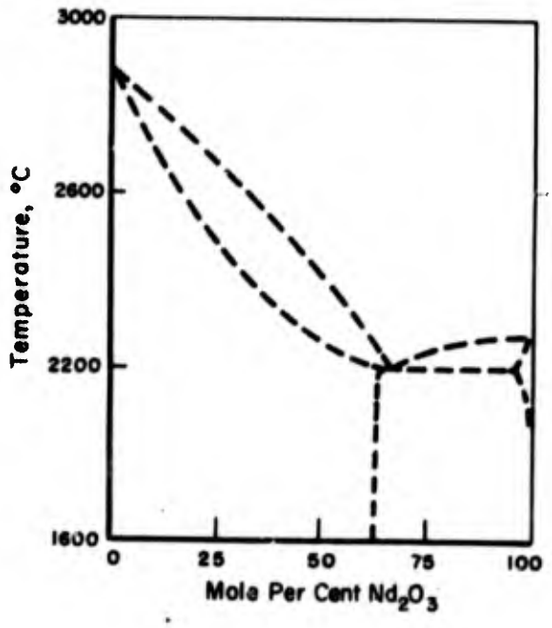
Magnesium (39)



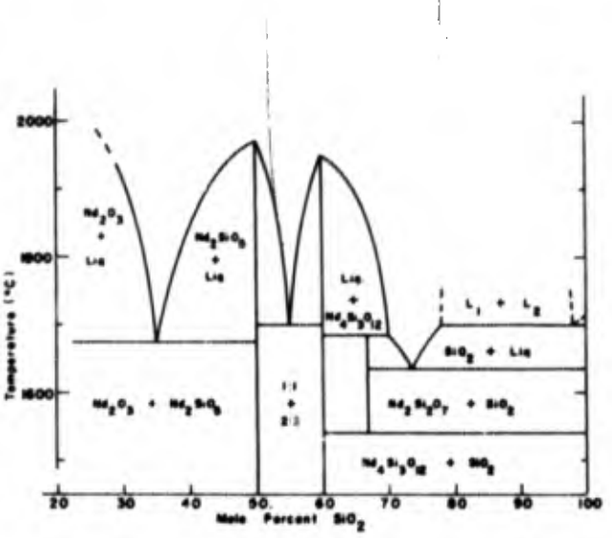
Scandium (5)



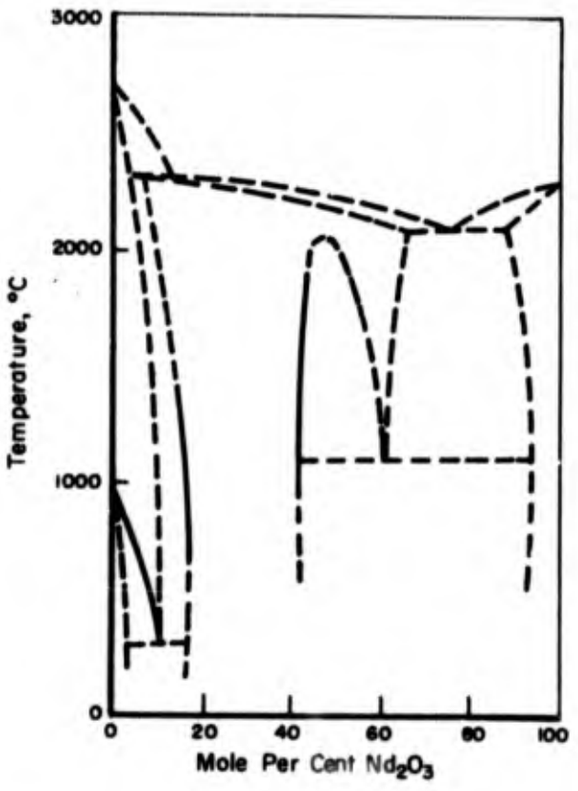
Titanium (40)
(Permission of Elsevier Publishing Co.)



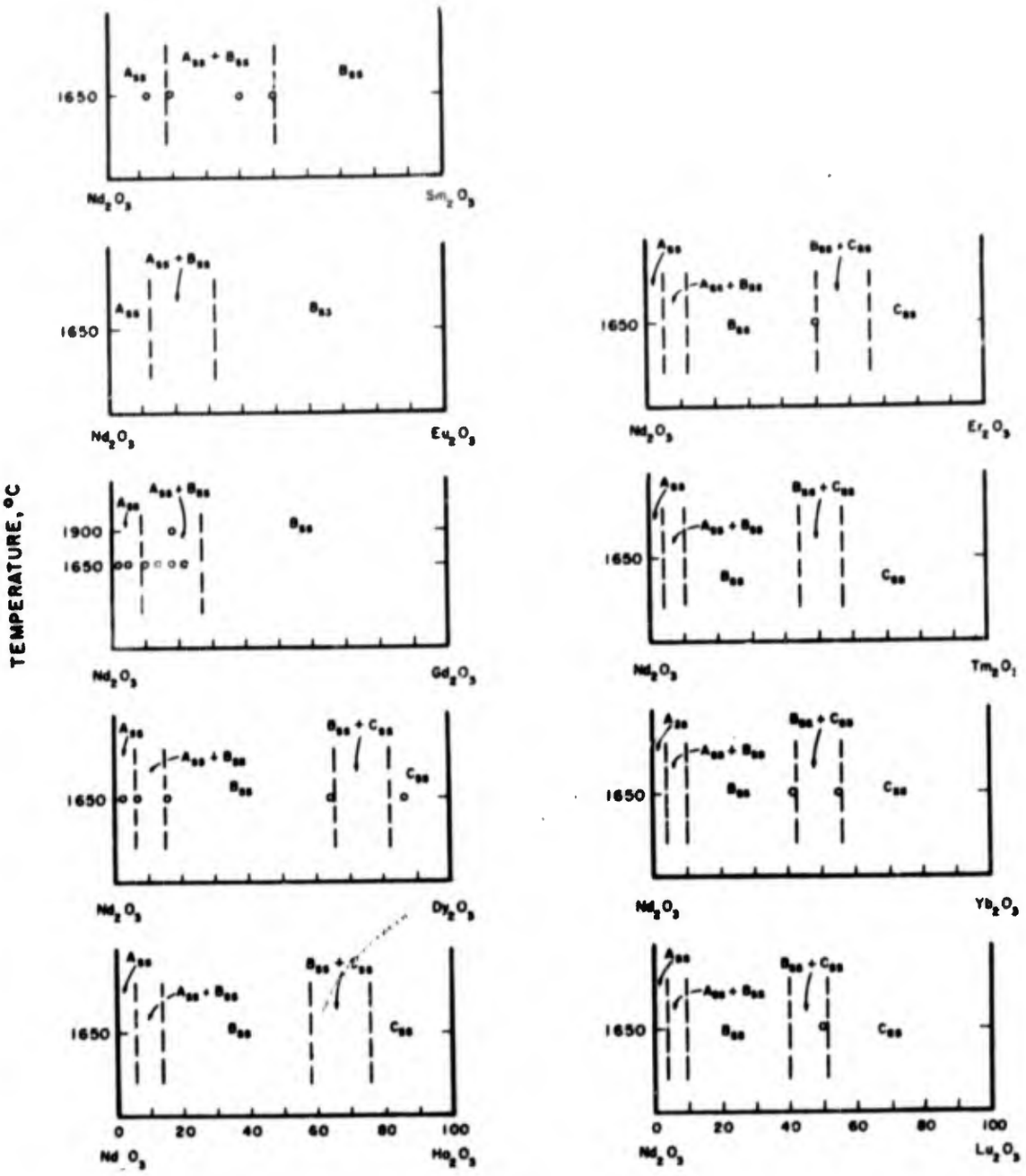
Nd_2O_3-UO_2 (37)



Nd_2O_3-SiO_2 (41)
(Permission of American Ceramic Society)

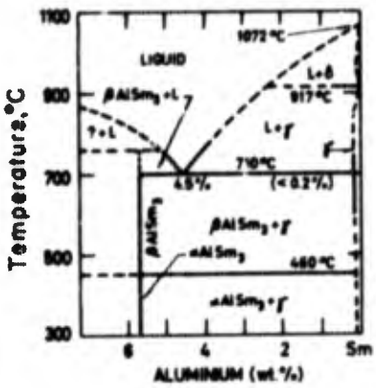


Nd_2O_3-ZrO_2 (37)

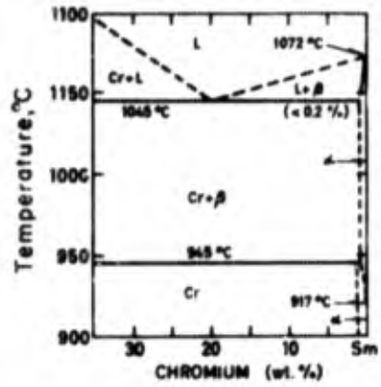


Nd_2O_3 – Rare-Earth Oxides (26)

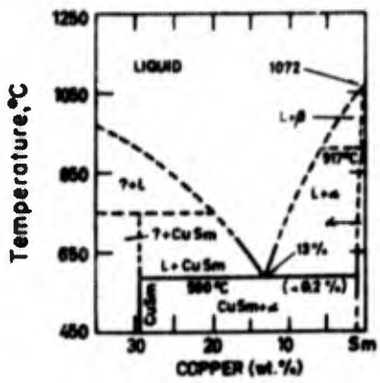
SAMARIUM



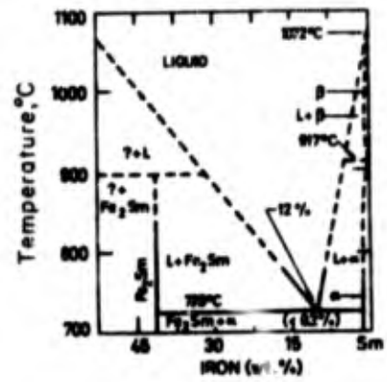
Aluminum (214)



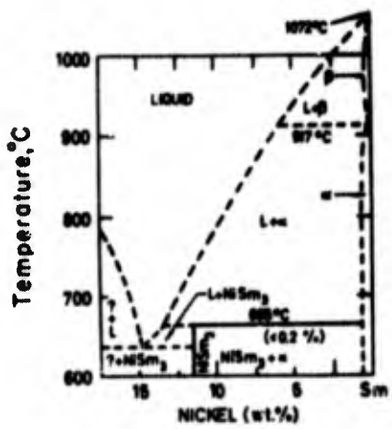
Chromium (214)



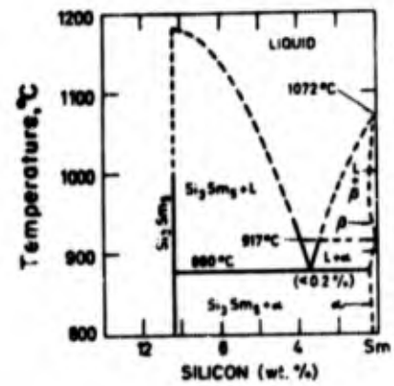
Copper (214)



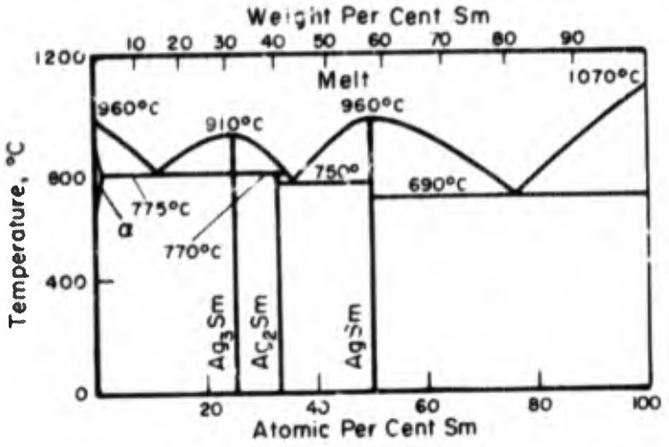
Iron (214)



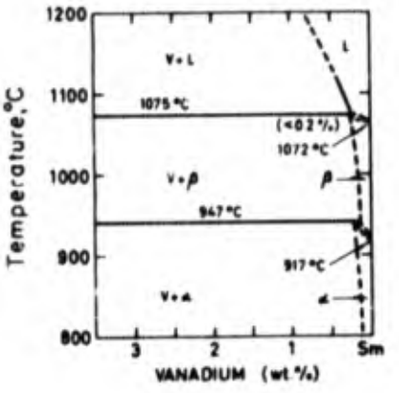
Nickel (214)



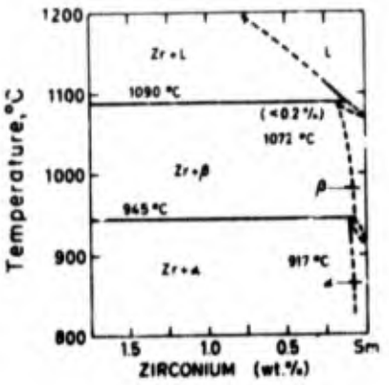
Silicon (214)



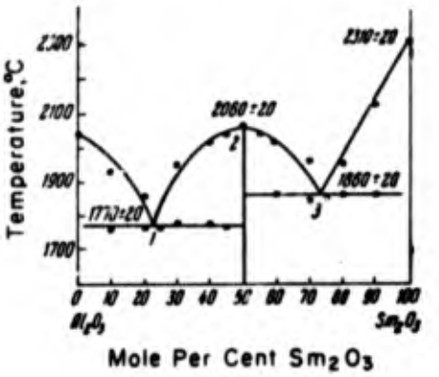
Silver (144)
(Permission of Metallurgical Society AIME)



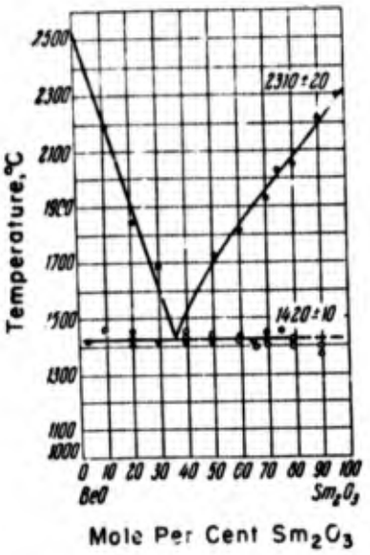
Vanadium (214)



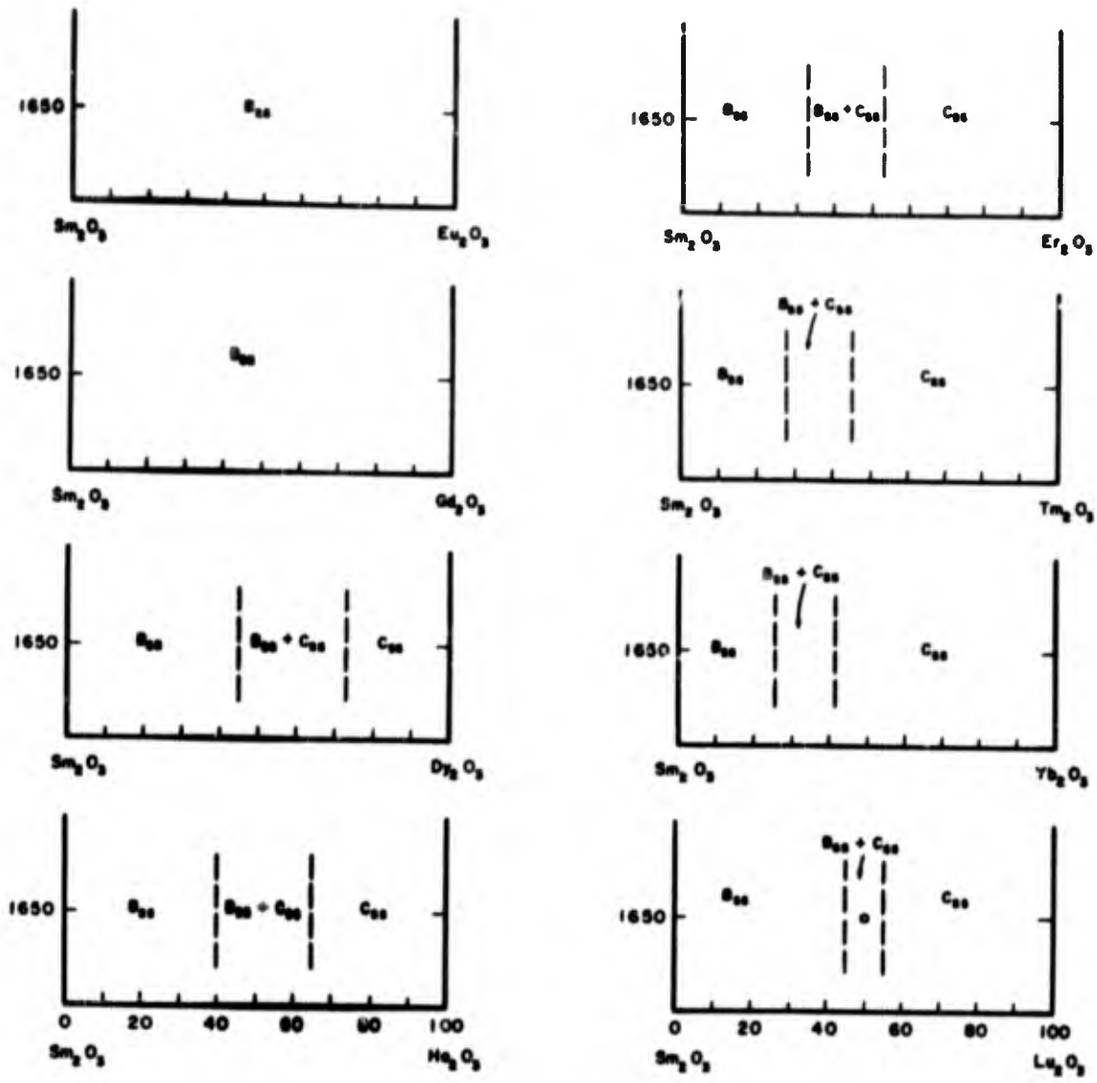
Zirconium (214)



Sm_2O_3-Al_2O_3 (37)



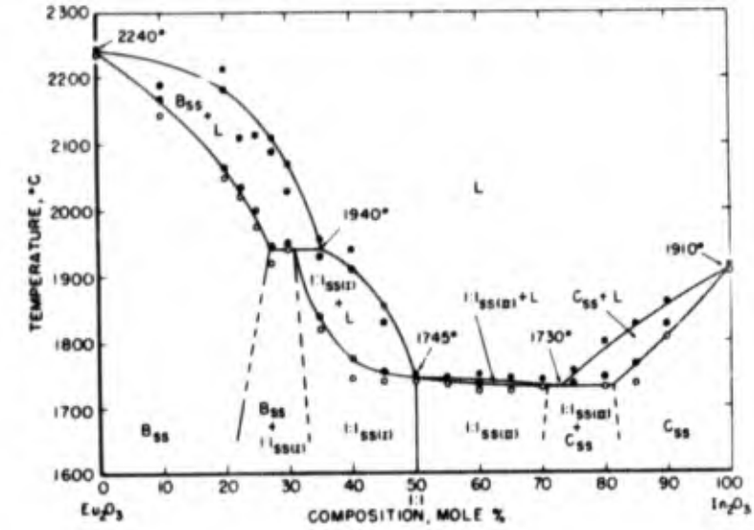
Sm_2O_3-BeO (37)



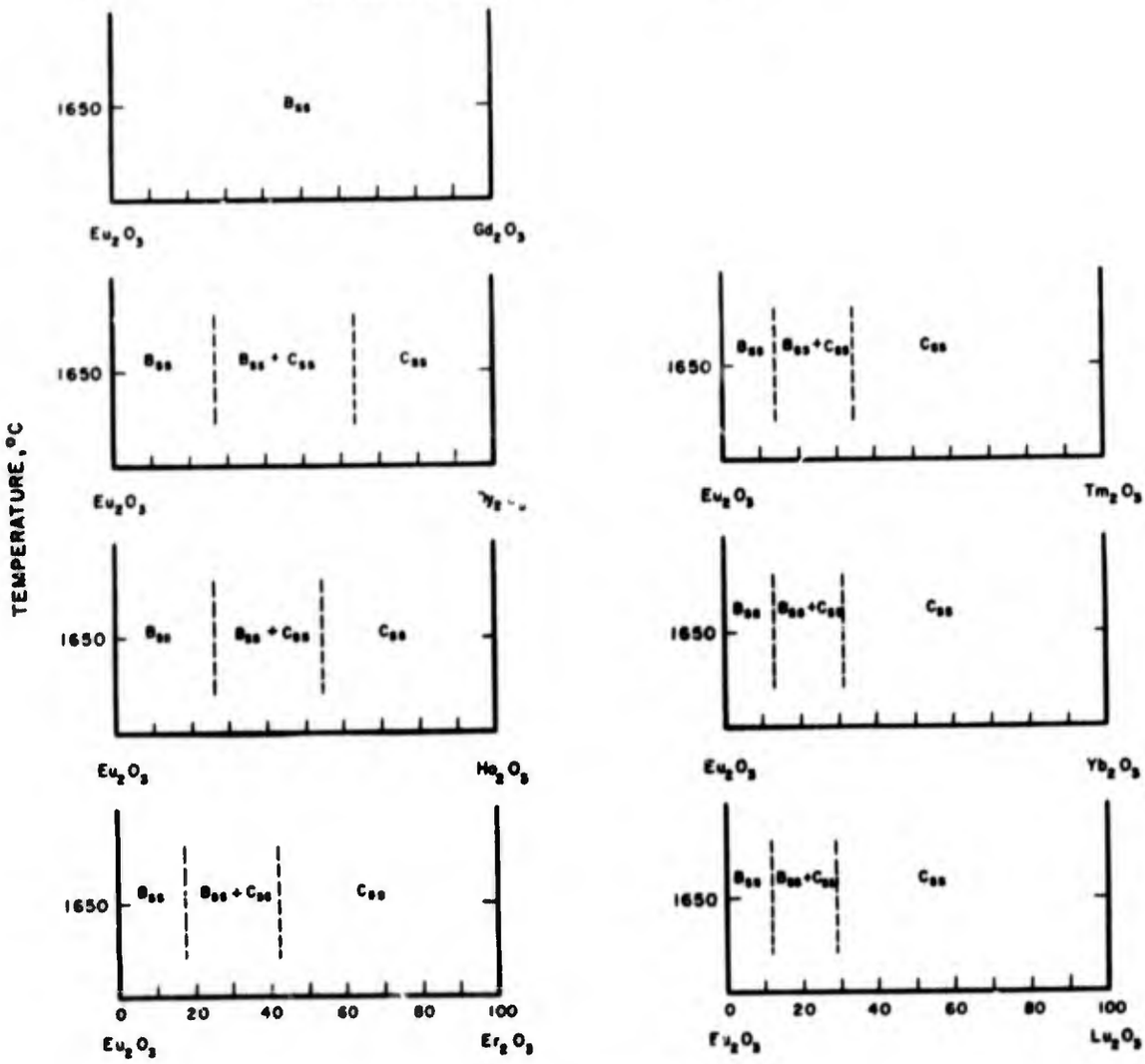
COMPOSITION, MOLE %

Sm_2O_3 – Rare-Earth Oxides (26)

EUROPIUM



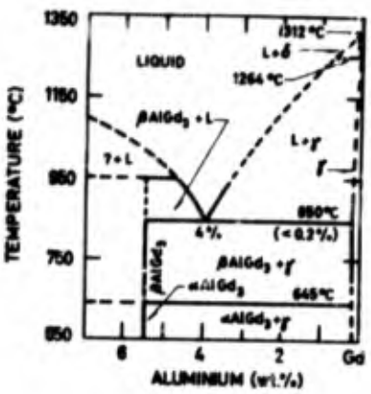
Eu_2O_3-In_2O_3 (42)



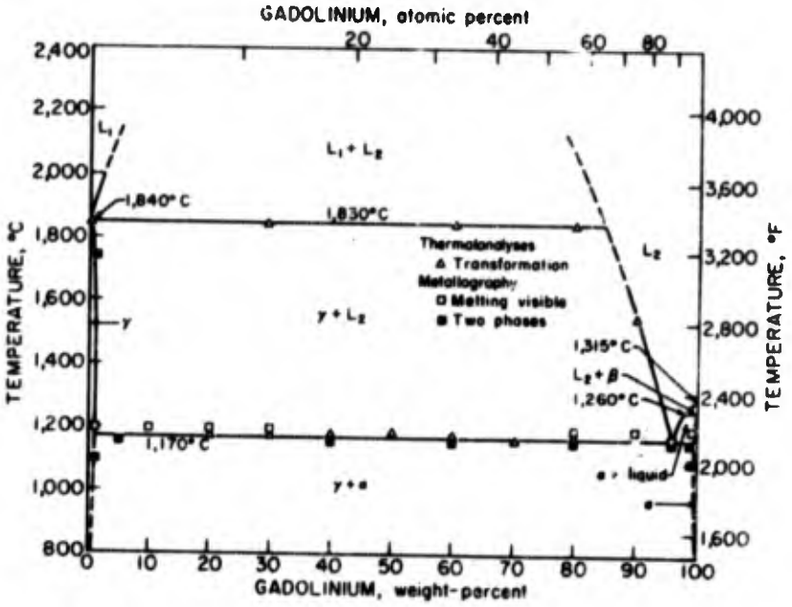
COMPOSITION, MOLE %

Eu_2O_3 – Rare-Earth Oxides (26)

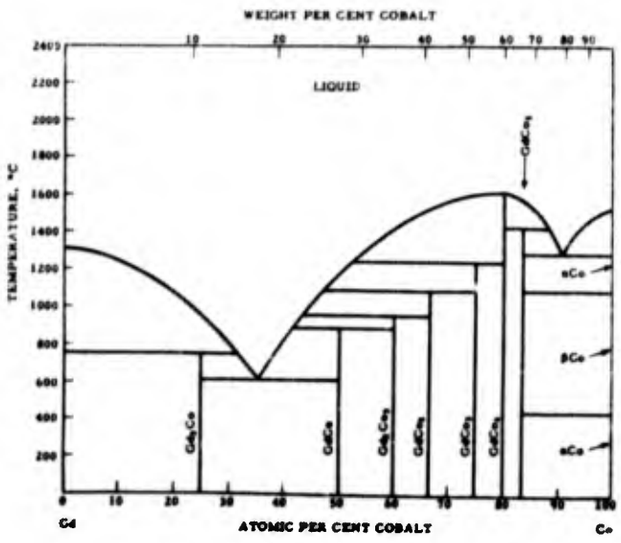
GADOLINIUM



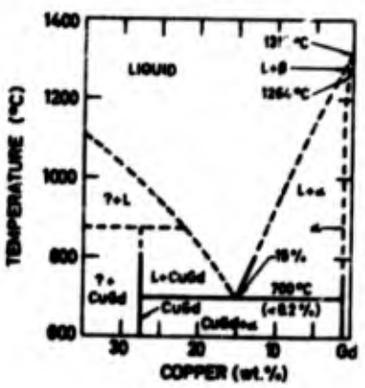
Aluminum (214)



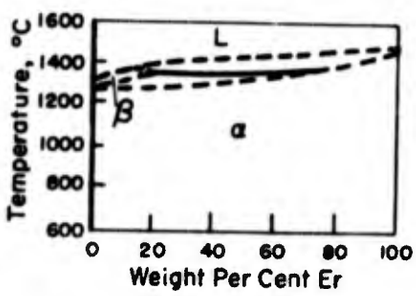
Chromium (43)



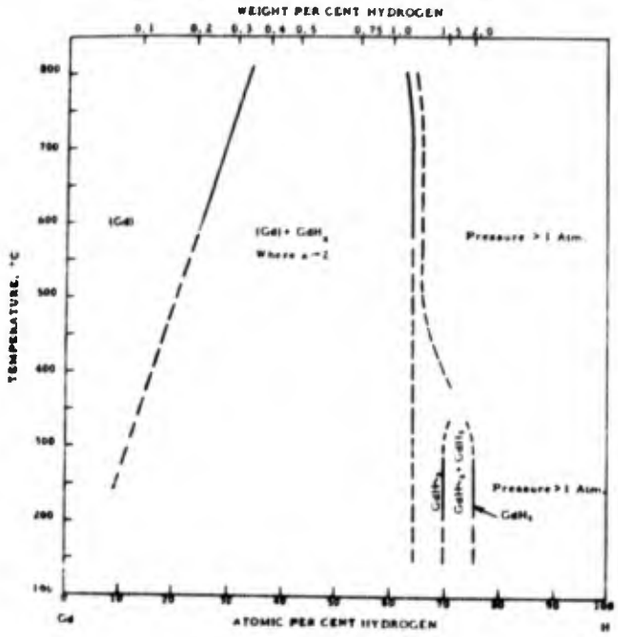
Cobalt (1)
(Permission of U. S. AEC)



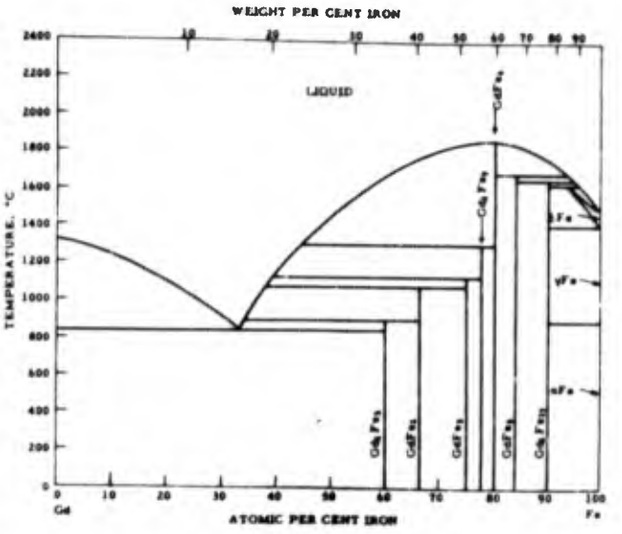
Copper (214)



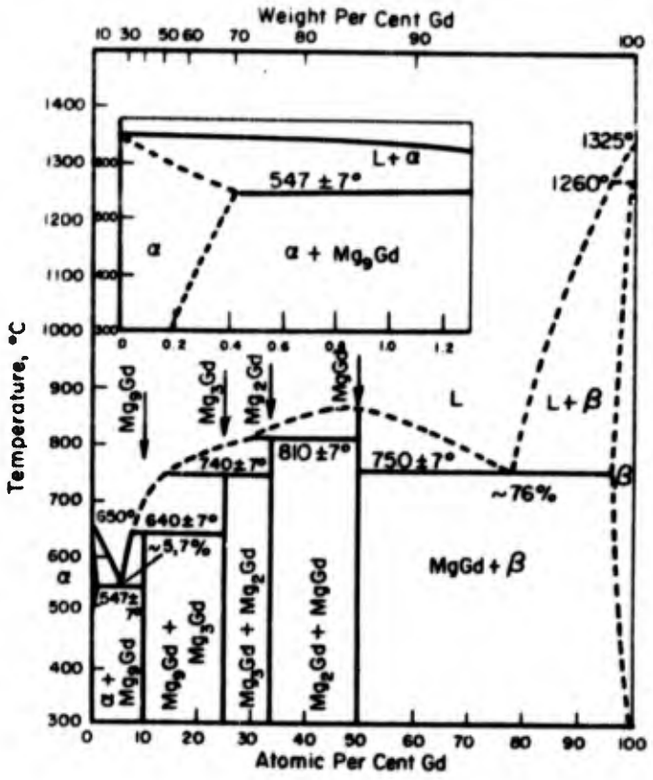
Erbium (44)



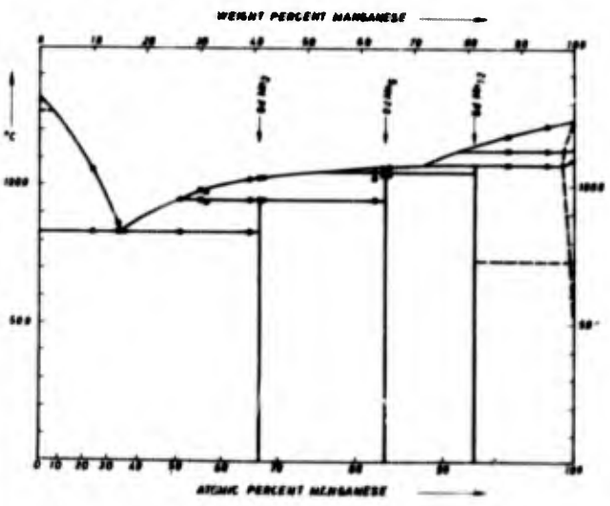
Hydrogen (1)
(Permission of U. S. AEC)



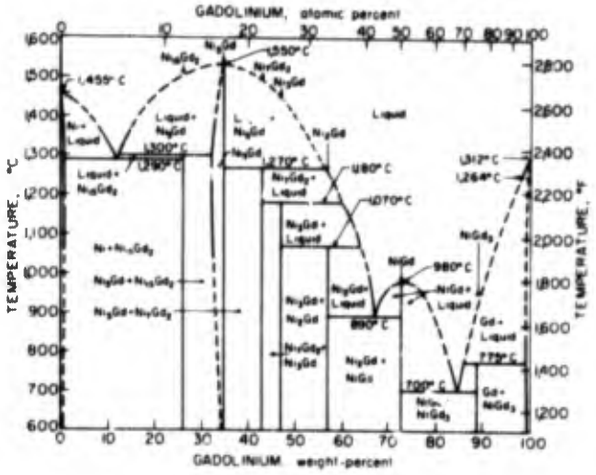
Iron (1)
(Permission of U. S. AEC)



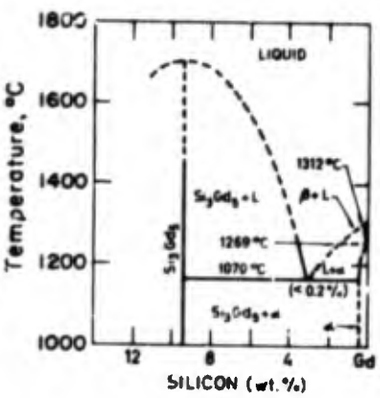
Magnesium (29)



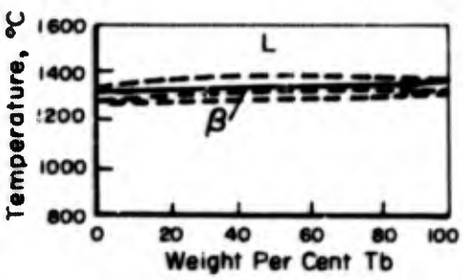
Manganese (274)



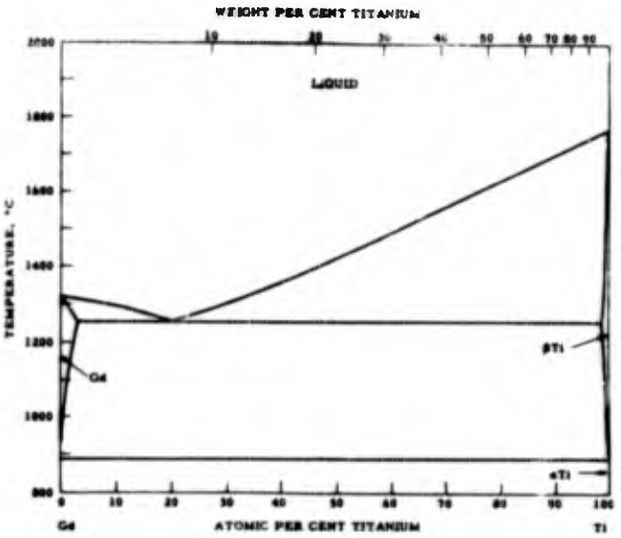
Nickel (45)



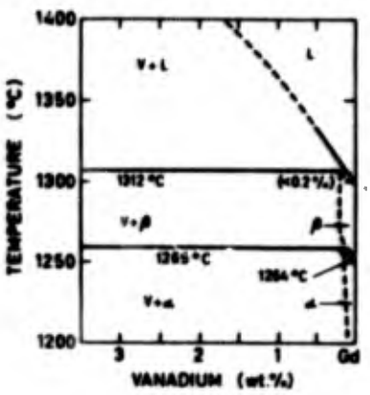
Silicon (214)



