

AD-A128 905

PROPERTIES OF GRAPHITE INTERCALATES AND OF AIRCRAFT
STRUCTURAL METALS AND... (U) THERMOPHYSICAL AND
ELECTRONIC PROPERTIES INFORMATION ANALYSIS..

1/1

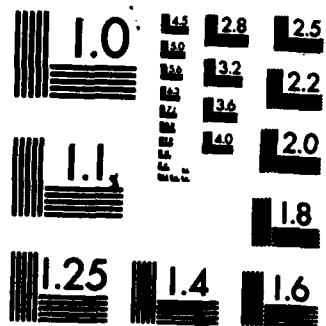
UNCLASSIFIED

Y S TOULOUKIAN ET AL. MAY 74 CINDAS-32

F/G 20/13

NL

END
DATE
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TPRC

THERMOPHYSICAL PROPERTIES RESEARCH CENTER

CINDAS REPORT

32

①

PROPERTIES OF GRAPHITE INTERCALATES AND OF AIRCRAFT STRUCTURAL METALS AND ALLOYS

A Comprehensive Data Survey

Y. S. TOULOUKIAN
Director

C. Y. HO
Assistant Director - Research

WA 128905

Prepared for

LASER HARDENED MATERIALS AND STRUCTURES SUBPANEL
High Energy Laser Review Group

May 1974

FILE

DTIC
ELECTE
JUN 02 1974
S
COPY

Prepared by

THERMOPHYSICAL AND ELECTRONIC PROPERTIES
INFORMATION ANALYSIS CENTER

operated by

THERMOPHYSICAL PROPERTIES RESEARCH CENTER

Purdue University

2595 Yeager Road

West Lafayette, Indiana 47906

This document has been approved
for public release and sale; its
distribution is unlimited.

88 06 01 334

UNCLASSIFIED

FORM 100-101

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Properties of Graphite Intercalates and of Aircraft Structural Metals and Alloys A Comprehensive Data Survey		5. TYPE OF REPORT & PERIOD COVERED State-of-the-Art Report
6. PERFORMING ORG. REPORT NUMBER CINDAS Report 32		7. CONTRACT OR GRANT NUMBER(s) DSA-900-74-C-2428
8. AUTHOR(s) Y. S. Touloukian and C. Y. Ho		9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
10. PERFORMING ORGANIZATION NAME AND ADDRESS Thermophysical and Electronic Properties Information Analysis Center, CINDAS/Purdue Univ., 2595 Yeager Rd., W. Lafayette, IN 47906		11. REPORT DATE May 1974
12. CONTROLLING OFFICE NAME AND ADDRESS Defense Technical Information Center, Defense Logistics Agency, Attn: DTIC-AI, Cameron Station, Alexandria, VA 22314		13. NUMBER OF PAGES 45
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Army Materials and Mechanics Research Center Attn: DRXMR-P Arsenal Street Watertown, MA 02172		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report) Distribution unlimited		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES (DTIC Source Code 413571); TEPIAC Publication Microfiche copies available from DTIC		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) *Thermophysical properties *Electrical properties---Optical properties---Thermal radiative properties--- Thermal conductivity---Thermal diffusivity---Thermal expansion---Specific heat---Heat of fusion---Graphite compounds---Composites---Carbides---Aluminum Aluminum alloy---Titanium---Titanium alloy---Magnesium alloy---Stainless steels---Data Survey		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents the results of a comprehensive literature search and data survey for the electrical, electronic, optical, and thermal radiative properties of graphite intercalates and for the thermal conductivity, thermal diffusivity, thermal expansion, specific heat, and heat of fusion of several aircraft structural metals and alloys for both the solid and liquid states in the vicinity of the melting point. The findings on the properties of graphite intercalates are summarized in		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Cont)

the table on the next page, where the letter "D" indicates the availability of some data for that property of that material.

TABLE 1. Data for the properties of the materials.

TABLE 2. Data for the properties of the materials.

TABLE 3. Data for the properties of the materials.

TABLE 4. Data for the properties of the materials.

TABLE 5. Data for the properties of the materials.

TABLE 6. Data for the properties of the materials.

TABLE 7. Data for the properties of the materials.

TABLE 8. Data for the properties of the materials.

TABLE 9. Data for the properties of the materials.

TABLE 10. Data for the properties of the materials.

TABLE 11. Data for the properties of the materials.

TABLE 12. Data for the properties of the materials.

TABLE 13. Data for the properties of the materials.

**PROPERTIES OF GRAPHITE INTERCALATES AND OF
AIRCRAFT STRUCTURAL METALS AND ALLOYS**

A Comprehensive Data Survey

Y. S. TOULOUKIAN
Director

C. Y. HO
Assistant Director - Research

Prepared for
LASER HARDENED MATERIALS AND STRUCTURES SUBPANEL
High Energy Laser Review Group

May 1974

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

Prepared by
**THERMOPHYSICAL AND ELECTRONIC PROPERTIES
INFORMATION ANALYSIS CENTER**
operated by
THERMOPHYSICAL PROPERTIES RESEARCH CENTER
Purdue University
2595 Yeager Road
West Lafayette, Indiana 47906



FOREWORD

This comprehensive literature search and data survey was conducted by the Thermophysical and Electronic Properties Information Analysis Center (TEPIAC), a DoD Information Analysis Center operated by the Thermophysical Properties Research Center (TPRC), Purdue University, West Lafayette, Indiana.

The survey was to provide the urgently needed information to the Laser Hardened Materials and Structures Subpanel of the High Energy Laser Review Group (HELRG).

SUMMARY

This report presents the results of a comprehensive literature search and data survey for the electrical, electronic, optical, and thermal radiative properties of graphite intercalates and for the thermal conductivity, thermal diffusivity, thermal expansion, specific heat, and heat of fusion of several aircraft structural metals and alloys for both the solid and liquid states in the vicinity of the melting point.

The findings on the properties of graphite intercalates are summarized in the table on the next page, where the letter "D" indicates the availability of some data for that property of that material.

	Electrical Resistivity	Hall Coefficient	Magnetoresistance	Thermoelectric Power	Energy Gap	Thermionic Emission	Work Function	Emissance	Reflectance
Cesium Carbide (CsC_3)	D		D						
Potassium Carbide (KC_3)	D		D						
Potassium Carbide (KC_{36})	D		D						
Rubidium Carbide (RbC_3)	D		D						
Graphite, Boron Filled				D					
Graphite, Bromide Filled	D	D	D						
Graphite, Bromine Filled				D					
Graphite, Chloride Filled		D							
Graphite, Chlorine Filled	D			D					
Graphite, Fluorine Filled	D								
Graphite, Lithium Acetate Aqueous Solution Filled							D		
Graphite, Nickel Filled	D	D			D				
Graphite, (Nonspecific) Filled	D								
Graphite, Potassium Filled	D			D					
Graphite, Thorium Oxide Filled						D			
Graphite, Thorium Oxide + Nitric Acid Solution Filled							D		
Graphite, Uranium Carbide Filled	D								
Graphite, Yttrium Oxide Filled						D			
Graphite, Yttrium Oxide + Nitric Acid Solution Filled							D		
Graphite, Zirconium Carbide Filled									D
Graphite, Silicon Carbide Bonded								D	D
Graphite, Silicon Carbide Coated								D	

The findings on the thermophysical properties of the several metals and alloys are summarized in the following table with the letters "D" and "V" having the following designations:

D - Data or recommended values available.

V - Data not available but estimated values obtainable.

	Thermal Conductivity		Thermal Diffusivity		Thermal Expansion		Specific Heat		Heat of Fusion
	Immediately		Immediately		Immediately		Immediately		
	Below M. P.	Above M. P.	Below M. P.	Above M. P.	Below M. P.	Above M. P.	Below M. P.	Above M. P.	
Aluminum	D	D	D	D	D	V	D	D	D
Al Alloy 7075-T6	V	V	V	V	V	V	V	V	V
Titanium	D	V	D	V	V	V	D	D	D
Ti Alloy 6Al-4V	V	V	V	V	V	V	V	V	V
Mg + Al Alloys	V	V	V	V	V	V	V	V	D
Stainless Steels AISI 304 and 347	D	V	V	V	V	V	V	V	V

CONTENTS

	Page
FOREWORD	ii
SUMMARY	iii
I. PROPERTIES OF GRAPHITE INTERCALATES	1
1. INTRODUCTION	1
2. AVAILABLE DATA	2
A. Electrical Resistivity	2
B. Hall Coefficient	2
C. Magnetoresistance	2
D. Thermoelectric Power	2
E. Energy Gap	2
F. Thermionic Emission	3
G. Work Function	3
H. Emittance	3
I. Reflectance	3
3. REFERENCES	4
II. PROPERTIES OF AIRCRAFT STRUCTURAL METALS AND ALLOYS IN THE VICINITY OF THE MELTING POINT	6
1. INTRODUCTION	6
2. AVAILABLE DATA	7
A. Thermal Conductivity	7
a. Aluminum	7
b. Aluminum Alloy 7075-T6	7
c. Titanium	8
d. Titanium Alloy 6Al-4V	9
e. Magnesium + Aluminum Alloys	10
f. Stainless Steels 304 and 347	11
g. References	12
B. Thermal Diffusivity	18
a. Aluminum	18
b. Aluminum Alloy 7075-T6	18
c. Titanium	20
d. Titanium Alloy 6Al-4V	20
e. Magnesium + Aluminum Alloys	21
f. Stainless Steels 304 and 347	21
g. References	22

C. Thermal Expansion	24
a. Aluminum	24
b. Aluminum Alloy 7075-T6	25
c. Titanium	25
d. Titanium Alloy 6Al-4V	26
e. Magnesium + Aluminum Alloys	26
f. Stainless Steels 304 and 347	27
g. References	28
D. Specific Heat	32
a. Aluminum	32
b. Aluminum Alloy 7075-T6	32
c. Titanium	32
d. Titanium Alloy 6Al-4V	33
e. Magnesium + Aluminum Alloys	33
f. Stainless Steels 304 and 347	34
g. References	34
E. Heat of Fusion	37
a. Aluminum	37
b. Aluminum Alloy 7075-T6	37
c. Titanium	37
d. Titanium Alloy 6Al-4V	37
e. Magnesium + Aluminum Alloys	37
f. Stainless Steels 304 and 347	37
g. References	37

I. PROPERTIES OF GRAPHITE INTERCALATES

1. INTRODUCTION

Presented in this section are the results of a comprehensive survey of the available data on the electrical, electronic, optical, and thermal radiative properties of graphite intercalates. The properties on which data are uncovered include electrical resistivity, Hall coefficient, magnetoresistance, thermoelectric power, energy gap, thermionic emission, work function, emittance, and reflectance. The materials reported herein include graphite intercalation compounds (which are graphite compounds where atoms and molecules have been inserted into the graphite matrix material thus giving rise to periodically alternating atomic arrangements of the graphite matrix and the introduced material) and graphite-base materials filled with various substances.