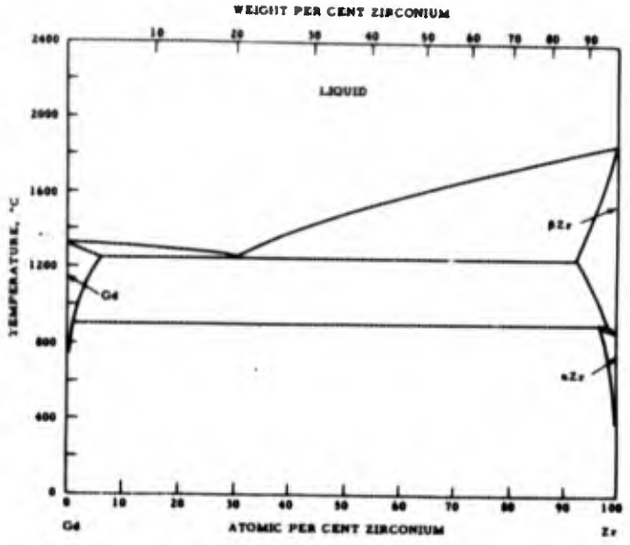
Terbium (44)



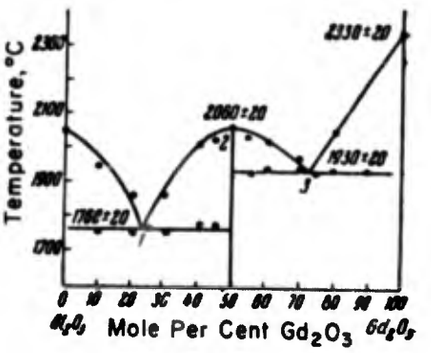
Titanium (1)
(Permission of U. S. AEC)



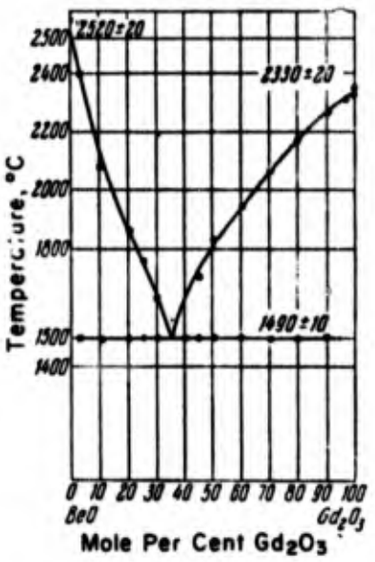
Vanadium (214)



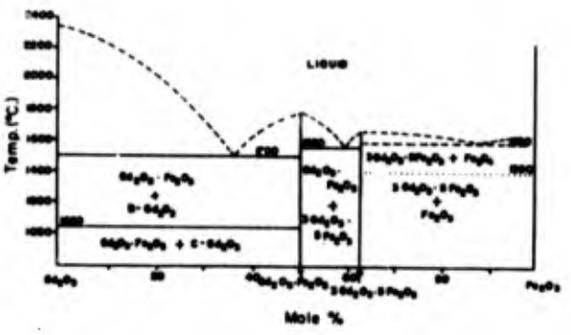
Zirconium (1)
(Permission of U. S. AEC)



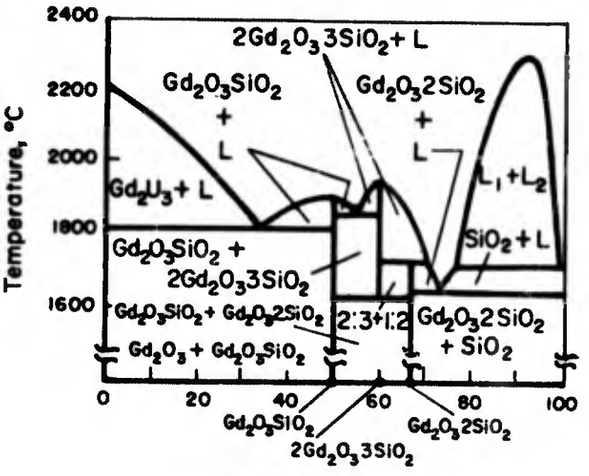
Gd_2O_3-Al_2O_3 (37)



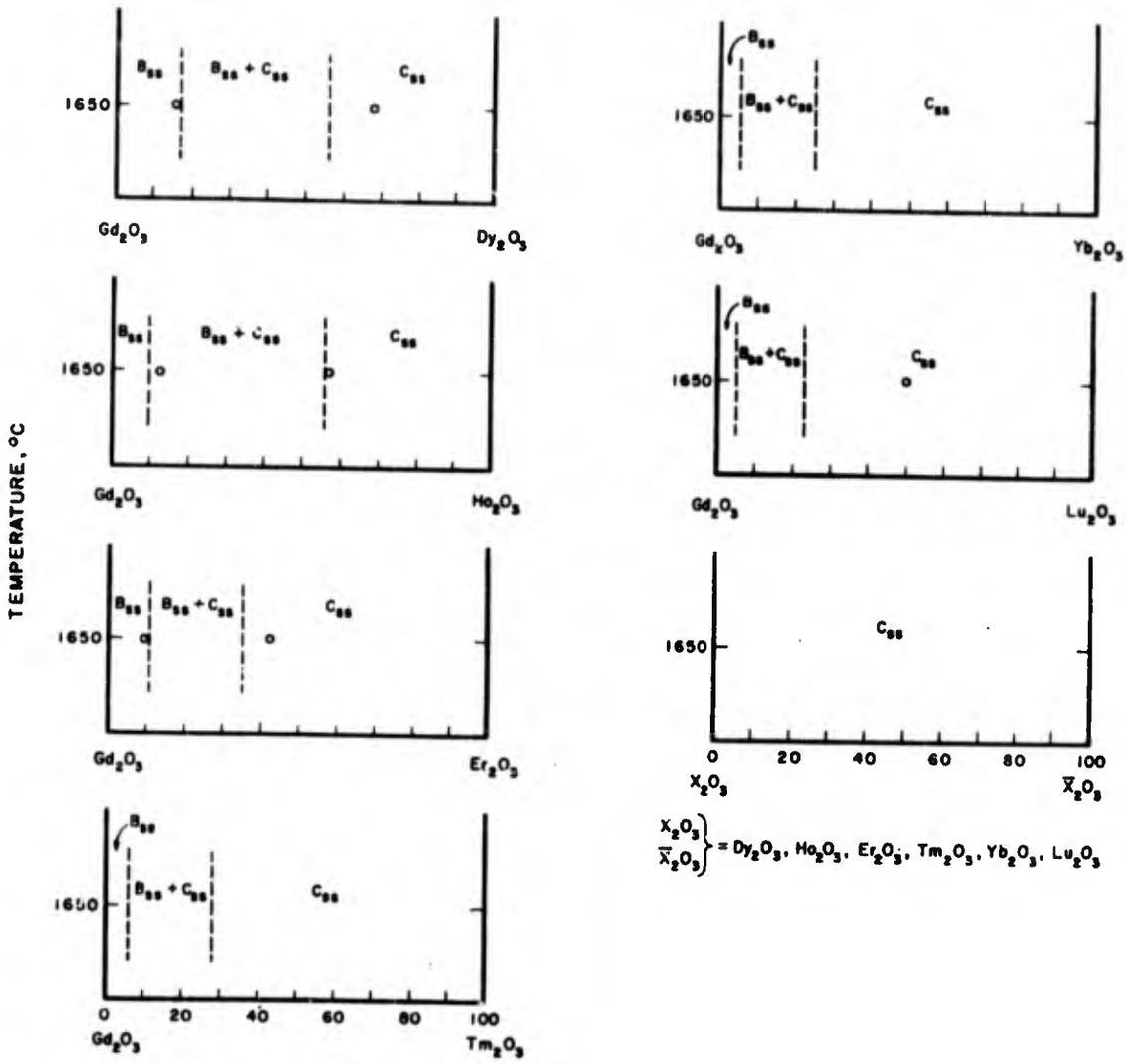
Gd_2O_3-BeO (37)



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

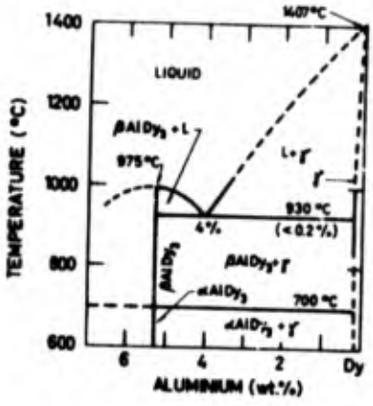


Gd_2O_3-SiO_2 (46)

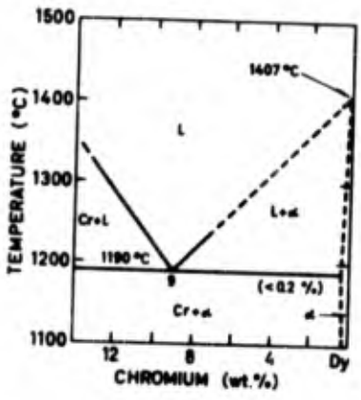


Gd_2O_3 – Rare-Earth Oxides (26)

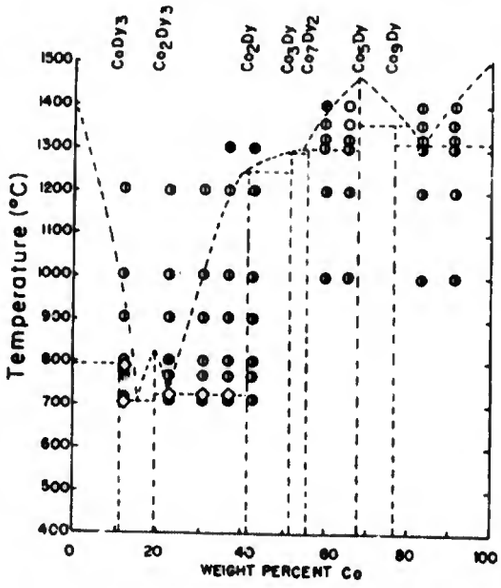
DYSPROSIUM



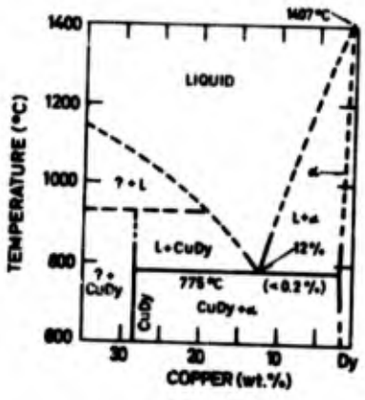
Aluminum (214)



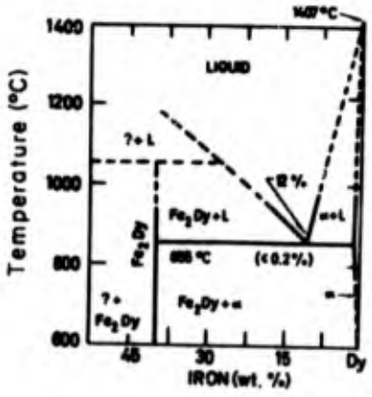
Chromium (214)



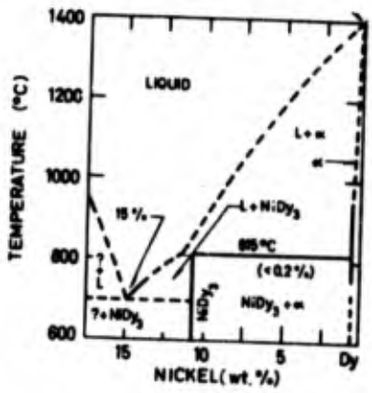
Cobalt (47)
(Permission of Gordon and Breach, Science Publishers, Inc.)



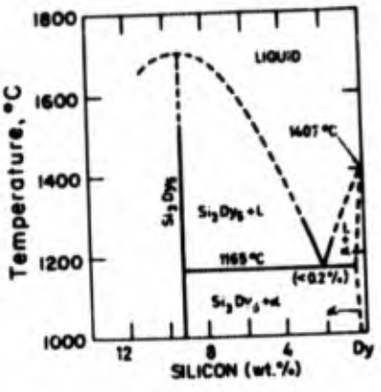
Copper (214)



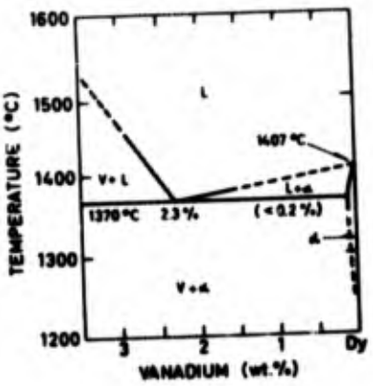
Iron (214)



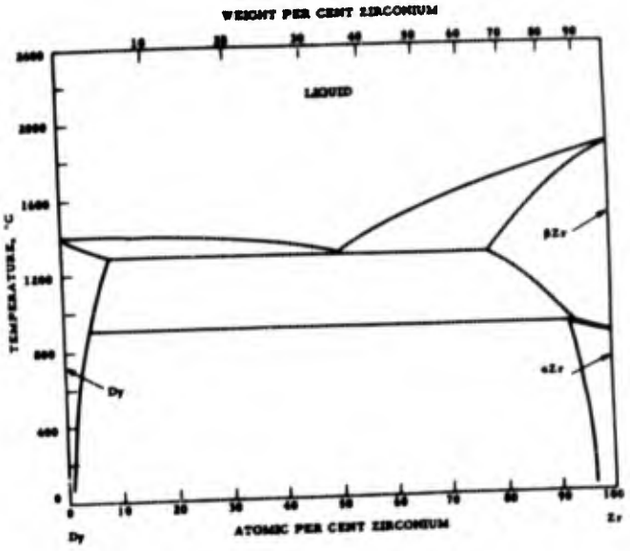
Nickel (214)



Silicon (214)

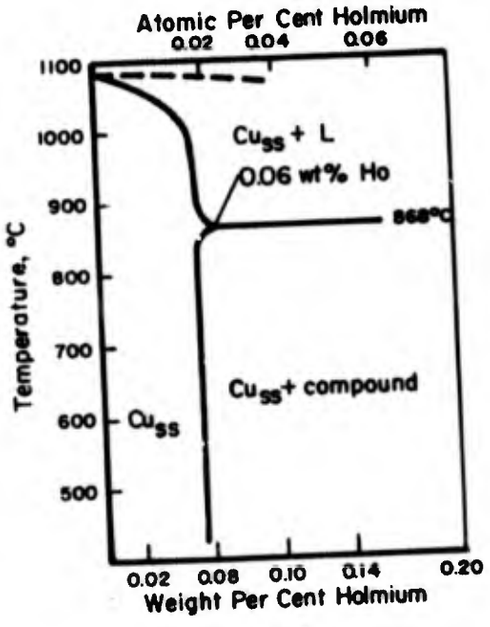


Vanadium (214)

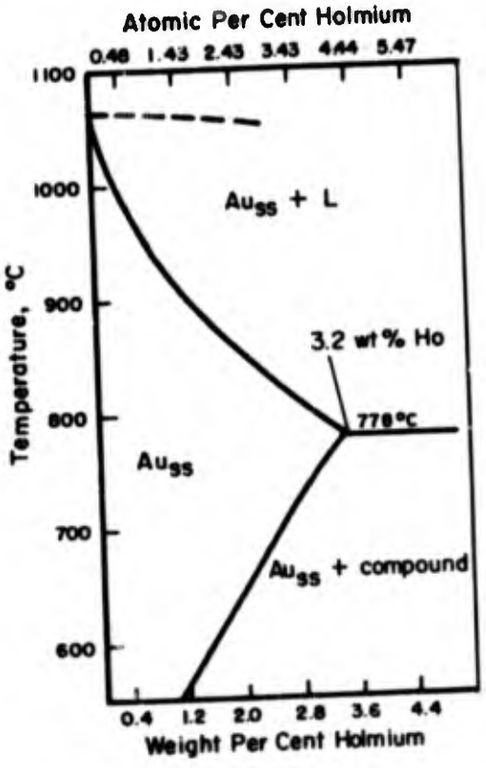


Zirconium (1)
(Permission of U. S. AEC)

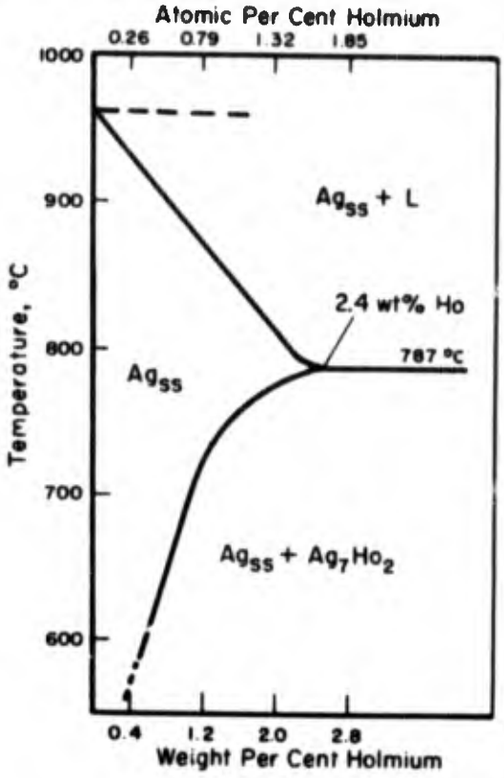
HOLMIUM



Copper (48)
(Permission of Metallurgical Society AIME)

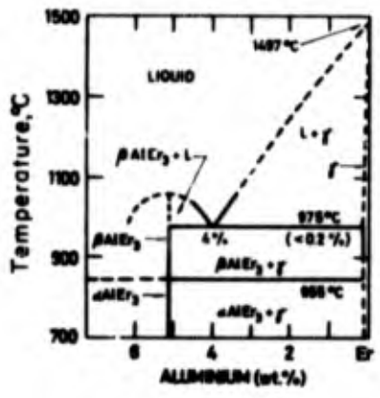


Gold (48)
(Permission of Metallurgical Society AIME)

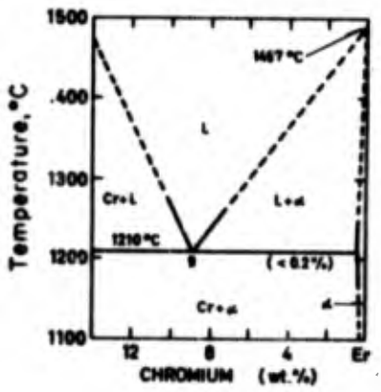


Silver (48)
(Permission of Metallurgical Society AIME)

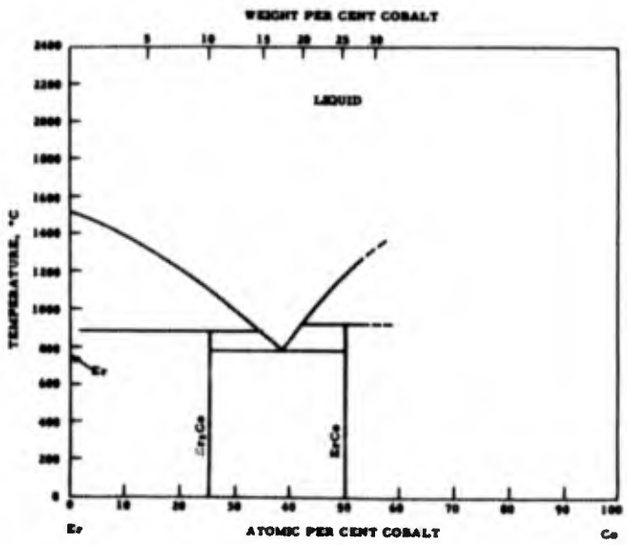
ERBIUM



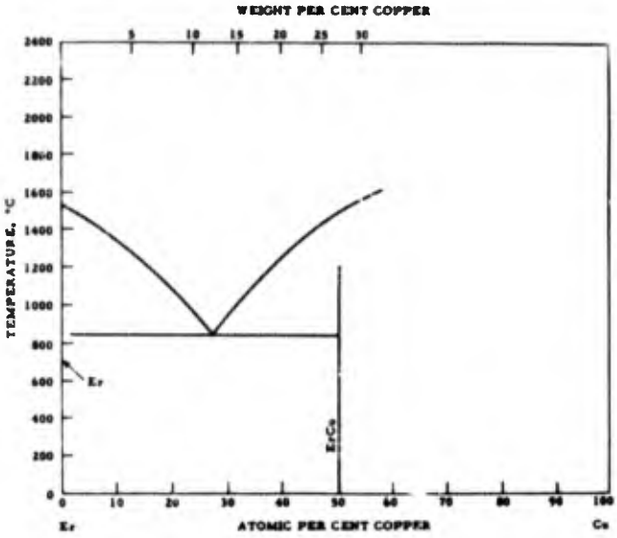
Aluminum (214)



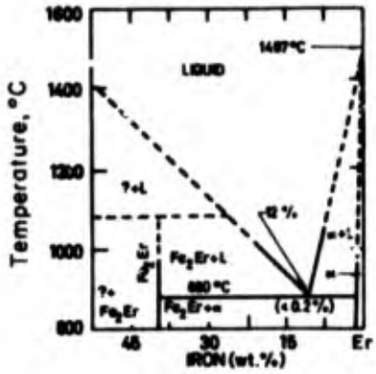
Chromium (214)



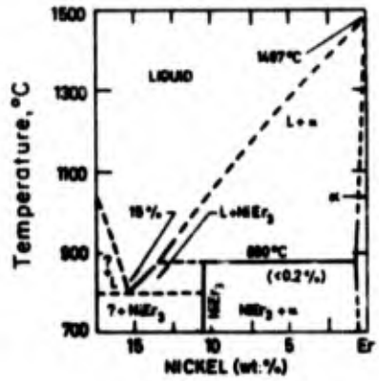
Cobalt (1)
(Permission of U. S. AEC)



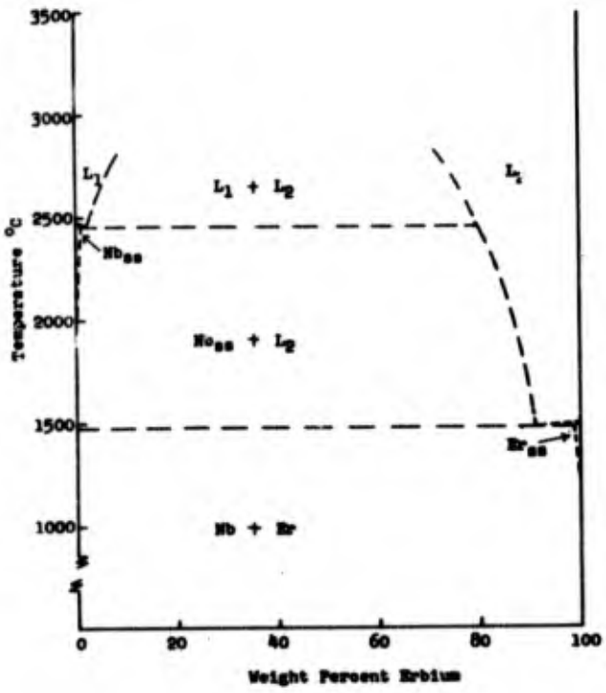
Copper (1)
(Permission of U. S. AEC)



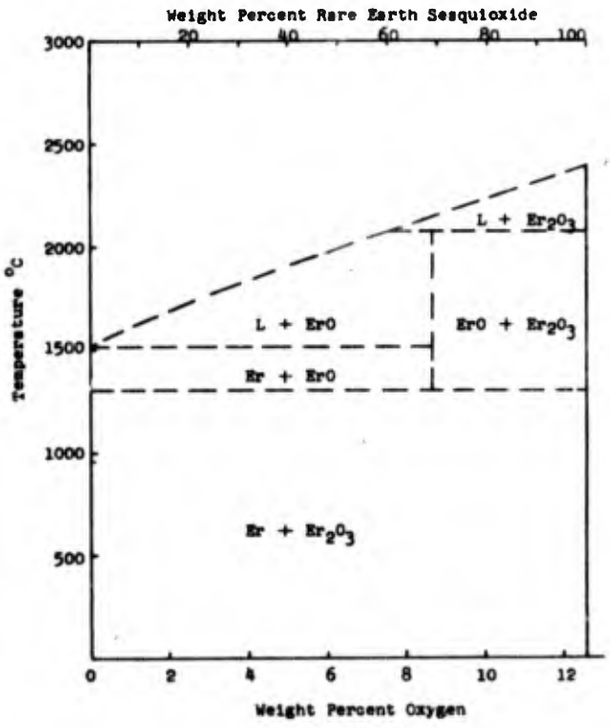
Iron (214)



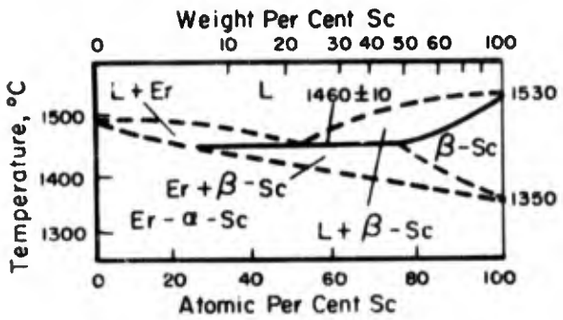
Nickel (214)



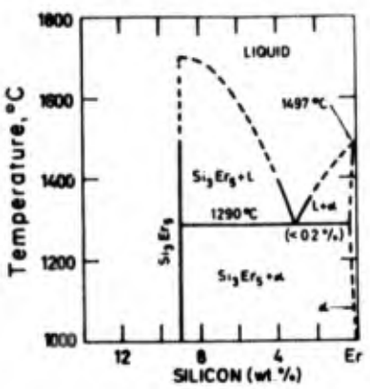
Niobium (53)



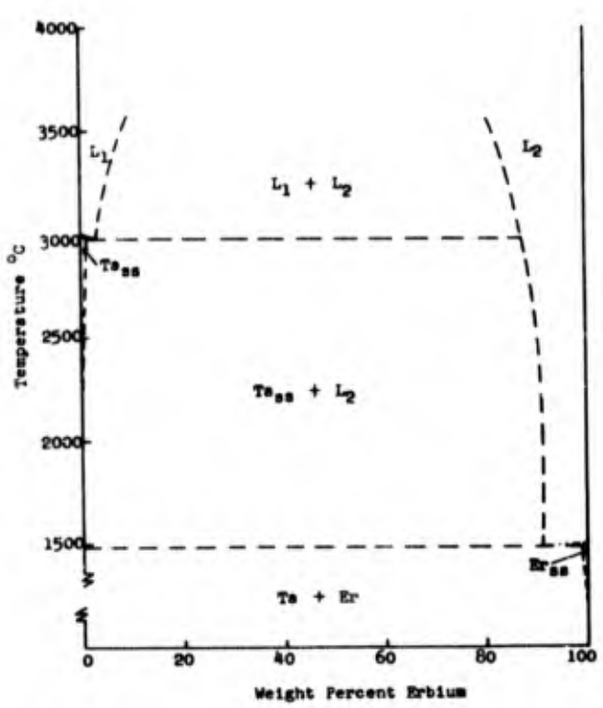
Oxygen (50)



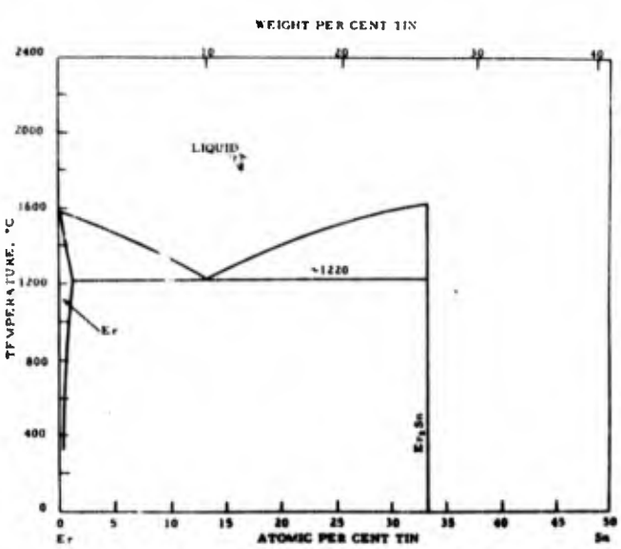
Scandium (32)



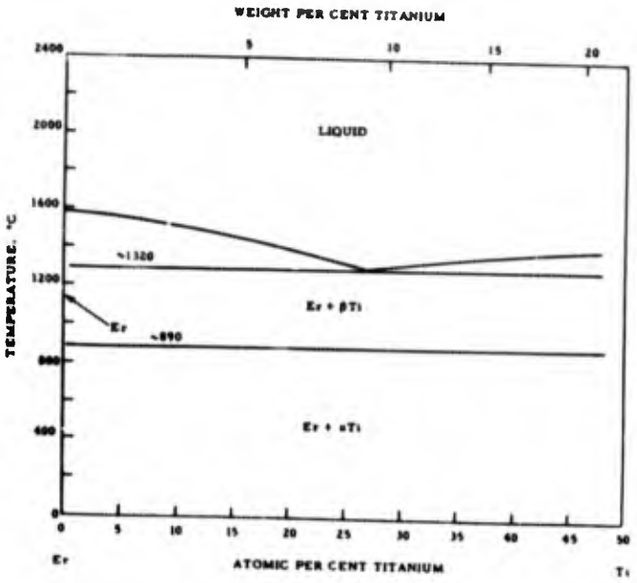
Silicon (214)



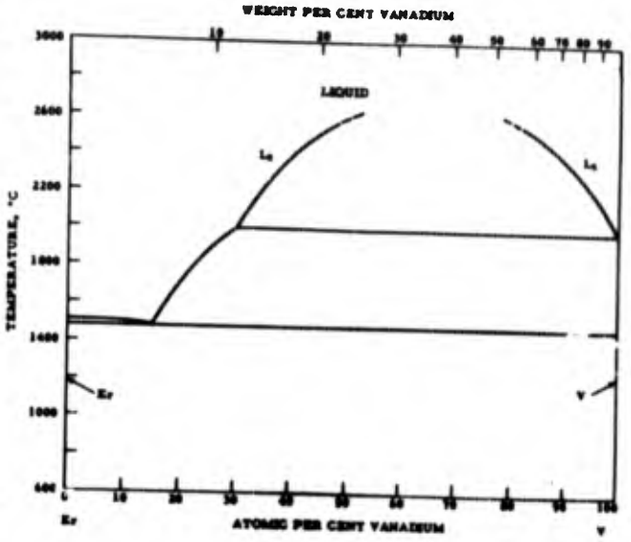
Tantalum (50)



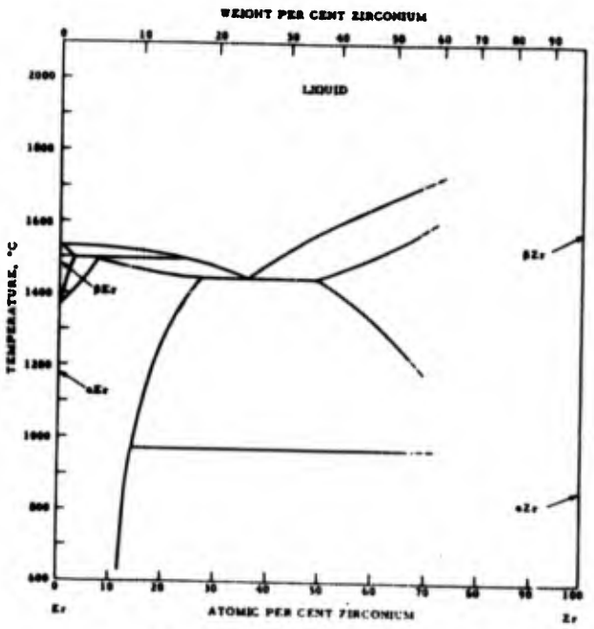
Tin (1)
(Permission of U. S. AEC)



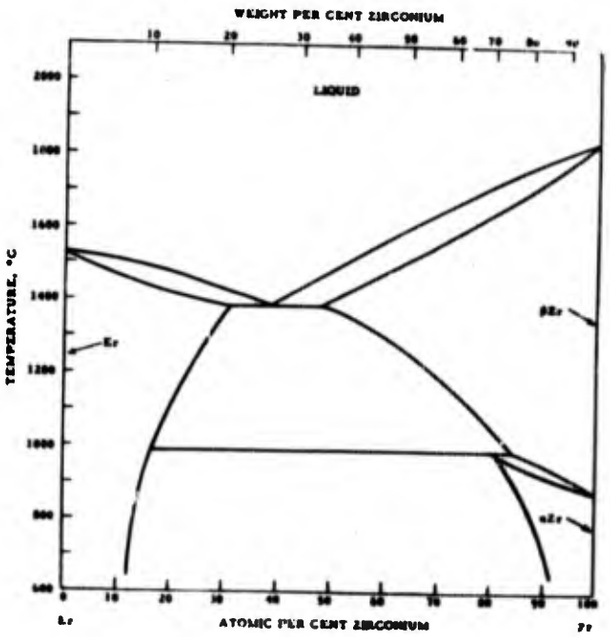
Titanium (1)
(Permission of U. S. AEC)



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



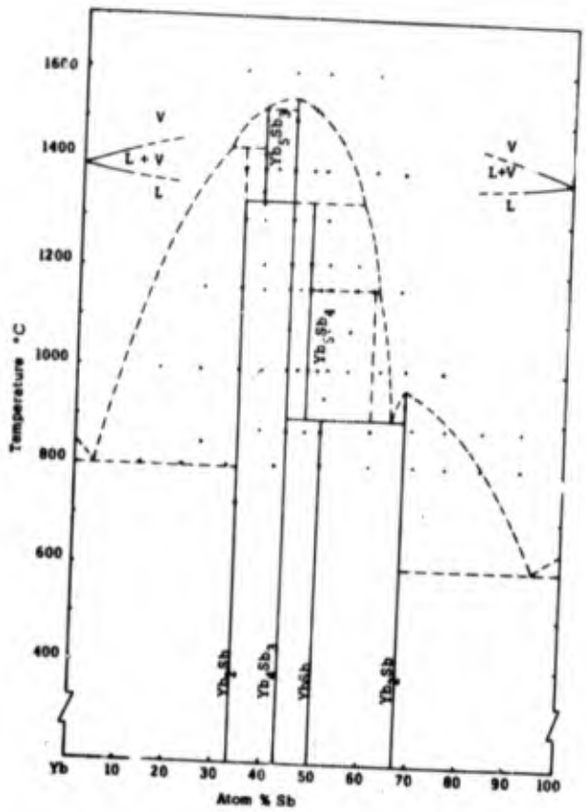
a. Tentative Partial Diagram



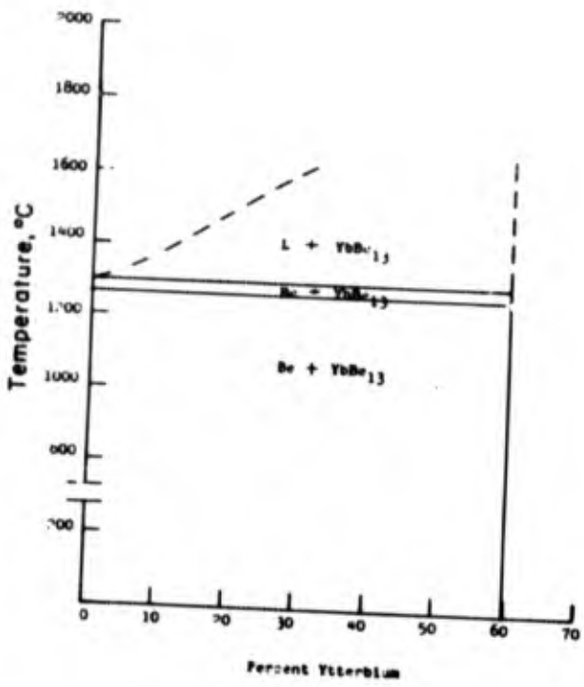
b. Complete Diagram.

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

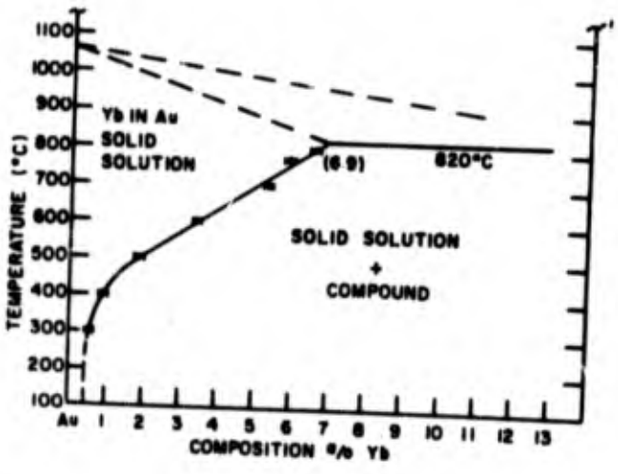
YTTERBIUM



Antimony (273)



Beryllium (49)



Gold (272)

YTTRIUM

Symbol Y | Atomic Number 39 | Atomic Weight 88.92

PHYSICAL PROPERTIES

		Authority
Abundance	28-70 ppm (approx. 28)	51
Density	4.472 g/cm^3	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)	10.8×10^{-6}/C	61
Thermal Conductivity (28 C)	0.035 cal/(cm^2)(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		

			Authority
CRYSTAL PROPERTIES			
Structure	HCP	BCC	61
Lattice Constants	a_o = 3.6474 c_o = 5.7306	a_o = 4.11 A -- A	61
Density	4.472	4.25 g/cm^3	67
Metallic Radius	1.801	1.83 A	67
Atomic Volume	19.886	-- cm^3/mole	65
Transition Temperature	1460 C		66
Heat of Transition	1.18 kcal/mole		61
Ionic Radius (Trivalent Ion)	0.88 A		55
Closest Approach of Atoms	3.59 A		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_3, 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 x 10^{-3}/C		63

		Authority
MAGNETIC PROPERTIES		
Susceptibility (25 C)	191×10^{-6} 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	6.63×10^{11} dynes/cm^2	64
Shear Modulus	2.62×10^{11} dynes/cm^2	64
Poisson's Ratio	0.265	64
Compressibility	2.09×10^{-6} cm^2/kg	64
Hardness	38 DPH	57
Tensile Strength (70 F)	22.0×10^3 psi	72
Yield Strength (70 F)	9.7×10^3 psi	72
Elongation (70 F)	25 per cent	72
Ultimate Compressive Strength	113.8×10^3 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.

Authority

NUCLEAR PROPERTIES

58

Isotopes

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

Thermal-Neutron Cross Section: 1.38 ± 0.14 barns/atom, or 0.0094 cm^2/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

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

Authority

Thermodynamic Functions of Yttrium, joules/(g-atom)(K) 79

T, K	C_p	S^o	$(H^o-H^o_o)/T$	$(-F^o-H^o_o)/T$
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 77
(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	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.)

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

ΔH_{1773} (fusion) = 4,100.

For liquid yttrium:

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

$C_p = 8.00$.

Heat Content and Entropy of Gaseous Yttrium
(Base: ideal gas 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	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:

$H_T-H_{298.15} = 2.77T + 0.74 \times 10^{-3}T^2 - 2.64 \times 10^{5}T^{-1} - 6$ (0.7 percent; 3,000° - 6,000°K.);
$C_p = 2.77 + 1.48 \times 10^{-3}T + 2.64 \times 10^{5}T^{-2}$.

YTTRIUM COMPOUNDS

		Authority
Antimonides		162, 168
	YSb	
Structure	Cubic	
Lattice Type	N.Cl	
a_o, A	6.16	
Melting Point, C	1925	
Resistivity, microhm-cm	65	
Arsenides		169
	YAs	
Lattice Type	NaCl	
a_o, A	5.805	
Beryllides		146, 161
	YBe_{13}	
Structure	Cubic	
Lattice Type	$NaZn_{13}$	
a_o, A	10.238	
Heat of Vaporization, kcal/mole	75.0	
Dissociatic Rate, $g/(cm^2)(sec)$	3.63×10^{-7} at 1040 C 3.01×10^{-5} at 1290 C	

Bismuthides

Authority: 162, 168

	YBi
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.23
Resistivity, microhm-cm	196

Borides

Authority: 153, 154, 155, 171

	YB_2	YB_3	YB_4	YB_6	YB_{12}	YB_{70}
Molecular Weight	110.56	121.28	132.20	153.84	218.56	846.32
Structure	Hexagonal	Tetragonal	Tetragonal	Cubic	Cubic	Tetragonal
a_o, A	3.298	3.78	7.111	4.113	7.500	11.75
c_o, A	3.843	3.55	4.017	--	--	12.62
Density, g/cm^3	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, $10^{-6}/C$	--	--	--	1.24	--	--
Coefficient of Thermal Expansion, $10^{-6}/C$	--	--	--	6.24	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	--	0.070	--	--

(Continued)

Authority

Borides (Continued)

	YB_2	YB_3	YB_4	YB_6	YB_{12}	YB_{70}
Effective Magnetic Moment, Bohr magnetons	--	--	--	0.0	--	--
Work Function, e	--	--	--	2.22	--	--
Microhardness, kg/mm^2	--	--	--	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

	YC	YC_2	Y_2C_3	Y_3C
Molecular Weight	100.92	112.92	213.84	278.76
Structure	--	Tetragonal	--	Cubic
Lattice Type	--	CaC_2	--	Fe_4N
a_o, A	--	3.664	--	5.102
c_o, A	--	6.169	--	--
Density, g/cm^3	--	4.528	--	5.41
Melting Point, C	1950	2300	1800	--
Resistivity, microhm-cm	4.54×10^4	88.7	3.5×10^2	--
Coefficient of Thermal Expansion, $10^{-6}/C$	1.36	--	--	--
Microhardness, kg/mm^2	120	700	900	--
Emissivity (λ = 0.655 μ)				
1100 C	0.81	0.87	0.78	--
1800 C	0.81	0.73	0.91	--

Germanides

	YGe_2	Authority
Structure	Imperfect	170
a_o, A	3.96	
c_o, A	4.14	

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

	YBr_3	YCl_3	YF_3	YI_3	YOCl	YOF
Structure	Hexagonal	Monoclinic	Orthorhombic Cubic	Hexagonal	Tetragonal	--
a_o, A	4.102	11.94	6.353 (orth.) 5.644 (cubic)	4.340	3.903	--
b_o, A	--	--	6.850	--	--	--
c_o, A	6.399	--	4.393	6.960	6.597	--
β, deg	--	111.0	--	--	--	--
Density, g/cm^3	--	--	5.069	--	--	5.13
Heat of Formation, 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)

Authority

Halides (Continued)

	YBr_3	YCl_3	YF_3	YI_3	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.

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

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

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

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

Reaction	Temperature Range, K	$-\Delta H_{F298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, 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
$Y(s) + \frac{3}{2}F_2(g) = YF_3(\ell)$	1660-1750	--	--	14.0	-2.9	--	1.2	7.141	132.4	146.4
$Y(\ell) + \frac{3}{2}F_2(g) = YF_3(\ell)$	1750-2300	--	--	12.1	-0.7	--	1.2	3.097	124.4	136.5
$Y(\ell) + \frac{3}{2}F_2(g) = YF_3(g)$	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
$Y(s) + \frac{3}{2}Cl_2(g) = YCl_3(\ell)$	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

Hydrides — Authority: 163,164,165

	YH_2	YD_2	YH_3	YD_3
Structure	--	--	Hcp	Hcp
a_o, A	5.205	--	3.672	3.659
c_o, 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

	YN
Molecular Weight	102.93
Structure	Fcc
Lattice Type	NaCl
a_o, A	4.877
Density, g/cm^3	5.60
Heat of Formation, kcal/mole	71.5
Entropy of Formation, eu	25
Resistivity, microhm-cm	93
Temperature Coefficient of Resistivity (-193 to 827 C), 10^{-3}/C	1.9

Oxides

Authority: 156,172,173, 176,177

	Y_2O_3
Molecular Weight	225.81
Structure	Bcc
a_o, A	10.60
Density, g/cm^3	5.03
Heat of Formation, kcal/g-atom	227.73
Entropy of Formation, eu/g-atom	35.54
Melting Point, C	2410
Coefficient of Thermal Expansion, $10^{-6}/C$	
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	Temperature Range, K	$-\Delta H_{F298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$2Y(s) + \frac{3}{2} O_2(g) = Y_2O_3(s)$	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)

Authority

Oxides (Continued)

Thermodynamic Functions for Y_2O_3 174

T, K	C_p, cal/(mole)(K)	S_o, cal/(mole)(K)	$H^o-H^o_o$, cal/mole	$(-F^o-H^o_o)/T$, 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_3 175
(smooth values)

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(α)	42.92(α)
1330	30,620(β)	43.16(β)
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

Phosphides — Authority: 169

	YP
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.662

Selenides — Authority: 166,168, 169,213

	YSe	Y_2Se_3
Structure	NaCl	Fcc
a_o, A	5.703	5.75
Density, g/cm^3	--	4.81
Melting Point, C	--	>1800
Color	--	Gray black

Silicides — Authority: 152,153, 160

	YSi	α-YSi_2	β-YSi_2	Y_3Si_5	Y_5Si_3
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	α-YSi_2	α-$ThSi_2$	--	Mn_5Si_3
a_o, A	4.25	4.04	4.04	3.842	8.403
b_o, A	10.52	3.95	--	--	--
c_o, A	3.82	13.23	13.42	4.140	6.303
Density, g/cm^3	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	α-YSi_2	β-YSi_2	Y_3Si_5	Y_5Si_3
Curie Temperature, K	--	Paramagnetic	--	--	--
Transformation Temperature, C	--	α → β at 540	--	--	--

Sulfides 153

	YS	YS_2	δ-Y_2S_3	Y_5S_7	Y_2O_2S
Molecular Weight	120.99	153.05	274.04	669.06	241.91
Structure	Cubic	Tetragonal	Monoclinic	Monoclinic	Hexagonal
a_o, A	5.466	7.71	10.71	12.67	3.78
b_o, A	--	--	4.02	3.81	--
c_o, A	--	7.89	17.47	11.45	6.56
β, deg	--	--	81.17	74	--
Density, g/cm^3	4.92	4.33	3.87	4.18	4.95
Melting Point, C	2060	1630	1600	1630	2120
Magnetic Susceptibility at 20 C, 10^6 emu/mole	100	125	83.4	39.3	>0
Color	Ruby red	Brown violet	Yellow	--	Gray white

Authority

Tellurides 168,169

	YTe	Y_2Te_3
Structure	Fcc	--
Lattice Type	NaCl	--
a_o, A	6.080	--
Melting Point, C	--	1525
Resistivity at 20 C, microhm-cm	--	10^7

Miscellaneous 150,151

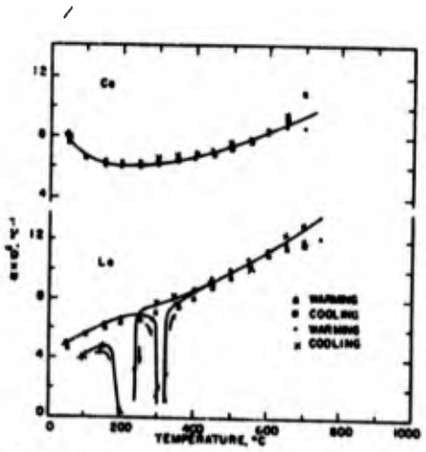
	Structure	Lattice Constants, A a_o	c_o	Superconducting Transition Temperature, K
YIr_2	Cubic	7.500	--	2.18
YOs_2	Hexagonal	5.307	8.786	4.7
YPd_3	Cu_3Au	4.074	--	--
YPt_3	Cu_3Au	4.075	--	--
YRe_2	Hexagonal	5.396	8.819	1.83
YRh_2	Cubic	7.459	--	--
YRu_2	Hexagonal	5.256	8.792	1.52
YPt_2	Cubic	7.590	--	1.57
YAl_2	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^3	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 x 10^{-6}/C (-173 – 310 C)	61



(Permission of American Physical Society) 90

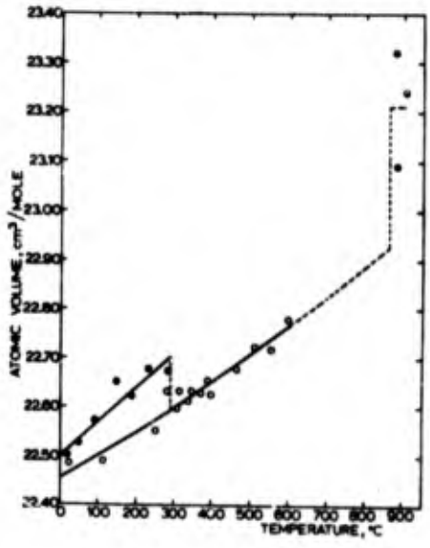
Thermal Conductivity	0.033 cal/(cm^2)(sec)(C/cm)	54
Heat of Sublimation		

		Authority
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	(α) HCP	(β) FCC	(γ) BCC	
Lattice Constants	a_o = 3.770 c_o = 12.159	a_o = 5.304 --	a_o = 4.26 A -- A	61
Density	6.162	6.190	5.97 g/cm^3	67
Metallic Radius	1.877	1.875	1.90 A	67
Atomic Volume	22.50	22.46	23.2 cm^3/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

		Authority
Closest Approach of Atoms	3.73 A	56
Allotropic Modifications	A Fcc structure with a_o = 5.17 A 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	[La = La^{+3} + $3e^-$] + 2.4 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.

Authority

Corrosion Data

91

Corrosive attack on crucible materials:

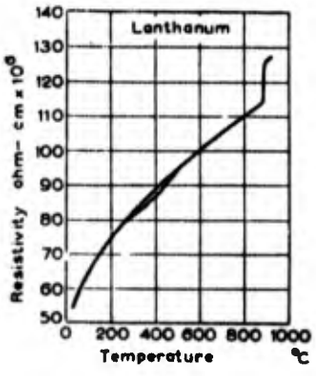
Material	Onset of Attack
BeO	None < 1150 C
CaO	Mild at 1250 C
La_2O_3	590 C
Ta	None < 1200 C

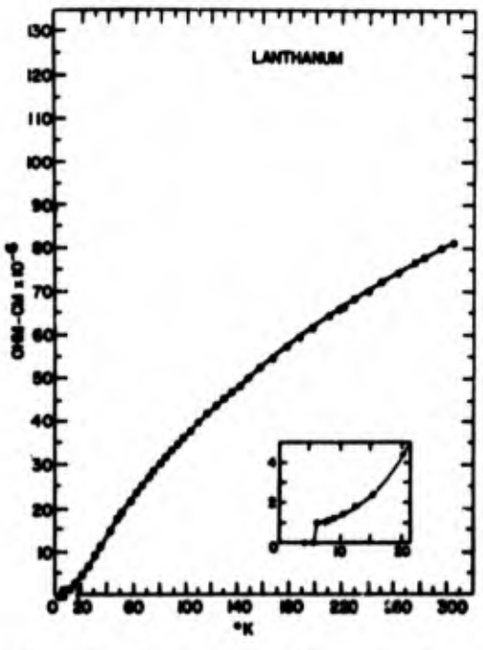
ELECTRICAL PROPERTIES

Resistivity	Hcp (α, 25 C) - 56.8 microhm-cm Fcc (β, 560 C) - 96 microhm-cm Bcc (γ, 890 C) - 126 microhm-cm	61
Temperature Coefficient of Resistivity (25 C)	2.18×10^{-3}/C	61

Temperature Versus Resistivity

53, 86





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MAGNETIC PROPERTIES

Susceptibility (25 C)	101×10^{-6} emu/mole	61
Effective Magnetic Moment	Theoretical – 0.00 Bohr magnetons Measured – 0.49 Bohr magnetons	61

					Authority
Curie Temperature	None				61
Néel Temperature	None				61
MECHANICAL PROPERTIES					
Young's Modulus	3.84×10^{11} dynes/cm^2				57
Shear Modulus	1.49×10^{11} dynes/cm^2				57
Poisson's Ratio	0.228				61
Compressibility	3.24×10^{-6} cm^2/kg				57
Hardness (DPH)	37				57
	70 F	400 F	800 F		
Tensile Strength	18.9	15.3	6.7	10^3 psi	88
Yield Strength	18.2	12.4	3.75	10^3 psi	88
Elongation	8	9.4	21	per cent	88
Ultimate Compressive Strength	41.2×10^3 psi				61
Impact Strength (Izod)	4.5 ft-lb				71
Workability	Fair				88
General Fabrication	(See references)				70, 113

Authority

NUCLEAR PROPERTIES

Isotopes

94, 58, 145

Whole-Number Mass	Relative Abundance, per cent	Half Life	Decay Mode
135	--	19 ? hr	K, γ
136	--	2.1 ? r	β^+
137	--	>400 yr	--
138	0.089	Stable	--
139	99.911	Stable	--
140	--	40 hr	β^-, γ
141	--	3.7 hr	β^-, γ
142	--	75 min	β^-, γ
143	--	19 min	β^-
144	--	Short	β^-
145	--	Short	β^-

Thermal Neutron Cross Section: 8.9 ± 0.3 barns/atom or 0.039 cm^2/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.

Authority

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.

CAUTION: $La_2(SO_4)_3 + 3H_2O = 2La + 3H_2SO_4 + 3/2O_2$

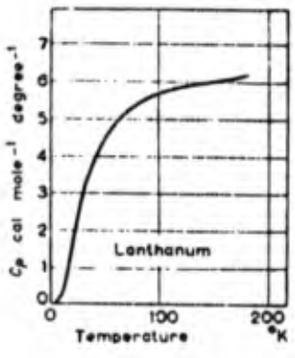
THERMODYNAMIC PROPERTIES

53, 76, 77

	Room Temperature	Melting Point
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

Authority

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

77

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	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)

77

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	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:

$H_T - H_{298.15} = 6.19T + 0.48 \times 10^{-3}T^2 + 0.92 \times 10^{5}T^{-1} - 2,197$
(0.8 percent; 298-2000 K)

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

$H_T - H_{298.15} = 7.20T + 0.10 \times 10^{-3}T^2 + 1.60 \times 10^{5}T^{-1} - 2,730$
(0.2 percent; 2000-5000 K)

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

LANTHANUM COMPOUNDS

			Authority
Antimonides			162, 168
		LaSb	
	Structure	NaCl	
	a_o, A	6.49	
	Melting Point, C	1540	
	Resistivity, microhm-cm	120	
Arsenides			169
		LaAs	
	Structure	NaCl	
	a_o, A	6.137	
Beryllides			161, 179
		$LaBe_{13}$	
	a_o, A	10.450	
	Heat of Vaporization (kcal/mole)	75.8	
	Dissociation Rate	1.35×10^{-6} g/(cm^2)(sec) at 1082 C 3.70×10^{-5} g/(cm^2)(sec) at 1267 C	
Bismuthides			162
		LaBi	
	Structure	NaCl	
	a_o, A	6.58	

Borides	LaB_3	LaB_4	LaB_6	153, 171
Molecular Weight	171.38	182.20	203.84	
Structure	Tetragonal	Tetragonal	Cubic	
a_o, A	3.82	7.30	4.154	
c_o, A	3.96	4.17	--	

(Continued)

Borides (Continued)

	LaB_3	LaB_4	LaB_6	Authority
Density, g/cm^3	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, $10^{-3}/C$	--	--	2.68	
Coefficient of Thermal Expansion, $10^{-6}/C$	--	--	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^2	--	--	2770	
Color	--	--	Violet	
Emissivity at 1500 C ($\lambda = 0.655\ \mu$)	--	--	0.7	
Metallic Radius, A	--	--	2.20	

Carbides — Authority: 153

	α-LaC_2	β-LaC_2	La_2C_3
Molecular Weight	162.94	162.94	313.84
Structure	Tetragonal	Cubic	Bcc
Lattice Type	CaC_2	FeS_2	Pu_2C_3
a_o, A	3.92	6.0	8.8185
c_o, A	6.56	--	--
Density, g/cm^3	5.35	5.0	6.079
Melting Point, C	2438	2438	2020
Resistivity, microhm-cm	68	--	144
Coefficient of Thermal Expansion, 10^{-6}/C	12.1	--	9.9

Germanides — Authority: 170,180,183

	α-$LaGe_2$	β-$LaGe_2$	La_5Ge_3
Structure	--	--	Hexagonal
Lattice Type	$ThSi_2$	$GdSi_2$	--
a_o, A	4.321	4.41	8.958
b_o, A		4.30	
c_o, A	14.209	14.190	6.795
Density, g/cm^3	--	7.059	3.72
Volume of Unit Cell, A^3	266.8	269.1	--

Halides

	$LaBr_3$	$LaCl_3$	LaF_3	LaI_3	LaOBr	LaOCl	LaOF	LaOI	Authority
Molecular Weight	--	--	195.92	--	--	--	--	--	
Structure	Hexagonal	Hexagonal	Hcp	--	Tetragonal	Tetragonal	Cubic	Tetragonal	
Lattice Type	UCl_3	UCl_3	--	--	--	--	--	PbFCl	
a_o, A	--	--	7.186	--	4.149	4.149	7.132	4.144	
c_o, A	--	--	7.352	--	7.359	7.359	--	9.126	
Density, g/cm^3	--	--	5.94	--	--	--	6.00	--	
Heat of Formation, kcal/mole	--	255.91	--	160	--	242.6	--	--	93,108,157, 159,181, 182,184, 185,186, 211,215, 216,217, 218,222, 235,236, 269,279
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), $\log P_{mm\ Hg}$	$\left[12.568 - \frac{15446}{T}\right]$	$\left[11.828 - \frac{15796}{T}\right]$	--	$\left[12.845 - \frac{15397}{T}\right]$	--	--	--	--	
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^{-6}/C	--	--	15.0	--	--	--	--	--	
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	0.025	--	--	--	--	--	
$\Delta H_{mp} - \Delta H_{298}$, kcal/mole	20.3	22.8	--	--	--	--	--	--	
Refractive Index	--	--	--	--	--	1.80	--	--	
Color	--	--	White	--	--	--	--	--	
Young's Modulus, 10^7 psi	--	--	1.2	--	--	--	--	--	
Compressive Strength, 10^3 psi	--	--	100	--	--	--	--	--	

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.

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

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

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

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

Reaction	Temperature Range, K	$-\Delta H_{F298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$La(s) + \frac{3}{2}F_2(g) = LaF_3(s)$	298-1153	421	406	1.6	6.7	--	1.2	-0.372	70.0	71.6
$La(l) + \frac{3}{2}F_2(g) = LaF_3(s)$	1153-1800	--	--	0.5	8.3	--	1.2	-2.433	65.9	66.4
$La(l) + \frac{3}{2}F_2(g) = LaF_3(l)$	1800-2500	--	--	11.8	-0.7	--	1.2	2.807	128.8	140.6
$La(s) + \frac{3}{2}Cl_2(g) = LaCl_3(s)$	298-1125	255.68	238.8	3.1	7.4	--	1.0	-0.918	75.9	79.0
$La(l) + \frac{3}{2}Cl_2(g) = LaCl_3(s)$	1125-1153	--	--	12.7	-2.0	--	1.0	3.230	124.7	137.4
$La(l) + \frac{3}{2}Cl_2(g) = LaCl_3(l)$	1153-2020	--	--	11.6	-0.4	--	1.0	1.169	120.6	132.2
$La(l) + \frac{3}{2}Cl_2(g) = LaCl_3(g)$	2020-2500	--	--	-0.4	-0.4	--	1.0	69.41	7.5	7.1

Hydrides 91,186, 187

	LaH_2	LaH_3
Structure	--	Amorphous
a_o, A	5.667	--
Density, g/cm^3	5.14	5.26
Heat of Formation, kcal/mole of H_2	49.7	40.09
Entropy of Formation, eu/mole of H_2	49	--

(Continued)

Authority

Hydrides (Continued)

	LaH_2	LaH_3
Heat Capacity, cal/(mole)(C)	--	12.3
Color	--	Blue black

Nitrides 149,153, 167

	LaN
Molecular Weight	152.93
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.286
Density, g/cm^3	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^{-6}/(C) (-173 - 427 C)	9.0

		Authority
Oxides		156, 172, 173, 174, 176, 186, 199, 212, 218, 219, 220
	La_2O_3	
Molecular Weight	325.82	
Structure	Hcp	
a_o, A	3.94	
c_o, A	6.15	
Density, g/cm^3	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	Temperature Range, K	$-\Delta H_{f\,298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$2La(s) + \frac{3}{2}O_2(g) = La_2O_3(s)$	298-1153	428.6	409.5	4.12	-0.51	--	-0.5	-1.508	88.0	92.1
$2La(l) + \frac{3}{2}O_2(g) = La_2O_3(s)$	1153-2500	--	--	1.9	2.7	--	-0.5	-5.630	79.8	81.7

Authority

Thermodynamic Functions for La_2O_3 174

T, K	C_p, cal/(mole)(K)	S° cal/(mole)(K)	$H^\circ-H^\circ_o$, cal/mole	$-(F^\circ-H^\circ_o)/T$, cal/(mole)(K)
16	0.526	0.1535	1.838	0.03862
20	0.860	0.3049	4.578	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

	LaP
Structure	Fcc
Lattice Type	NaCl
a_o, A	6.016
Density, g/cm^3	5.18
Microhardness, kg/mm^2	158

Authority

Selenides

189, 190, 191, 192, 193, 194

	LaSe	$LaSe_2$	La_2Se_3	La_3Se_4	La_2O_2Se
Structure	Fcc	Tetragonal	Bcc	Bcc	Hcp
Lattice Type	NaCl	--	Th_3P_4	Th_3P_4	--
a_o	6.048 kX	8.47 kX	9.037 kX	9.037 kX	4.09 A
c_o	--	8.53 kX	--	--	7.14 A
Density, g/cm^3	6.34	6.33	6.15	6.47	--
Resistivity, microhm-cm	50	1.46×10^6	2.4×10^4	--	--
Temperature Coefficient of Resistivity at 27 C, 10^{-3}/C	1.7	--	--	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.058	--	--	--	--
Magnetic Susceptibility, 10^{-6} 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

	LaSi	$LaSi_2$
Structure	Orthorhombic	Tetragonal
Lattice Type	FeB	α-$ThSi_2$
a_o, A	8.48	4.31
b_o, A	4.02	--
c_o, A	6.04	13.80
Density, g/cm^3	--	5.0
Heat of Formation, kcal/mole	≈64	≈52

(Continued)

Authority

Silicides (Continued)

	LaSi	$LaSi_2$
Melting Point, C	--	1520
Resistivity, microhm-cm	--	236
Coefficient of Thermal Expansion 10^{-6}/C (20 - 750 C)	--	7.67
Microhardness, kg/mm^2	--	324
Transverse Rupture Strength, 10^3 psi	--	37.3

Sulfides

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

	LaS	LaS_2	γ-La_2S_3	La_3S_4	La_2O_2S
Molecular Weight	170.99	203.05	374.04	545.04	341.91
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal
a_o, A	5.854	8.20	8.723	8.748	4.051
c_o, A	--	--	--	--	6.943
Density, g/cm^3	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	--	2×10^{12}	2.4×10^4	--
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)

Authority

Sulfides (Continued)

	LaS	LaS_2	γ-La_2S_3	La_3S_4	La_2O_2S
Thermal Conductivity, cal/(cm)(sec)(C)	0.054	--	0.0061	--	--
Magnetic Susceptibility, 10^{-6} (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

169,201, 202,203, 204,205

	LaTe	$LaTe_2$	$LaTe_3$	La_3Te_4	La_4Te_7	La_2O_2Te
Structure	Fcc	Tetragonal	Tetragonal	Bcc	Orthorhombic	Hexagonal
Lattice Type	NaCl	Fe_2As	--	Ce_2S_3	--	--
a_o, A	6.422	4.53	4.407	9.619	4.607	4.12
b_o, A	--	--	--	--	4.483	--
c_o, A	--	9.22	26.14	--	9.142	13.10
Density, g/cm^3	6.682	6.97	6.92	6.65	--	6.36
Melting Point, C	1725	1535	835	1595	--	--
Resistivity, microhm-cm	1.5×10^{11}	6.4×10^{6}	--	--	--	--
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	--	--

Authority

150, 206

Miscellaneous

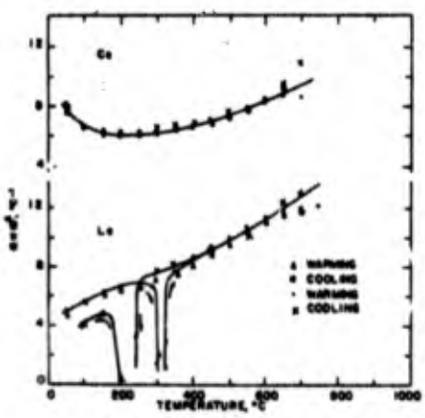
	Structure	a_o, A	Melting Point, C	Superconducting Transition Temperature, K
$LaIr_2$	Cubic	7.686	--	--
$LaOs_2$	Cubic	7.737	--	6.5
$LaPt_2$	Cubic	7.774	--	--
$LaRh_2$	Cubic	7.746	--	--
$LaRu_2$	Cubic	7.702	1431	1.63

CERIUM

Symbol Ce | Atomic Number 58 | Atomic Weight 140.13

PHYSICAL PROPERTIES

		Authority
Abundance	20-46 ppm (approx. 46)	51
Density	6.678 g/cm^3	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 x 10^{-6}/C (25-725 C)	61
		90



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		Authority
Thermal Conductivity (28 C)	0.026 cal/(cm^2)(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

	(α) FCC	(β) HCP	(γ) FCC	(δ) BCC	
Structure					61
Lattice Constants	a_o = 4.85 A --	a_o = 3.68 A c_o = 11.92 A	a_o = 5.1612 A --	a_o = 4.11 A --	61
Density	8.23	6.66	6.768	6.70 g/cm^3	67
Metallic Radius	1.71 A	1.82 A	1.825 A	1.83 A	67
Atomic Volume	--	--	20.695 cm^3/mole	21.0 cm^3/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 A				92,93
Closest Approach of Atoms	3.46 A				56
Allotropic Modifications	(1) a Fcc structure with a_c = 4.82 A 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^{+3} + 3e$^-$]	+2.335 volts (standard hydrogen electrode)	81

		Authority
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

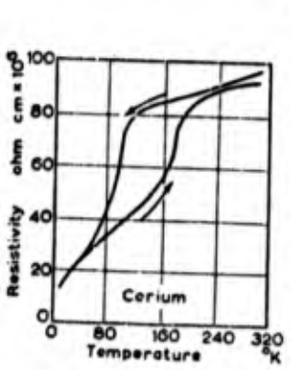
Corrosive attack on crucible materials:

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

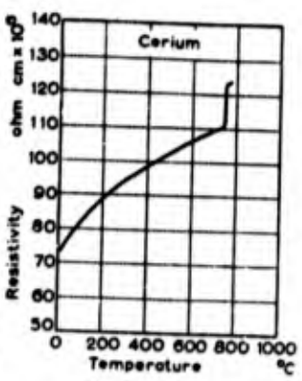
ELECTRICAL PROPERTIES

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

Resistivity Versus Temperature — 53

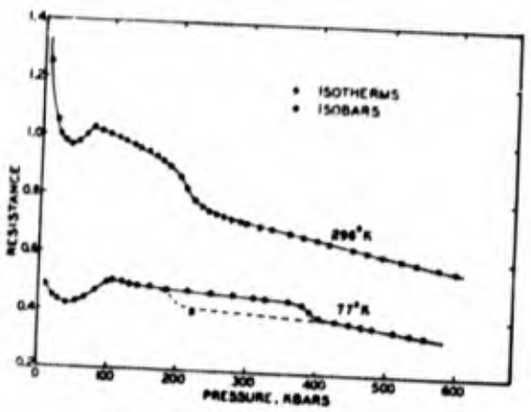


0 to 300 K



0 to 800 C

		Authority
Resistance Versus Pressure		96



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MAGNETIC PROPERTIES

				Authority
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

				Authority
Young's Modulus	3.00×10^{11} dynes/cm^2			57
Shear Modulus	1.20×10^{11} dynes/cm^2			57
Poisson's Ratio	0.248			61
Compressibility	4.95×10^{-6} cm^2/kg			57
Hardness (DPH)	24 (not annealed)			57
	70 F	400 F		
Tensile Strength	15.0	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	42.6	--	10^3 psi	61

		Authority
Impact Strength (Izod)	2.2 ft-l	71
Workability	Good	88
General Fabrication	(See references)	70, 72, 113

NUCLEAR PROPERTIES

Isotopes

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

Thermal Neutron Cross Section: 0.70 ± 0.08 barns/atom or 0.0030 cm^2/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

	Room Temperature	Melting Point	95
Entropy	$S_{298} = 18.12$	$S_{1077} = 28.48$ eu	
Heat Capacity	$Cp_{298} = 6.44$	$Cp_{1077} = 9.05$ (cal)(mole)(C)	

Thermodynamic Functions of Cerium 95

T, K	Cp, cal/(K)(mole)	$S^o-S^o_o$, cal/(K)(mole)	$H^o-H^o_{298.15}$[a], cal/(K)(mole)	$-\left(\frac{F^o-H^o_{298.15}}{T}\right)$, 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)

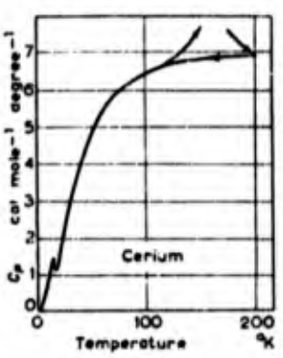
Authority

Thermodynamic Functions of Cerium (Continued)

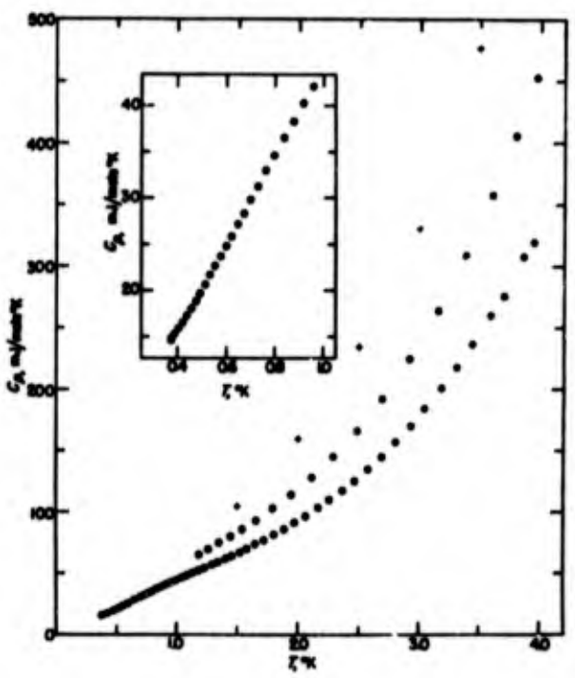
T, K	Cp, cal/(K)(mole)	$S^{o}-S^{o}_{o}$, cal/(K)(mole)	$H^{o}-H^{o}_{298.15}$ (a), cal/(K)(mole)	$-\frac{F^{o}-H^{o}_{298.15}}{T}$, cal/(K)(mole)
1050	9.05	28.25	6.238	22.01
1077.15	9.05	28.43	6.309	22.17
1077.15	9.35	29.63	7.458	22.17
1100	9.35	29.83	7.497	22.33
1150	9.35	30.24	7.577	22.66
1200	9.35	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) $(H^{o}_{298.15}-H^{o}_{o})/T = 7.63$ cal. degree^{-1} mole^{-1} based on a private communication from Jennings.

Specific Heat 53,97



0 to 200 K

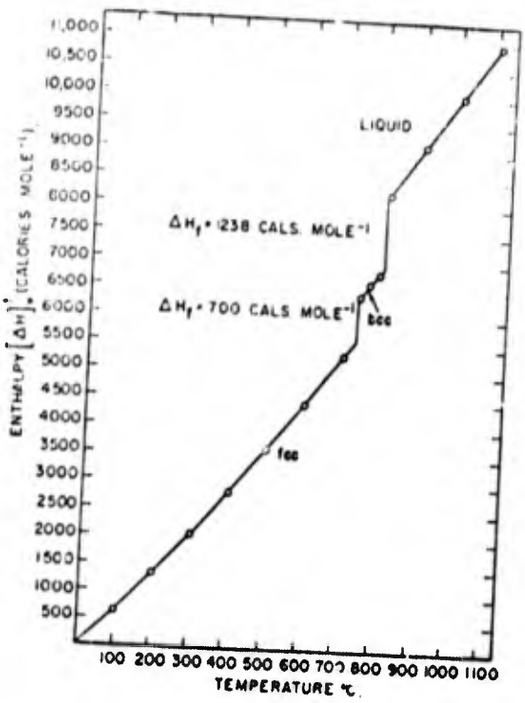


O-62% of α-cerium; •-39% of α-cerium; +-3% of α-cerium (Permission of Gordon and Breach, Science Publishers, Inc.)