The temperature ranges of the available data for the properties of the materials together with the source references are presented in the next subsection. A summary of the findings is given in the SUMMARY.

2. AVAILABLE DATA

A. Electrical Resistivity

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1) Cesium Carbide (CsC_8)	50-310	1	
(2) Potassium Carbide (KC_8)	50-300	1	
(3) Potassium Carbide (KC_{36})	50-300	1	
(4) Rubidium Carbide (RbC_8)	50-300	1	
(5a) Graphite, Bromide Filled	93-298	2	Resistance ratio
(5b) Graphite, Bromide Filled	77-2238	3	Resistance ratio
(5c) Graphite, Bromide Filled	90-288	4	Conductance
(6) Graphite, Chlorine Filled	298	3	Resistance ratio
(7) Graphite, Fluorine Filled	90-288	4	Resistance ratio
(8) Graphite, Potassium Filled	90-288	4	
(9) Graphite, Nickel Filled	223-1473	5	
(10) Graphite, (Nonspecific) Filled	203-973	6	
(11) Graphite, Uranium Carbide Filled	253-1173	7	

B. Hall Coefficient

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1) Graphite, Bromide Filled	77-2238	3	
(2) Graphite, Chloride Filled	298	3	
(3) Graphite, Nickel Filled	223-1473	6	

C. Magnetoresistance

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1) Cesium Carbide (CsC_8)	50-300	1	Magnetic field 4880 G
(2) Potassium Carbide (KC_8)	50-300	1	Magnetic field 4880 G
(3) Potassium Carbide (KC_{36})	50-300	1	Magnetic field 4880 G
(4) Rubidium Carbide (RbC_8)	50-300	1	
(5) Graphite, Bromide Filled	298	3	Magnetic field 0-14000 G

D. Thermoelectric Power

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1) Graphite, Boron Filled	298	8	Thermoelectric power
(2) Graphite, Bromine Filled	298	4	Thermoelectric voltage
(3) Graphite, Fluorine Filled	298	4	Thermoelectric voltage
(4) Graphite, Potassium Filled	298	4	Thermoelectric voltage

E. Energy Gap

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1) Graphite, Nickel Filled	223-1473	5	

F. Thermionic Emission

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1) Graphite, Yttrium Oxide Filled	398-523	9	
(2) Graphite, Thorium Oxide Filled	298-523	9	

G. Work Function

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1) Graphite, Lithium Acetate Aqueous Soln Filled	1823	9	
(2) Graphite, Yttrium Oxide + Nitric Acid Soln Filled	1823	9	
(3) Graphite, Thorium Oxide + Nitric Acid Soln Filled	1823	9	

H. Emittance

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1a) Graphite, SiC Bonded	505-1617	10	Total normal
(1b) Graphite, SiC Bonded	645-1645	11	Black body radiation
(1c) Graphite, SiC Bonded	645-1645	12	Black body radiation
(2a) Graphite, SiC Coated	645-1645	12	Black body radiation
(2b) Graphite, SiC Coated	645-1645	12	Black body radiation

I. Reflectance

<u>Material</u>	<u>Temperature (K)</u>	<u>Reference</u>	<u>Remarks</u>
(1a) Graphite, SiC Bonded	700-1645	13	Total normal
(1b) Graphite, SiC Bonded	700-1645	14	Total normal
(2) Graphite, ZrC Filled	298	15	Measured data 0-60 Vol. % Graphite

3. REFERENCES

Ref. TPRC/EPIC
No. No.

- 1 E41388 Murray, J. J. and Ubbelohde, A. R., "Electronic Properties of Some Synthetic Metals Derived from Graphite," Royal Soc. of London, Proc., A, 312(1510), 371-380, 1969.
- 2 E2778 Blackman, L. C. F., Matthews, J. F., and Ubbelohde, A. R., "Electrical Properties of Crystal Compounds of Graphite I. Conductance of Graphite/Bromine," Royal Soc., Proc., 256(1284), 15-27, 1960.
- 3 E2832 Hennig, G., "The Properties of the Interstitial Compounds of Graphite. III. The Electrical Properties of the Halogen Compounds of Graphite," J. Chem. Phys., 20(9), 1443-7, 1952.
- 4 E6315 McDonnell, F. R. M., Pink, R. C., and Ubbelohde, A. R., "Some Physical Properties Associated with Aromatic Electrons. Pt. 3. The Pseudo-Metallic Properties of Potassium Graphite and Graphite Bromide," J. Chem. Soc. London, 191-7, 1951.
- 5 E7886 Pohl, H. A. and Hoglen, J. J., "Semi-Conduction in Nickel-Doped Polymer Carbons," Princeton Univ., Plastics Lab., 1959. [AD216487]
- 6 E11716 Beutell, M., Fitzer, E., Gain, R., and Vohler, O., "Preliminary Results on Radiation Damage in Various Graphites," Proc. 5th Carbon Conf., Macmillan, 2, 319-33, 1961.
- 7 E29304 Tye, R. P. and Woodman, M. J., "The Thermal Conductivity of Compacted Powder Carbons and Mixtures of Carbon Powders with Uranium Carbide Particles," Carbon, 4(2), 167-78, 1966.
- 8 E4693 Shepard, R. L., Pattin, H. S., and Westbrook, R. D., "A High-Temperature Boron Graphite-Graphite Thermocouple," Amer. Phys. Soc., Bull., 1, 119, 1956.
- 9 E43016 Morozov, Yu. M., Kul'varakaya, B. S., and Kan, Kh. S., "Thermionic Emission Properties of Graphites," Acad. of Sci., USSR, Bull., Phys. Ser., 33(3), 406-9, 1969.
- 10 24453 Nowak, J. M., "Ceramic Materials for Leading Edges of Hypersonic Aircraft," Ceram. Age, 77(10), 109-12, 1961.
- 11 16727 Anthony, F. M. and Pearl, H. A., "Investigation of Feasibility of Utilizing Available Heat Resistant Materials for Hypersonic Leading Edge Applications. Vol. 3. Screening Test Results and Selection of Materials," Bell Aircraft Corp., Buffalo, N. Y., 1960. [AD247110 L]

Ref.	TPRC/EPIC
No.	No.

- | | | |
|----|-------|--|
| 12 | 19559 | Anthony, F.M., Merrihew, F.A., Mistretta, A.L., and Dukes, W.H., "Investigation of Feasibility of Utilizing Available Heat Resistant Materials for Hypersonic Leading Edge Applications. Vol. 1, Summary," Bell Aerosystems Co., Buffalo, N.Y., 1961. [AD264 861] |
| 13 | 30646 | Pears, C.D., "Some Problems in Emittance Measurements at the Higher Temperatures and Surface Characterization," From Proc. Symp. on Measurement of Thermal Radiation Properties of Solids, Dayton, Ohio, Sept. 5-7, 1962, Southern Research Inst., Birmingham, Ala., NASA-SP-31, 541-51, 1963. |
| 14 | 24864 | Pears, C.D., "The Determination of the Emittance of Refractory Materials to 5000 F," From Progress in International Research on Thermodynamic and Transport Properties, ASME Second Symposium on Thermophysical Properties, Princeton, N.J., 588-98, 1962. |
| 15 | 29087 | Hasselman, D.P.H. and Shaffer, P.T.B., "Factors Affecting Thermal Shock Resistance of Polyphase Ceramic Bodies," U.S. Air Force Rept. WADD-TR-60-749 (Part II), 155 pp., 1962. [AD277 605] |

II. PROPERTIES OF AIRCRAFT STRUCTURAL METALS AND ALLOYS IN THE VICINITY OF THE MELTING POINT

1. INTRODUCTION

Presented in this section are the results of a comprehensive survey of the available data on the thermal conductivity, thermal diffusivity, thermal expansion, specific heat, and heat of fusion of several aircraft structural metals and alloys (aluminum, aluminum alloy 7075-T6, titanium, titanium alloy 6Al-4V, magnesium + aluminum alloys, and stainless steels 304 and 347) for both the solid and liquid states in the vicinity of the melting point. As seen from what is presented in the next subsection, data are not available for most of the cases. However, for each of such cases, the feasibility of estimating the needed values was studied and the possible method for the estimation is discussed.

The temperature ranges of the available data for the properties of the materials together with the source references are presented in the next subsection. A summary of the findings is given in the SUMMARY.