Authority

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

95



CERIUM COMPOUNDS

Antimonides

169

	CeSb
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.412

Arsenides

169

	CeAs
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.072

Beryllides		Authority
	$CeBe_{13}$	179
a_o, A	10.378	
Bismuthides		
	CeBi	169
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	6.500	
Borides		
	CeB_4	CeB_6	153
Molecular Weight	182.86	205.05	
Structure	Tetragonal	Cubic	
a_o, A	7.205	4.137	
c_o, A	4.090	--	
Density, g/cm^3	5.74	4.80	
Heat of Formation, kcal/mole	84	81	
Melting Point, C	--	2190	
Resistivity, microhm-cm	--	43.3	
Temperature Coefficient of Resistivity, $10^{-3}/C$	--	1.0	
Coefficient of Thermal Expansion, $10^{-6}/C$	--	6.2	
Thermal Conductivity, cal/(cm)(sec)(C)	--	0.081	
Magnetic Susceptibility, 10^{-6} emu/mole	--	2260	
Effective Magnetic Moment, Bohr magnetons	--	2.60	

(Continued)

Authority

Borides (Continued)

	CeB_4	CeB_6
Work Function, ev	--	2.59
Microhardness, kg/mm^2	--	3140
Color	Gray brown	Blue violet
Emissivity at 1500 C ($\lambda = 0.655\ \mu$)	--	0.68

Carbides

153

	CeC_2	Ce_2C_3
Molecular Weight	164.15	316.24
Structure	Body-centered tetragonal	Bcc
Lattice Type	CaC_2	Pu_2C_3
a_o, A	3.88	8.448
c_o, A	6.49	--
Density, g/cm^3	5.56	6.969
Melting Point, C	2540	--
Resistivity, microhm-cm	58.8	202
Coefficient of Thermal Expansion, $10^{-6}/C$	10.1	10.4
Magnetic Susceptibility, 10^{-6} emu/mole	1640	--
Effective Magnetic Moment, Bohr magnetons	2.19	--

Germanides

	α-$CeGe_2$	β-$CeGe_2$	Ce_5Ge_3	Authority
Structure	--	--	Hcp	170, 183, 221
Lattice Type	α-$ThSi_2$	α-$GdSi_2$	--	
a_o, A	4.27	4.36	8.875	
b_o, A	--	4.26	--	
c_o, A	14.08	14.07	6 570	
Density, g/cm^3	--	--	3.92	
Volume of Unit Cell, A^3	256.7	262.5	--	

Halides

	$CeBr_3$	$CeCl_3$	CeF_3	CeI_3	CeOCl	CeOF	Authority
Structure	Hexagonal	Hexagonal	Hexagonal	Orthorhombic	Tetragonal	Fcc	55, 93, 108, 158, 159, 181, 184, 185, 186, 211, 215, 218, 235, 236, 237, 279
Lattice Type	UCl_3	UCl_3	--	$PuBr_3$	--	--	
a_o, A	--	7.450	7.114	14.0	4.080	5.703	
b_o, A	--	--	--	4.4	--	--	
c_o, A	--	4.315	7.273	10.1	6.831	--	
Density, g/cm^3	--	--	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	--	--	

(Continued)

Halides (Continued)

	$CeBr_3$	$CeCl_3$	CeF_3	CeI_3	CeOCl	CeOF	Authority
Vapor Pressure (T in K), log $P_{mm\ Hg}$	$\left[12.334 - \frac{14990}{T}\right]$	$\left[12.035 - \frac{15544}{T}\right]$	--	--	--	--	
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

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	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$Ce(s) + \frac{3}{2}F_2(g) = CeF_3(s)$	298-1048	416	398	3.5	1.1	--	1.2	-0.680	78.5	82.0
$Ce(\ell) + \frac{3}{2}F_2(g) = CeF_3(s)$	1048-1733	--	--	--	7.1	--	1.2	-2.407	62.5	62.5
$Ce(\ell) + \frac{3}{2}F_2(g) = CeF_3(\ell)$	1733-2500	--	--	11.7	-0.7	--	1.2	-1.970	131.0	142.7
$Ce(s) + 2F_2(g) = CeF_4(s)$	298-1048	442	420	4.0	2.1	--	1.6	-0.755	96.5	100.5
$Ce(\ell) + 2F_2(g) = CeF_4(s)$	1048-1250	--	--	0.5	8.1	--	1.6	-2.482	80.5	81.0
$Ce(\ell) + 2F_2(g) = CeF_4(\ell)$	1250-2000	--	--	13.5	-0.9	--	1.6	-0.701	153.2	166.7
$Ce(\ell) + 2F_2(g) = CeF_4(g)$	2000-2500	--	--	-4.5	4.1	--	1.6	73.30	2.3	-2.2
$Ce(s) + \frac{3}{2}Cl_2(g) = CeCl_3(g)$	298-1048	252.84	235.1	4.5	2.4	--	1.0	-1.104	84.8	89.3
$Ce(\ell) + \frac{3}{2}Cl_2(g) = CeCl_3(s)$	1048-1085	--	--	1.0	8.4	--	1.0	-2.831	68.8	69.8
$Ce(\ell) + \frac{3}{2}Cl_2(g) = CeCl_3(\ell)$	1085-2000	--	--	11.0	-0.4	--	1.0	0.189	121.1	132.1
$Ce(\ell) + \frac{3}{2}Cl_2(g) = CeCl_3(g)$	2000-2500	--	--	-1.0	-0.4	--	1.0	70.19	6.9	5.9

Authority

Hydrides 91, 187

	CeH_2	CeH_3
Structure	Fluorite	Fluorite
a_o, A	5.581	--
Density, g/cm^3	5.43	5.55
Heat of Formation, kcal/mole H_2	33.9	42.26
Color	--	Dark blue

Nitrides 153, 167, 258

	CeN
Molecular Weight	154.14
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.02
Density, g/cm^3	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, $10^{-6}/C$	30.0
Magnetic Susceptibility, 10^{-6} emu/mole	433
Color	Bronze

Oxides

	CeO_2	Ce_2O_3	Authority
Structure	Fcc	Hexagonal	156,172,176, 177,212,218, 219,220,224, 245,259
a_o, A	5.41	3.880	
c_o, A	--	6.057	
Density, g/cm^3	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, $10^{-6}/C$	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)

Authority

Oxides (Continued)

Thermodynamic Properties of CeO_2 and Ce_2O_3 224,245

CeO_2			Ce_2O_3		
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	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_o, A	5.909

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

	CeSe	$CeSe_2$	Ce_2Se_3	Ce_3Se_4	Ce_2O_2Se
Structure	Fcc	Tetrago		Bcc	Hcp
Lattice Type	NaCl	--	Th_3P_4	Th_3P_4	--
a_o, A	5.992	8.43	8.960	8.973	4.04
c_o, A	--	8.49	--	--	7.06
Density, g/cm^3	6.55	6.45	6.35	6.76	6.51
Melting Point, C	1820	--	1825	--	--

(Continued)

Authority

Selenides (Continued)

	CeSe	$CeSe_2$	Ce_2Se_3	Ce_3Se_4	Ce_2O_2Se
Resistivity, microhm-cm	100	2.92×10^8	3.3×10^3	8.0×10^3	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.03	--	--	--	--
Magnetic Susceptibility, 10^{-6} emu/mole	2186	2220	2068	--	--
Effective Magnetic Moment, Bohr magnetons	2.3	2.2	2.2	--	--
Color	--	--	Violet	--	Maroon

Silicides

153

	CeSi	$CeSi_2$
Molecular Weight	168.22	196.31
Structure	Orthorhombic	Tetragonal
Lattice Type	FeB	α-$ThSi_2$
a_o, A	--	4.175
c_o, A	--	13.848
Heat of Formation, kcal/mole	--	50
Density, g/cm^3	--	5.45
Resistivity, microhm-cm	--	408
Microhardness, kg/mm^2	--	540

Authority

Selenides (Continued)

	CeSe	$CeSe_2$	Ce_2Se_3	Ce_3Se_4	Ce_2O_2Se
Resistivity, microhm-cm	100	2.92×10^8	3.3×10^3	8.0×10^3	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.03	--	--	--	--
Magnetic Susceptibility, 10^{-6} emu/mole	2186	2220	2068	--	--
Effective Magnetic Moment, Bohr magnetons	2.3	2.2	2.2	--	--
Color	--	--	Violet	--	Maroon

Silicides

153

	CeSi	$CeSi_2$
Molecular Weight	168.22	196.31
Structure	Orthorhombic	Tetragonal
Lattice Type	FeB	α-$ThSi_2$
a_o, A	--	4.175
c_o, A	--	13.848
Heat of Formation, kcal/mole	--	50
Density, g/cm^3	--	5.45
Resistivity, microhm-cm	--	408
Microhardness, kg/mm^2	--	540

Sulfides

	CeS	CeS_2	γCe_2S_3	Ce_3S_4	Ce_2O_2S	Authority
Molecular Weight	172.20	204.26	376.46	548.65	344.33	153,186, 193,198, 200,230, 231,239
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal	
a_o, A	5.778	8.12	8.635	8.623	4.00	
c_o, A	--	--	--	--	6.82	
Density, g/cm^3	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	--	1.19×10^{12}	400	--	
Temperature Coefficient of Resistivity, $10^{-3}/C$	0.67	--	--	--	--	
Coefficient of Thermal Expansion, (20-1000 C), $10^{-6}/C$	12.37	--	10.45	--	--	
Thermal Conductivity, cal/(cm)(sec)(C)	0.039	--	0.0093	--	--	
Magnetic Susceptibility, 10^{-6} 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	--	--	

Tellurides

Authority: 169, 193, 202, 205, 233

	CeTe	$CeTe_2$	Ce_2Te_3	Ce_3Te_4	Ce_2O_2Te
Structure	Fcc	Tetragonal	--	Bcc	Hexagonal
Lattice Type	NaCl	Fe_2As	--	Th_3P_4	--
a_o, A	6.359	4.51	9.535	9.528	4.09
c_o, A	--	9.10	--	--	12.92
Density, g/cm^3	--	7.06	6.6	6.7	6.64
Resistivity, microhm-cm	200	--	1.1×10^4	1.8×10^3	--
Temperature Coefficient of Resistivity, $10^{-3}/C$	1.2	--	--	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.027	--	0.0029	0.005	--
Color	--	--	--	--	Maroon

Miscellaneous

Authority: 150, 206

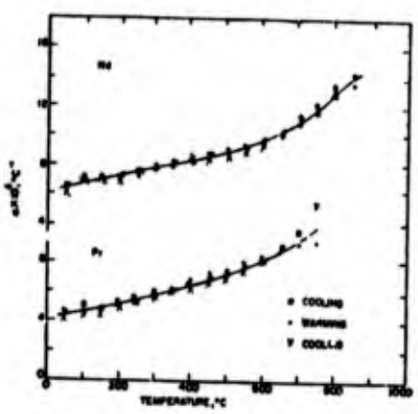
	Structure	a_o, A	Melting Point, C	Superconducting Transition Temperature, K
$CeIr_2$	Cubic	7.571	--	--
$CeOs_2$	Cubic	7.593	--	--
$CeRh_2$	Cubic	7.538	--	--
$CeRu_2$	Cubic	7.5364	1539	4.9

PRASEODYMIUM

Symbol Pr | Atomic Number 59 | Atomic Weight 140.92

PHYSICAL PROPERTIES

		Authority
Abundance	3.5-5.5 ppm (approx. 5.5)	51
Density	6.769 g/cm^3	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 x 10^{-6}/C (-173 – 800 C)	61



90

(Permission of the American Physical Society)

		Authority
Thermal Conductivity (28 C)	0.028 cal/(cm^2)(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	HCP	BCC	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^3	67
Metallic Radius	1.828	1.84 A	67
Atomic Volume	20.778	21.2 cm^3/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

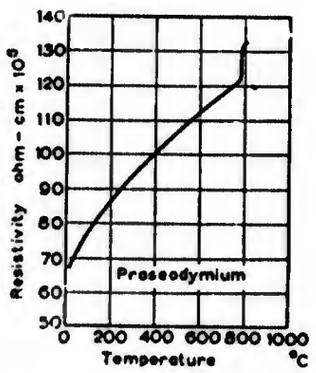
CHEMICAL PROPERTIES

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

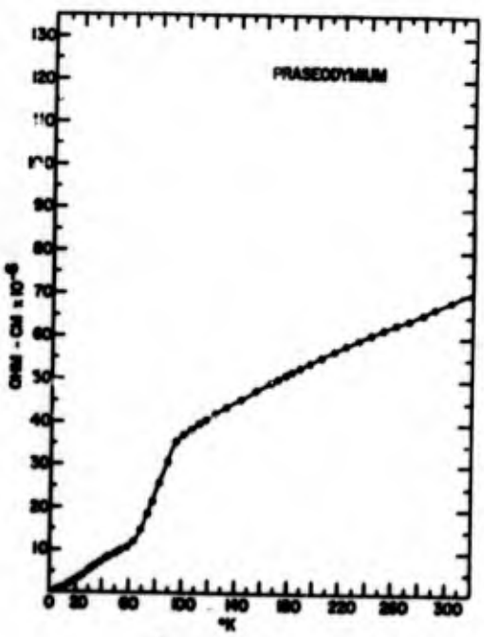
		Authority
Metallographic Polishing and Etching	Praseodymium may be sectioned, mounted and polished in a manner similar to that used for lanthanum. Praseodymium etches readily in air and reacts with various inorganic acid etchants as does lanthanum.	62
Corrosion Rates (In Air)	17 mil/year at 200 C 8,100 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: Material: MgO — Onset of Attack: None <1150 C Material: Ta — Onset of Attack: None <1200 C	91

ELECTRICAL PROPERTIES

			Authority
Temperature Coefficient of Resistivity	1.71×10^{-3}/C		61
Resistivity	(α) HCP (25 C) 68	(β) BCC (820 C) 132 microhm-cm	61
Resistivity Versus Temperature			53, 86



0 to 820 C



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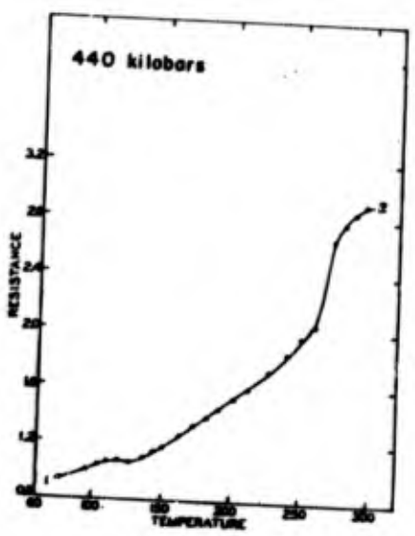
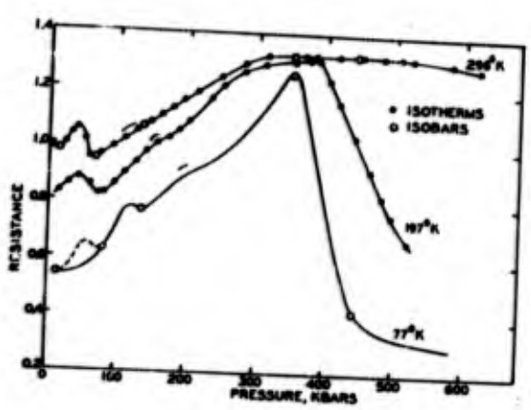
Authority

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 Measured 3.56 Bohr magnetons	61
Curie Temperature	None	61
Néel Temperature	None	61

MECHANICAL PROPERTIES

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

NUCLEAR PROPERTIES

Isotopes — 58, 98

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

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

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

	Room Temperature	Melting Point	76, 77
Entropy	$S_{298} = 17.6$	$S_{1208} = 28.37$ eu	
Heat Capacity	$C_{p298} = 6.48$	$C_{pl208} = 8.00$ cal/(mole)(C)	

Heat Capacities of Praseodymium 76

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

Heat Content and Entropy of Solid and Liquid Praseodymium
(Base: α-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	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(α)	5,950	9.51	2400	19,700	18.58
1071(β)	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(β)	7,360	10.77			

(Continued)

Authority

Heat Capacities of Praseodymium (Continued) 76

For α-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);
$C_p = 5.50 + 3.20 \times 10^{-3}\ T$;
ΔH_{1071} (transition) = 320.

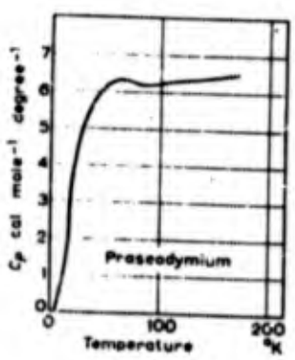
For β-praseodymium solid:

$H_T - H_{298.15} = 8.00\ T - 2,300$
(0.1 percent; 1071 - 1208 K);
$C_p = 8.00$;
ΔH_{1208} (fusion) = 2,800.

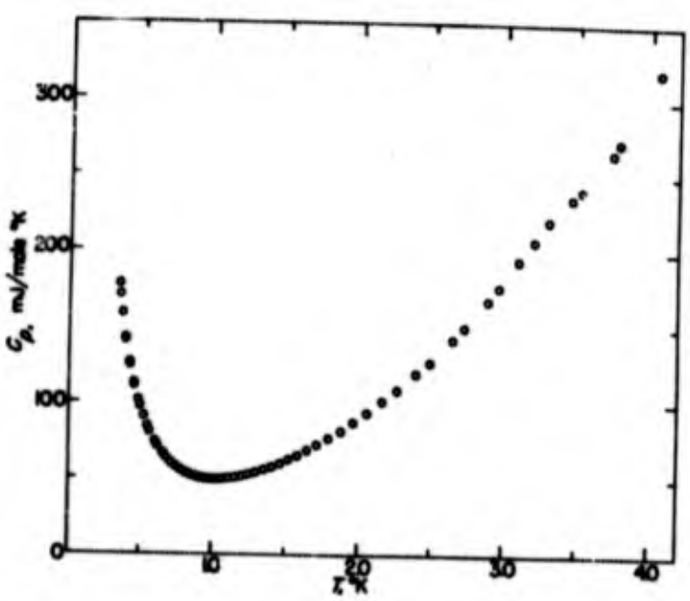
For Liquid praseodymium:

$H_T - H_{298.15} = 8.00\ T + 500$
(0.1 percent; 1208 - 3000 K);
$C_p = 8.00$.

Specific Heat 53, 97



0 to 180 K



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

				Authority
Antimonides	PrSb			169, 270
Structure	Cubic			
Lattice Type	NaCl			
a_o, A	6.366			
Effective Magnetic Moment, Bohr magnetons	3.63			
Arsenides	PrAs			169, 270
Structure	Cubic			
Lattice Type	NaCl			
a_o, A	6.009			
Effective Magnetic Moment, Bohr magnetons	3.80			
Beryllides	$PrBe_{13}$			179
a_o, A	10.367			
Bismuthides	PrBi			169, 270
Structure	Cubic			
Lattice Type	NaCl			
a_o, A	6.461			
Effective Magnetic Moment, Bohr magnetons	3.52			
Borides	PrB_3	PrB_4	PrB_6	153, 155, 171
Molecular Weight	173.38	184.20	205.84	
Structure	Pseudo-cubic	Tetragonal	Cubic	
a_o, A	3.81	7.20	4.130	
c_o, A		4.11		

(Continued)

Borides (Continued)	PrB_3	PrB_4	PrB_6	Authority
Density, g/cm^3	5.20	5.74	4.851	
Resistivity, microhm-cm	--	--	20	
Temperature Coefficient of Resistivity, $10^{-3}/C$	--	--	1.92	
Coefficient of Thermal Expansion, $10^{-6}/C$	--	--	7.55	
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	0.98	
Magnetic Susceptibility, 10^{-6} 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	

Carbides	PrC_2	Pr_2C_3	153
Molecular Weight	164.94	317.84	
Structure	Body-centered tetragonal	Bcc	
Lattice Type	CaC_2	Pu_2C_3	
a_o, A	3.85	8.7072	
c_c, A	6.42		
Density, g/cm^3	5.73	6.621	

(Continued)

			Authority
Carbides (Continued)	PrC_2	Pr_2C_3	
Melting Point, C	2535	--	
Resistivity, microhm-cm	25.7	--	
Coefficient of Thermal Expansion, 10^{-6}/C	11.4	--	
Magnetic Susceptibility, 10^{-6} emu/mole	4500	--	
Effective Magnetic Moment, Bohr magnetons	(3.15)	--	
Curie Temperature, K	5.2	--	
Germanides	$PrGe_2$		183
Lattice Type	α-$ThSi_2$		
a_o, A	4.26		
c_o, A	13.98		
Volume of Unit Cell, A^3	253.7		

Halides	$PrBr_3$	$PrCl_3$	PrF_3	PrI_3	PrOCl	PrOF	55,93, 108,157, 158,181, 182,184, 185,186, 212,215, 218,235, 236,211, 279
Structure	--	Hexagonal	Hexagonal	Orthorhombic	Tetragonal	Rhombohedral	
Lattice Type	--	UCl_3	--	$PuBr_3$	--	--	
a_o, A	--	7.422	7.061	13.9	4.051	7.016	
b_o, A	--	--	--	4.3	--	--	
c_o, A	--	4.275	7.218	10.0	6.810	--	
B, deg	--	--	--	--	--	33.03	
Density, g/cm^3	--	--	6.18	--	--	6.39	
Heat of Formation, kcal/mole	--	252.09	--	157	242.8	--	

(Continued)

Authority

Halides (Continued)

	$PrBr_3$	$PrCl_3$	PrF_3	PrI_3	PrOCl	PrOF
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_{mm} Hg	$\left[\begin{matrix}12.508\\ -14916/T\end{matrix}\right]$	$\left[\begin{matrix}12.1\\ \frac{-15439}{T}\end{matrix}\right]$		$-\left[\begin{matrix}12.703\\ \frac{-14640}{T}\end{matrix}\right]$	--	--
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.

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

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

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

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

Reaction	Temperature Range, K	$-\Delta H_{F298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, ev	$-\Delta(B-a)$
$Pr(s) + \frac{3}{2}F_2(g) = PrF_3(s)$	298-1205	413	395	2.4	4.3	--	1.2	-0.485	73.4	75.8
$Pr(\ell) + \frac{3}{2}F_2(g) = PrF_3(s)$	1205-1643	--	--	-0.6	8.9	--	1.2	-2.709	59.8	59.2
$Pr(\ell) + \frac{3}{2}F_2(g) = PrF_3(\ell)$	1643-2500	--	--	11.1	-0.7	--	1.2	-0.975	125.8	176.9
$Pr(s) + \frac{3}{2}Cl_2(g) = PrCl_3(s)$	298-1049	253.02	235.4	3.7	3.4	--	1.0	-0.900	80.2	83.9
$Pr(s) + \frac{3}{2}Cl_2(g) = PrCl_3(\ell)$	1049-1205	--	--	13.9	-5.0	--	1.0	0.22	139.7	148.5
$Pr(\ell) + \frac{3}{2}Cl_2(g) = PrCl_3(\ell)$	1205-1980	--	--	10.9	-0.4	--	1.0	-1.202	121.1	132.0
$Pr(\ell) + \frac{3}{2}Cl_2(g) = PrCl_3(g)$	1980-2500	--	--	-1.1	-0.4	--	1.0	68.56	6.8	5.7

Hydrides 186, 187

	PrH_2	PrH_3
Structure	Fluorite	Fluorite
a_o, A	5.517	--
Density, g/cm^3	5.65	5.56
Heat of Formation, kcal/mole H_2	47.8	39.52

(Continued)

Nitrides

	PrN	Authority
Molecular Weight	154.93	149, 153, 169, 223
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	5.16	
Density, g/cm^3	7.467	
Resistivity, microhm-cm	110	
Temperature Coefficient of Resistivity (80-500 K), 10^{-3}/C	1.9	
Coefficient of Thermal Expansion (60-500 K), 10^{-6}/C	13.0	
Magnetic Susceptibility, 10^{-6} emu/mole	4460	
Effective Magnetic Moment, Bohr magnetons	3 66	
Curie Temperature, K	0.0	

Oxides

	PrO_2	Pr_2O_3		Pr_6O_{11}	Authority
Structure	--	Cubic; Hexagonal		Cubic	156, 172, 177, 238
a_o, A	--	10.9	--	5.4695	
Density, g/cm^3	--	7.0		--	
Heat of Formation, kcal/mole	--	218.4	217.9	--	
Entropy of Formation, eu/mole	--	35.4	35.4	--	

(Continued)

Authority

Oxides (Continued)

	PrO_2	Pr_2O_3	Pr_6O_{11}
Melting Point, C	--	2200	--
Magnetic Susceptibility, 10^{-6} 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	$-\Delta H_{F298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$2Pr(s) + \frac{3}{2}O_2(g) = Pr_2O_3(s)$	298-1205	433.8	414.5	6.6	-5.6	--	-1.2	-2.246	101.5	108.1
$2Pr(\ell) + \frac{3}{2}O_2(g) = Pr_2O_3(s)$	1205-2200	--	--	0.6	3.6	--	-1.2	-6.694	74.3	74.9
$2Pr(\lambda) + \frac{3}{2}O_2(g) = Pr_2O_3(\ell)$	2200-2500	--	--	7.6	-0.4	--	-2.8	-9.770	109.4	117.0
$Pr(s) + O_2(g) = PrO_2(s)$	298-700	230	216.5	4.3	-1.5	--	-0.9	-1.626	70.2	74.6

Phosphides

169, 270

	PrP
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.872
Effective Magnetic Moment, Bohr magnetons	3.77

Selenides

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

	PrSe	$PrSe_2$	Pr_2Se_3	Pr_3Se_4	Pr_2O_2Se
Structure	Fcc	Tetragonal	Bcc	Bcc	Hcp
Lattice Type	--	--	Th_3P_4	Th_3P_4	--
a_o, A	5.940	8.37	8.909	8.927	4.01
c_o, A	--	8.44	--	--	7.04

(Continued)

Authority

Selenides (Continued)

	$PrSe$	$PrSe_2$	Pr_2Se_3	Pr_3Se_4	Pr_2O_2Se
Density, g/cm^3	6.80	6.68	--	6.89	6.65
Temperature Coefficient of Resistivity, $10^{-3}/C$	0.9	--	--	--	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.022	--	--	--	--
Magnetic Susceptibility, 10^{-6} emu/mole	4611	4631	4465	--	--
Magnetic Moment, Bohr magnetons	3.3	3.3	3.38	--	--
Color	--	Dark gray	Green	--	Beige

Silicides 153, 160

	α-$PrSi_2$	β-$PrSi_2$
Molecular Weight	197.0	197.0
Structure	Orthorhombic	Tetragonal
Lattice Type	α-YSi_2	α-$ThSi_2$
a_o, A	4.23	4.140
b_o, A	4.40	--
c_o, A	13.68	13.65
Density, g/cm^3	5.38	5.64
Resistivity, microhm-cm	--	202
Curie Temperature, K	10.5	--
Transformation Temperature, K	$\alpha \rightarrow \beta$ at 153	

Sulfides

	PrS	PrS_2	γPr_2S_3	Pr_3S_4	Pr_2O_2S	Authority
Molecular Weight	172.99	205.04	378.05	551.02	345.91	153, 198, 230, 239
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal	
a_o, A	5.747	8.08	8.611	8.611	3.974	
c_o, A	--	--	--	--	6.825	
Density, g/cm^3	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	--	1.1×10^{12}	--	--	
Temperature Coefficient of Resistivity (20-1000C), $10^{-3}/C$	0.54	--	--	--	--	
Coefficient of Thermal Expansion, $10^{-6}/C$	14.3	--	12.09	--	--	
Thermal Conductivity, 10^{-2} cal(cm)(sec)(C)	3.3	--	0.716	--	--	
Magnetic Susceptibility, 10^{-6} emu/mole	4730	4800	4640	--	--	

(Continued)

Authority

Sulfides (Continued)

	PrS	PrS_2	γPr_2S_3	Pr_3S_4	Pr_2O_2S
Work Function, ev	3.90	--	3.84	--	--
Debye Temperature, K	638	--	855	--	--
Emissivity (λ = 0.655 μ)	0.73	--	--	--	--
Color	Gold	--	--	--	--

Tellurides

169, 202, 205, 240, 242

	PrTe	$PrTe_2$	Pr_2Te_3	Pr_2O_2Te
Structure	Fcc	Tetragonal	--	Hexagonal
Lattice Type	NaCl	Fe_2As	--	--
a_o, A	6.322	4.46	9.482	4.06
c_o, A	--	9.05	--	12.83
Density, g/cm^3	--	--	6.6	--
Thermal Conductivity, cal/(cm)(sec)(C)	0.019	--	--	--
Color	--	--	--	Light green

Miscellaneous

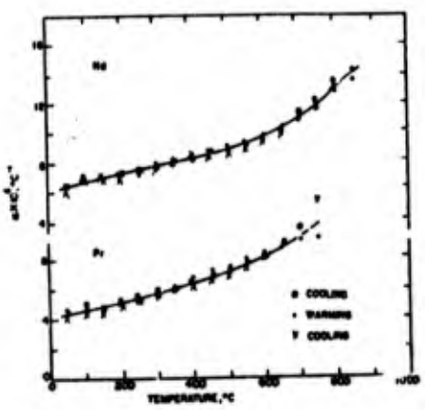
150, 206

	Structure	Lattice Type	a_o, A	c_o, A	Melting Point, C	Curie Temperature, K	Superconducting Transition Temperature, K
$PrIr_2$	--	--	7.821	--	--	18.5	--
$PrMg_{12}$	Body-centered tetragonal	$ThMn_{12}$	10.34	5.98	--	--	--
$PrOs_2$	--	--	7.663	--	--	>35	--
$PrPt_2$	--	--	7.709	--	--	7.9	--
$PrRh_2$	--	--	7.575	--	--	8.6	--
$PrRu_2$	--	--	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^3	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 x 10^{-6}/C (-173 - 850 C)	61
		90



(Permission of American Physical Society)

		Authority
Thermal Conductivity (28 C)	0.031 cal/(cm^2)(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

T, C	σ, dyne/cm
1030	688
1054	685
1072	684
1094	681
1110	682
1154	680
1167	681
1186	674

CRYSTAL PROPERTIES

Structure	HCP	BCC	61
Lattice Constants	a_o = 3.6579 c_o = 11.7992	a_o = 4.13 A A	61
Density	7.016	6.80 g/cm^3	67
Metallic Radius	1.821	1.84 A	67
Atomic Volume	20.60	21.2 cm^3/mole	66
Transition Temperature	868 C		66
Heat of Transition	0.713 kcal/mole		61
Ionic Radius (Trivalent Ion)	0.995 A		55
Closest Approach of Atoms	3.62 A		56

		Authority
Allotropic Modification	(1) a Fcc structure with a_o = 4.80 A occurs at 20 C when metal is subjected to a static pressure of 50 kilobars	84

CHEMICAL PROPERTIES

Stable Oxidation State	+3	81
Electrode Potential	$[Nd = Nd^{+3} + 3\bar{e}]$ + 2.24 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

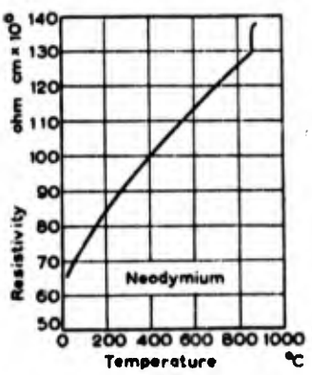
Material	Onset of Attack
CaO	Mild > 900 C
MgO	None < 1200 C
Ta	None < 1100 C

ELECTRICAL PROPERTIES

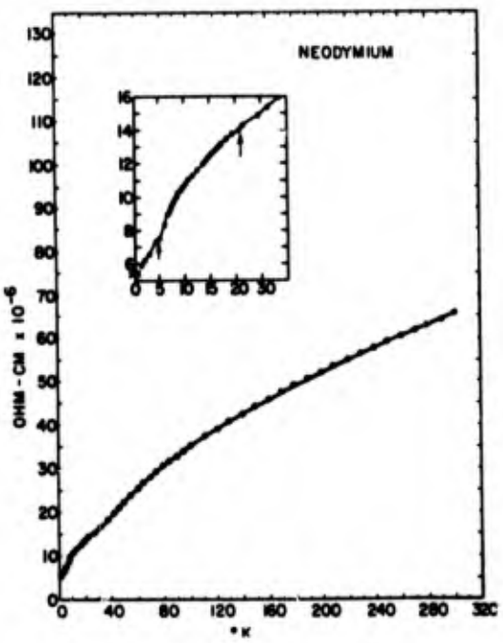
	(α) HCP (25 C)	(β) BCC (890 C)	
Resistivity	64.3	137 microhm-cm	61
Temperature Coefficient of Resisitivity	1.64×10^{-3}/C		61

Authority

Resistivity Versus Temperature 53,86



0 to 850 C



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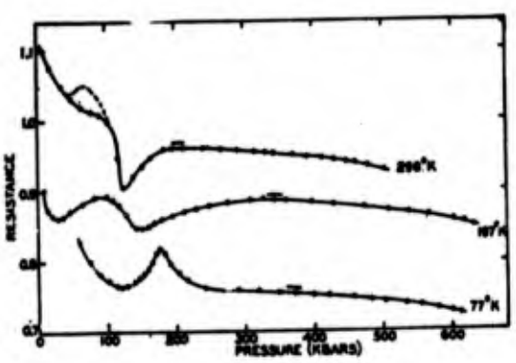
Resistance Versus Pressure 96
(Permission of the American Physical Society)



			Authority
MAGNETIC PROPERTIES			
Susceptibility (25 C)	$5,650 \times 10^{-6}$ cmu/mole		61
Effective Magnetic Moment	Theoretical 3.68 Bohr magnetons Measured 3.3 Bohr magnetons		61
Curie Temperature			
Néel Temperature	7.7 K		61
MECHANICAL PROPERTIES			
Young's Modulus	3.79×10^{11} dynes/cm^2		57
Shear Modulus	1.45×10^{11} dynes/cm^2		57
Poisson's Ratio	0.306		61
Compressibility	3.02×10^{-6} cm^2/kg		57
Hardness (DPH)	35		57
	70 F	800 F	
Tensile Strength	24.7	6.0 10^3 psi	88
Yield Strength	23.9	5.7 10^3 psi	88
Elongation	11	13 per cent	88
Ultimate Compressive Strength	35.5 10^3 psi		61
Impact Strength (Izod)	8.3 ft-lb		71
Workability	Good		88
General Fabrication	(See references)		70, 113

NUCLEAR PROPERTIES

Authority

58, 98

Isotopes

Whole-Number Mass	Relative Abundance, per cent	Half Life	Decay Mode
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, β^-, e^-, γ
148	5.72	Stable	--
149	--	1.7 days	β^-, γ or X
150	5.60	Stable	--
151	--	Short	β^-

Thermal Neutron Cross Section: 46 ± 2 barns/atom or 0.19 cm^2/cm — 73

83

SAFETY

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.

THERMODYNAMIC PROPERTIES

	Room Temperature	Melting Point	Authority
Entropy	$S_{298} = 17.5$	$S_{1297} = 30.21$ eu	95
Heat Capacity	$C_{p296} = 6.57$	$C_{p1297} = 10.65$ cal/(mole)(C)	

Thermodynamic Functions of Neodymium

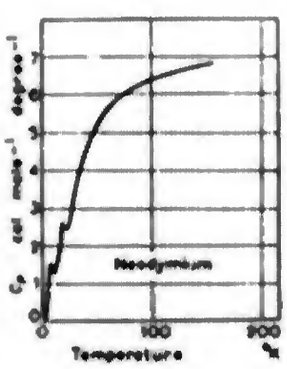
95

T, K	C_p	$S^\circ - S^\circ_0$ cal/(K)(mole)	$\frac{H^\circ - H^\circ_{298.15}}{T}$ [(4)] cal/(K)(mole)	$\frac{F^\circ - H^\circ_{298.15}}{T}$ 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	0.984	17.58
400	6.87	19.47	1.710	17.76
450	7.06	20.29	2.294	18.00
500	7.24	21.04	2.778	18.26
550	7.44	21.74	3.193	18.55
600	7.67	22.40	3.554	18.84
650	7.90	23.02	3.882	19.14
700	8.16	23.62	4.178	19.44
750	8.43	24.19	4.452	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	5.186	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	7.206	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	8.661	22.90
1350	11.66	31.99	8.763	23.23
1373.15	11.66	32.18	8.812	23.37

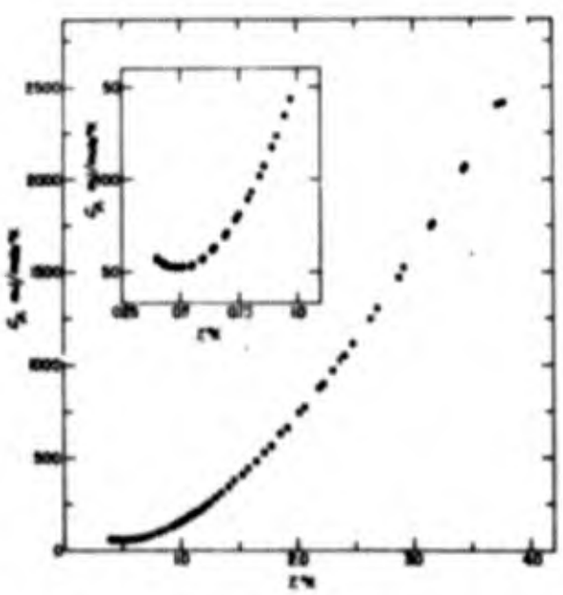
(4) $(H^\circ_{298.15} - H^\circ_0)/T = 6.01$ cal. degree^{-1} mole^{-1}

Authority

Specific Heat 53, 97



0 to 150 K



o - 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.

$C_p = 125.7T^3 + 22.5T + 6.4T^{-2}$. (Permission of Gordon and Breach Science Publishers, Inc.)

NEODYMIUM COMPOUNDS

		Authority
Antimonides		169, 229
	NdSb	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	6.322	
Resistivity, microhm-cm	76	
Arsenides		169, 229
	NdAs	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	5.970	
Resistivity, microhm-cm	150	
Beryllides		179
	$NdBe_{13}$	
a_o, A	10.356	
Bismuthides		169
	NdBi	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	6.424	

Borides

Authority: 153, 171

	NdB_4	NdB_6
Molecular Weight	187.55	209.19
Structure	Tetragonal	Cubic
a_o, A	7.219	4.125
c_o, A	4.1020	--
Density, g/cm^3	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^{-3}/C	--	1.93
Coefficient of Thermal Expansion, 10^{-6}/C	--	7.26
Thermal Conductivity, cal/(cm)(sec)(C)	--	0.113
Magnetic Susceptibility, 10^{-6} emu/mole	--	2420
Effective Magnetic Moment, Bohr magnetons	--	3.82
Work Function, ev	--	3.97
Microhardness, kg/mm^2	--	2530
Color	--	Dark blue
Emissivity, ($\lambda = 0.655\,\mu$)	--	0.64
Effective Metallic Radius, A	--	2.18

Properties

			Authority
Carbides			153
	NdC_2	Nd_2C_3	
Molecular Weight	168.29	324.54	
Structure	Body-centered tetragonal	Bcc	
Lattice Type	CaC_2	Pu_2C_3	
a_o, A	3.82	8.5478	
c_o, A	6.37	--	
Density, g/cm^3	6.00	6.902	
Melting Point, (C)	>2000	--	
Effective Magnetic Moment, Bohr magnetons	3.53	--	
Curie Temperature, K	40	--	
			170, 183
Germanides			
	$NdGe_2$		
Lattice Type	α-$ThSi_2$		
a_o, A	4.230		
c_o, A	13.920		
Volume of Unit Cell, A^3	249.9		

Halides

Authority: 93, 108, 157, 158, 181, 182, 184, 185, 186, 212, 215, 217, 235, 236, 211, 279

	$NdBr_3$	$NdCl_3$	NdF_3	NdI_3	NdOCl	NdOF
Molecular Weight	--	--	201.27	--	--	--
Structure	--	Hexagonal	Hexagonal	Orthorhombic	Tetragonal	Rhombohedral
Lattice Type	$PuBr_3$	UCl_3	--	$PuBr_3$	--	--
a_o, A	--	--	7.030	13.988	4.018	6.953
b_c A	--	--	--	4.316	--	--
c_o, A	--	--	7.200	9.977	6.782	--
β, deg	--	--	--	--	--	33.04
Density, g/cm^3	--	--	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 $P_{mm\ Hg}$	$\left[\begin{smallmatrix}12.555\\-14829/T\end{smallmatrix}\right]$	$\left[\begin{smallmatrix}12.014\\-15145/T\end{smallmatrix}\right]$	--	$\left[\begin{smallmatrix}12.475\\-14495/T\end{smallmatrix}\right]$	--	--
Heat of Sublimation, kcal/mole	67	68.8	--	--	--	--
Entropy of Sublimation, eu/mole	44	41.3	--	--	--	--

(Continued)

Authority

Halides (Continued)

	$NdBr_3$	$NdCl_3$	NdF_3	NdI_3	NdOCl	NdOF
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 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.

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

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

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

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

Reaction	Temperature Range, K	$-\Delta H_{F298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, 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
$Nd(\ell) + 3/2\ F_2(g) = NdF_3(s)$	1297 - 1683	--	--	-0.9	7.7	--	1.2	-2.981	58.2	57.3
$Nd(\ell) + 3/2\ F_2(g) = NdF_3(\ell)$	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
$Nd(s) + 3/2\ Cl_2(g) = NdCl_3(\ell)$	1033 1297	--	--	12.2	-5.7	--	1.0	2.528	123.7	135.9
$Nd(\ell) + 3/2\ Cl_2(g) = NdCl_3(\ell)$	1297 1960	--	--	8.8	-0.4	--	1.0	0.012	107.6	116.4
$Nd(\ell) + 3/2\ Cl_2(g) = NdCl_3(g)$	1960 2500	--	--	-2.2	-0.4	--	1.0	67.57	0.8	-1.4

Hydrides

Authority: 91, 165, 186, 187

	NdH_2	NdH_3
Structure	Fluorite	Fluorite
a_o, A	5.464	--
Density, g/cm^3	5.94	--
Heat of Formation, kcal/mole H_2	44.8	--
Entropy of Formation, eu/mole H_2	43	--
Color	--	Indigo blue
Dissociation Rate (log P)	$\begin{bmatrix} 9.370 \\ -9796/T \end{bmatrix}$	--

Nitrides

Authority: 149, 153, 223

	NdN
Molecular Weight	158.28
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.151
Density, g/cm^3	7.691
Resistivity, microhm-cm	75
Temperature Coefficient of Resistivity (80-500 K), $10^{-3}/C$	0.70
Magnetic Susceptibility, 10^{-6} emu/mole	5850
Effective Magnetic Moment, Bohr magnetons	3.71

(Continued)

		Authority
Nitrides (Continued)		
	NdN	
Color	Black	
Curie Temperature, K	19	
Oxides		156, 172, 173, 176, 177
	Nd_2O_3	
Molecular Weight	336.48	
Structure	Hexagonal	
a_o, A	3.831	
c_o, A	5.999	
Density, g/cm^3	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 magnetons	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	$-\Delta H_{T298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$2Nd(s) + 3/2O_2(g) = Nd_2O_3(s)$	298 - 1297	428.6	409.5	4.12	-0.51	--	-1.3	-1.964	95.6	101.0
$2Nd(\beta) + 3/2O_2(g) = Nd_2O_3(s)$	1297 - 2500	--	--	1.9	2.7	--	-1.3	-6.997	63.4	61.8

Authority

Thermodynamic Functions for Neodymium Oxide 174

T, K	C_p, cal/(mole)(K)	$S_T - S_{16}$, cal/(mole)(K)	$H_T - H_{16}$, cal/mole	$-(F_T - H_{16})/T$, cal/(mole)(K)
16	1.988			
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	26.59	33.607	4970.9	16.935
300	26.65	33.774	5019.4	17.043

186

T, K	C_p, cal/(K)(1/2 mole)
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) 175
Neodymium Oxide

T, K	$H_T - H_{298.15}$, cal/mole	$S_T - S_{298.15}$, cal/(mole)(K)
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(α)	48.98(α)
1395	36,350(β)	49.08(β)
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

	NdP
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.838

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

	NdSe	$NdSe_2$	Nd_2Se_3	Nd_3Se_4	Nd_2O_2Se
Structure	Fcc	Tetragonal	Bcc	Bcc	Hcp
Lattice Type	NaCl	--	Th_3P_4	Th_3P_4	--
a_o, A	5.879	8.33	8.841	8.859	3.97
c_o, A	--	8.41	--	--	6.97

(Continued)

Selenides (Continued)

	$NdSe$	$NdSe_2$	Nd_2Se_3	Nd_3Se_4	Nd_2O_2Se	Authority
Density, g/cm^3	6.93	6.83	6.69	7.15	6.99	
Resistivity, microhm-cm	50	--	--	--	--	
Temperature Coefficient of Resistivity, $10^{-3}/C$	0.8	--	--	--	--	
Thermal Conductivity, cal/(cm)(sec)(C)	0.013	--	--	--	--	
Magnetic Susceptibility, 10^{-6} emu/mole	4780	4763	4685	--	--	
Effective Magnetic Moment, Bohr magnetons	3.4	3.4	3.58	--	--	
Color	--	--	Violet	--	Bluish white	

Silicides

	α-$NdSi_2$	β-$NdSi_2$	Authority
Molecular Weight	200.45	200.45	
Structure	Orthorhombic	Tetragonal	
Lattice Type	α-YSi_2	α-$ThSi_2$	
a_o, A	4.18	4.103	
b_o, A	4.15	--	
c_o, A	13.56	13.53	
Density, g/cm^3	5.62	5.84	
Melting Point, C	--	1525	152, 153, 160

(Continued)

Silicides (Continued)

	α-$NdSi_2$	β-$NdSi_2$	Authority
Resistivity, microhm-cm	349	--	
Transition Temperature, C	$\alpha \rightarrow \beta$ at 20 to 150		
Transverse Rupture Strength, 10^3 psi	8.5	--	

Sulfides 153, 186, 193, 198, 200, 230, 241

	NdS	NdS_2	γNd_2S_3	Nd_3S_4	Nd_2O_2S
Molecular Weight	176.34	208.39	384.74	561.07	352.61
Structure	Cubic	Cubic	Cubic	Cubic	Hexagonal
a_o, A	5.690	8.04	8.527	8.524	3.946
c_o, A	--	--	--	--	6.790
Density, g/cm^3	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	--	7×10^{13}	1.2×10^6	--
Temperature Coefficient of Resistivity, 10^{-3}/C	1.4	--	--	--	--

(Continued)

Sulfides (Continued)

	NdS	NdS_2?	γNd_2S_3	Nd_3S_4	Nd_2O_2S	Authority
Coefficient of Thermal Expansion (20-1000 C), 10^{-6}/C	15.35	--	12.90	--	--	
Thermal Conductivity, cal/(cm)(sec)(C)	0.046	--	0.0092	--	--	
Magnetic Susceptibility, 10^{-6} 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

	NdTe	$NdTe_2$	Nd_2Te_3	Nd_3Te_4	Nd_2O_2Te	202, 205, 228, 229, 232, 246
Structure	Fcc	Tetragonal	Orthorhombic	Bcc	Hexagonal	
Lattice Type	NaCl	Fe_2As	--	Th_3P_4	--	
a_o, A	6.249	4.41	12.12	9.438	4.03	
b_o, A	--	--	11.93	--	--	
c_o, A	--	9.04	4.37	--	12.77	
Density, g/cm^3	--	--	6.65	6.8	7.18	

(Continued)

Authority

Tellurides (Continued)

	$NdTe$	$NdTe_2$	Nd_2Te_3	Nd_3Te_4	Nd_2O_2Te
Melting Point, C	--	--	1650	1685	--
Resistivity, microhm-cm	40	--	1.7×10^3	350	--
Color	--	--	--	--	Green

Miscellaneous 150

	Structure	a_o, A	c_o, A	Curie Temperature, K
$NdIr_2$	Cubic	7.605	--	11.8
$NdOs_2$	Hexagonal	5.368	8.945	27.5
$NdPt_2$	Cubic	7.694	--	6.7
$NdRh_2$	Cubic	7.564	--	8.1
$NdRu_2$	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.

		Authority
PHYSICAL PROPERTIES		
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
ALL OTHER PROPERTIES		
Metallic Radius	(1.810) A	67
Stable Oxidation State	+3	67
Ionic Radius (Trivalent Ion)	0.979 A	55
Compressibility	3.06×10^{-6} cm^2/kg	89
Crystal Structure	Fcc	91
Preparation of Metallic Pm	(See reference)	102

Authority

Isotopes 58

Whole Number Mass	Relative Abundance per cent	Half Life	Decay Mode
144	0.0	200 days	K, γ
147	0.0	3.7 yr	β^-
148	0.0	5.3 days	β^-, γ
149	0.0	47 hr	β^-, γ
151	0.0	12 min	β^-
153	0.0	<5 min	β^-
156	0.0	<5 min	β^-

	Room Temperature	Melting Point	
Entropy	$S_{298} = (17.2)$	$S_{1300} = (28.17)$ eu	76, 77
Heat Capacity	$C_{p298} = (6.50)$	$C_{p1300} = (8.98)$ cal/(mole)(C)	

Heat Content and Entropy of Solid and Liquid Promethium

(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	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	10.26	2800	22,760	19.42
1300(s)	7,760	10.97	3000	24,360	19.99

For solid promethium:

$H_T - H_{298.15} = 5.76T + 1.24 \times 10^{-3}T^2 - 1,828$
(0.2 per cent; 298-1,300 K;
$C_p = 5.76 + 2.48 \times 10^{-3}T$;
ΔH_{1300}(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 — $PmBe_{13}$ — 179

a_o, A: 10.33

Bismuthides

Borides

Carbides

Germanides

Halides — 93, 236, 276

	$PmBr_3$	$PmCl_3$	PmF_3	PmI_3	α-PmOF	β-PmOF
Structure	--	Hexagonal	Hexagonal	--	Fcc	Tetragonal
a_o, A	--	7.397	6.96	--	5.56	3.95
c_o, 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

Authority: 156, 172, 276

Pm_2O_3

Type:	A	B	C
Structure	Hexagonal	Monoclinic	Cubic
a_o, A	3.806	14.15	10.99
b_o, A	--	3.69	--
c_o, 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^3	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)	$\text{Log } P_{mmHg} = 8.781 - \frac{10784}{T}$	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		

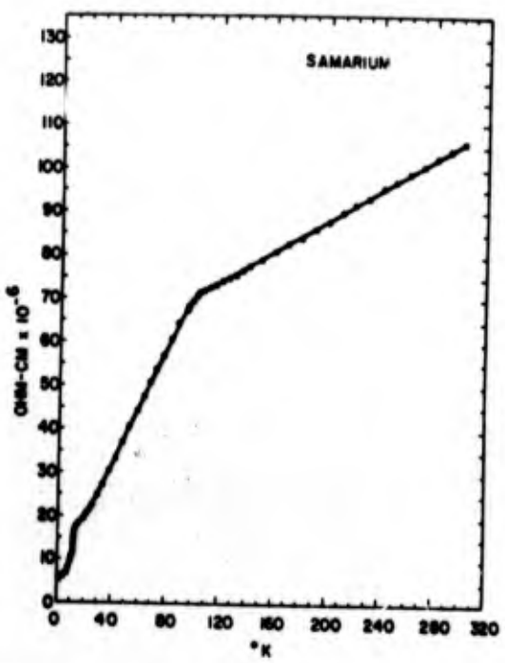
				Authority
CRYSTAL PROPERTIES				
Structure	Rhombohedral	BCC		61
Lattice Constants	a_o = 8.966 α = 23° 13'	a_o = 4.07 A --		61
Density	7.536	--	g/cm^3	66
Metallic Radius	1.802	1.81 A		67
Atomic Volume	19.0	--	cm^3/mole	56
Transition Temperature	917 C			66
Heat of Transition	0.744 kcal/mole			61
Ionic Radius	+2 = 1.16, +3 = 0.964 A			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^{+3} + $3e^-$] + 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

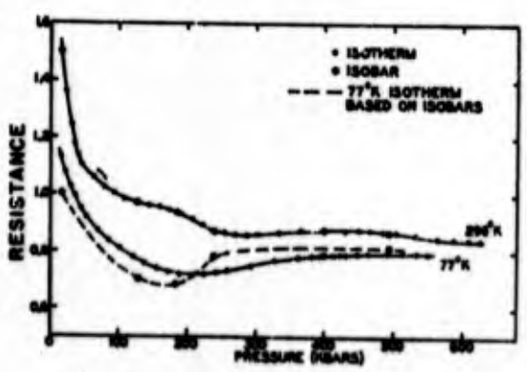
ELECTRICAL PROPERTIES

Resistivity (25 C)	88 microhm-cm	61
Temperature Coefficient of Resistivity	1.48×10^{-3}/C	61

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



Resistance Versus Pressure
(Permission of the American Physical Society) 96



		Authority
MAGNETIC PROPERTIES		
Susceptibility (25 C)	1275 x 10^{-6} 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
MECHANICAL PROPERTIES		
Young's Modulus	3.41 x 10^{11} dynes/cm^2	57
Shear Modulus	1.26 x 10^{11} dynes/cm^2	57
Poisson's Ratio	0.352	61
Compressibility	2.56 x 10^{-6} cm^2/kg	57
Hardness (DPH)	45	57

	70 F	400 F	800 F		
Tensile Strength	18.0	21.0	12.0	10^3 psi	88
Yield Strength	16.2	17.9	11.0	10^3 psi	88
Elongation	3	10.4	5.6	per cent	88

Ultimate Compressive Strength	47.6 x 10^3 psi	61
Impact Strength (Izod)	0.53 ft-lb	71
Workability		
General Fabrication	(See references)	70, 113

Authority

NUCLEAR PROPERTIES

Isotopes 58, 105

Whole Number Mass	Relative Abundance, per cent	Half Life	Decay Mode
144	3.16	Stable	--
145	--	70 days	K, γ, e^-
147	15.07	Stable	--
148	11.27	Stable	--
149	13.84	Stable	--
150	7.47	Stable	--
151	--	20 yr	β^-
152	26.63	2.5×10^{11} yr	α
153	--	47 hr	β^-, γ, e^-
154	22.53	Stable	--
155	--	25 min	β^-, γ
156	--	10 hr	β^-

Thermal Neutron Cross Section: 5500 ± 200 barns/atom or 22 cm^2/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	$S_{298} = 16.64$	$S_{1345} = 31.67$ eu	95
Heat Capacity	$C_{p298} = 6.76$	$C_{p1345} = 11.22$ cal/(mole)(C)	

Authority

NUCLEAR PROPERTIES

Isotopes

58, 105

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144	3.16	Stable	--
145	--	70 days	K, γ, e^-
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148	11.27	Stable	--
149	13.84	Stable	--
150	7.47	Stable	--
151	--	20 yr	β^-
152	26.63	2.5×10^{11} yr	α
153	--	47 hr	β^-, γ, e^-
154	22.53	Stable	--
155	--	25 min	β^-, γ
156	--	10 hr	β^-

Thermal Neutron Cross Section: 5500 ± 200 barns/atom or 22 cm^2/g — 73

SAFETY

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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

95

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

Authority

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Thermodynamic Functions

T, K	C_p, joules/ mole-K	S^o, joules/ mole-K	$\frac{H^o-H_o^o}{T}$, joules/ mole-K	$\frac{F^o-H_o^o}{T}$, joules/ mole-K
20.0	7.23	5.495	3.731	1.764
25.0	10.05	7.410	4.710	2.699
30.0	13.00	9.506	5.848	3.657
35.0	15.77	11.724	7.071	4.653
40.0	18.28	13.999	8.318	5.680
45.0	20.55	16.289	9.554	6.735
50.0	22.57	18.561	10.756	7.804
55.0	24.45	20.802	11.917	8.885
60.0	26.20	23.006	13.035	9.970
65.0	27.79	25.167	14.110	11.056
70.0	29.32	27.283	15.143	12.140
75.0	30.75	29.355	16.136	13.219
80.0	32.21	31.386	17.095	14.291
85.0	33.68	33.384	18.028	15.355
90.0	35.09	35.350	18.938	16.412
95.0	36.42	37.281	19.821	17.459
100.0	37.98	39.189	20.690	18.498
102.0	38.86	39.949	21.038	18.911
104.0	40.33	40.715	21.391	19.323
104.2	40.57	40.792	21.428	19.364
104.4	40.82	40.870	21.465	19.405
104.6	41.16	40.949	21.502	19.446
104.8	41.68	41.028	21.540	19.487
105.0	42.04	41.108	21.579	19.528
105.2	42.17	41.188	21.618	19.570
105.4	41.74	41.268	21.657	19.611
105.6	39.98	41.346	21.694	19.652
105.8	37.45	41.419	21.725	19.693
106.0	34.14	41.486	21.752	19.734
106.5	29.51	41.633	21.796	19.837
107.0	28.43	41.769	21.829	19.939
107.5	27.97	41.900	21.859	20.041
108.0	27.66	42.029	21.887	20.142
110.0	27.12	42.531	21.986	20.545
115.0	26.61	43.723	22.196	21.527
120.0	26.37	44.850	22.374	22.475
130.0	26.23	46.955	22.677	24.278
140.0	26.22	48.898	22.930	25.968
150.0	26.29	50.708	23.152	27.556
160.0	26.42	52.409	23.352	29.056
170.0	26.57	54.016	23.537	30.478
180.0	26.71	55.538	23.710	31.828
190.0	26.86	56.986	23.872	33.114
200.0	27.07	58.3[illegible]	24.027	34.342
210.0	27.27	59.695	24.177	35.518
220.0	27.48	60.969	24.322	36.646
230.0	27.71	62.195	24.464	37.730
240.0	27.93	63.379	24.604	38.774
250.0	28.22	64.525	24.743	39.781
260.0	28.49	65.638	24.883	40.755
270.0	28.70	66.717	25.020	41.698
273.15	28.78	67.050	25.063	41.987
280.0	28.98	67.765	25.156	42.608
290.0	29.28	68.788	25.293	43.494
298.15	29.53	69.603	25.406	44.196
300.0	29.58	69.786	25.432	44.354
310.0	29.88	70.761	25.570	45.190
320.0	30.17	71.714	25.710	46.004
330.0	30.45	72.647	25.849	46.797
340.0	30.73	73.560	25.989	47.571
350.0	31.00	74.455	26.128	48.326
360.0	31.27	75.331	26.267	49.064

(Continued)

Authority

Thermodynamic Functions (Continued)

95

T, K	C_p, cal/(K)(mole)	$S^o - S^o_o$, cal/(K)(mole)	$\frac{H^o - H^o_{298.15}}{T}$ [a] cal/(K)(mole)	$-\frac{F^o - H^o_{298.15}}{T}$, 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	1.064	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) $(H^o_{298.15} - H^o_o)/T = 6.07$ cal degree^{-1} mole^{-1} unpublished value according to Jennings, Hill and Spedding.

Specific Heat

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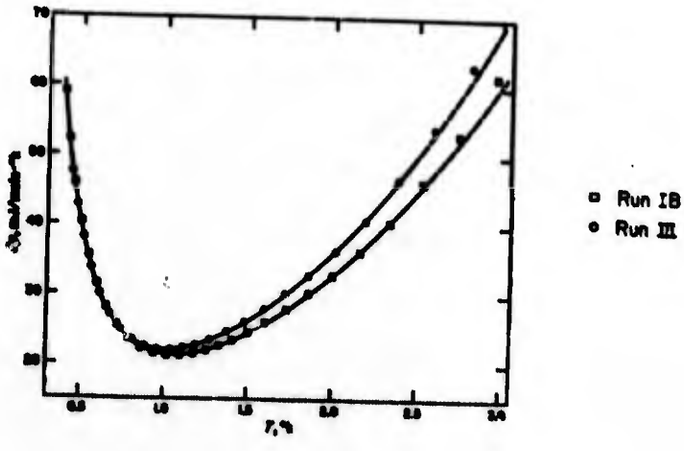


SAMARIUM COMPOUNDS

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

Borides

	SmB_4	SmB_6	Authority
Molecular Weight	193.71	215.35	153, 171
Structure	Tetragonal	Cubic	
a_o, A	7.174	4.131	
c_o, A	4.070	--	
Density, g/cm^3	6.19	5.08	
Melting Point, C	--	1810	
Resistivity, microhm-cm	--	200	
Temperature Coefficient of Resistivity, 10^{-3}/C	--	-4.2	
Coefficient of Thermal Expansion, 10^{-6}/C	--	6.5	
Thermal Conductivity, cal/(cm)(sec)(C)	--	0.033	
Magnetic Susceptibility, 10^{-6} emu/mole	--	1810	
Effective Magnetic Moment, Bohr magnetons	--	2.52	
Work Function, ev	--	4.4	
Microhardness, kg/mm^2	--	2500	
Color	Gray brown	Dark blue	
Emissivity (λ = 0.655 μ)	--	0.68	
Effective Metallic Radius, A	--	2.19	

Authority

Carbides 153

	SmC_2	Sm_2C_3	Sm_3C
Molecular Weight	174.45	366.86	463.29
Structure	Body-centered tetragonal	Bcc	Cubic
Lattice Type	CaC_2	Pu_2C_3	Fe_4N
a_o, A	3.76	8.4257	5.172
c_o, A	6.29	--	--
Density, g/cm^3	6.50	7.477	8.139
Melting Point, C	>2200	--	--
Magnetic Susceptibility, 10^{-6} emu/mole	~2300	--	--
Effective Magnetic Moment, Bohr magnetons	2.85	--	--

Germanides 170, 183

	$SmGe_2$
Lattice Type	α-$ThSi_2$
a_o, A	4.193
c_o, A	13.835
Volume of Unit Cell, A^3	241.4

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

	$SmBr_2$	$SmCl_2$	SmF_2	SmI_2	$SmBr_3$	$SmCl_3$	SmF_3	SmI_3
Molecular Weight	--	--	--	--	--	--	207.35	--
Structure	--	Ortho-rhombic	--	--	--	Hexagonal	Hexagonal, Orthorhombic	Hexagonal
a_o, A	--	8.973	--	--	--	7.378	Hex 6.956 Ortho. 6.669	4.415
b_o, A	--	7.532	--	--	--	--	Ortho. 7.059	--
c_o, A	--	4.497	--	--	--	4.171	Hex. 7.120 Ortho. 4.405	6.976
Density, g/cm^3	--	--	--	--	--	--	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)	--	--	(62)	--
Entropy of Vaporization, eu/mole	(23)	25.4	(29)	(22)	--	--	(24)	--
Color	--	--	--	--	--	--	White	--
Volume of Unit Cell, A^3	--	--	--	--	--	--	Hex. 298.3 Ortho. 207.4	--

(Continued)

Halides (Continued)

Authority

	SmOCl	SmOF	SmOI
Structure	Tetragonal	Rhombohedral	Tetragonal
Lattice Type	--	--	PbFCl
a_o, A	3.982	6.857	4.008
c_o, A	6.721	--	9.192
β, deg	--	33.07	--
Density, g/cm^3	--	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	$-\Delta H_{F298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$Sm(c) + F_2(g) = SmF_2(c)$	298-1623	237	225	0.7	3.8	--	0.8	-0.110	64.3	65.0
$Sm(l) + F_2(g) = SmF_2(c)$	1623-1650	--	--	-1.6	7.2	--	0.8	-4.555	35.1	33.5
$Sm(l) + F_2(g) = SmF_2(l)$	1650-2500	--	--	6.2	-0.4	--	0.8	-3.080	77.9	84.1
$Sm(c) + \frac{3}{2}F_2(g) = SmF_3(c)$	298-1623	405	387	1.1	5.3	--	1.2	-0.152	66.3	67.4
$Sm(l) + \frac{3}{2}F_2(g) = SmF_3(c)$	1623-1670	--	--	-1.2	8.7	--	1.2	-4.997	57.1	55.9
$Sm(l) + \frac{3}{2}F_2(g) = SmF_3(l)$	1670-2500	--	--	9.6	-0.7	--	1.2	-1.425	117.3	126.9
$Sm(c) + Cl_2(g) = SmCl_2(c)$	298-1013	195.6	187.1	0.8	5.1	--	0.6	-0.257	42.7	43.6
$Sm(c) + Cl_2(g) = SmCl_2(l)$	1013-1623	--	--	9.3	-3.7	--	0.6	1.446	98.1	97.7
$Sm(l) + Cl_2(g) = SmCl_2(l)$	1623-1700	--	--	7.2	-0.3	--	0.6	-2.999	78.9	86.2
$Sm(l) + Cl_2(g) = SmCl_2(g)$	1700-2500	--	--	-2.8	-0.3	--	0.6	55.00	-19.5	-22.2
$Sm(c) + \frac{3}{2}Cl_2(g) = SmCl_3(g)$	298-951	260	252	2.5	6.6	--	1.0	-0.694	69.4	71.9
$Sm(c) + \frac{3}{2}Cl_2(g) = SmCl_3(l)$	951-1623	--	--	11.7	-3.8	--	1.0	3.260	116.2	128.9
$Sm(l) + \frac{3}{2}Cl_2(g) = SmCl_3(l)$	1623-1830	--	--	9.4	-0.4	--	1.0	-1.185	105.0	119.4
$Sm(l) + \frac{3}{2}Cl_2(g) = SmCl_3(g)$	1830-2500	--	--	-2.1	-0.4	--	1.0	66.86	-7.1	-9.2

Hydrides

	SmH_2	SmH_3	Authority
Structure	Fluorite	Hexagonal	165, 187
a_o, A	5. 374	3. 782	
c_o, A	--	6. 779	
Density, g/cm^3	6. 52	--	

Nitrides

	SmN	Authority
Molecular Weight	164. 44	153, 223
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	5. 046	
Density, g/cm^3	8. 495	
Magnetic Susceptibility, 10^{-6} emu/mole	1125	

Oxides

	SmO	α-Sm_2O_3	β-Sm_2O_3	Authority
Molecular Weight	--	348. 70	348. 70	172,176, 177,186, 247,271
Structure	Cubic	Monoclinic	Cubic	
Lattice Type	NaCl	--	--	
a_o, A	4. 988	--	10. 90	
b_o, A	--	--	--	
c_o, A	--	--	--	
β, deg	--	--	--	

(Continued)

Authority

Oxides (Continued)

	SmO	α-Sm_2O_3	β-Sm_2O_3
Density, g/cm^3	--	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, $10^{-6}/C$	--	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:

Reaction	Temperature Range, K	$-\Delta H_{f298}$, kcal/mole	$-\Delta F_{298}$, kcal/mole	Δa	Δb	Δc	Δd	ΔA, kcal/mole	$-\Delta B$, eu	$-\Delta(B-a)$
$2Sm(s) + \frac{3}{2} O_2(g) = Sm_2O_3(s)$	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)

Authority

Oxides (Continued)

Heat Content and Entropy Increments for Samarium Oxide (Smooth Values) 175

	Monoclinic Form (Sm_2O_3)		Cubic Form (Sm_2O_3)	
T, K	$H_T - H_{298.15}$, 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	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

	SmP
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.760
Magnetic Susceptibility, 10^{-6} emu/mole	1112

Selenides

Authority: 168,189, 191,192, 194,225, 226,227, 228

	$SmSe$	$SmSe_2$	Sm_2Se_3	Sm_3Se_4	Sm_2O_2Se
Structure	Fcc	Tetragonal	Bcc	Bcc	Hcp
Lattice Type	NaCl	--	Th_3P_4	Th_3P_4	--
a_o, A	6.159	8.16	8.76	8.84	3.93
c_o, A	--	8.36	--	--	6.93
Density, g/cm^3	6.42	6.94	6.93	7.33	7.40
Melting Point, C	(2100)	--	(1540)	--	--
Resistivity, microhm-cm	1.38×10^9	--	1.7×10^3	--	--
Magnetic Susceptibility, 10^{-6} emu/mole	4440	1200	1049	--	--
Effective Magnetic Moment, Bohr magnetons	3.3	1.6	1.6	--	--
Color	--	--	Dark gray	--	Gray

Silicides

153, 160

	α-$SmSi_2$	β-$SmSi_2$
Molecular Weight	206.61	206.61
Structure	Orthorhombic	Tetragonal
Lattice Type	α-YSi_2	α-$ThSi_2$
a_o, A	4.105	4.041
b_o, A	4.035	--
c_o, A	13.46	13.33
Density, g/cm^3	6.13	6.26
Transition Temperature, C	$\alpha \rightarrow \beta$ at 380	

Sulfides

	SmS	SmS_2	γSm_2S_3	Sm_3S_4	Sm_2O_2S	Authority
Molecular Weight	182.50	214.55	397.06	579.55	364.93	153,169, 240,248
Structure	Fcc	Cubic	Cubic	Cubic	Hexagonal	
Lattice Type	NaCl	Unknown	Th_3P_4	Th_3P_4	--	
a_o, A	5.967	7.87	8.448	8.556	3.893	
c_o, A	--	--	--	--	6.717	
Density, g/cm^3	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	8.5×10^4	7.1×10^{11}	8.2×10^{13}	5.9×10^6	--	
Thermal Conductivity, 10^{-3} cal/(cm)(sec)(C)	7.0	--	--	--	--	
Magnetic Susceptibility, 10^{-6} emu/mole	5070	1238	1020	2350	1020	
Effective Magnetic Moment, Bohr magnetons	4.34	--	--	--	--	
Color	Black	Brown	Yellow	Black	Gray brown	

Tellurides

Authority: 169,202, 205,228

	$SmTe$	Sm_2Te_3	Sm_2O_2Te
Structure	Fcc	Bcc	Hexagonal
Lattice Type	NaCl	Th_3P_4	--
a_o, A	6.58	9.480	4.00
c_o, A	--	--	12.61
Density, g/cm^3	--	7.11	7.58
Melting Point, C	1920	(1475)	--
Resistivity, microhm-cm	1.64×10^9	--	--
Magnetic Susceptibility, 10^{-6} emu/mole	4292	--	--
Effective Magnetic Moment, Bohr magnetons	4.33	--	--
Color	--	--	Dark green

Miscellaneous

150

	Structure	a_o, A	c_o, A
$SmOs_2$	Hexagonal	5.336	8.879

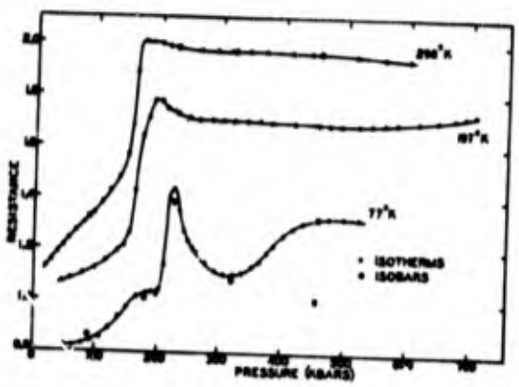
EUROPIUM

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^3	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)	32×10^{-6}/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		

		Authority
CRYSTAL PROPERTIES		
Structure	Bcc	61
Lattice Constants	a_o = 4.5820 A	61
Density	5.245 g/cm^3	67
Metallic Radius	2.042 A	67
Atomic Volume	28.91 cm^3/mole	66
Transition Temperature	None	66
Heat of Transition	None	66
Ionic Radius (Trivalent Ion)	0.950 A	55
Closest Approach of Atoms	3.960 A	56
Allotropic Modifications		
CHEMICAL PROPERTIES		
Stable Oxidation State	+2, +3	81
Electrode Potential	[Eu = Eu^{+3} + 3e$^-$] + 2.2 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 microhm-cm	61
Temperature Coefficient of Resistivity (25 C)	4.80 x 10^{-3}/C	61

		Authority
Resistance Versus Pressure (Permission of the American Physical Society)		96



MAGNETIC PROPERTIES

Susceptibility (25 C)	33,100 x 10^{-6} 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

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

Thermal Neutron Cross Section: 4600 ± 200 barns/atom or 18 cm^2/g 73

SAFETY 83

Details unknown.