2. AVAILABLE DATA

A. Thermal Conductivity

a. Aluminum

The melting point of pure aluminum is 933.5 K. There are plenty of experimental data on the thermal conductivity and electrical resistivity of pure aluminum near the melting point in solid and liquid states. TPRC has already generated the recommended thermal conductivity values for pure aluminum in solid and liquid states [24].

The temperature ranges of the available thermal conductivity data together with the source references are given in the following table.

Thermal Conductivity of Aluminum

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
0-8500	24	Recommended reference values; solid and liquid states.
389-1073	28	Solid and liquid states.
298-1173	3	Solid and liquid states.
273-1073	25a	Solid and liquid states.
973-1273	41	Solid and liquid states.
933-1873	39	Liquid state.
933-8650	21	Liquid state; calculated from electrical resistivity according to the Wiedemann-Franz-Lorenz Law.

b. Aluminum Alloy 7075-T6

The melting range of aluminum alloy 7075-T6 is from 750 to 911 K. This alloy is also designated as 75S-T6. Experimental data on the thermal conductivity of aluminum alloy 7075-T6 are available up to 700 K and can be extrapolated to the melting point without large uncertainty.

No information is available for the molten alloy. However, since this alloy contains about 90% aluminum, the ratio of the thermal conductivities of the solid and of the liquid aluminum at the melting point, k_s/k_l , may be used as a guide for the rough estimation of the thermal conductivity of this alloy in the molten state.

The temperature ranges of the available thermal conductivity data together with the source references are given in the following table.

Thermal Conductivity of Aluminum Alloy 7075-T6

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
117-702	33	75S-T6.
311-700	54	Not original.
117-700	32	Density, thermal expansion coefficient, specific heat, and thermal diffusivity also reported.
117-622	1	
273-573	26	75S-T6.

c. Titanium

The melting point of pure titanium is 1953 K. There are plenty of thermal conductivity data from room temperature to about 1700 K. TPRC has generated the recommended thermal conductivity values covering the range 0 to 1950 K [24].

No information is available for the thermal conductivity of molten titanium. However, since there are electrical resistivity data for pure titanium up to the melting point and above, thermal conductivity of titanium can possibly be estimated for the molten state. The temperature ranges of the available thermal conductivity and electrical resistivity data together with the source references are given in the following two tables.

Thermal Conductivity of Titanium

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
0-1950	24	Recommended values.
1006-1499	53, 52	Calculated from thermal diffusivity using different values of specific heat.
1106-1497	19, 49	Electrical resistivity and Lorenz number also reported up to 1500 K.
753-1606	43	Calculated from thermal diffusivity.
900-1700	53	Calculated from thermal diffusivity.
300-1400	34	Measured for bulk and porous specimens; thermal expansion coefficient and electrical resistivity also reported.
1000-1700	2	Thermal diffusivity, heat capacity, and electrical resistivity also reported; data from other references presented.
1000-1700	15	Heat capacity and electrical resistivity also reported up to 1700 K; written in Russian; seems to be original.
1000-1500	53	Calculated from thermal diffusivity using different value of specific heat.
1100-1500	19	Effect of phase transformation from c.p.h. to b.c.c. in titanium studied.

Electrical Resistivity of Titanium

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
273-1473	17	Data compiled from other references.
1100-1500	19	Effect of phase transformation from c.p.h. to b.c.c. in titanium studied.
273-2000	9	Electrical resistivity of 3d-transition metals on melting measured; ratio of electrical resistivities above the melting point and below melting point reported; theoretical value of the ratio reported from reference [1] of this paper.
1000-1750	51	
1200-1900	29	99.86 Ti.
300-1400	38	Resistivity and total emissivity of commercial titanium measured.
332-1935	20	Compiled data [see their Reference 53].

d. Titanium Alloy 6Al-4V

The melting range of titanium alloy 6Al-4V is from 1877 to 1933 K. This alloy has the following various designations [50]:

Republic Steel Co., Titanium Metal Division: Ti-6Al-4V
Special Metal Division: RS-120A

Crucible Steel Co., Titanium Division: C-120AV

Harvey Aluminum Co., Titanium Division: HA-6510

Reactive Metal Products: MST-6Al-4V

Aeronautical Material Specifications: 4928A

Military designation: OS-10737

Both thermal conductivity and electrical resistivity data for this alloy have been reported up to about 1200 K. However, most of the data are from company literature and, therefore, they are only nominal values. There is no data available at all above 1200 K at the present time.

One way to obtain estimates of the thermal conductivity values of the solid near the melting point is to extrapolate the thermal conductivity curve to the melting point following the thermal conductivity curve of pure titanium. The extrapolation can be done reasonably well by adjusting the thermal conductivity values to be consistent with the electrical resistivity values extrapolated in a similar way. At 1000 K the thermal conductivity of this alloy differs only by about 25% from that of pure titanium. The difference between them might decrease further at higher temperatures. Therefore, the

extrapolated thermal conductivity values near the melting point will be fairly reasonable and the uncertainties will be within about 10%.

No information is available for the thermal conductivity of this alloy in the molten state. Rough estimates might be obtained by assuming that k_g/k_l of this alloy at the melting point is the same as that of pure titanium, which, however, is also a rough estimate.

The temperature ranges of the available thermal conductivity and electrical resistivity of this alloy are given in the following two tables.

Thermal Conductivity of Titanium Alloy 6Al-4V

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
311-811	7	Electrical resistivity reported.
422-922	37	
300-1173	23	Literature data reported including those on density and specific heat.
293-1144	6	Nominal values from a company bulletin.
33-1089	8	Compiled data.

Electrical Resistivity of Titanium Alloy 6Al-4V

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
311-1256	5	Compiled data.
293-1173	22	$\Delta R/R_0$ reported.

e. Magnesium + Aluminum Alloys

The melting ranges of Mg + Al alloys are from 923 (pure Mg) to above 710 K depending on the composition. The solubility of Al in Mg is about 12.7% Al. Thermal conductivities of Mg + Al alloys have been reported up to 736 K. TPRC has already generated the recommended electrical resistivity values for the solid solution region up to near the melting point and is generating the recommended thermal conductivity values.

Thermal conductivity or electrical resistivity data for molten Mg + Al alloys have not been reported. Rough estimates of the thermal conductivity for the molten state might be made by assuming that the ratio of the electrical resistivities of the solid and of the molten alloy, ρ_g/ρ_l , at the melting point is the same as that of pure magnesium.

The temperature ranges of the available thermal conductivity and electrical resistivity data together with the source references are given in the following two tables.

Thermal Conductivity of Mg + Al Alloys

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
373-623	36	11% and 6% Al alloys.
375-736	18	0.8% Al alloy.
387-674	18	Magnox; 8 ~ 9% Al, 0.501% Zn, and 0.2% Mn.
293-773	40	Magnox B; 1.0% Al and 0.002-0.003% Be; data for pure Mg and many other Mg alloys also reported up to 773 K.
87-476	35	6%, 8%, and 12% Al alloys.

Electrical Resistivity of Mg + Al Alloys

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
293.2	44	9 specimens with composition ranging from 0.32 to 2.67% Al.
293-773	40	Magnox B; 1.0% Al and 0.002-0.003% Be.
87-476	35	6%, 8%, and 12% Al alloys.

f. Stainless Steels 304 and 347

The melting range of stainless steel 304 is from 1672 to 1728 K and that of stainless steel 347 is from 1672 to 1700 K.

Russian 18-8 stainless steel seems to be the same alloy as the stainless steel 304. Stainless steel 304L is not the same as the stainless steel 304 but the amount of each of its constituents is within 1 or 2% of that of the stainless steel 304. Therefore, the data for stainless steel 304L can possibly be used as a guide to extrapolate the data for stainless steel 304.

Experimental data for the thermal conductivity of stainless steel 304 are available up to 1225 K and those for stainless steel 347 up to 1543 K. TPRC has recommended values for the thermal conductivity of stainless steels 304 and 347 up to the melting point [46].

No experimental data are available for the thermal conductivity of either stainless steel 304 or 347 in the molten state. However, since the ratios of electrical resistivities of the liquid and of the solid, ρ_L/ρ_S , at the melting point of pure elements Fe, Ni, and Cr (theoretical value) are available [9, 55], ρ_L/ρ_S of stainless steel 304 and of 347 can probably be estimated by simple mixing rule. Thus, the electrical resistivity of molten stainless steels 304 and 347 can be roughly estimated, from which the thermal conductivity can be estimated roughly.

The temperature ranges of the available thermal conductivity and electrical resistivity data together with the source references are given in the following tables. No data were uncovered for the electrical resistivity of stainless steel 347 at high temperatures.

Thermal Conductivity of Stainless Steel 304

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
923-1082	45	Extrapolated up to 1600 K.
373-998	4	Not original; discussed about TPRC's recommendation of the thermal conductivity of stainless steel 304; extrapolated up to 1623 K.
373-998	10	Original data source of the above reference.
442-1225	30	18-8 stainless steel.
573-1673	11, 12	Stainless steel 304L.
404-1264	47	Stainless steel 304L.
300-1200	48	Electrical resistivity also reported.

Electrical Resistivity of Stainless Steel 304

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
300-1200	48	
373-973	30	18-8 stainless steel.
299-1651	11	304L.
295-1273	47	304L.

Thermal Conductivity of Stainless Steel 347

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
362-1174	33	
330-1543	14, 13	
273-1173	25a, 25b	

g. References

Ref. TPRC/EPIC No. No.

- 1 16987 Adolphson, D.R., "Elevated Temperature Properties of 7075-T6 Aluminum Alloys," U.S. Atomic Energy Commission, SCTM 299-68 (16), 23 pp., 1968.
- 2 64652 Arutyunov, A.V., Banchila, S.N., and Filippov, L.P., "Properties of Titanium at Temperatures Above 1000 K," Teplofiz. Vys. Temp., 9(3), 535-8, 1971; English translation: High Temp., 9(3), 487-9, 1971.

**Ref. TPRC/EPIC
No. No.**

- 3 101 Bidwell, C.C. and Hogan, C.L., "Thermal Conductivity of Aluminum, Solid and Liquid States," *J. Appl. Phys.*, 18, 776-9, 1947.
- 4 54190 Brassfield, H.C., White, J.F., Sjodahl, L., and Bittel, J.T., "Recommended Property and Reaction Kinetics Data for Use in Evaluating a Light-Water-Cooled Reactor Loss-of-Coolant Incident Involving Zircaloy -4-or 304-ss-Clad UO_2 ," Missile and Space Division, General Electric Co., Cincinnati, Ohio, GEMP-482, 89 pp., 1968.
- 5 E20038 Brooks and Perkins, Inc., "Electrical Resistivity of Magnesium Alloys," Tech. Data Sheet, n.d.
- 6 10941 Crucible Steel Co. of America, "Crucible C-120AV Titanium Base Alloy," Crucible Steel Co. of America, Pittsburgh, Pa., Data Sheet C-120 AV, 19 pp., 1963.
- 7 9951 Deem, H.W., Wood, W.D., and Lucks, C.F., "The Relation Between Electrical and Thermal Conductivities of Titanium Alloys," *Trans. Met. Soc., AIME*, 212, 520-3, 1958.
- 8 16736 Defense Metals Information Center, "Memorandum on Thermal Properties of Titanium and Titanium Alloys," DMIC Memo. 1, 23 pp., 1958.
- 9 E37605 Eliutin, V.P., Turov, V.D., and Maurakh, M.A., "Change of Electric Conductivity of 3d-Transition Metals on Melting," *Izv. Vyssh. Ucheb. Zaved. Chern. Met.*, No. 1, 112-4, 1965.
- 10 1681 Ewing, C.T., Seebold, R.E., Grand, J.A., and Miller, R.R., "Thermal Conductivity of Mercury and Two Sodium-Potassium Alloys," *J. Phys. Chem.*, 59, 524-8, 1955.
- 11 53604 Feith, A.D., Hein, R.A., Johnstone, C.P., and Flagella, P.N., "Thermophysical Properties of Low Carbon 304 Stainless Steel to 1350 C," From Proceedings of the Eighth Conference on Thermal Conductivity, TPRC, Purdue University, W. Lafayette, Ind., Oct. 7-10, 1968, 1051-65, 1969.
- 12 55077 Feith, A.D., Hein, R.A., Johnstone, C.P., and Flagella, P.N., "Thermophysical Properties of Low-Carbon 304 Stainless Steel to 1350 C," General Electric Co., Cincinnati, Ohio, GEMP-643, 14 pp., 1968.
- 13 6477 Fieldhouse, I.B., "Thermal Conductivity of Aircraft Structural and Reactor Materials," From Thermodynamic and Transport Properties of Gases, Liquids, and Solids, ASME Symp. on Thermal Properties, Purdue University, W. Lafayette, Ind., 391-9, 1959.
- 14 7689 Fieldhouse, I.B., Hedge, J.C., and Lang, J.L., "Measurements of Thermal Properties," U.S. Air Force Rept. WADC-TR-58-274, 79 pp., 1958. [AD206 892]
- 15 70104 Filippov, L.P., "Research of Thermophysical Properties at the Moscow State University," *Int. J. Heat Mass Transfer*, 16(5), 868-85, 1973.

Ref. TPRC/EPIC
No. No.

- 16 65570 Filippov, L. P. and Yurchak, R. P., "High Temperature Investigations of Heat Properties of Solids," *Inzh. Fiz. Zhur.*, 21(3), 561-77, 1971.
- 17 E11062 Fuschillo, N. and Lindberg, R.A., "Electrical Conductors at Elevated Temperatures," Melpar, Inc., Technical Documentary Report No. ASD-TRD-62-481. [AD299 020]
- 18 47994 Giuliani, S., "Measurement of the Thermal Conductivity of Materials for Nuclear Use Between 100 and 500 C," European Atomic Energy Community, Ispra, Italy, EUR-36441, 38 pp., 1967.
- 19 E44891 Goel, T.G. and Unvala, B.A., "Effect of Phase Transformation on the Measurements of Thermal Conductivity and Other Physical Properties of Titanium," *Phys. Letters*, 32A(7), 521-2, 1970.
55804
- 20 7696 Goldsmith, A. and Waterman, T.E., "Thermophysical Properties of Solid Materials," U.S. Air Force Rept. WADC TR 58-476, 416 pp., 1959. [AD207 905]
- 21 23463 Gross, A.U., "Electrical and Thermal Conductivities of Metals Over Their Entire Liquid Range," *Rev. Hautes Temp. Refractaires*, 3(2), 115-46, 1966.
- 22 E16718 Gusev, Y.E., Lashko, N.F., and Khatsinskaya, I. M., "Abnormal Variation in the Electrical Resistivity of Titanium Alloys of the Transition Class," *Phys. Metals Metallography*, 16(1), 56-9, 1963.
- 23 34753 Hertz, J., "Survey of Thermal Properties of Selected Materials," ZZL-65-008, AR-504-1-553, 172 pp., 1965.
- 24 66323 Ho, C.Y., Powell, R.W., and Liley, P.E., "Thermal Conductivity of the Elements," *J. Phys. Chem. Ref. Data*, 1(2), 279-421, 1972.
- 25a 24428 Hogan, C.L., "The Thermal Conductivity of Metals at High Temperature," Lehigh University, Ph.D. Thesis, 42 pp., 1950.
- 25b 7582 Hogan, C.L. and Sawyer, R.B., "The Thermal Conductivity of Metals at High Temperature," *J. Appl. Phys.*, 23(2), 177-80, 1952.
- 26 10106 Jackson, L.R., "Material Properties for Design of Airframe Structures to Operate at High Temperatures," ASTIA TM-RPT-38, 60 pp., 1956. [AD 90 948]
- 27 56069 Jacobs, D.C., "The In-Pile Thermal Conductivity of Selected ThO₂-UO₂ Fuels at Low Depletions," Westinghouse Electric Corp. Atomic Products Division Rept. WAPD-TM-758, 70 pp., 1969.
- 28 7670 Konno, S., "On the Variation of Thermal Conductivity During the Fusion of Metals," *Sci. Reports Tohoku Imp. University*, 8, 169-79, 1919.

Ref. TPRC/EPIC

- | Ref. No. | TPRC/EPIC No. | |
|----------|---------------|--|
| 29 | E25887 | Kovenskiy, I.I. and Samsonov, G.V., "Electrical Resistivity of Certain Transition Metals at High Temperatures," <i>Phys. Metals Metallography</i> , 124-5, 1963. |
| 30 | 8861 | Krzhizhanovskii, R. E., "Heat Conductivity of Some Heat-Resistant Steels as a Function of the State and Their Thermal Treatment," <i>Teploenergetika</i> , 5(1), 44-8, 1958. |
| 31 | 31460 | Lockheed-Georgia Co., Marietta, Georgia, "Determination of Design Data for Heat Treated Titanium Alloy Sheet," ASD-TDR-62-335, 326 pp., 1962. [AD297 803] |
| 32 | 9736 | Lucks, C.F. and Deem, H.W., "Thermal Properties of Thirteen Metals," ASTM Special Technical Publication No. 227, 29 pp., 1958. |
| 33 | 6940 | Lucks, C.F., Thompson, H.B., Smith, A.R., Curry, F.P., Deem, H.W., and Bing, G.F., "The Experimental Measurement of Thermal Conductivities, Specific Heats, and Densities of Metallic, Transport, and Protective Materials, Part I," AF-TR-6145 (Part I), ATI-117715, 127 pp., 1951. |
| 34 | 63410 | Mal'ko, P.I., Arensburger, D.S., Pugin, V.S., Nemehenko, V.H., and L'vov, S.N., "Thermal and Electrical Properties of Porous Titanium," <i>Porosh. Met.</i> , USSR, 10(8), 35-8, 1970; English translation: <i>Soviet Powder Met. Metal Ceramics</i> , 10(8), 642-4, 1970. |
| 35 | 22782 | Mannchen, W., "Heat Conductivity, Electrical Conductivity and the Lorenz Number for a Few Light-Metal Alloys," <i>Z. Metallkunde</i> , 23, 193-6, 1931. |
| 36 | 9374 | Maybrey, H.J., "Thermal Conductivities of Some Light Alloys," <i>Metal Ind. (London)</i> , 33, 5-6, 1928. |
| 37 | 31540 | McGee, W.M. and Metthews, B.R., "Determination of Design Data for Heat Treated Titanium Alloy Sheet. Vol. 2A. Details of Data Collection Program. Test Techniques and Results for Tension, Compression, Bearing, Shear, Crippling, Joints, and Physical Properties," Lockheed Georgia Co., Marietta, Georgia, ASD-TR-62-335(2A), 413 pp., 1962. [AD298765] |
| 38 | E19169 | Michels, W.C. and Wilford, S., "The Physical Properties of Titanium I. Emissivity and Resistivity of the Commercial Metals," <i>J. Appl. Phys.</i> , 20(12), 1223-8, 1949. |
| 39 | 44820 | Nikolskii, N.A., "The Determination of the Thermal Conductivity in Molten Aluminum at 725-1570 Degrees," <i>Teploobmen Elem. Energ. Ustanovok Akad. Nauk SSSR Energ. Inst.</i> , 83-91, 1966. |
| 40 | 37865 | Powell, R.W., Hickman, M.J., and Tye, R.P., "The Thermal and Electrical Conductivity of Magnesium and Some Magnesium Alloys," <i>Metallurgia</i> , 70, 159-63, 1964. |

Ref. TPRC/EPIC
No. No.