Authority

THERMODYNAMIC PROPERTIES

	Room Temperature	Melting Point	
Entropy	$S_{298} = 17.0$	$S_{1100} = 26.18$ eu	76, 77
Heat Capacity	$C_{p298} = 6.40$	$C_{p1100} = 8.99$ cal/(mole)(C)	

Heat Content and Entropy of Solid and Liquid Europium 77

(Base: crystals at 298.15 K)

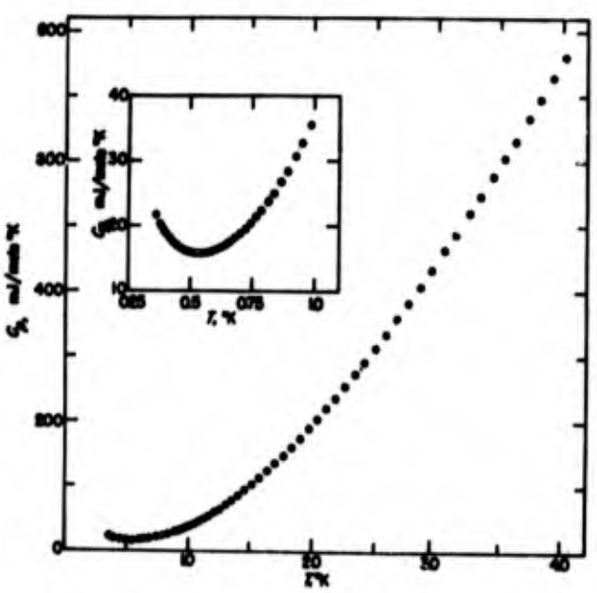
T, K	$H_T - H_{298.15}$, cal/mole	$S_T - S_{298.15}$, cal/(deg)(mole)	T, K	$H_T - H_{298.15}$, cal/mole	$S_T - S_{298.15}$, cal/(deg)(mole)
400	660	1.91	1100(l)	8,270	11.45
500	1,330	3.40	1200	9,070	12.15
600	2,020	4.66	1300	9,870	12.79
700	2,730	5.76	1400	10,670	13.38
800	3,460	6.73	1500	11,470	13.93
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}(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 97

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



EUROPIUM COMPOUNDS

		Authority
Antimonides		
Arsenides		
Beryllides	$EuBe_{13}$	179
a_o, A	10.288	
Bismuthides		
Borides	EuB_6	153, 171, 249
Molecular Weight	216.92	
Structure	Cubic	
a_o, A	4.178	
Density, g/cm^3	4.938	
Melting Point, C	2200	
Resistivity, microhm-cm	84.7	
Temperature Coefficient of Resistivity, $10^{-4}/C$	9.0	
Coefficient of Thermal Expansion, $10^{-6}/C$	6.86	
Thermal Conductivity cal/(cm)(sec)(C)	0.055	
Work Function, ev	4.9	
Color	Blue black	
Emissivity (λ = 0.655 μ)	0.83	
Effective Metallic Radius, A	2.21	

		Authority
Carbides		
Germanides		
Lattice Type	AlB_2 defect	183
a_o, A	4.09	
c_o, A	4.99	
Volume of Unit Cell, A^3	72.79	

Halides

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

	$EuBr_2$	$EuCl_2$	EuF_2	EuI_2	$EuBr_3$	$EuCl_3$	EuF_3	EuI_3
Structure	--	Orthorhombic	Cubic	--	Orthorhombic	Hexagonal	Hex. Ortho.	--
a_o, A	--	8.914	5.796	--	12.712	7.369	Hex. 6.916 Ortho 6.622	--
b_o, A	--	7.499	--	--	4.019	4.133	7.019	--
c_o, A	--	4.493	--	--	9.128		Hex. 7.091 Ortho 4.396	--
Density, cm^3	--	--	--	--	--	--	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, A^3	--	--	--	--	--	--	Hex. 293.7 Ortho. 204.3	--

(Continued)

			Authority
Halides (Continued)			211, 279
	EuOCl	**EuOF**	
Structure	Tetragonal	Rhombohedral	
a_o, A	3.965	6.827	
c_o, A	6.695	--	
β, deg	--	33.05	
Volume of Unit Cell, A^3	105.25	--	
Hydrides	**EuD_2**		251
Structure	Orthorhombic		
a_o, A	6.21		
b_o, A	3.77		
c_o, A	7.16		
Nitrides	**EuN**		153, 169
Structure	Cubic		
Lattice Type	NaCl		
a_o, A	5.014		
Density, g/cm^3	8.767		
Color	Black		

Oxides

	EuO	a-Eu_2O_3	β-Eu_2O_3	Eu_3O_4	Ortho I ($Eu_{16}O_{21}$)
Molecular Weight	--	382.52	382.52	--	--
Structure	Fcc	Bcc	Monoclinic	Orthorhombic	Orthorhombic
a_o, A	5.142	10.869	14.082	10.085	9.75
b_o, A	--	--	3.640	12.054	49.5
c_o, A	--	--	8.788	3.502	5.63
β, deg	--	--	100.0	--	--
Density, g/cm^3	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^{-6}/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

Authority

172, 177, 252, 253, 271

(Continued)

Authority

Oxides (Continued)

Heat Content and Entropy Increments for Europium Oxide (Eu_2O_3) (Smooth Values)

	Monoclinic Form		Cubic Form	
T, K	$H_T-H_{298.15}$, 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(α)	35.37(α)	--	--
895	19,640(β)	35.51(β)	--	--
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	EuSe	189, 194, 254
Structure	Fcc	
Lattice Type	NaCl	
a_o, A	6.178	
Density, g/cm^3	6.42	
Magnetic Susceptibility, 10^{-6} emu/mole	2286	
Effective Magnetic Moment, Bohr magnetons	7.65	
Color	Dark brown	
Curie Temperature, K	6	
Silicides	β-$EuSi_2$	153, 160
Molecular Weight	208.18	
Structure	Tetragonal	
Lattice Type	α-$ThSi_2$	
a_o, A	4.29	
c_o, A	13.66	
Density, g/cm^3	5.50	
Melting Point, C	1500	
Transition Temperature, C	$\alpha \rightarrow \beta$ at - 150	

Sulfides — Authority: 254, 255

	EuS	Eu_2S_3	$Eu_2S_{3.81}$	Eu_3S_4	Eu_2O_2S
Structure	Fcc	--	Tetragonal	Cubic	Hexagonal
Lattice Type	NaCl	--	--	Th_3P_4	--
a_o, A	5.970	8.415	7.86	8.537	3.87
c_o, A	--	--	8.03	--	6.68
Density, g/cm^3	5.745	--	5.70	6.27	7.04
Magnetic Susceptibility, 10^{-6} (emu/mole)	22600	--	5800	11500	--
Color	Black	--	--	Black	Pink
Curie Temperature, K	16	--	--	--	--

Tellurides — Authority: 169, 202, 254, 280

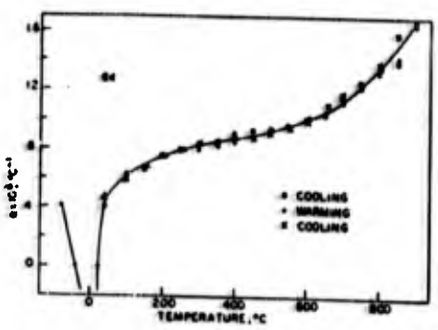
	EuTe	Eu_2O_2Te
Structure	Fcc	Hexagonal
Lattice Type	NaCl	--
a_o, A	6.585	3.98
c_o, A	--	12.57
Density, g/cm^3	--	7.74
Color	Black	Maroon
Néel Temperature, K	6	--

GADOLINIUM

Symbol Gd | Atomic Number 64 | Atomic Weight 157.26

PHYSICAL PROPERTIES

		Authority
Abundance	4.5-6.4 ppm (approx. 6.4)	51
Density	7.886 g/cm^3	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 x 10^{-6}/C (25-950 C)	61



53

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

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

CRYSTAL PROPERTIES

Structure	HCP	BCC	
Lattice Constants	a_o = 3.6360 c_o = 5.7826	a_o = 4.06 A -- A	61 61
Density	7.886	-- g/cm^3	67
Metallic Radius	1.802	-- A	67
Atomic Volume	19.88	20.2 cm^3/mole	66
Transition Temperature	1262 C		66
Heat of Transition	1.03 kcal/mole		61
Ionic Radius			
Closest Approach of Atoms	3.554 A		56
Allotropic Modifications			

CHEMICAL PROPERTIES

Stable Oxidation State	+3	
Electrode Potential	[Gd = Gd^{+3} + 3$\bar{e}$] + 2.2 volts (standard hydrogen electrode)	81
Ionization Potential	1st = 6.7 volts	81
Metallographic Polishing and Etching		82

62

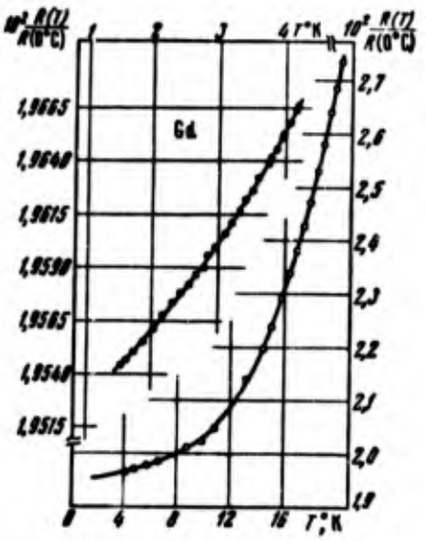
Gadolinium may be cut, mounted and prepared in a manner similar to that for any metal. As a matter of practice the authors continue to carry out the preliminary grinding and polishing operations in kerosene. The final polish may be done using water and the structure is revealed after etching with 5%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

		Authority
Corrosion Rates (In Air)	0 mil/year at 200 C 38 mil/year at 400 C 2900 mil/year at 600 C	68
Corrosion Data	Corrosive attack on crucible materials:	91

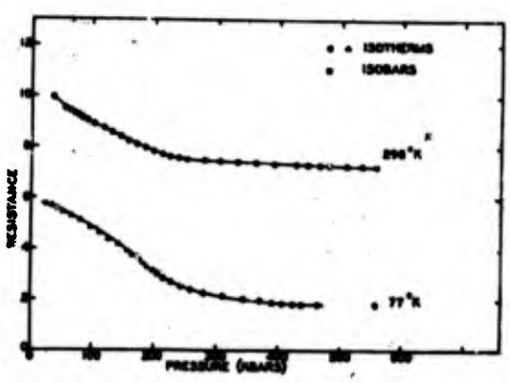
Material	Onset of Attack
MgO	None < 1300 C
Ta	None < 1300 C

ELECTRICAL PROPERTIES

Resistivity (25 C)	140.5 microhm-cm	61
Temperature Coefficient of Resistivity	1.76×10^{-3}/C	61
Resistance Versus Temperature		118



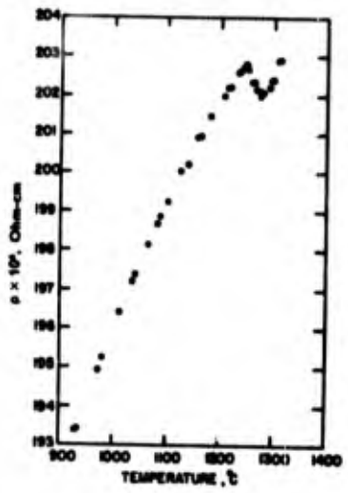
Resistance Versus Pressure (Permission of the American Physical Society) 96



Authority

Resistivity Versus Temperature

87, 117



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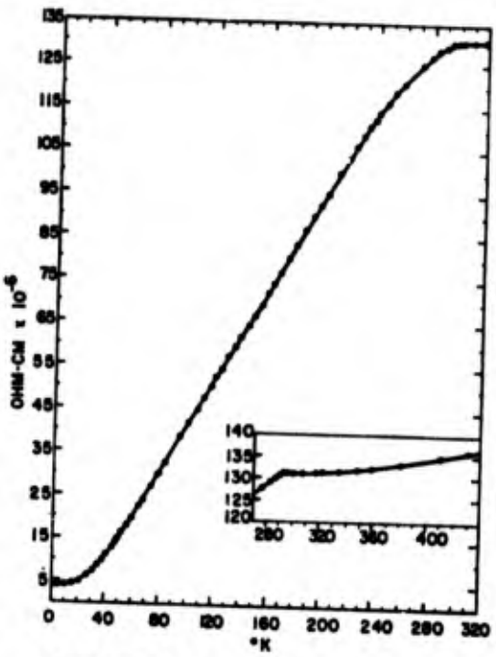

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MAGNETIC PROPERTIES

Susceptibility (25 C)	356,000 x 10^{-6} 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^{11} dynes/cm^2				57
Shear Modulus	2.23 x 10^{11} dynes/cm^2				57
Poisson's Ratio	0.259				61
Compressibility	2.52 x 10^{-6} cm^2/kg				57
Hardness (DPH)	57				57
Tensile Strength	70 F 27.6	400 F 18.0	800 F 14.1	10^3 psi	88
Yield Strength	25.1	15.6	13.0	10^3 psi	88

				Authority
	70 F	400 F	800 F	
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

Whole Number Mass	Relative Abundance, percent	Half Life	Decay Mode
152	0.20	Stable	--
153	--	72 days	e^-, 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^2/g — 73

SAFETY — 83

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 — 76, 77

	Room Temperature	Melting Point
Entropy	$S_{298} = 16.2$	$S_{1600} = 29.23$ eu
Heat Capacity	$Cp_{298} = 8.80$	$Cp_{1600} = 8.90$ cal/(mole)(C)

Authority

Heat Content and Entropy of Solid and Liquid Gadolinium

77

(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):

$C_p = 6.60 + 1.44 \times 10^{-3}\ T$;

ΔH_{1600}(fusion) = 3,700.

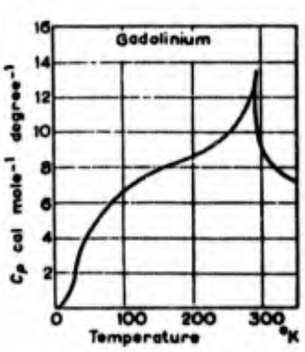
For liquid gadolinium:

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

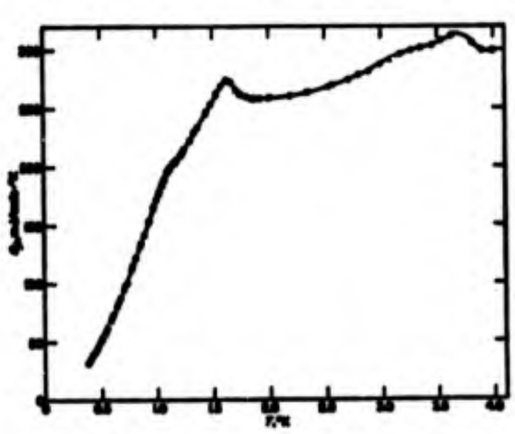
$C_p = 8.00$.

Specific Heat

53, 119



0 to 350 K



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GADOLINIUM COMPOUNDS

Antimonides

Authority: 169, 256

	GdSb	Gd_4Sb_3
Structure	Cubic	Bcc
Lattice Type	NaCl	Th_3P_4
a_o, A	6.217	9.224
Density, g/cm^3	--	--
Resistivity, microhm-cm	--	220
Magnetic Susceptibility, 10^{-6} emu/mole	25,575	--
Effective Magnetic Moment, Bohr magnetons	7.87	--

Arsenides

Authority: 168, 169

	GdAs
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.862
Melting Point, C	>2270
Magnetic Susceptibility, 10^{-6} emu/mole	27,548
Effective Magnetic Moment, Bohr magnetons	8.18

Beryllides

Authority: 179

	$GdBe_{13}$
a_o, A	10.27

Bismuthides

	GdBi	Gd_4Bi_3	Authority
Structure	Cubic	--	169, 256
Lattice Type	NaCl	--	
a_o, A	6.316	9.383	
Density, g/cm^3	--	10.09	
Resistivity, microhm-cm	--	190	
Magnetic Susceptibility, 10^{-6} emu/mole	24,038	--	
Effective Magnetic Moment, Bohr magnetons	8.20	--	
Curie Temperature, K	--	340	

Borides

	GdB_2	GdB_3	GdB_4	GdB_6	Authority
Molecular Weight	--	189.36	200.18	221.82	153, 155, 171
Structure	Hexagonal	Tetragonal	Tetragonal	Cubic	
a_o, A	3.31	3.79	7.114	4.112	
c_o, A	3.94	3.63	4.047	--	
Density, g/cm^3	--	6.03	6.446	5.30	
Melting Point, C	--	--	--	>2100	
Resistivity, microhm-cm	--	--	--	94.0	
Temperature Coefficient of Resistivity, 10^{-3}/C	--	--	--	1.40	

(Continued)

Authority

Borides (Continued)

	GdB_2	GdB_3	GdB_4	GdB_6
Coefficient of Thermal Expansion, 10^{-6}/C	--	--	--	8.68
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	--	0.049
Magnetic Susceptibility, 10^{-6} emu/mole	--	--	--	21000
Effective Magnetic Moment, Bohr magnetons	--	--	--	7.68
Work Function, ev	--	--	--	2.05
Microhardness, kg/mm^2	--	--	--	2340
Emissivity ($\lambda = 0.655\ \mu$)	--	--	--	0.65
Color	--	--	Gray brown	Blue
Effective Metallic Radius, A	--	--	--	2.18
Transverse Rupture Strength, 10^3 psi	--	--	--	30

Carbides

	GdC_2	Gd_2C_3	Gd_3C	Authority
Molecular Weight	180.9	349.8	482.7	153
Structure	Body-centered tetragonal	Bcc	Cubic	
Lattice Type	CaC_2	Pu_2C_3	Fe_4N	
a_o, A	3.718	8.3407	5.126	
c_o, A	6.275	--	--	
Density, g/cm^3	6.939	8.024	8.701	
Melting Point, C	>2200	--	--	
Effective Magnetic Moment, Bohr magnetons	7.92	--	--	
Curie Temperature, K	41.3	--	--	

Germanides

	GdGe	$GdGe_2$	Authority
Structure	Orthorhombic	--	183, 262
Lattice Type	CrB	α-$ThSi_2$	
a_o, A	4.175	4.12	
b_o, A	3.960	--	
c_o, A	10.61	13.72	
Volume of Unit Cell, A^3	175.4	232.9	

Halides

	$GdBr_3$	$BdCl_3$	GdI_3	GdI_3	GdOCl	GdOF	Authority
Structure	Hexagonal	Hexagonal	Orthorhombic	Hexagonal	Tetragonal	Rhombohedral	55, 58, 93, 108, 157, 158, 159, 182, 186, 210, 235, 236
a_o, A	4.172	7.363	6.570	4.383	3.950	6.800	
b_o, A	--	--	6.894	--	--	--	
c_o, A	6.441	4.105	4.393	6.968	6.672	--	
β, deg	--	--	--	--	--	33.05	
Density, g/cm^3	--	--	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^3	--	--	201.6	--	104.10	--	

Hydrides

	GdH_2	GdH_3	Authority
Structure	Fluorite	Hexagonal	186, 187, 251
a_o, A	5.303	3.73	
c_o, A	--	6.71	
Density, g/cm^3	7.08	--	
Heat of Formation, kcal/mole H_2	46.9	--	
Entropy of Formation, eu/mole H_2	40	--	

Nitrides

	GdN	Authority
Molecular Weight	171.27	153, 223
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	4.999	
Density, g/cm^3	9.105	
Magnetic Susceptibility, 10^{-6} emu/mole	35,600	
Effective Magnetic Moment, Bohr magnetons	8.2	
Curie Temperature, K	60	

Oxides

	α-Gd_2O_3	β-Gd_2O_3	Authority
Molecular Weight	362.50	362.50	156, 172, 173, 175, 176, 177, 247
Structure	Cubic	Monoclinic	
a_o, A	10.79	--	

(Continued)

Authority

Oxides (Continued)

	α-Gd_2O_3	β-Gd_2O_3
Density, g/cm^3	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^{-6}/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_2O_3 (Smooth Values) 175

T, K	Monoclinic Form		Cubic Form	
	$H_T-H_{298.15}$, cal/mole	$S_T-S_{298.15}$, cal/(deg)(mole)	$H_T-H_{298.15}$, cal/mole	$S_T-S_{298.15}$, 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	42.38	30,080	43.08
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	--	--

Phosphides

Authority: 169

	GdP
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.723
Magnetic Susceptibility, 10^{-6} emu/mole	28,450
Effective Magnetic Moment, Bohr magnetons	7.95

Selenides

Authority: 169, 189, 192, 227, 228, 260

	GdSe	$GdSe_2$	Gd_2Se_3	Gd_3Se_4	Gd_2O_2Se
Structure	Cubic	Orthorhombic	Bcc	Bcc	Hcp
Lattice Type	NaCl	$ThSe_2$	Th_3P_4	Th_3P_4	--
a_o, A	5.758	7.27	8.72	8.718	3.90
b_o, A	--	4.03	--	--	--
c_o, A	--	8.30	--	--	6.87
Density, g/cm^3	8.2	--	7.36	--	7.80
Melting Point, C	1865	Decomposes at >300 C	1750	(1500)	--
Resistivity, microhm-cm	72	--	1.3×10^3	1.1×10^3	--
Magnetic Susceptibility, 10^{-6} emu/mole	22,090	--	21,994	--	--
Effective Magnetic Moment, Bohr magnetons	8.20	--	--	--	--

(Continued)

Selenides (Continued)

	GdSe	$GdSe_2$	Gd_2Se_3	Gd_3Se_4	Gd_2O_2Se	Authority
Color	--	--	--	--	Beige	
Volume of Unit Cell, A^3	190.0	--	664.2	--	--	

Silicides

	α-$GdSi_2$	β-$GdSi_2$	Gd_3Si_5	Authority
Molecular Weight	213.08	213.08	--	152, 153, 160, 261
Structure	Orthorhombic	Tetragonal	Hexagonal	
Lattice Type	α-YSi_2	α-$ThSi_2$	--	
a_o, A	4.09	4.10	3.877	
b_o, A	4.01	--	--	
c_o, A	13.44	13.61	4.172	
Density, g/cm^3	6.43	6.19	--	
Melting Point, C	1540	2100	--	
Resistivity, microhm-cm	263	--	--	
Transition Temperature, C		$\alpha \rightarrow \beta$ at 400		
Transverse Rupture Strength, 10^3 psi	6.1	--	--	

Sulfides

	GdS	GdS_2	γ-Gd_2S_3	Gd_2O_2S	Authority
Molecular Weight	189.33	221.39	410.72	378.59	153, 169
Structure	Cubic	Tetragonal	Cubic	Hexagonal	
a_o, A	5.574	7.85	8.387	3.851	
c_o, A	--	7.96	--	6.667	

(Continued)

Sulfides (Continued)

	GdS	GdS_2	γ-Gd_2S_3	Gd_2O_2S	Authority
Density, g/cm^3	7.26	5.98	6.15	7.34	
Melting Point, C	--	--	1885	--	
Magnetic Susceptibility, 10^{-6} emu/mole	30,300	21,510	27,800	--	
Effective Magnetic Moment, Bohr magnetons	8.01	--	--	--	

Tellurides

	GdTe	$GdTe_2$	$GdTe_4$	Gd_2Te_3	Gd_3Te_4	Gd_2O_2Te	Authority
Structure	Fcc	Tetragonal	Rhombohedral	Tetragonal	--	Hexagonal	168, 169, 202, 228, 229, 232
Lattice Type	NaCl	--	--	--	--	--	
a_o, A	6.139	9.10	13.0	--	--	3.96	
c_o, A	--	9.30	--	--	--	12.54	
α, deg	--	--	25.5	--	--	--	
Density, g/cm^3	--	6.8	--	--	--	8.0	
Melting Point, C	1870	--	--	1505	1410	--	
Resistivity, microhm-cm	700	5.5×10^4	--	1.5×10^4	460	--	
Magnetic Susceptibility, 10^{-6} emu/mole	26,042	--	--	--	--	--	
Effective Magnetic Moment, Bohr magnetons	7.63	--	--	--	--	--	
Color	--	--	--	--	--	Brown	

Miscellaneous

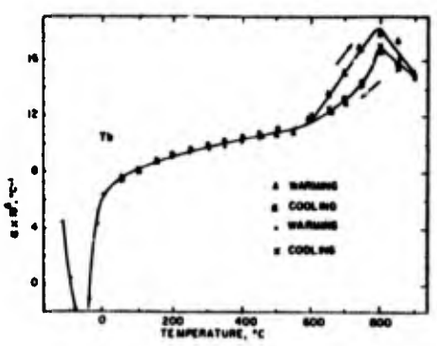
	Structure	Lattice Type	a_o, A	b_o, A	c_o, A	Volume of Unit Cell, A^3	Curie Temperature, K	Authority
GdAg	--	CsCl	3.6478	--	--	48.53	--	150, 256, 262
$GdAg_2$	Tetragonal	$MoSi_2$	3.728	--	9.296	129.2	--	
$GdAu_2$	Tetragonal	$MoSi_2$	3.7320	--	9.014	125.5	--	
GdGa	Orthorhombic	CrB	4.314	4.006	11.02	194.5	--	
$GdGa_2$	Hexagonal	AlB_2	4.22.	--	4.141	63.89	--	
GdIn	--	CsCl	3.830	--	--	56.18	--	
$GdIn_3$	--	$AuCu_3$	4.6103	--	--	97.99	--	
$GdIr_2$	Cubic	--	7.550	--	--	--	88	
GdMn	--	$MgCu_2$	7.732	--	--	462.2	--	
$GdOs_2$	Hexagonal	--	5.319	--	8.838	--	>77	
GdPt	Orthorhombic	FeB	5.574	4.458	7.164	178.0	--	
$GdPt_2$	--	$MgCu_2$	7.6349	--	--	445.05	>77	
$GdRh_2$	Cubic	--	7.514	--	--	--	>77	
$GdRu_2$	Hexagonal	--	5.271	--	8.904	--	>77	
GdTl	--	CsCl	3.7797	--	--	54.00	--	
$GdTl_3$	--	$AuCu_3$	4.696	--	--	103.6	--	

TERBIUM

Symbol Tb | Atomic Number 65 | Atomic Weight 158.93

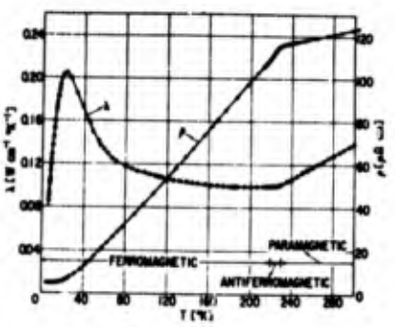
PHYSICAL PROPERTIES

		Authority
Abundance	0.7-1.0 ppm (approx. 0.9)	51
Density	8.253 g/cm^3	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 x 10^{-6}/C (25-950 C)	61
		90



(Permission of the American Physical Society)

		Authority
Thermal Conductivity	0.031 cal/(cm^2)(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_o = 3.6010 A	67
	c_o = 5.6936 A	
Density	8.253 g/cm^3	67
Metallic Radius	1.782 A	67
Atomic Volume	19.245 cm^3/mole	66
Transition Temperature	1317 C	66
Heat of Transition	1.06 kcal/mole	61
Ionic Radius	(+3) = 0.923 A, (+4) = 0.91 A	55,93

		Authority
Closest Approach of Atoms	3.508 A	56
Allotropic Modifications		

CHEMICAL PROPERTIES

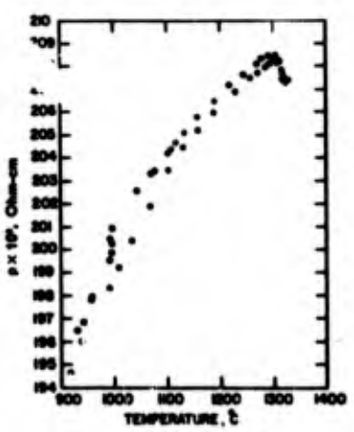
Stable Oxidation State	+3, +4	81
Electrode Potential	[$Tb = Tb^{+3} + 3e^-$] +2.2 volts (standard hydrogen electrode)	81
Ionization Potential	1st = 6.7 volts	82
Metallographic Polishing and Etching		62

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	$0.91 \times 10^{-3}\ C^{-1}$	61
Resistivity Versus Temperature		87,121



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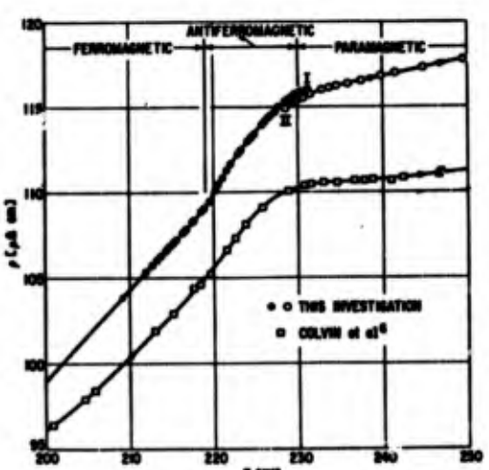
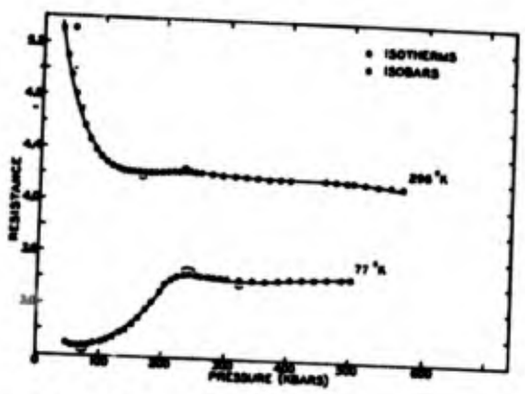


(Permission of the American Physical Society)

		Authority
Resistance Versus Pressure		96



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MAGNETIC PROPERTIES

Susceptibility (25 C)	$193,000 \times 10^{-6}$ emu/mole	61
Effective Magnetic Moment	Theoretical 9.72 Bohr magnetons Measured 9.7 Bohr magnetons	61
Curie Temperature	237 K	61
Néel Temperature	230 K	61

MECHANICAL PROPERTIES

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

Authority

Workability

General Fabrication (See references) 70,113

NUCLEAR PROPERTIES

Isotopes 58,110

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

Thermal Neutron Cross Section: 44 ± 4 barns/atom or 0.166 cm^2/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

	Room Temperature	Melting Point
Entropy	$S_{298} = 17.5$	$S_{1700} = 30.47$ eu
Heat Capacity	$C_{p298} = 6.92$	$C_{p1700} = 8.88$ cal/(mole)(C)

Heat Capacities, cal/(K)(mole) 76

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

Authority

77

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);

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

ΔH_{1700} (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

120

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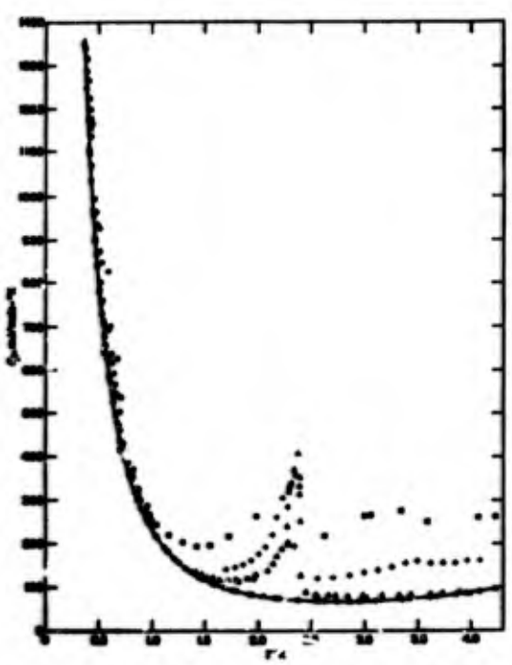


(Results of several investigators)

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

		Authority
Antimonides		169
	TbSb	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	6.180	
Magnetic Susceptibility, 10^{-6} emu/mole	36232	
Effective Magnetic Moment, Bohr magnetons	9.57	
Arsenides		169
	TbAs	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	5.827	
Magnetic Susceptibility, 10^{-6} emu/mole	39033	
Effective Magnetic Moment, Bohr magnetons	9.65	
Beryllides		179
	$TbBe_{13}$	
a_o, A	10.251	

Authority

Bismuthides 169

	TbBi
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.280
Magnetic Susceptibility, 10^{-6} emu/mole	38086
Effective Magnetic Moment, Bohr magnetons	9.64

Borides 153,155

	TbB_2	TbB_4	TbB_6	TbB_{12}
Molecular Weight	--	202.48	224.12	289.04
Structure	Hexagonal	Tetragonal	Cubic	Cubic
a_o, A	3.28	7.118	4.1020	7.504
c_o, A	3.86	4.0286	--	--
Density, g/cm^3	--	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^2	--	--	3500	--
Color	--	Gray brown	Blue	--
Emissivity (λ = 0.655 μ)	--	--	0.74	--
Effective Metallic Radius, A	--	--	2.18	--

Carbides

Authority: 153

	TbC_2	Tb_2C_3	Tb_3C
Molecular Weight	182.93	355.86	489.6
Structure	Body-centered tetragonal	Bcc	Cubic
Lattice Type	CaC_2	Pu_2C_3	Fe_4N
a_o, A	3.690	8.2617	5.107
c_o, A	6.217	--	--
Density, g/cm^3	7.176	8.335	8.882
Magnetic Susceptibility, 10^{-6} emu/mole	~28500	--	--
Effective Magnetic Moment, Bohr magnetons	9.57	--	--

Germanides

Authority: 183

	Tb_2Ge_3
Lattice Type	AlB_2 defect
a_o, A	3.95
c_o, A	4.16
Volume of Unit Cell, A^3	56.21

Authority

Halides

158,211, 235,236, 279,281

	$TbBr_3$	$TbCl_3$	TbF_3	TbI_3	TbF_4	TbOCl	TbOF
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Monoclinic	Tetragonal	Rhombohedric
a_o, A	4.129	6.163	6.513	4.357	12.1	3.927	6.758
b_o, A	--	3.848	6.949	--	10.3	--	--
c_o, A	6.391	8.357	4.384	6.954	7.9	6.645	--
β, deg	--	107.59	--	--	126	--	33.02
Density, g/cm^3	--	--	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, A^3	--	--	198.4	--	--	102.47	--

Hydrides

165

	TbH_2	TbH_3
Structure	Cubic	Hexagonal
a_o, A	5.246	3.700
c_o, A	--	6.658

Nitrides

	TbN	Authority
Molecular Weight	172.94	153,223
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	4.933	
Density, g/cm^3	9.567	
Magnetic Susceptibility, 10^{-6} emu/mole	42900	
Effective Magnetic Moment, Bohr magnetons	9.5	
Curie Temperature, K	38	

Oxides

	TbO_2	Tb_2O_3	Tb_4O_7	Authority
Structure	--	Bcc	Cubic	172,176, 186,218, 238
a_o, A	--	10.69	10.70	
Density, g/cm^3	--	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^{-6} emu/mole	--	35800	30100	
Effective Magnetic Moment, Bohr magnetons	--	9.7	--	
Color	--	--	Dark brown	

Phosphides — Authority: 169

	TbP
Structure	Fcc
Lattice Type	NaCl
a_o, A	5.686
Magnetic Susceptibility, 10^{-6} emu/mole	39526
Effective Magnetic Moment, Bohr magnetone	9.56

Selenides — 169

	TbSe
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.740
Magnetic Susceptibility, 10^{-6} emu/mole	33755
Effective Magnetic Moment, Bohr magnetons	9.82

Silicides — 263,264

	$TbSi_2$	$TbSi_{2-n}$
Structure	Ortho-rhombic	Hexagonal
Lattice Type	α-YSi_2	AlB_2 defect
a_o, A	4.045	3.847
b_o, A	3.96	--
c_o, A	13.38	4.146
Volume of Unit Cell, A^3		53.1

			Authority
Sulfides			153,169
	TbS	Tb_2O_2S	
Molecular Weight	--	381.93	
Structure	Fcc	Hexagonal	
Lattice Type	NaCl	--	
a_o, A	5.517	3.825	
c_o, A	--	6.626	
Density, g/cm^3	--	7.56	
Magnetic Susceptibility, 10^{-6} emu/mole	35088	--	
Effective Magnetic Moment, Bohr magnetons	9.63	--	

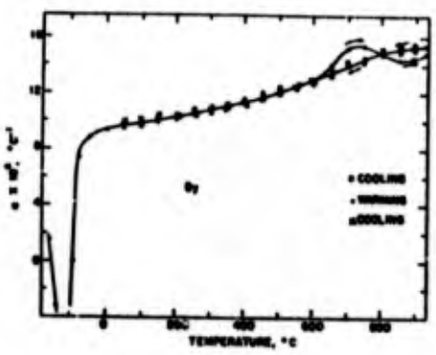
Tellurides		169
	TbTe	
Structure	Fcc	
Lattice Type	NaCl	
a_o, A	6.101	
Magnetic Susceptibility, 10^{-6} emu/mole	38760	
Effective Magnetic Moment, Bohr magnetons	9.57	