- 41 38399 Powell, R.W., Tye, R. P., and Metcalf, S. C., "The Thermal Conductivity of Pure and Alloyed Aluminum. I. Solid Aluminum as a Reference Material," From Advances in Thermophysical Properties at Extreme Temperatures and Pressures, 3rd ASME Symp. on Thermophysical Properties, Purdue University, W. Lafayette, Ind., March 22-25, 1965, 296-300, 1965.
- 42 9974 Przybycian, W. M. and Linde, D. W., "Thermal Conductivities of Gases, Metals, and Liquid Metals," KAPL-M-WMP-1, 24 pp., 1957.
- 43 24367 Rudkin, R. L., Parker, W. J., and Jenkins, R. J., "Thermal Diffusivity Measurements on Metals and Ceramics at High Temperatures," U.S. Radiological Defense Lab., San Francisco, Cal., ASD-TDR-62-24, 20 pp., 1963. [AD 297 836]
- 44 E19397 Salkovitz, E. I., Schindler, A. I., and Kammer, E. W., "Transport Properties of Dilute Binary Magnesium Alloys," Phys. Rev., 105(3), 887-96, 1957.
- 45 51484 Taylor, R. E., Powell, R. W., Nalbantyan, M., and Davis, F. E., "Evaluation of Direct Electrical Heating Methods for the Determination of Thermal Conductivity at Elevated Temperature," AFML-TR-68-227, 74 pp., 1968.
- 46 Touloukian, Y. S., "Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides," TPRC Rept. 16, prepared under NBS Sub-Contract No. CST-7590, NASA Order R-45, 540 pp., 1966.
- 47 59508 Tye, R. P., "An Experimental Investigation of the Thermal Conductivity and Electrical Resistivity of Three Porous 304L Stainless Steel 'Regimes' Material to 1300 K," NASA CR-72710, 23 pp., 1970.
- 48 E50453 Tye, R. P., Hayden, R. W., and Spinny, S. C., "The Thermal Conductivity of a Number of Alloys at Elevated Temperatures," High Temperature-High Pressures, 4, 503-11, 1972.
- 49 61883 Unvala, B. A. and Goel, T. C., "Thermal Conductivity, Electrical Resistivity, and Total Emittance of Titanium at High Temperatures," Rev. Int. Hautes Temp. Refract., 7(4), 359-64, 1970.
- 50 29754 Wood, R. A., "A Tabulation of Designations, Properties, and Treatments of Titanium and Titanium Alloys," Defense Metals Information Center, DMIC Memorandum 171, 8 pp., 1963. [AD 424 412]
- 51 E36915 Zhorov, G. A., "Relation Between the Emissive Power and Specific Electrical Resistivity in Metals," High Temp., 5(6), 881-8, 1967.
- 52 53271 Zinovev, V. E., Krenstsis, R. P., and Geld, P. V., "Thermal Diffusivity
53911 and Thermal Conductivity of Titanium at High Temperatures," Teplofiz.
E39874 Vys. Temp., 6(5), 927-8, 1968.

Ref. TPRC/EPIC
No. No.

- 53 67921 Zinov'ev, V.E., Masharov, S.I., Chupina, L.I., and Gel'd, P.V., "Kinetic Properties and Electron Scattering Mechanisms of Ti, Zr, and Hf at High Temperature," Fiz. Tverd. Tela, 14(4), 1053-7, 1972; English translation: Sov. Phys. - Solid State, 14(4), 902-5, 1972.
- 54 23881 Dukes, W.H. and Schnitt, A. (Editors), "Structural Design for Aerodynamic Heating. Part I. Design Information," U.S. Air Force Rept. WADC-TR-55-305 (Part 1), Vol. 1, 1955. [AD98114]
- 55 Greig, D. and Morgan, G.J., "The Electrical Resistivity of Transition Metals at High Temperatures," Phil. Mag., 927-40, 1973.

B. Thermal Diffusivity

a. Aluminum

One set of experimental data [19] in the liquid state is available. The values in Ref. 5 are calculated from the TPRC recommended thermal conductivity and the selected values of specific heat and density. These values agree with those in Ref. 4 at M. P. in solid state and agree well with the general trend of the results of Refs. 1 and 3. In liquid state the values are believed to be good within $\pm 10\%$ of the true values. Schriempf's liquid phase data [19] show a trend of negative temperature dependence which is probably due to the thermocouple response error. The values in Ref. 5 had been revised and extended to higher temperatures to become TPRC's recommended values covering up to 8000 K.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Diffusivity of Aluminum

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
365-754	1	} General trend of temperature dependence consistent among the three curves.
349-823	1	
340-829	1	
326-799	2	Temperature dependence markedly different from the above set of curves.
295-408	3	Temperature range narrow, supersedes the above 4 curves only barely but temperature range is seen to agree with those of Ref. 1.
933	4	Solid state at M. P.
1-1500	5	Calculated from TPRC recommended thermal conductivity, specific heat, and density.
293-1073	19	In solid and liquid states.
2-8000	20	Recommended values.

b. Aluminum Alloy 7075-T6

No experimental data are available in the liquid state. In solid state, no data are available above 793 K. To obtain values beyond this temperature, three methods are presently applicable:

- (1) If the thermal conductivity in the liquid state is known, then the diffusivity can be calculated from the thermal conductivity, the specific heat, and the density. Usually those data are not available, but for specific heat and

density the values can be calculated from that of each of the component element with reasonable reliability, more reliable than in the solid state, by the simple additive formula

$$P_a = \sum_i c_i P_i \quad (1)$$

where P_i indicates the property of the i th component and c_i is its concentration in the alloy. Even the thermal conductivity values in liquid state may be calculated using a formula similar to the one given by Filippov and Novoselova [8]:

$$k_a = \sum_i c_i k_i - \frac{1}{2} \sum_{i,j} 0.72 k_i - k_j c_i c_j \quad (2)$$

though the accuracy of the result is questionable.

- (2) We may correlate the values of α_s/α_l of the elements at M. P., then generate a simple relation for the alloy and calculate the value in the liquid state from the known solid state value. This method cannot generate values beyond the immediate neighborhood of M. P.
- (3) Thermal diffusivity values may be calculated from a formula similar to Eq. (2). Actually, all three methods may be used to complement each other to obtain the best result.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Diffusivity of Aluminum Alloy 7075-T6

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
348.2	6	
373-643	6	
348-793	6	
348,473	6	
348-633	6	
373-603	6	
513,653	6	
473,673	6	
348-583	6	
773,783	6	
116-700	7	Calculated from measured thermal conductivity, specific heat, and density.
144-700	7	Same as above.

c. Titanium

Recommended values are available up to the melting point, but no experimental data or estimated values are available for the liquid state. However, values for the liquid state can be calculated from the thermal conductivity, the specific heat, and the density values.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Diffusivity of Titanium

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
1168-1598	9	
1023-1506	10	Values lower than others.
1056-1662	11	Values relatively high.
885-1596	12	
1000-1700	13	Values high.
1-1953	5	Calculated from TPRC recommended thermal conductivity and selected specific heat and density.
1-1953	20	Recommended values.

d. Titanium Alloy 6Al-4V

In solid state the thermal diffusivity have been measured up to 1183 K, about 740 K below the melting point. No data are available for the liquid state. For extrapolation of data to higher temperatures and for estimation of values for the molten alloy, the same methods as those discussed in the section on aluminum alloy 7075-T6 may be used.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Diffusivity of Titanium Alloy 6Al-4V

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
398-1118	6	
448-1023	6	
373-1183	6	

e. Magnesium + Aluminum Alloys

Experimental data are available up to 623 K for one alloy and up to 589 K for another. For extrapolation and estimation of values in the vicinity of the melting point, the same methods as those discussed in the section on aluminum alloy 7075-T6 may be used.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Diffusivity of Magnesium + Aluminum Alloys

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
116-589	14	94.34/95.94 Mg, 2.5/3.5 Al, 0.7/1.3 Zn, 0.2 Mn, and others.
116-589	14	Same as above.
298-623	15	95.3 Mg, 3.0 Al, 1.0 Zn, 0.2 Mn, and others.

f. Stainless Steels 304 and 347

No data are available in the vicinity of the melting point. For estimation of such values, the same methods as those discussed in the section on aluminum alloy 7075-T6 may be used.

The temperature ranges of the available data together with the source references are given in the following two tables.

Thermal Diffusivity of Stainless Steel 304

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
291-1261	16	Data consistent.
403-1243	16	Data consistent.
460-1273	16	Data consistent.
1043	16	Data consistent.
552-1390	17	Having larger temperature dependence and higher values.
580-1379	17	Same as above.

Thermal Diffusivity of Stainless Steel 347

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
293-1151	16	Data consistent.
361-1097	16	Data consistent.
490-1136	16	Data consistent.
343-1113	16	Data consistent.
615-1036	18	Data consistent.
117-1255	14	Data consistent.

g. References

<u>Ref. No.</u>	<u>TPRC No.</u>	
1	15663	Sonnenschein, G. and Winn, R.A., "A Relaxation Time Technique for Measurement of Thermal Diffusivity," U.S. Air Force Rept. WADC-TR-59-273, 23 pp., 1960. [AD 236 660]
2	27539	Mikryukov, V. E. and Karagezyan, A.G., "Thermal and Electrical Properties of Alloys of the Systems Al-Mg and Al-Cu," Inzh. - Fiz. Zh., Akad. Nauk Belorussk. SSR, 4(12), 90-3, 1961.
3	24813	Jenkins, R.J. and Parker, W.J., "A Flash Method for Determining Thermal Diffusivity Over a Wide Temperature Range," U.S. Air Force Rept. WADD-TR-61-95, 29 pp., 1961. [AD 268 752]
4	62357	Gonsalves, J.N. and Duley, W.W., "Interaction of CO ₂ Laser Radiation With Solids. I. Drilling of Thin Metallic Sheets," Can. J. Phys., 49(13), 1708-13, 1971.
5	53600	Powell, R.W., Ho, C.Y., and Wu, K.Y., "Thermal Diffusivity of the Elements," Proc. 8th Thermal Conductivity Conference, 971-98, 1969.
6	6693	Butler, C.P. and Inn, E.C.Y., "Thermal Diffusivity of Metals at Elevated Temperatures," USNRDL-TR-177, 27 pp., 1957. [AD 143 863]
7	9736	Lucks, C.F. and Deem, H.W., "Thermal Properties of Thirteen Metals," ASTM Spec. Tech. Publ. No. 227, 29 pp., 1958.
8	111	Filippov, L.P. and Novoselova, N.S., "Heat Conductivity of Normal Liquid Solutions," Vestnik Moskov. Gos. Univ., 10(3), 37-40, 1955.
9	23846	Rudkin, R.L., Jenkins, R.J., and Parker, W.J., "Thermal Diffusivity Measurements on Metals at High Temperatures," NRDL-TR-518, 1961. [AD 260 752 L]
10	53911	Zinov'ev, V. E., Krentsis, R.P., and Gel'd, P.V., "Thermal Diffusivity and Conductivity of Titanium at High Temperatures," High Temp., 6(5), 888-90, 1968.

- | Ref. No. | TPRC No. | |
|----------|----------|--|
| 11 | 64652 | Arutyunov, A. V., Banchila, S. N., and Filippov, L. P., "Properties of Titanium at Temperatures Above 1000 K," <i>High Temp.</i> , <u>9</u> (3), 487-9, 1971. |
| 12 | 67921 | Zinov'ev, V. E., Masharov, S. I., Chupina, L. I., and Gel'd, P. V., "Kinetic Properties and Electron Scattering Mechanisms of Ti, Zr, and Hf at High Temperatures," <i>Sov. Phys.-Solid State</i> , <u>14</u> (4), 902-5, 1972. |
| 13 | 70104 | Filippov, L. P., "Research of Thermophysical Properties at the Moscow State University," <i>Int. J. Heat Mass Transfer</i> , <u>16</u> (5), 865-85, 1973. |
| 14 | 6940 | Lucks, C. F., Thompson, H. B., Smith, A. R., Curry, F. P., Deem, H. W., and Bing, G. F., "The Experimental Measurement of Thermal Conductivities, Specific Heat, and Densities of Metallic, Transparent, and Protective Materials," Part 1, U. S. Air Force Rept. AF-TR-6145, 127 pp., 1951. |
| 15 | 31597 | Foley, E. L., "Thermal Diffusivity of Metals at High Temperatures," Univ. Microfilms Publ., 59 pp., 1962. |
| 16 | 16597 | Jenkins, R. J. and Westover, R. W., "The Thermal Diffusivity of Stainless Steel Over the Temperature Range 20-1000 C," USNRDL-TR-484, 13 pp., 1960. [AD 249 578] |
| 17 | 55077 | Feith, A. D., Hein, R. A., Johnstone, C. P., and Flagella, P. N., "Thermophysical Properties of Low Carbon 304 Stainless Steel to 1350 C," GEMP-643, 14 pp., 1968. |
| 18 | 29500 | Deem, H. W. and Wood, W. D., "Flash Thermal Diffusivity Measurements Using a Laser," <i>Rev. Sci. Instr.</i> , <u>33</u> (10), 1107-9, 1962. |
| 19 | 70153 | Schriempf, J. T., "A Laser Flash Technique for Determining Thermal Diffusivity of Liquid Metal at Elevated Temperatures: Application to Mercury and Aluminum," <i>High Temp.-High Pressures</i> , <u>4</u> (4), 411-6, 1972. |
| 20 | | Touloukian, Y. S., Powell, R. W., Ho, C. Y., and Nicolaou, M. C., <u>Thermal Diffusivity, Vol. 10 of Thermophysical Properties of Matter - The TPRC Data Series</u> , IFI/Plenum Data Corp., New York, 780 pp., 1973. |

C. Thermal Expansion

a. Aluminum

TPRC Report 16 [1] contains values for the density of aluminum from room temperature to 600 K above the melting point. We also have experimental data on thermal linear expansion within two degrees of the melting point. On the basis of this information, obtaining thermal expansion information on aluminum above and below the melting point seems to be no problem.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Expansion of Aluminum

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
0-1600	1	Data on density.
523-923	2	Experimental data.
293-773	3	Experimental data.
293-773	4	Experimental data.
293-873	5	Experimental data.
503-929	6	Experimental data.
293-873	7	Experimental data.
273-923	8	Experimental data.
300-900	9	Experimental data.
82-896	10	Experimental data.
293-927	11	Experimental data.
473-931	12	Experimental data.
600-864	13	Experimental data.
273-923	14	Experimental data.
melting point	15	Percent volume change, experimental data.
melting point	16	Theory and other researchers experimental data.
melting point	17	Percent volume change, α_{solid} , α_{liquid} ; summary paper.
293-873	18	Experimental data.
297-811	42	Experimental data.

b. Aluminum Alloy 7075-T6

Most of the needed information is in TPRC report 16 [1]. This report has density values well above and below the melting point. We have experimental data up to 700 K; this can be extrapolated up to the melting point by using the slope of the ρ vs T curve in Ref. 1 around the melting point. Also these values can be compared to values extrapolated from our data using the principle of the corresponding states.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Expansion of Aluminum Alloy 7075-T6

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
0-2400	1	Data on density.
116-699	19	Experimental data.
18-573	20	Experimental data.
293-573	21	Experimental data (2 curves).

c. Titanium

TPRC Report 16 has most of the desired information for the density of titanium above and below the melting point. The other experimental data may be extrapolated to the melting point by using the principle of the corresponding states. Therefore, the thermal expansion of titanium can be obtained above and below the melting point.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Expansion of Titanium

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
0-2400	1	Data on density.
293, 1473	22	Experimental data.
330-1273	23	Experimental data.
74-1294	24	Experimental data.
273-1273	25	Experimental data.
311-1100	26	Experimental data.
293-1699	27	Experimental data (2 curves).
294-1180	28	Experimental data.
381-1119	29	Experimental data.

d. Titanium Alloy 6Al-4V

We can probably extrapolate the experimental data to the melting point. These values could then be checked using the density values for titanium alloy A-110AT in Ref. 1 as a guide. The density values of alloy A-110AT could also be used as a first approximation for the thermal expansion of alloy 6Al-4V above the melting point. Also, the mixing rule: $P = \sum_i \rho_i x_i$ could be used to check these values above the melting point. The resulting values for alloy 6Al-4V would have greater uncertainty above the melting point than those predictions for Al, 7075-Tb, and Ti previously mentioned.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Expansion of Titanium Alloy 6Al-4V

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
293-1699	27	Experimental data (2 curves).
4-922	30	Experimental data.
310-922	31	Experimental data (4 curves).
275-1366	42	Experimental data.

e. Magnesium + Aluminum Alloys

The melting ranges of Mg-Al alloys are between about 710 and 293 K depending on composition. The available data can probably be extrapolated to the melting point for any composition between 55-99% Mg. Thermal expansion above the melting point may be calculated from the mixing rule. The melting point for a specific composition will have to be read from a phase diagram which may have unknown uncertainty. As a result, thermal expansion will have more uncertainty above the melting point since the melting point may be uncertain and the accuracy of the mixing rule is unknown in this region.

The temperature ranges of the available data together with the source references are given in the following table.

Thermal Expansion of Magnesium + Aluminum Alloys

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Composition</u>		<u>Remarks</u>
		<u>Mg</u>	<u>Al</u>	
293-573	32	90-96%	10-4%	Experimental data (9 curves).
293-673	32	90	10	Experimental data (2 curves).
293-573	32	~96	4	Experimental data (2 curves).
293-573	33	94	6	Experimental data.
273-673	34	57-98	43-2	Experimental data (14 curves).
293-673	35	99	1	Experimental data.
83-673	36	~96	3	Experimental data (3 curves).
293-673	37	55-97	45-3	Experimental data (8 curves).

f. Stainless Steels 304 and 347

No experimental data are available near the melting point. Some density information is given in Ref. 1. The estimation of thermal expansion to the melting point may be possible by extrapolating the information from Ref. 1 to the melting point. The mixing rule could possibly be used above the melting point. Again, however, the results from the mixing rule here may be rather uncertain.

Information for stainless steel 347 is slightly better than that for 304 because more high-temperature data for 347 are available. However, the rest of the situation is essentially the same. There is no experimental data above the melting point. The thermal expansion to the melting point may possibly be estimated by extrapolating the information from Ref. 1 to the melting point. The mixing rule could possibly be used above the melting point.

The temperature ranges of the available data together with the source references are given in the following two tables.

Thermal Expansion of Stainless Steel 304

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
0-1600	1	Data on density only.
89-811	38	Experimental data.
293-806	39	Experimental data.
297-922	43	Experimental data.