DYSPROSIUM

Symbol Dy | Atomic Number 66 | Atomic Weight 162.51

PHYSICAL PROPERTIES

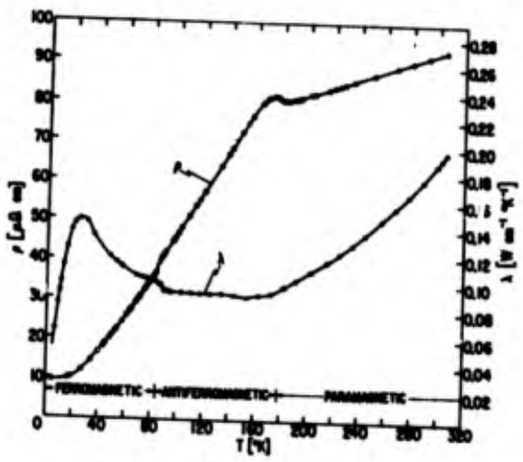
		Authority
Abundance	4.5-7.5 ppm (approx. 5)	51
Density	8.559 g/cm^3	67
Melting Point	1407 C	66
Heat of Fusion	3.8 kcal/mole	61
Boiling Point	2600 C	57
Heat of Vaporization (25 C)	67 kcal/mole	57
Vapor Pressure (1257-1690 K)	$\text{Log } P_{\text{mm Hg}} = 8.882 - \frac{15,090}{T}$	60
Specific Heat (25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



90

Thermal Conductivity (28 C)	0.024 cal/(cm^2)(sec)(C/cm)	115

		Authority
Thermal Conductivity and Electrical Resistivity Versus Temperature		128



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_o = 3.5903 A	61
	c_o = 5.6475 A	61
Density	8.559 g/cm^3	67
Metallic Radius	1.773 A	67
Atomic Volume	19.032 cm^3/mole	66
Transition Temperature		
Heat of Transition		

		Authority
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	
Electrode Potential	[$Dy = Dy^{+3} + 3e^-$] + 2.2 volts (standard hydrogen electrode)	81
Ionization Potential	1st = 6.8 volts	81
Metallographic Polishing and Etching	Dysprosium exhibits considerable resistance to oxidation and to etching. The most satisfactory etch is based on hydrofluoric acid.	82 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

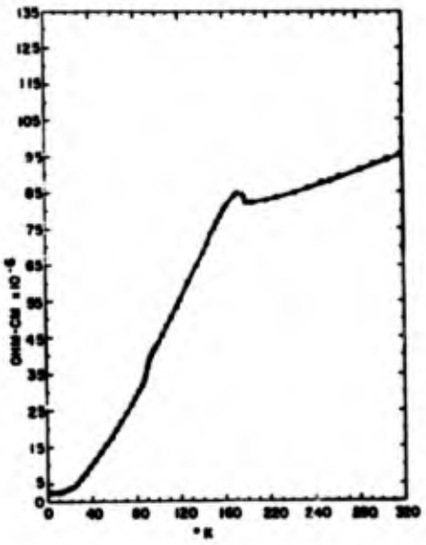
Material	Onset of Attack
Ta	None <1400 C

ELECTRICAL PROPERTIES

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

Authority

Resistivity Versus Temperature 117, 127



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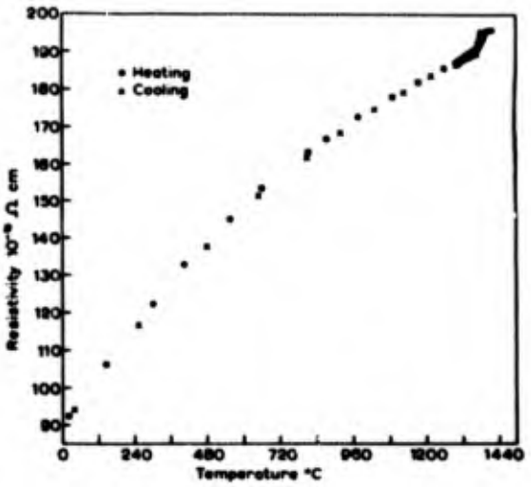

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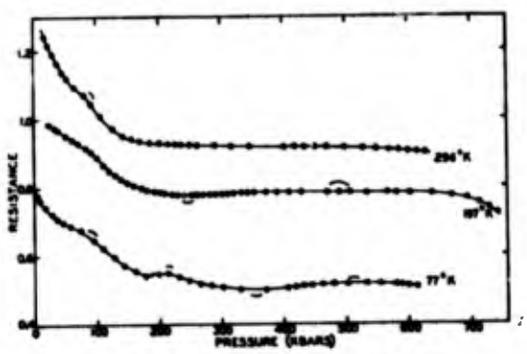
Resistance Versus Pressure 96



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MAGNETIC PROPERTIES

Susceptibility (25 C)	99,800 x 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	6.31×10^{11} dynes/cm^2			57
Shear Modulus	2.54×10^{11} dynes/cm^2			57
Poisson's Ratio	0.243			61
Compressibility	2.39×10^{-6} cm^2/kg			57
Hardness (DPH)	42			57
	70 F	400 F		
Tensile Strength	35.7	30.8	10^3 psi	88
Yield Strength	32.6	20.8	10^3 psi	88
Elongation	6	8.3	per cent	88
Ultimate Compressive Strength	73.8 10^3 psi			61
Impact Strength (Izod)	1.6 ft-lb			71
Workability	Fair			88
General Fabrication	(See references)			70, 113

NUCLEAR PROPERTIES

Isotopes — 58, 123

Whole-Number Mass	Relative Abundance, percent	Half Life	Decay Mode
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^-, e^-, γ

Thermal Neutron Cross Section	1100 ± 150 barns/atom or 4.1 cm^2/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

	Room Temperature	Melting Point	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

10 K	25 K	50 K	100 K	150 K	200 K	298.15 K
(0.18)	2.20	5.52	8.32	10.88	6.97	6.73

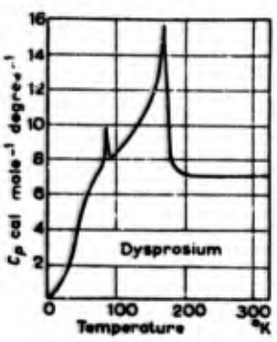
Heat Content and Entropy of Solid and Liquid Dysprosium 77
(Base: crystals at 298.15 K)

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	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	18,960	17.24
1300	7,370	10.53	2400	20,560	17.93
1400	8,200	11.15	2600	21,160	18.57

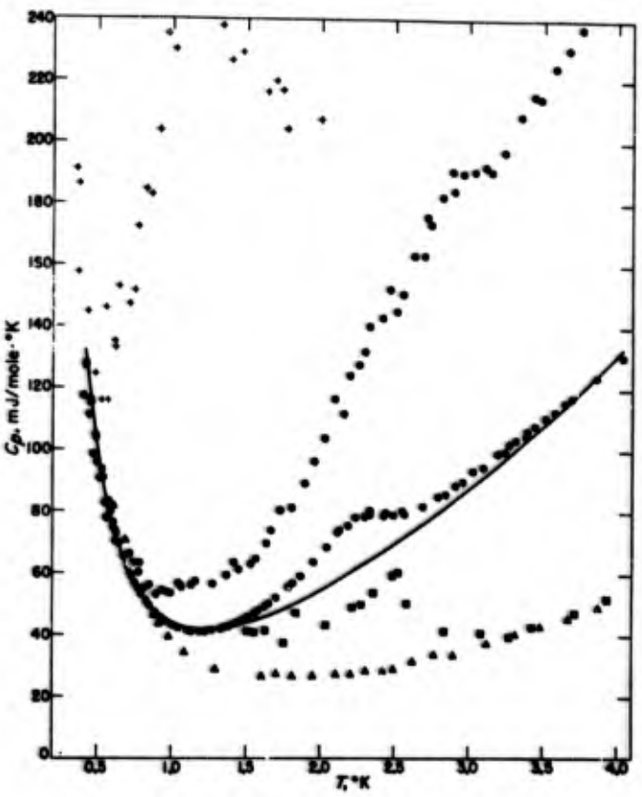
$H_T-H_{298.15} = 6.00T + 0.85 \times 10^{-3}T^2 - 1,864$
(0.1 percent; 298-1773 K);
$C_p = 6.00 + 1.70 \times 10^{-3}T$;
H_{1773}(fusion) = 4,100.

$H_T-H_{298.15} = 8.00T + 1,360$
(0.1 percent; 1773-2600 K);
$C_p = 8.00$.

	Authority
Specific Heat	53, 125



0 - 300 K



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

DYSPROSIUM COMPOUNDS

Antimonides

169

	DySb
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.160
Magnetic Susceptibility 10^{-6} emu/mole	45558
Magnetic Moment, Bohr magnetons	10.62

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

Borides

	DyB_2	DyB_4	DyB_6	DyB_{12}	Authority
Molecular Weight	184.10	205.74	227.38	292.30	153,154, 155,171
Structure	Hexagonal	Tetragonal	Cubic	Cubic	
a_o, A	3.285	7.101	4.0976	7.501	
c_o, A	3.835	4.0174	--	--	
Density, g/cm^3	--	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

	Dy_3C	Dy_2C_3	DyC_2	Authority
Molecular Weight	499.38	360.92	186.46	153
Structure	Cubic	Bcc	Body-centered tetragonal	
Lattice Type	Fe_4N	Pu_2C_3	CaC_2	
a_o, A	5.079	8.198	3.669	
c_o, A	--	--	6.176	
Density, g/cm^3	9.211	--	7.450	
Magnetic Susceptibility, 10^{-6} emu/mole	--	--	~38500	
Magnetic Moment, Bohr magnetons	--	--	10.53	

Authority

Germanides

183,262

	DyGe	Dy_2Ge_3
Structure	Orthorhombic	--
Lattice Type	CrB	Defective AlB_2
a_o, A	4.112	3.92
b_o, A	3.924	--
c_o, A	10.81	4.13
Volume of Unit Cell, A^3	174.4	54.96

Halides

93,108, 157,158, 209,210, 211,235, 236

	$DyBr_3$	$DyCl_3$	DyF_3	DyI_3	DyOCl	DyOF
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Tetragonal	Rhombohedral
a_o, A	4.114	6.91	6.460	4.335	3.911	--
b_o, A	--	11.97	6.906	--	--	--
c_o, A	6.400	6.40	4.376	6.958	6.620	--
β, deg	--	111.2	--	--	--	--
Density, g/cm^3	--	--	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, A^3	--	--	195.2	--	101.26	--

Hydrides

	DyH_2	DyH_3	Authority
Structure	Cubic	Hexagonal	165, 265
a_o, A	5.201	3.671	
c_o, A	--	6.615	
Magnetic Susceptibility, 10^{-6} emu/mole	46,700	38,900	
Magnetic Moment, Bohr magnetons	10.8	9.5	
Néel Temperature, K	8	--	

Nitrides

	DyN	Authority
Molecular Weight	176.52	149,153, 223
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	4.905	
Density, g/cm^3	9.567	
Resistivity, microhm-cm	100	
Temperature Coefficient of Resistivity (300-750 K), 10^{-3}/C	0.75×10^{-3}	
Magnetic Susceptibility, 10^{-6} emu/mole	48,900	
Magnetic Moment, Bohr magnetons	10.6	
Curie Temperature, K	22	

Oxides

Authority

156,172
173,176,
177,245

	Dy_2O_3
Molecular Weight	373.0
Structure	Bcc
a_o, A	10.63
Density, g/cm^3	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^{-6}/C	7.7
Magnetic Moment, Bohr magnetons	10.6
Color	White

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

245

T, K	$H_T-H_{298.15}$, 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	2,920	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			

Phosphides

	DyP	Authority
Structure	Cubic	169
Lattice Type	NaCl	
a_o, A	5.654	
Magnetic Susceptibility 10^{-6} emu/mole	46729	
Magnetic Moment, Bohr magnetons	10.34	

Selenides

166,168, 169,192, 194,213

	DySe	Dy_2Se_3	Dy_2O_2Se
Structure	Cubic	Orthorhombic	Hcp
Lattice Type	NaCl	--	--
a_o, A	5.711	3.69	3.83
b_o, A	--	10.85	--
c_o, A	--	11.0	6.79
Density, g/cm^3	--	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

	α-$DySi_2$	β-$DySi_2$	$DySi_2$-n	Authority
Molecular Weight	218.62	218.62	--	152,153, 160,264
Structure	Orthorhombic	Tetragonal	Hexagonal	
Lattice Type	α-YSi_2	α-$ThSi_2$	AlB_2 defect	
a_o, A	4.04	4.03	3.83	
b_o, A	3.95			
c_o, A	13.34	13.38	4.11	
Density, g/cm^3	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, 10^3 psi	9.5	--	--	
Volume of Unit Cell, A^3	--	--	52.2	

Sulfides

Authority: 153,169, 227

	DyS	Dy_5S_7	γ-Dy_2S_3	δ-Dy_2S_3	DyS_2	Dy_2O_2S
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_3P_4	--	--	--
a_o, A	5.490	12.84	8.292	10.17	7.69	3.803
b_o, A	--	3.81	--	4.03	--	--
c_o, A	--	11.61	--	17.57	7.85	6.603
β, deg	--	74	--	--	--	--
Density, g/cm^3	--	6.14	6.54	5.75	6.11	7.84
Melting Point, C	--	1540	1480	--	--	--
Magnetic Susceptibility, 10^{-6} emu/mole	40000	--	47700	--	--	--
Magnetic Moment, Bohr magnetons	10.39					

Tellurides

Authority: 169,202, 205,242

	DyTe	$DyTe_{2-n}$	Dy_3Te_4	Dy_2O_2Te
Structure	Fcc	--	--	Hexagonal
Lattice Type	NaCl	--	--	--
a_o, A	6.075	4.29	--	3.92
c_o, A		8.91		12.38
Density, g/cm^3	--	--	--	8.46
Resistivity, microhm-cm	--	--	3.1×10^3	--
Magnetic Susceptibility, 10^{-6} emu/mole	45977	--	--	--
Magnetic Moment, Bohr magnetons	10.47	--	--	--
Color	--	--	--	Maroon

Authority

262

Miscellaneous

Compound	Structure	Lattice Type	a_o, A	b_o, A	c_o, A	Volume of Unit Cell, A^3
$DyAg_2$	Tetragonal	$MoSi_2$	3.6957	--	9.213	125.8
$DyAu_2$	Tetragonal	$MoSi_2$	3.6940	--	8.956	122.2
DyGa	Orthorhombic	CrB	4.300	4.067	10.89	190.4
$DyGa_2$	Hexagonal	AlB_2	4.2011	--	4.0655	62.14
DyIn	--	CsCl	3.7866	--	--	54.29
$DyIn_3$	--	$AuCu_3$	4.5762	--	--	95.83
Dy_3In	Tetragonal	$CuTi_3$	4.602	--	4.495	104.7
$DyMn_2$	--	$MgCu_2$	7.5731	--	--	434.33
DyPt	Orthorhombic	FeB	5.466	4.453	7.118	173.3
$DyPt_2$	--	$MgCu_2$	7.5966	--	--	438.39
$DyPt_3$	--	$AuCu_3$	4.072	--	--	67.52
DyTl	--	CsCl	3.7866	--	--	54.29
$DyTl_3$	--	$AuCu_3$	4.6720	--	--	101.98

HOLMIUM

Symbol Ho | Atomic Number 67 | Atomic Weight 164.94

PHYSICAL PROPERTIES

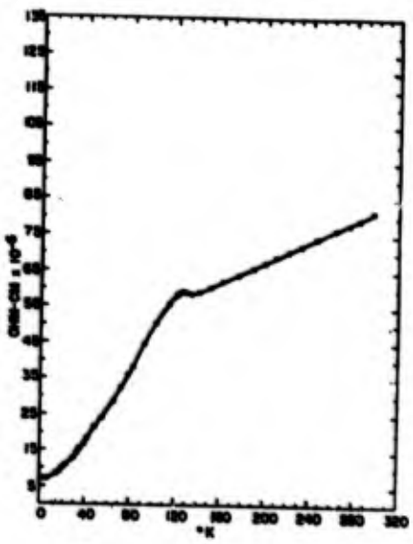
		Authority
Abundance	0.7-1.2 ppm	51
Density	8.799 g/cm^3	67
Melting Point	1461 C	66
Heat of Fusion	4.1 kcal/mole	61
Boiling Point	2600 C	57
Heat of Vaporization (25 C)	67 kcal/mole	57
Vapor Pressure		
Specific Heat (25 C)	6.49 cal/(mole)(C)	76
Heat of Combustion	224.78 kcal/g-atom	134
Coefficient of Linear Thermal Expansion (20-708 C)	9.5 x 10^{-6}/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		

		Authority
CRYSTAL PROPERTIES		
Structure	Hcp	61
Lattice Constants	a_o = 3.5773 A c_o = 5.6158 A	61
Density	8.799 g/cm^3	67
Metallic Radius	1.766 A	67
Atomic Volume	18.742 cm^3/mole	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ion)	0.894 A	55
Closest Approach of Atoms	3.480 A	56
Allotropic Modifications	(1) Resistivity measurements indicate a structural change at high temperature.	
CHEMICAL PROPERTIES		
Stable Oxidation State	+3	81
Electrode Potential	[Ho = Ho^{+3} + 3e$^-$] + 2.1 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		

ELECTRICAL PROPERTIES

		Authority
Resistivity (25 C)	87 microhm-cm	61
Temperature Coefficient of Resistivity	1.71×10^{-3}/C	61

Resistivity Versus Temperature — 117, 127



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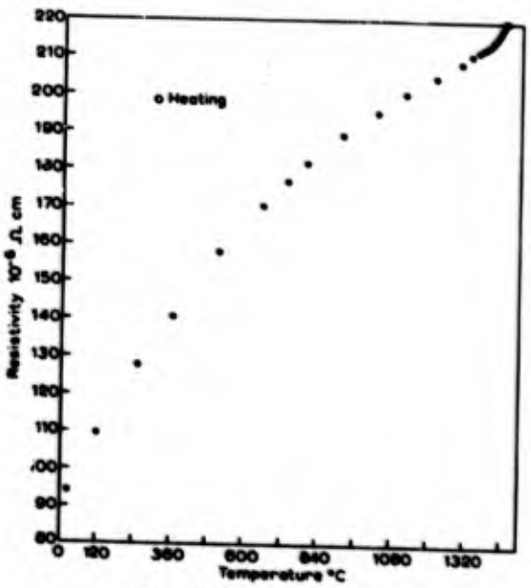

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Resistance Versus Pressure
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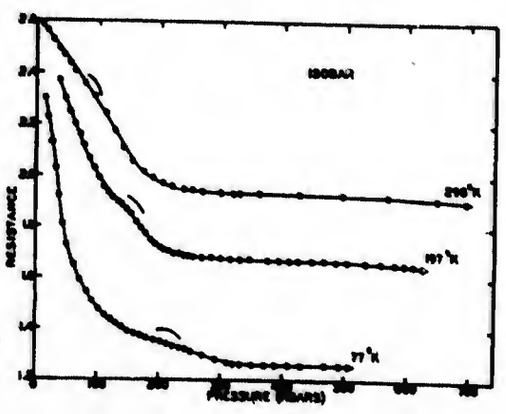


MAGNETIC PROPERTIES

		Authority
Susceptibility (25 C)	70,200 x 10^{-6} 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

MECHANICAL PROPERTIES

		Authority
Young's Modulus (Y)	6.71 dynes/cm^2	57
Shear Modulus	2.67 dynes/cm^2	57
Poisson's Ratio (ν)	0.266	
Compressibility (β)	2.14 x 10^{-6} cm^2/kg (calculated from $\beta = \frac{3(1-2\nu)}{Y}$)	57
Hardness (DPH)	42	57

	70 F	400 F		Authority
Tensile Strength	37.5	30.8	10^3 psi	88
Yield Strength	32.1	24.6	10^3 psi	88
Elongation	5	6	per cent	88

		Authority
Ultimate Compressive Strength	72.4 10^3 psi	61
Impact Strength (Izod)	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, γ, e^-
162	--	4.5 hr	K, X, γ, e^-, β^+
163	--	7 days	K, X, γ, e^-
164	--	35 min	β^-
165	100	Stable	--
166	--	27.^{c} hr	β^-, γ

Thermal Neutron Cross Section: 64 ± 3 barns/atom or 0.23 cm^2/g — 73

SAFETY

Details unknown. — 83

THERMODYNAMIC PROPERTIES

	Room Temperature	Melting Point	
Entropy	S_{298} = 18.0	S_{1773} = 31.2 eu	76, 77
Heat Capacity	C_{p298} = 6.49	C_{p1773} = 9.02 cal/(mole)(C)	

Heat Capacities, cal/(K)(mole) — 76

10 K	25 K	50 K	100 K	150 K	200 K	298.15 K
(.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	$H_T-H_{298.15°}$ 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	670	1.94	1500	9,050	11.74
500	1,350	3.44	1600	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)

Authority

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);

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

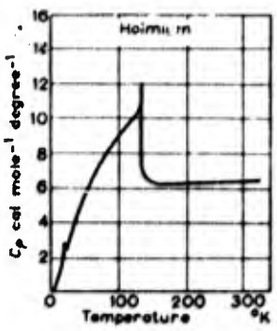
H_{1773}(fusion) = 4,100.

For liquid holmium:

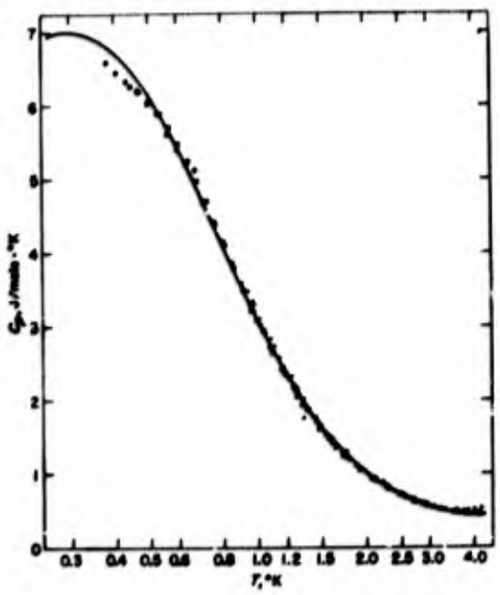
$H_T - H_{298.15} = 8.00\ T + 1,360$
(0.1 percent; 1773-2600 K);

$C_p = 8.00$.

Specific Heat 53, 129



0 to 300 K



HOLMIUM COMPOUNDS

Antimonides 169

	HoSb
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.130
Magnetic Susceptibility, 10^{-6} emu/mole	44,743
Magnetic Moment, Bohr magnetons	10.35

Arsenides — Authority: 169

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

Beryllides — 179

	$HoBe_{13}$
a_o, A	10.220

Bismuthides — 169

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

Borides — 153, 155

	HoB_2	HoB_4	HoB_6	HoB_{12}
Molecular Weight	175.26	206.78	228.42	294.78
Structure	Hexagonal	Tetragonal	Cubic	Cubic
a_o, A	3.17	7.064	4.096	7.492
c_o, A	3.81	4.000	--	--
Density, g/cm^3	--	6.88	5.53	4.655
Coefficient of Thermal Expansion, 10^{-6}/C	--	--	3.0	--

(Continued)

Authority

Borides (Continued)

	HoB_2	HoB_4	HoB_6	HoB_{12}
Work Function, ev	--	--	3.42	--
Color	--	Gray brown	Blue	--
Emissivity (λ = 0.665 μ)	--	--	--	0.7
Effective Metallic Radius, Å	--	--	2.17	--

153

Carbides

	HoC_2	Ho_2C_3	Ho_3C
Molecular Weight	188.94	365.88	506.82
Structure	Body-centered tetragonal	Bcc	Cubic
Lattice Type	CaC_2	Pu_2C_3	Fe_4N
a_o, A	3.643	8.176	5.061
c_o, A	6.139	--	--
Density, g/cm^3	7.701	8.892	9.434
Magnetic Susceptibility, 10^{-6} emu/mole	~43,500	--	--
Magnetic Moment, Bohr magnetons	10.57	--	--

183

Germanides

	Ho_2Ge_3
Lattice Type	Defective AlB_2
a_o, A	3.90
c_o, A	4.11
Volume of Unit Cell, A^3	54.14

Halides

	$HoBr_3$	$HoCl_3$	HoF_3		HoI_3	HoOCl	Authority
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Hexagonal	Tetragonal	93, 108, 158, 182, 209, 210, 235, 236
a_o, A	4.088	6.85	6.404	6.833	4.319	3.893	
b_o, A	--	11.85	6.875	--	--	--	
c_o, A	6.391	6.39	4.379	6.984	6.946	6.602	
β, deg	--	110.8	--	--	--	--	
Density, g/cm^3	--	--	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^3	--	485	192.8	282.4	--	100.06	
Color	--	--	Brown pink	--	--	--	

Hydrides — Authority: 165

	HoH_2	HoH_3
Structure	Cubic	Hexagonal
a_o, A	5.165	3.642
c_o, A	--	6.560

Nitrides — Authority: 149, 153, 223

	HoN
Molecular Weight	178.95
Structure	Cubic
Lattice Type	NaCl
a_o, A	4.87
Density, g/cm^3	10.26
Resistivity, microhm-cm	110
Temperature Coefficient of Resistivity (300-1500 K), $10^{-3}/C$	1
Magnetic Susceptibility, 10^{-6} emu/mole	47,800
Magnetic Moment, Bohr magnetons	10.3
Curie Temperature, K	19

Oxides — Authority: 156, 172, 177, 259, 266

	Ho_2O_3
Structure	Bcc
a_o, A	10.58
Density, g/cm^3	8.36
Heat of Formation, kcal/mole	224.78
Entropy of Formation, eu/mole	(35.7)

(Continued)

Authority

Oxides (Continued)

	Ho_2O_3
Heat Capacity at 300 K, cal/(mole)(C)	27.05
Coefficient of Thermal Expansion, 10^{-6}/C	7.9
Magnetic Moment, Bohr magnetons	10.6
Color	Light yellow

Heat Content and Entropy Increments for Holmium 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	3,820	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	54.63
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 169

	HoP
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.626
Magnetic Susceptibility, 10^{-6} emu/mole	46,083
Magnetic Moment, Bohr magnetons	10.34

Selenides

	HoSe	Authority
Structure	Cubic	169
Lattice Type	NaCl	
a_o, A	5.680	
Magnetic Susceptibility, 10^{-6} emu/mole	43,478	
Magnetic Moment, Bohr magnetons	10.62	

Silicides

	$HoSi_2$	$HoSi_{2-n}$	263, 264
Structure	Orthorhombic	Hexagonal	
Lattice Type	α-YSi_2	Defect AlB_2	
a_o, A	4.03	3.816	
b_o, A	3.97	--	
c_o, A	13.40	4.107	
Volume of Unit Cell, A^3	--	51.5	

Sulfides

	HoS	169
Structure	Fcc	
Lattice Type	NaCl	
a_o, A	5.465	
Magnetic Susceptibility, 10^{-6} emu/mole	41,464	
Magnetic Moment, Bohr magnetons	10.50	

Authority

Tellurides 169

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

Miscellaneous 267

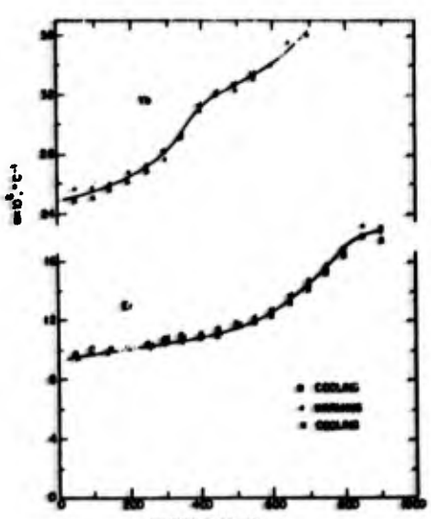
Compound	Lattice Type	a_o, A
$HoGa_3$	$AuCu_3$	4.226

ERBIUM

Symbol Er | Atomic Number 68 | Atomic Weight 167.27

PHYSICAL PROPERTIES

		Authority
Abundance	2.5-6.5 ppm	51
Density	9.062 g/cm^3	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 x 10^{-6}/C (-178 - 950 C)	61
		90



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		Authority
Thermal Conductivity (28 C)	0.023 cal/(cm^2)(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_o = 3.5588 A	61
	c_o = 5.5874 A	
Density	9.062 g/cm^3	67
Metallic Radius	1.757 A	67
Atomic Volume	18.473 cm^3/mole	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ions)	0.881	55
Closest Approach of Atoms	3.459 A	56
Allotropic Modifications		
CHEMICAL PROPERTIES		
Stable Oxidation State	+3	81
Electrode Potential	[Er = Er^{+3} + 3e$^-$] + 2.1 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.

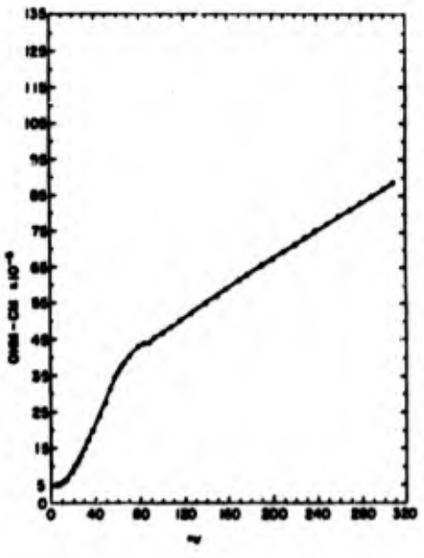
Corrosion Rates (In Air)	<1 mil/year up to 200 C 14 mil/year at 400 C 114 mil/year at 600 C	68
Corrosion Data		91

Corrosive attack on crucible materials:

Material	Onset of Attack
Ta	None < 1400 C

ELECTRICAL PROPERTIES

Resistivity (25 C)	107 microhm-cm	61
Temperature Coefficient of Resistivity	2.01×10^{-3}/C	61
Resistivity Versus Temperature		117,127



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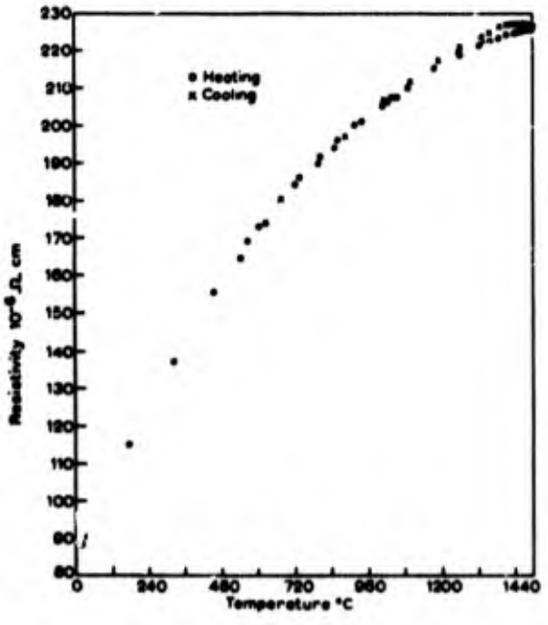

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Authority

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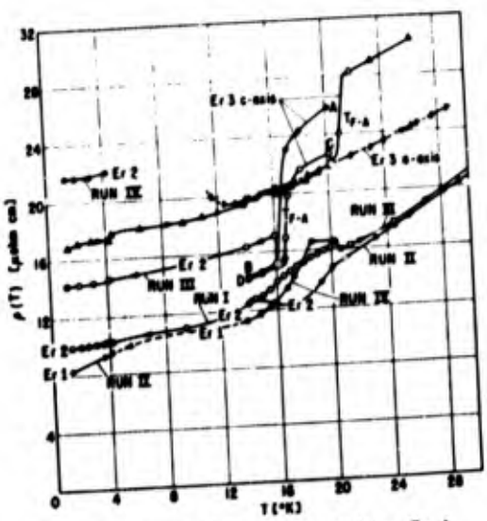
Resistivity Versus Temperature



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Resistance Versus Pressure

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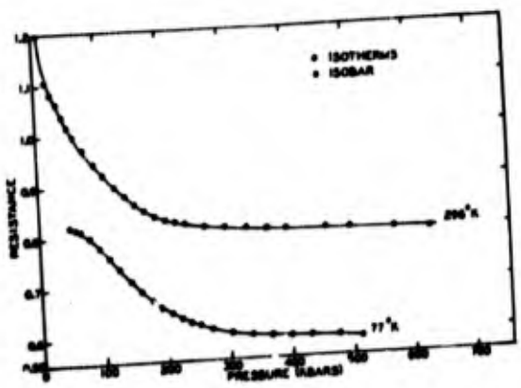


MAGNETIC PROPERTIES

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

					Authority
MECHANICAL PROPERTIES					
Young's Modulus	7.33×10^{11} dynes/cm^2				57
Shear Modulus	2.96×10^{11} dynes/cm^2				57
Poisson's Ratio	0.238				61
Compressibility	2.11×10^{-6} cm^2/kg				57
Hardness (DPH)	44				57
	70 F	400 F	800 F		
Tensile Strength	42.4	34.7	25.1	10^3 psi	88
Yield Strength	38.7	29.6	21.8	10^3 psi	88
Elongation	4	5.5	6.8	per cent	88
Ultimate Compressive Strength	110.1	10^3 psi			61
Impact Strength (Izod)	1.2 ft-lb				71
Workability	Poor				88
General Fabrication	(See references)				70,113
NUCLEAR PROPERTIES					
Isotopes					58,133

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

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

Authority

SAFETY

Details unknown. 83

THERMODYNAMIC PROPERTIES

76,77

	Room Temperature	Melting Point
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

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

77

Heat Content and Entropy of Solid and Liquid Erbium

(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	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	5,080	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);

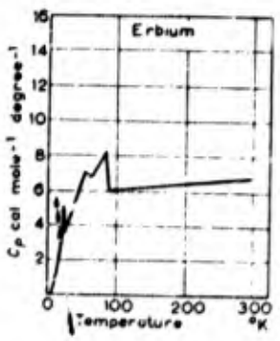
$C_p = 6.29 + 1.48 \times 10^{-3}\ T$;

ΔH_{1800}(fusion) = 4,100.