Thermal Expansion of Stainless Steel 347

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
116-1144	19	Experimental data.
367-1311	40	Experimental data.
300-1494	41	Experimental data.
83-1273	36	Experimental data.
297-1140	42	Experimental data.
294-1255	44	Experimental data.
0-1600	1	Data on density only.

g. References

<u>Ref. No.</u>	<u>TPRC No.</u>	
1		Touloukian, Y. S., "Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides," TPRC Rept. 16, Purdue University, Lafayette, Ind., 540 pp., 1966.
2	40154	King, A. D., Cornish, A. J., and Burke, J., "Technique for Measuring Vacancy Concentrations in Metals at the Melting Point," J. Appl. Phys., <u>37</u> (13), 4717-22, 1966.
3	6348	Taylor, C. S., Willey, L. A., Smith, D. W., and Edwards, J. D., "The Properties of High-Purity Aluminum," Metals and Alloys, <u>7</u> (8), 189-92, 1938.
4	52254	Irmann, R., "Properties and Uses of Sintered Aluminum," <u>Metal Treatment and Drop Forging</u> , <u>22</u> , 245-50, 1955.
5	35401	Souder, W. H. and Hidnert, P., "Thermal Expansion of Ni, Monel Metal, Stellite, Stainless Steel, and Al," National Bureau of Standards Tech. News Bulletin, <u>17</u> , 497-519, 1921.
6	35426	Simmons, R. O. and Balluffi, R. W., "Measurements of Equilibrium Vacancy Concentrations in Aluminum," Phys. Rev., <u>117</u> (1), 52-61, 1960.
7	35453	Hidnert, P., "Thermal Expansion of Aluminum and Various Important Aluminum Alloys," J. Res. Nat. Bur. Stand., <u>19</u> , 697-731, 1925.
8	56413	Wilson, A. J. C., "The Thermal Expansion of Aluminum From 0 to 650 C," Proc. Phys. Soc., <u>53</u> , 235-44, 1941.
9	57244	Pathak, P. O. and Vasavada, N. G., "Thermal Expansion and the Law of Corresponding States," J. Phys. C (Solid State Phys.), <u>3</u> (2), L-44 to 8, 1970.

- | Ref. No. | TPRC No. | |
|----------|----------------|--|
| 10 | 58065 | Richards, J.W., "The Over-All Linear Expansion of Three Face-Centered Cubic Metals (Al, Cu, Pb) From -190 C to Near Their Melting Points," <i>Trans. Am. Soc. Metals</i> , <u>30</u> , 326-36, 1942. |
| 11 | 58923 | Cornish, A.J. and Burke, J., "A High Temperature Attachment for an X-Ray Diffractometer for Precision Lattice Parameter Measurements," <i>J. Sci. Instrum.</i> , <u>42</u> , 212-8, 1965. |
| 12 | 38669 | Feder, R. and Nowick, A.S., "Use of Thermal Expansion Measurements to Detect Lattice Vacancies Near the Melting Point of Pure Lead and Aluminum," <i>Phys. Rev.</i> , <u>109</u> (6), 1959-63, 1958. |
| 13 | 57689 | Ellwood, E.C. and Silcock, J.M., "The Lattice Spacings of the Solid Solution of Copper in Aluminum," <i>J. Inst. Metals</i> , <u>74</u> , 457-67, 1948. |
| 14 | 58588 | Simmons, R.O., "Use of fcc Metals as Internal Temperature Standards in X-Ray Diffraction," <i>J. Appl. Phys.</i> , <u>41</u> (5), 2235-40, 1970. |
| 15 | 57683 | Endo, H., "On the Measurement of the Change of Volume in Metals During Solidification," <i>J. Inst. Metals</i> , <u>30</u> , 121-38, 1923. |
| 16 | 41812 | Eckstein, B., "A Disorder Model of Melting and Melts," <i>Phys. Status Solidi</i> , <u>20</u> (1), 83-93, 1967. |
| 17 | 6383 | Kubaschewski, O., "The Change of Entropy, Volume, and Binding State of the Elements on Melting," <i>Trans. Faraday Soc.</i> , <u>45</u> (10), 931-40, 1949. |
| 18 | 59454
55265 | Ryabov, V.R., Logovskaya, A.V., and Vasil, V.G., "Properties of the Intermetallic Compounds of the System Iron-Aluminum," <i>Phys. Metals Metallogr.</i> , <u>27</u> (4), 98-103, 1969. |
| 19 | 9736 | Lucks, C.F. and Deem, H.W., "Thermal Properties of Thirteen Metals," <i>Am. Soc. Testing Materials, Spec. Tech. Publ. No. 227</i> , 29 pp., 1958. |
| 20 | 46067 | Rhodes, B.L., Moeller, C.E., Hopkins, V., and Marx, T.L., "Thermal Expansion of Several Technical Metals from -255 to 300 C," <i>Advan. Cryogen. Eng.</i> , <u>8</u> , 278-86, 1963. |
| 21 | 56783 | Willey, L.A. and Fink, W.L., "An Interferometer Type of Dilatometer and Some Typical Results," <i>Trans. Am. Inst. Mining Met. Engrs.</i> , <u>162</u> , 642-55, 1945. |
| 22 | 48587 | Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B., "Elastic Constants and Characteristics of the Electron Structure of Certain Classes of Refractory Compounds Obtained by the Metal-Powder Method," <i>Inorg. Mater.</i> , <u>3</u> (1), 6-12, 1967. |
| 23 | 43792
43793 | Komilov, I.I. and Boriskina, N.G. (Editors), "Mechanical and Engineering Properties of Titanium Alloys," <i>Novyye Issled. Splavov</i> , Pt. III, (Moscow), 167-333, 1966; English translation: Joint Publications Research Service Rept. JPRS-36680, 235 pp., 1966. |

- | Ref. No. | TPRC No. | |
|----------|----------|--|
| 24 | 46128 | Kovtun, S. F. and Ul'yanov, R. A., "Effect of Alloying on the Physico-chemical Properties of Titanium," From Works of the Fifth Conf. on Metallurgy, Physical Metallurgy and Application of Titanium and its Alloys, 1963; NASA-TT-F-338, 120-36, 1965. |
| 25 | 51109 | Yaggee, F. L. and Styles, J. W., "Linear Thermal Expansion of Vanadium, Titanium, Chromium, and Some Vanadium-Base Binary and Ternary Alloys," Argonne National Laboratory Annual Progress Rept. ANL-7299, 77-8, 1966. |
| 26 | 48242 | Greiner, E. S. and Ellis, W. C., "Thermal and Electrical Properties of Ductile Titanium," Am. Inst. Mining Met. Engrs. Tech. Pub., 9 pp., 1948. |
| 27 | 43639 | Williams, D. N., "Thermal Expansion of Beta-Titanium," Trans. Met. Soc. AIME, <u>221</u> , 411-2, 1961. |
| 28 | 55154 | Yaggee, F. L., Gilbert, E. R., and Styles, J. W., "Thermal Expansions, Thermal Conductivities, and Densities of Vanadium, Titanium, Chromium, and Some Vanadium-Base Alloys," J. Less-Common Metals, <u>19</u> (1), 39-51, 1969. |
| 29 | 42935 | Makin, S. M., Standring, J., and Hunter, P. M., "Determination of the Coefficient of Linear Thermal Expansion of Metals at 7 C: A Review of Progress from 1 December 1952-1 June 1953," United Kingdom Atomic Energy Authority, Risley, Worrington, Lancashire, RDB-(C)-TN-45, 8 pp., 1953. |
| 30 | 31540 | McGee, W. M. and Matthews, B. R., "Determination of Design Data for Titanium Alloy Sheet. Vol. 2a. Details of Data Collection Program. Test Techniques and Results for Tension, Compression, Bearing, Shear, Crippling, Joints, and Physical Properties," U. S. Air Force Rept. ASD-TDR-62-335, 413 pp., 1962. |
| 31 | 31460 | Lockheed-Georgia Co., Marietta, Georgia, "Determination of Design Data for Titanium Alloy Sheet. Vol. 3," U. S. Air Force Rept. ASD-TDR-62-335, 326 pp., 1962. |
| 32 | 41428 | Hidnert, P. and Sweeney, W. T., "Thermal Expansion of Magnesium and Some of its Alloys," J. Res. Nat. Bur. Stand., <u>1</u> , 771-92, 1928. |
| 33 | 56075 | Hidnert, P. and Fox, J. F., "Autographic Thermal Expansion Apparatus," J. Res. Nat. Bur. Stand., <u>13</u> (4), 497-513, 1934. |
| 34 | 57748 | Takahasi, K. and Kikuti, R., "Thermal Expansion Coefficients of Magnesium and its Alloys," Nippon Kinzoku no Kenkyu, <u>13</u> , 401-14, 1936. |
| 35 | 47254 | Bell, I. P., "Thermal Reactor-Physical Properties of Materials of Construction," United Kingdom Atomic Energy Authority, Industrial Group, Risley, England, Tech. Memo. 225, 5 pp., 1954. |

Ref. No.	TPRC No.	
36	6940	Lucks, C.F., Thompson, H.B., Smith, A.R., Curry, F.P., Deem, H.W., and Bing, G.F., "The Experimental Measurement of Thermal Conductivities, Specific Heats, and Densities of Metallic, Transparent, and Protective Materials. Part I," U.S. Air Force Rept. AFTR-6145, Pt. 1, 127 pp., 1951.
37	16277	Losana, L., "Contribution to the Knowledge of Some Light Alloys," Ind. Chim. (Milan), <u>5</u> , 145-50, 1930.
38	55979	Furman, D.E., "Thermal Expansion Characteristics of Stainless Steels, Between -300 and 1000 F," Trans. AIME, <u>188</u> , 688-91, 1950.
39	37995	Valentich, J., "New Values for Thermal Coefficients," Product Engineering, 63-71, 1965.
40	52518	Aerojet-General Corporation, Liquid Rocket Plant, Sacramento, Calif., "Coefficient of Thermal Expansion of Inconel 718 and 347," AGC-4-433, DVR-63-566, 2 pp., 1963.
41	7689	Fieldhouse, I.B., Hedge, J.C., and Lang, J.I., "Measurements of Thermal Properties," U.S. Air Force Rept. WADC TR 58-274, 79 pp., 1958.
42	63999	Technical Utilization Division, National Aeronautics and Space Administration, Washington, D.C., "Technical Support Package for Tech. Brief 69-10055-Thermal Expansion Properties of Aerospace Materials," NTIS PB-184 749, 174 pp., 1969.
43		United States Steel, Steels for Elevated Temperature Service, Pittsburgh.
44		International Nickel Co., VSMF, Microfilm Film, 9th Issue 1963, 378919-21, 378943.