Authority

Specific Heat

53



0 to 300 K

ERBIUM COMPOUNDS

Antimonides

168,169

	ErSb
Structure	Cubic
Lattice Type	NaCl
a_o, 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

		Authority
Arsenides		169
	ErAs	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	5.745	
Magnetic Susceptibility, 10^{-6} emu/mole	37,453	
Magnetic Moment, Bohr magnetons	9.34	
Beryllides		179
	$ErBe_{13}$	
a_o, A	10.215	
Bismuthides		169
	ErBi	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	6.202	
Magnetic Susceptibility, 10^{-6} emu/mole	35,714	
Magnetic Moment, Bohr magnetons	9.32	

Authority

Borides

153, 155, 171

	ErB_2	ErB_4	ErB_6	ErB_{12}
Molecular Weight	188.91	210.48	232.12	297.04
Structure	Hexagonal	Tetragonal	Cubic	Cubic
a_o, A	3.28	7.071	4.110	7.484
c_o, A	3.79	3.9972	--	--
Density, g/cm^3	--	7.261	5.58	4.706
Coefficient of Thermal Expansion, $10^{-6}/C$	--	--	--	3.0
Work Function, ev	--	--	3.37	--
Emissivity ($\lambda = 0.655\ \mu$)	--	--	0.7	--
Color	--	Gray brown	Blue	--
Effective Metallic Radius, A	--	--	2.18	--

Carbides

153

	ErC_2	Er_2C_3	Er_3C
Molecular Weight	191.2	370.4	513.6
Structure	Body-centered tetragonal	--	Cubic
Lattice Type	CaC_2	Y_2C_3	Fe_4N
a_o, A	3.620	--	5.034
c_o, A	6.094	--	--
Density, g/cm^3	7.954	--	4.708
Magnetic Susceptibility, 10^{-6} emu/mole	~33,300	--	--
Magnetic Moment, Bohr magnetons	8.	--	--
Curie Temperature, K	14.7	--	--

Authority

Germanides

183

	Er_2Ge_3
Lattice Type	Defective AlB_2
a_o, A	3.89
c_o, A	4.09
Volume of Unit Cell, A^3	53.60

Halides

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

	$ErBr_3$	$ErCl_3$	ErF_3	ErI_3	ErOCl
Structure	Hexagonal	Monoclinic	Orthorhombic	--	Tetragonal
a_o, A	4.070	6.80	6.354	--	3.88
b_o, A	--	11.79	6.846	--	--
c_o, A	6.388	6.39	4.380	--	6.58
β, deg	--	110.7	--	--	--
Density, g/cm^3	--	--	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, A^3	--	479	190.5	--	99.1
Color	--	--	Pink	--	--

Hydrides

	ErH_2	ErH_3	Authority
Structure	Cubic	Hexagonal	165,265
a_o, A	5.123	3.621	
c_o, A	--	6.526	
Magnetic Susceptibility, 10^{-6} emu/mole	36,200	34,900	
Magnetic Moment, Bohr magnetons	9.75	9.54	

Nitrides

	ErN	Authority
Molecular Weight	181.28	149,153, 223
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	4.831	
Density, g/cm^3	10.26	
Resistivity, microhm-cm	79	
Temperature Coefficient of Resistivity (80-800 K), $10^{-3}/C$	1.3	
Magnetic Susceptibility, 10^{-6} emu/mole	36,300	
Magnetic Moment, Bohr magnetons	9.2	
Curie Temperature, K	5	

Oxides

	Er_2O_3	Authority
Molecular Weight	328.52	156,172, 173,177, 266
Structure	Bcc	
a_o, A	10.51	
Density, g/cm^3	8.640	
Heat of Formation, kcal/mole	226.80	
Entropy of Formation, eu/mole	(35.5)	
Coefficient of Thermal Expansion (20-1300 C), $10^{-6}/C$	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)

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	2,710	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	47.89
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			

Phosphides — Authority: 169

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

Selenides — Authority: 166, 169, 192, 194, 213

	ErSe	Er_2Se_3	Er_2O_2Se
Structure	Cubic	Fcc	Hcp
Lattice Type	NaCl	NaCl	--
a_o, A	5.662	5.71	3.81
c_o, A	--	--	7.68
Density, g/cm^3	--	6.59	8.68
Melting Point, C	(1800)	1520	--
Resistivity, microhm-cm	170	7.9×10^6	--
Magnetic Susceptibility, 10^{-6} emu/mole	35,635	38,600	--
Magnetic Moment, Bohr magnetons	9.56	9.63	--
Color	--	Yellow brown	Pink

Silicides — Authority: 263, 264

	$ErSi_2$
Structure	Hexagonal
a_o, A	3.78
c_o, A	4.09
Volume of Unit Cell, A^3	51.1

Sulfides

	ErS	$ErS_{1.18}$	Er_5S_7	δ-Er_2S_3	Er_2O_2S	Authority
Molecular Weight	199.27	204.8	1060.80	430.74	398.61	153,169
Structure	Cubic	Cubic	Monoclinic	Monoclinic	Hexagonal	
a_o, A	5.424	5.452	12.63	10.07	3.760	
b_o, A	--	--	3.77	4.00	--	
c_o, A	--	--	11.47	17.33	6.552	
β, deg	--	--	74	--	--	
Density, g/cm^3	--	6.75	6.39	6.07	7.92	
Melting Point, C	--	--	1620	1730	--	
Magnetic Susceptibility, 10^{-6} emu/mole	35,088	--	--	38,600	--	
Magnetic Moment, Bohr magnetons	9.50	--	--	--	--	
Color	--	--	--	Bright ochre	--	

Tellurides

	ErTe	Er_2Te_3	Er_3Te_4	Authority
Structure	Fcc	--	--	168,169, 194,229, 232
Lattice Type	NaCl	--	--	
a_o, A	6.021	--	--	
Resistivity, microhm-cm	140	1.1×10^3	280	
Magnetic Susceptibility, 10^{-6} emu/mole	34965	--	--	
Magnetic Moment, Bohr magnetons	9.30	9.63	--	

Authority

Miscellaneous 150,267

Compound	Structure	Lattice Type	a_o, A	c_o, A	Curie Temperature, K
$ErGa_3$	--	$AuCu_3$	4.206	--	--
$ErRu_2$	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^3	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 x 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_o = 3.5375 A c_o = 5.5546 A	61
Density	9.318 g/cm^3	67

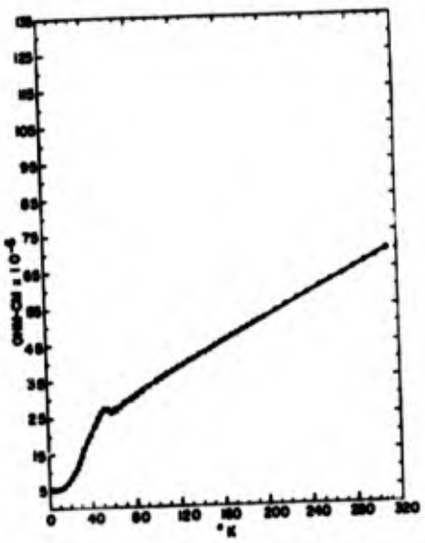
		Authority
Metallic Radius	1.746 A	67
Atomic Volume	18.151 cm^3/mole	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ion)	0.869 A	55
Closest Approach of Atoms	3.446 A	56
Allotropic Modifications		
CHEMICAL PROPERTIES		
Stable Oxidation State	+3	81
Electrode Potential	[$Tm = Tm^{+3} + 3e^-$] + 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	1.95×10^{-3}/C	61

Properties

Authority

117

Resistivity Versus Temperature



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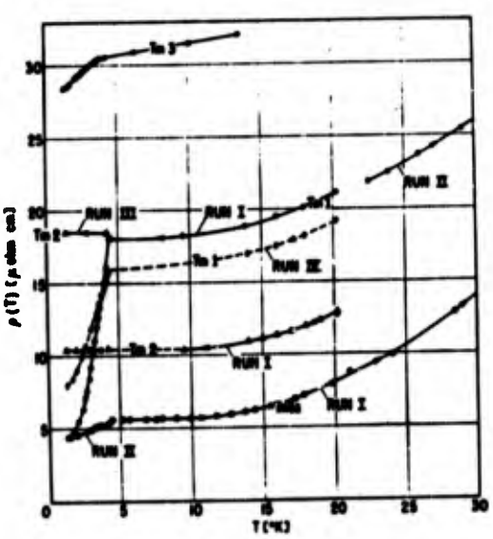

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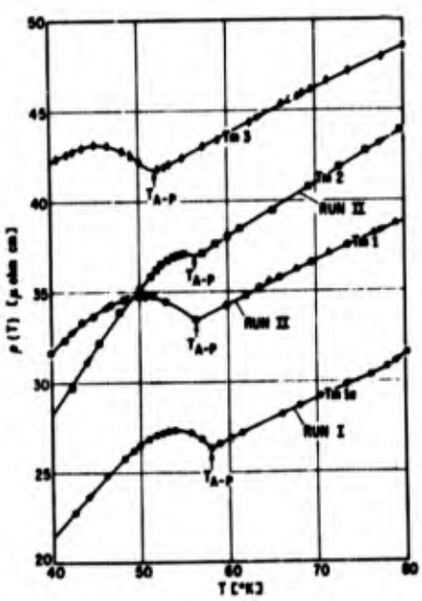

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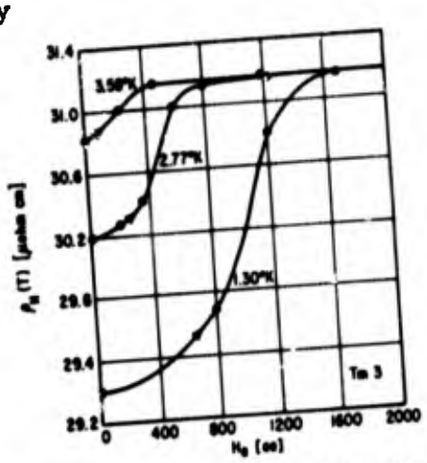
Authority

131

Magnetoresistivity



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Resistance Versus Pressure
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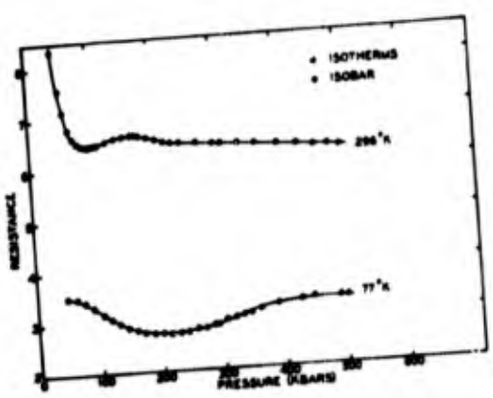


MAGNETIC PROPERTIES

61

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

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

NUCLEAR PROPERTIES

Isotopes — 58, 139

Whole-Number Mass	Relative Abundance, percent	Half Life	Decay Mode
166	--	7.7 hr	K, X, γ, β^+, e^-
167	--	9 days	K, X, γ, β^-
168	--	100 days	K, X, e^-
169	100	Stable	--
170	--	127 days	β
171	--	2 yr	β^-

Thermal Neutron Cross Section	118 ± 6 barns/atom or 0.42 cm^2/g	73

SAFETY

	Details unknown.	83

THERMODYNAMIC PROPERTIES

Authority

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

Heat Content and Entropy of Solid and Liquid Thulium 77

(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	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	12.03
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}(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

169

Antimonides

	TmSb
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.091
Magnetic Susceptibility, $\times 10^{-6}$ emu/mole	26,667
Effective Magnetic Moment, Bohr magnetons	8.14

Arsenides

Authority: 169

	TmAs
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.721
Magnetic Susceptibility, 10^{-6} emu/mole	24,390
Effective Magnetic Moment, Bohr magnetons	7.77

Beryllides

Authority: 179

	$TmBe_{13}$
a_o, A	10.192

Bismuthides

Authority: 169

	TmBi
Structure	Cubic
Lattice Type	NaCl
a_o, A	6.192
Magnetic Susceptibility, 10^{-6} emu/mole	25,000
Effective Magnetic Moment, Bohr magnetons	7.63

Borides

Authority: 153, 171

	TmB_4	TmB_6	TmB_{12}
Molecular Weight	212.22	233.86	299.24
Structure	Tetragonal	Cubic	Cubic
a_o, A	7.06	4.11	7.476
c_o, A	3.99	--	--

(Continued)

Authority

Borides (Continued)

	TmB_4	TmB_6	TmB_{12}
Density, g/cm^3	7.09	5.59	4.756
Work Function, ev	--	3.34	--
Color	Gray brown	Blue	--
Effective Metallic Radius, A	--	2.19	--

Carbides 153

	TmC_2	Tm_2C_3	Tm_3C
Molecular Weight	192.94	374.8	520.2
Structure	Body-centered tetragonal	--	Cubic
Lattice Type	CaC_2	Y_2C_3	Fe_4N
a_o, A	3.600	--	5.016
c_o, A	6.047	--	--
Density, g/cm^3	8.175	--	9.901

Germanides 183

	Tm_2Ge_3
Lattice Type	Defective AlB_2
a_o, A	3.88
c_o, A	4.07
Volume of Unit Cell, A^3	53.06

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

	$TmBr_3$	$TmCl_3$	TmF_3		TmI_3	TmOI
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Hexagonal	Tetragonal
Lattice Type	--	--	--	--	--	PbFCl
a_o, A	4.042	6.75	6.283	6.763	4.288	3.887
b_o, A	--	11.73	6.811	--	--	--
c_o, A	6.367	6.39	4.408	6.927	6.934	9.166
β, deg	--	110.6	--	--	--	--

(Continued)

Authority

Halides (Continued)

	$TmBr_3$	$TmCl_3$	TmF_3		TmI_3	TmOI
Density, g/cm^3	--	--	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^3	--	474	188.6	274.4	--	--

Hydrides 165, 265

	TmH_2	TmH_3
Structure	Cubic	Hexagonal
a_o, A	5.090	3.599
c_o, A	--	6.489
Magnetic Susceptibility, 10^{-6} emu/mole	21,870	21,140
Effective Magnetic Moment, Bohr magnetons	7.60	7.47

		Authority
Nitrides		153
	TmN	
Molecular Weight	182.95	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	4.809	
Density, g/cm^3	10.84	
Magnetic Susceptibility, 10^{-6} emu/mole	23,600	
Magnetic Moment, Bohr magnetons	7.5	
Curie Temperature, K	0	
Oxides		172, 173, 177, 251, 259, 266
	Tm_2O_3	
Molecular Weight	385.87	
Structure	Bcc	
a_o, A	10.52	
Density, g/cm^3	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^{-6}/C	7.7	
Color	Light green	
Effective Magnetic Moment, Bohr magnetons	7.6	

(Continued)

Authority

Oxides (Continued)

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	2,890	8.32	1400	34,000	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

	TmP
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.573
Magnetic Susceptibility, 10^{-6} emu/mole	25,316
Effective Magnetic Moment, Bohr magnetons	7.93

Selenides 169

	TmSe
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.640
Magnetic Susceptibility, 10^{-6} emu/mole	18,180
Effective Magnetic Moment, Bohr magnetons	6.89

Authority

Silicides 263, 264

	$TmSi_2$
Structure	Hexagonal
a_o, A	3.76
c_o, A	4.07
Volume of Unit Cell, A^3	50.52

Sulfides 169, 153

	TmS	Tm_2O_2S
Molecular Weight	--	401.95
Structure	Fcc	Hexagonal
Lattice Type	NaCl	--
a_o, A	5.412	3.747
c_o, A	--	6.538
Density, g/cm^3	--	8.59
Magnetic Susceptibility, 10^{-6} emu/mole	21,505	--
Effective Magnetic Moment, Bohr magnetons	7.42	--

Tellurides 169

	TmTe
Magnetic Susceptibility, 10^{-6} emu/mole	25,641
Effective Magnetic Moment, Bohr magnetons	7.63

Miscellaneous 267

Compound	Lattice Type	a_o, A
$TmGa_3$	$AuCu_3$	4.188

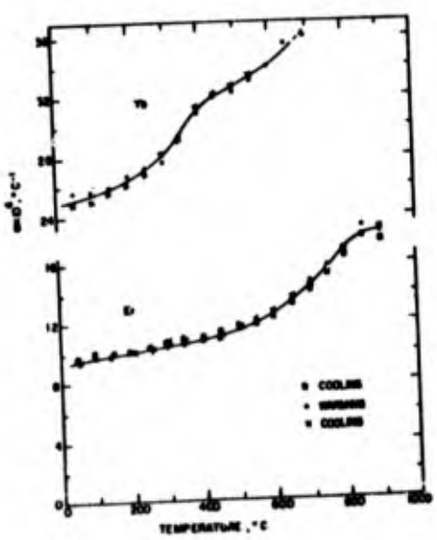
Properties

YTTERBIUM

Symbol Yb | Atomic Number 70 | Atomic Weight 173.04

PHYSICAL PROPERTIES

		Authority
Abundance	2.7-8.0 (approx. 2.7)	51
Density	6.959 g/cm^3	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 x 10^{-6}/C (25-700 C)	61



90

			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	61
Lattice Constants	a_o = 5.4862	a_o = 4.45 A	61
Density	6.959	6.52 g/cm^3	67
Metallic Radius	1.940	1.98 A	67
Atomic Volume	24.80	26.5 cm^3/mole	66
Transition Temperature	798 C		66
Heat of Transition	0.425 kcal/mole		61
Ionic Radius	(+2) 1.06 A, (+3) 0.858 A		55, 93
Closest Approach of Atoms	3.866 A		56
Allotropic Modifications			

	Authority
Atomic Volume Versus Temperature (Permission of Elsevier Publishing Co.)	87

CHEMICAL PROPERTIES

Stable Oxidation State	+2, +3	81
Electrode Potential	[Yb = Yb^{+3} + $3e^{-}$] + 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		

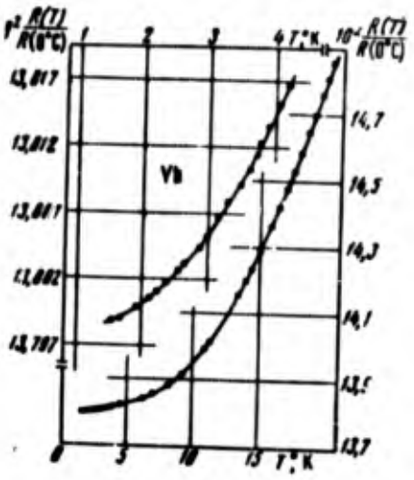
ELECTRICAL PROPERTIES

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

Authority

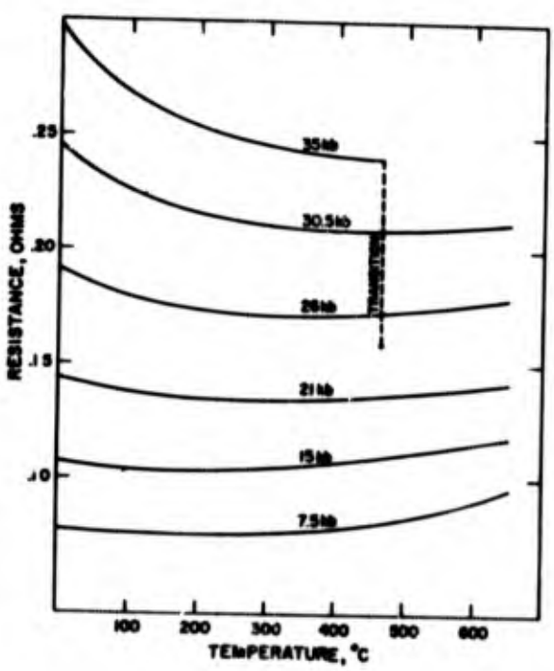
Resistivity Versus Temperature

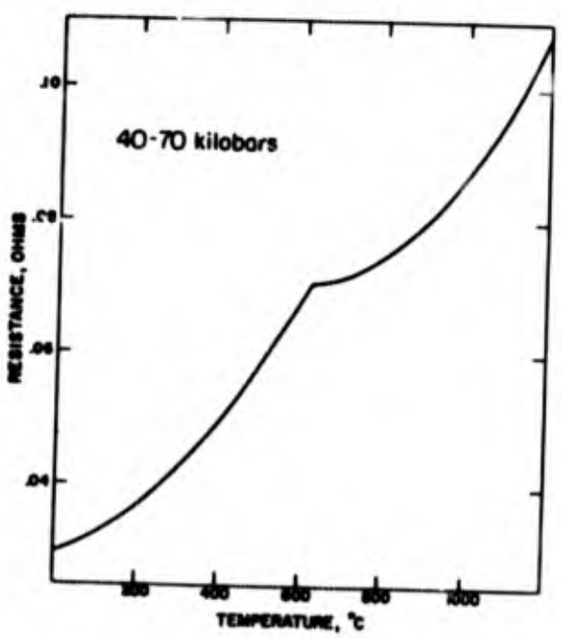
118



Resistance Versus Temperature
(Reprinted from Inorganic Chemistry)

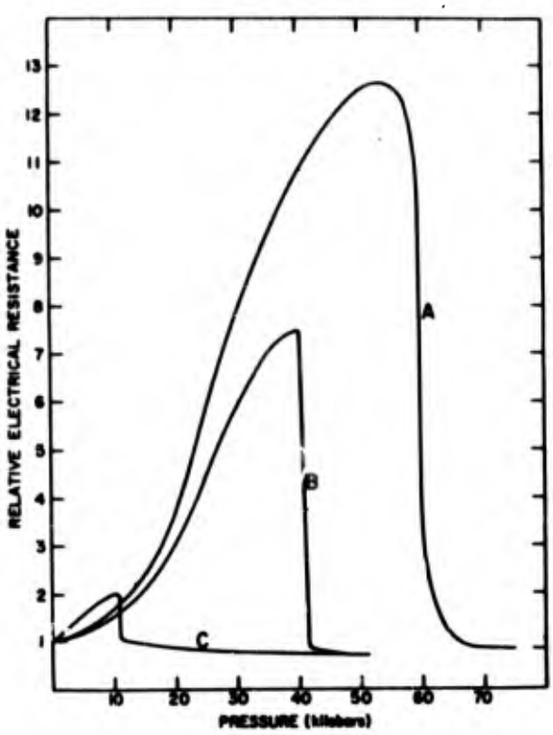
141



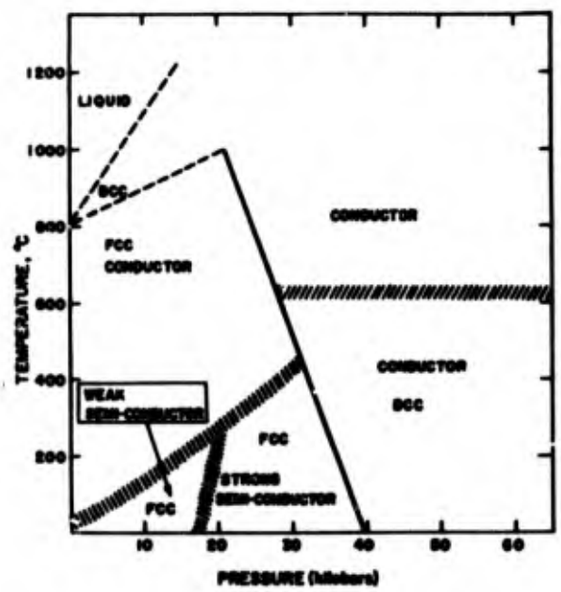


Authority

Resistance Versus Pressure 141
(Reprinted from Inorganic Chemistry)



Partial Pressure-Temperature Phase Diagram 141
(Reprinted from Inorganic Chemistry)



		Authority
MAGNETIC PROPERTIES		
Susceptibility (25 C)	71×10^{-6} 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	1.78×10^{11} dynes/cm^2	57
Shear Modulus	0.70×10^{11} dynes/cm^2	57
Poisson's Ratio	0.284	61
Compressibility	7.12×10^{-6} cm^2/kg	57
Hardness (DPH)	21 (not annealed)	57
	70 F 400 F	
Tensile Strength	10.4 10.2 10^3 psi	88
Yield Strength	9.5 7.8 10^3 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

Whole-Number Mass	Relative Abundance, percent	Half Life	Decay Mode
168	0.140	Stable	--
169	--	33 days	K, X, γ
170	3.03	Stable	--
171	14.31	Stable	--
172	21.82	Stable	--
173	16.13	Stable	--
174	31.82	Stable	--
175	--	99 hr	X, γ, β^-
176	12.73	Stable	--
177	--	2.1 hr	β^-

Thermal Neutron Cross Section: 36 ± 4 barns/atom or 125 cm^2/g — 73

83

SAFETY

Details unknown.

THERMODYNAMIC PROPERTIES

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

Authority

Specific Heat 119

T, K	C_p, mj/(mole)(K)	T, K	C_p, mj/(mole)(K)
	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	0.4268	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
0.6915	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
		3.9959	86.267

Authority

Heat Content and Entropy of Solid and Liquid Ytterbium 77

(Base: α-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	620	1.79	1097(l)	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(α)	5,230	8.45	1700	12,450	14.20
1071(β)	5,530	8.73	1800	13,200	14.64
1097(s)	5,730	8.92			

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

For β-ytterbium: $H_T-H_{298.15} = 7.70T - 2,717$
(0.1 percent; 1071-1097 K);
$C_p = 7.70$.
ΔH_{1097}(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

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

Authority

169

Arsenides

	YbAs
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.702
Magnetic Susceptibility, 10^{-6} emu/mole	7,825
Magnetic Moment, Bohr magnetons	4.61

179

Beryllides

	$YbBe_{13}$
a_o, A	10.19

Bismuthides

Properties

Borides

	YbB_3	YbB_4	YbB_6	YbB_{12}	Authority
Molecular Weight	205.50	216.32	237.96	--	153,155, 171
Structure	Tetragonal	Tetragonal	Cubic	Cubic	
a_o, A	3.77	7.01	4.144	7.476	
c_o, A	3.562	4.00	--	--	
Density, g/cm^3	6.74	7.31	5.556		
Resistivity, microhm-cm	--	--	36.5	--	
Temperature Coefficient of Resistivity, $10^{-3}/C$	--	--	2.34	--	
Coefficient of Thermal Expansion, $10^{-6}/C$	--	--	5.85	--	
Thermal Conductivity, cal/(cm)(sec)(C)	--	--	0.60	--	
Magnetic Susceptibility, 10^{-6} emu/mole	--	--	8,740	--	
Magnetic Moment, Bohr magnetons	--	--	4.58	--	
Work Function, ev	--	--	3.13	--	
Microhardness, kg/mm^2	--	--	3080	--	
Color	--	--	Black	--	
Emissivity ($\lambda = 0.655\mu$)	--	--	0.7	--	
Effective Metallic Radius, A	--	--	2.20	--	

Carbides

	YbC_2	Yb_3C	Authority
Molecular Weight	197.04	531.12	153
Structure	Body-centered tetragonal	Cubic	
Lattice Type	CaC_2	Fe_4N	
a_o, A	2.673	4.993	
c_o, A	6.109	--	
Density, g/cm^3	8.097	10.26	
Magnetic Susceptibility, 10-6 emu/mole	~2,500	--	
Effective Magnetic Moment, Bohr magnetons	3.69	--	183

Germanides

	Yb_2Ge_3
Structure	Defective AlB_2
a_o, A	3.96
c_o, A	4.18
Volume of Unit Cell, A^3	56.77

Halides

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

	$YbBr_2$	$YbCl_2$	YbF_2	YbI_2	$YbBr_3$	$YbCl_3$	YbF_3	YbI_3	YbOI
Structure	--	Orthorhombic	--	--	Hexagonal	Monoclinic	Orthorhombic	Hexagonal	Tetragonal
Lattice Type	--	--	--	--	--	--	--	--	PbFCl
a_o, A	--	6.53	--	--	4.032	6.73	6.216	4.285	3.870
b_o, A	--	6.68	--	--	--	11.65	6.786	--	--
c_o, A	--	6.91	--	--	6.382	6.38	4.434	6.931	9.181
β, deg	--	--	--	--	--	110.4	--	--	--
Density, g/cm^3	--	--	--	--	--	--	8.168	--	--
Heat of Formation, kcal/mole	--	185.5	--	--	--	(224)	--	--	--
Entropy of Formation, eu/mole	--	(39)	--	--	--	(62)	--	--	--
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	Decomposes	Decomposes	2230	Decomposes	--
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	Decomposes	Decomposes	24	Decomposes	--
Color	--	--	--	--	--	--	White	--	--

Authority

251

Hydrides

	YbH_2	YbD_2
Structure	Orthorhombic	Orthorhombic
a_o, A	--	5.871
b_o, A	--	3.561
c_o, A	--	6.763

153, 223

Nitrides

	YbN
Molecular Weight	187.05
Structure	Cubic
Lattice Type	NaCl
a_o, A	4.78
Density, g/cm^3	11.33
Magnetic Suceptibility, 10^{-6} emu/mole	7,250
Effective Magnetic Moment, Bohr magnetons	4.8
Color	Black

Oxides

	YbO	Yb_2O_3	Authority
Molecular Weight	--	394.08	156,172, 153,176, 177,259, 266,271
Structure	--	Bcc	
a_o, A	--	10.41	
Density, g/cm^3	--	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), $10^{-6}/C$	--	7.5	
Effective Magnetic Moment, Bohr magnetons	--	4.5	
Color	--	White	

Heat Content and Entropy Increments for Ytterbium Oxide (Yb_2O_3)
(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	2,910	8.38	1365	33,000(α)	46.42(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			

Authority

Phosphides

169

	YbP
Structure	Cubic
Lattice Type	NaCl
a_o, A	5.554
Magnetic Susceptibility, 10^{-6} emu/mole	7813
Magnetic Moment, Bohr magnetons	4.5

Selenides

192,194, 213,228, 232,268, 278

	YbSe	Yb_2Se_3	Yb_4Se_3	Yb_2O_2Se
Structure	Fcc	Fcc	--	Hcp
Lattice Type	NaCl	NaCl	--	--
a_o, A	5.94	5.66	--	3.76
c_o, A	--	--	--	6.69
Density, g/cm^3	--	7.33	--	9.26
Melting Point, C	1945	>1665	--	--
Resistivity, microhm-cm	1×10^8	--	6.6×10^5	--
Magnetic Susceptibility, 10^{-6} emu/mole	--	7,890	--	--
Magnetic Moment, Bohr magnetons	0.84	4.75	--	--
Color	--	Violet black	--	Beige

Silicides — Authority: 264

	$YbSi_2$
Structure	Hexagonal
a_o, A	3.77
c_o, A	4.10
Volume of Unit Cell, A^3	50.5

Sulfides — Authority: 153

	YbS	Yb_3S_4	Yb_2S_3	Yb_2O_2S
Molecular Weight	205.10	647.36	442.28	410.15
Structure	Cubic	Orthorhombic	Hexagonal	Hexagonal
a_o, A	5.673	12.81	6.784	3.723
b_o, A	--	12.97	--	--
c_o, A	--	3.84	18.29	6.503
Density, g/cm^3	6.75	6.71	6.04	8.72
Magnetic Susceptibility, 10^{-6} emu/mole	1,450	4,740	7,130	--
Color	--	--	Yellow	--

Tellurides — Authority: 168,228, 232

	YbTe	Yb_2Te_3
Structure	Fcc	--
Lattice Type	NaCl	--
a_o, A	6.39	--
Melting Point, C	1740	--
Resistivity, microhm-cm	7×10^9	1×10^7

LUTETIUM

Symbol Lu | Atomic Number 71 | Atomic Weight 174.99

PHYSICAL PROPERTIES

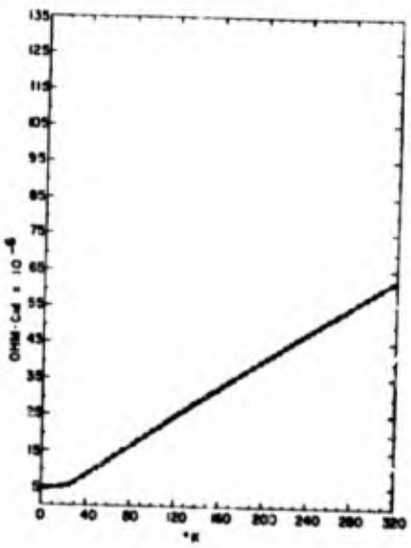
		Authority
Abundance	0.8-1.7 ppm (approx. 0.8)	51
Density	9.849 g/cm^3 (20 C)	67
Melting Point	1652 C	66
Heat of Fusion	4.5 kcal/mole	61
Boiling Point	3327 C	57
Heat of Vaporization (25 C)	90 kcal/mole	57
Vapor Pressure (1651-1932 K)	$\text{Log } P_{\text{mm Hg}} = 9.247 - \frac{21719}{T}$	60
Specific 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)	12.5×10^{-6}/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		

		Authority
CRYSTAL PROPERTIES		
Structure	Hcp	61
Lattice Constants	a_o = 3.5031 A c_o = 5.5509 A	61
Density	9.849 g/cm^3	67
Metallic Radius	1.734 A	67
Atomic Volume	17.779 cm^3/mole	66
Transition Temperature		
Heat of Transition		
Ionic Radius (Trivalent Ion)	0.848 A	55
Closest Approach of Atoms	3.439 A	56
Allotropic Modifications	Resistivity measurements indicate a structural change at high temperature.	66
CHEMICAL PROPERTIES		
Stable Oxidation State	+3	81
Electrode Potential	[Lu = Lu^{+3} + 3e$^-$] + 2.1 volts (standard hydrogen electrode)	81
Ionization Potential		
Metallographic Polishing and Etching		
Corrosion Rates		
Corrosion Data		
ELECTRICAL PROPERTIES		
Resistivity (25 C)	79 microhm-cm (25 C)	61
Temperature Coefficient of Resistivity	1.4 x 10^{-3}/C	61

Authority

Resistivity Versus Temperature

117, 87



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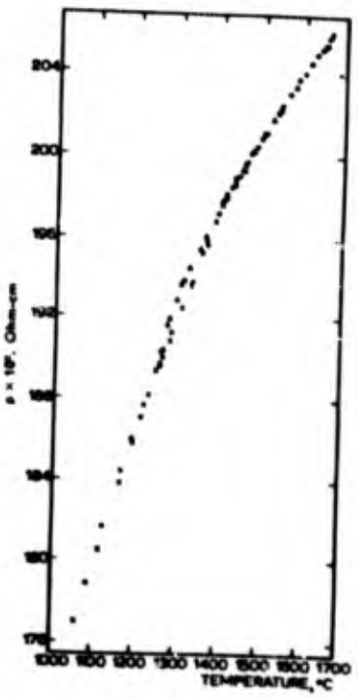

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Values were taken during both heating and cooling.

MAGNETIC PROPERTIES

Magnetic Susceptibility (25 C)	17.9×10^{-6} 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	2.3×10^{-6} cm^2/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

Whole-Number Mass	Relative Abundance, percent	Half Life	Decay Mode
170	--	2.15 days	K, e^-, γ, X, β^+
171	--	9 days	K, e^-, γ, X
172	--	100 days	K, e^-, γ, X
175	97.4	Stable	--
176	2.6	2.4×10^{10} years	K, γ, β^-, X
177	--	6.6 days	β^-

Thermal Neutron Cross Section: 108 ± 5 barns/atom or 0.37 cm^2/g — 73

SAFETY — 83

Details unknown.

THERMODYNAMIC PROPERTIES — 76, 77

	Room Temperature	Melting Point
Entropy	$S_{298} = 11.8$	$S_{2000} = 25.77$ eu
Heat Capacity	$C_{p298} = 6.45$	$C_{p2000} = 9.00$ 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)	$S°$, j/(g-atom)(K)	$\frac{H°-H°_0}{T}$, j/(g-atom)(K)	$\frac{(-F°-H°_0)}{T}$, 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	9.866	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	20.379	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

		Authority
Antimonides	LuSb	275
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	6.0555	
Arsenides	--	
Beryllides	$LuBe_{13}$	179
a_o, A	10.177	
Bismuthides	--	
Borides		153, 171

	LuB_2	LuB_4	LuB_6	LuB_{12}
Molecular weight	196.63	218.27	239.91	304.83
Structure	Hexagonal	Tetragonal	Cubic	Cubic
a_o, A	3.246	6.997	4.11	7.464
c_o, A	3.704	3.938	--	--
Density, g/cm^3	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	--

Carbides — Authority: 153

	Lu_3C	LuC_2
Molecular Weight	536.97	198.99
Structure	Cubic	Body-centered tetragonal
Lattice Type	Fe_4N	CaC_2
a_o, A	4.965	3.563
c_o, A	--	5.964
Density, g/cm^3	10.54	8.728

Germanides — Authority: 183

	Lu_2Ge_3
Lattice Type	Defective AlB_2
a_o, A	3.83
c_o, A	4.05
Volume of Unit Cell, A^3	51.45

Authority

Halides 93, 108, 158, 165, 209, 210, 235, 236

	$LuBr_3$	$LuCl_3$	LuF_3	LuI_3
Structure	Hexagonal	Monoclinic	Orthorhombic	Hexagonal
a_o, A	4.015	6.72	6.151	4.271
b_o, A	--	11.60	6.758	--
c_o, A	6.371	6.39	4.467	6.930
Density, g/cm^3	--	--	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	1480	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^3	--	467	185.7	--

Hydrides 165

	LuH_2	LuH_3
Structure	Cubic	Hexagonal
a_o, A	5.033	3.558
c_o, A		6.443

		Authority
Nitrides		
	LuN	153
Molecular Weight	189.00	
Structure	Cubic	
Lattice Type	NaCl	
a_o, A	4.766	
Density, g/cm^3	11.59	
Oxides		156, 172, 173, 177, 245
	Lu_2O_3	
Molecular Weight	397.94	
Structure	Bcc	
a_o, 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^{-6}/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

Lu_2Se_3

Structure	Fcc
a_o, A	5.62

Silicides 263, 264

$LuSi_2$

Structure	Hexagonal
a_o, A	3.74
c_o, A	4.04
Volume of Unit Cell, A^3	49.2

Sulfides 153

Lu_2O_2S

Molecular Weight	414.05
Structure	Hexagonal
a_o, A	3.709
c_o, A	6.486
Density, g/cm^3	8.89

Authority

Tellurides

Miscellaneous 150, 267

Compound	Structure	Lattice Type	a_o, A	c_o, A	Superconducting Transition Temperature, K
$LuCa_3$	--	$AuCu_3$	4.169	--	--
$LuRu_2$	Hexagonal	--	5.204	8.725	--
$LuOs_2$	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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