D. Specific Heat

a. Aluminum

Experimental data and recommended values are available below and above the melting point. The temperature ranges of the available evaluated data together with the source references are given below.

Specific Heat of Aluminum

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
0.1-3000	4	Good coverage.
0.1-2800	13	Excellent coverage, T_m and ΔH_m well established, C_p of liquid also well established.
0-2800	14	Good coverage.

b. Aluminum Alloy 7075-T6

No experimental data are available in the vicinity of the melting point. However, the data can be extrapolated or estimated to the melting point in the solid state, and estimated values for the liquid state are obtainable from the C_p values of the constituent elements using empirical relations and/or the Kopp-Neumann rule.

The temperature ranges of the available data together with the source references are given in the following table.

Specific Heat of Aluminum Alloy 7075-T6

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
273-573	10	Applies theoretical model $c = 3nR/M$; agreement poor.
311-644	11	Compilation.
1-800	4	$T_m = 750-911$ K; also density for 0-2400 K.

c. Titanium

Sufficient data are available. The temperature ranges of the available data together with the source references are given below.

Specific Heat of Titanium

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
1-3000	4	Good coverage.
1-3600	13	Good coverage.
0-4000	14	Good coverage.
1969-2315	15	Also reports ΔH_m .
298-2500	16	Compilation, gives T_m and ΔH_m .
298-3500	17	Same as above.
1400-1850	18	
320-1800	19	
1000-1700	20	
400-1900	21	

d. Titanium Alloy 6Al-4V

No data are available in the vicinity of the melting point. Values may be estimated from the C_p values of the constituent elements using empirical relations and/or the Kopp-Neumann rule.

The temperature ranges of the available data together with the source references are given in the following table.

Specific Heat of Titanium Alloy 6Al-4V

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
488-922	5	
273-1144	6	
293-1144	7	$T_m \approx 1803-1908$ K.
293-1144	8	
$T_m = 1866$ K	9	

e. Magnesium + Aluminum Alloys

Complete information for only one alloy is available. Since specific heat data are available for Al and Mg, rough estimation of the values for various magnesium + aluminum alloys can be made using various empirical relations and/or Kopp-Neumann rule.

The temperature range of the available data as well as other information is given below.

Specific Heat of Magnesium + Aluminum Alloys

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
280-1080	1	Alloy AZ-80; 8 Al, 0.55 Zn, 0.141 Mn, also gives ΔH_m .

f. Stainless Steels 304 and 347

The available data for the solid can be extrapolated to the melting point.

No data are available for the molten steels. From the C_p values of the constituent elements in the liquid state using empirical relations and/or Kopp-Neumann rule, values for stainless steels 304 and 347 in the liquid range can be estimated.

The temperature ranges of the available data together with the source references are given below.

Specific Heat of Stainless Steel 304

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
473-1623	2	
$T_m = 1673$	3	
373-1366	4	

Specific Heat of Stainless Steel 347

<u>Temperature Range (K)</u>	<u>Reference</u>	<u>Remarks</u>
1-1500	4	Reports also density for 0-1600 K.
451-1493	12	

g. References

<u>Ref. No.</u>	<u>TPRC No.</u>	
1	24547	McDonald, R.A. and Stull, D.R., "Heat Content, Specific Heat, and Heat of Melting of Magnesium Alloy AZ-80 from 280 to 1080 K," J. Chem. Eng. Data, <u>6</u> , 609-10, 1966.
2	53604	Feith, A.D., Hein, R.A., Johnstone, C.P., and Flagella, P.N., "Thermophysical Properties of Low Carbon 304 Stainless Steel to 1350 C," Proc. of Eighth Conference on Thermal Conductivity, TPRC, Purdue University, Nuclear Systems Programs, General Electric Co., Cincinnati, Ohio, Plenum Press, N.Y., 1051-65, 1969.
3	54190	Brassfield, H.C., White, J.F., Sjodahl, L.H., and Bittle, J.T., "Recommended Property and Reaction Kinetics Data for Use in Evaluating a Light Water Cooled Reactor Loss of Coolant Incident Involving Zircaloy-4- or 304 ss-Clad Uranium Dioxide," Missile and Space Div., General Electric Co., Cincinnati, Ohio, GEMP-482, 89 pp., 1968.

Ref. No.	TPRC No.	
4		Touloukian, Y.S., "Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides," TPRC Rept. 16, Purdue University, Lafayette, Ind., 1966.
5	31540	McGee, W.H. and Matthews, B.R., "Determination of Design Data for Heat Treated Titanium Alloy Sheet. Vol. 2A. Details of Data Collection Program. Test Techniques and Results for Tension, Compression, Bearing, Shear, Crippling, Joints, and Physical Properties," Lockheed Georgia Co., Marietta, Georgia, U.S. Air Force Rept. ASD-TDR-62-335 (Part 2A), 413 pp., 1962. [AD298 765]
6	16736	Holladay, J.W., "Memorandum on Thermal Properties of Titanium and Titanium Alloys," Battelle Memorial Institute Memo. 1, 23 pp., 1958.
7	10941	Crucible Steel Co. of America, "Crucible C-120AV Titanium Base Alloy," Data Sheet C-120AV, 11 pp., 1958.
8	20360	Maykuth, D.J., Holden, F.C., Williams, D.N., Ogden, H.R., and Jaffee, R.I., "The Effects of Alloying Elements in Titanium. Vol. B. Physical and Chemical Properties. Deformation and Transformation Characteristics," DMIC Rept. 136B, 150 pp., 1960. [AD260 226]
9	43639	Williams, D.N., "Thermal Expansion of Beta-Titanium," Trans. Met. Soc., AIME, <u>221</u> , 411-21, 1961.
10	10106	Jackson, L.R., "Material Properties for Design of Airframe Structures to Operate at High Temperatures," TML Rept. 38, 60 pp., 1956. [AD909 48]
11	16987	Adolphson, D.R., "Elevated Temperature Properties of 7075-T6 Aluminum Alloy," USAEC Rept. SCTM-299-58/161, 23 pp., 1958.
12	6453	Lang, L.I., "Specific Heat of Materials," <u>From Thermodynamic and Transport Properties of Gases, Liquids, and Solids</u> , ASME Symp. on Thermal Properties, 405-14, 1959.
13		Hultgren, R., Desai, P.D., Hawkins, D.T., Gleiker, M., Kelley, K.K., and Wagman, D.D., "Selected Values of the Thermodynamic Properties of Elements," American Society for Metals, 636 pp., 1973.
14		Stull, D.R. and Prophet, H., "JANAF Thermochemical Tables, Second Edition," Nat. Stand. Ref. Data Ser., Nat. Bur. Stand. (US), NSRDS-NBS 37, 1971.
15	64418	Treverton, J.A. and Margrave, J.L., "Enthalpies of Fusion and Heat Capacities for the Liquid Phases of Iron, Titanium, and Vanadium," J. Chem. Thermodyn., <u>3</u> (4), 473-81, 1971.
16	7006	Glassner, A., "The Thermochemical Properties of the Oxides, Fluorides, and Chlorides to 2500 K," Supt. of Documents, U.S. Government Printing Office, ANL-5750, 70 pp., 1957.

Ref. No.	TPRC No.	
17	16952	Douglas, T. B. and Victor, A. C., "High Temperature Heat Contents," From Preliminary Report on the Thermodynamic Properties of Selected Light-Element Compounds, NBS Rept. 6645, 19-31, 1960.
18	33943	Shestopal, V. O., "Specific Heat and Vacancy Formation in Titanium at High Temperatures," Sov. Phys. -Solid State, <u>7</u> (11), 2798-9, 1966.
19	38554	Kohlhaas, R., Braum, M., and Vollmer, O., "Atomic Heat of Ti, V, and Cr in the High Temperature Range," Z. Naturforsch., <u>20A</u> , 1077-9, 1965.
20	70104	Filippov, L. P., "Research of Thermophysical Properties at the Moscow State University," Int. J. Heat-Mass Transfer, <u>16</u> (5), 865-85, 1973.
21	47947	Affortit, C., "Specific Heat Measurements on Metals Up to Their Melting Point," USAEC Rept. CEA-R-3287, 63 pp., 1967.

E. Heat of Fusion

a. Aluminum

Experimental data and recommended value for the heat of fusion of aluminum are available [1].

b. Aluminum Alloy 7075-T6

No data were uncovered from a limited search of literature. Estimated value may be obtained from values of the constituent elements using empirical relations and/or the Kopp-Neumann rule.

c. Titanium

Experimental data and selected value for the heat of fusion of titanium are available [2-4].

d. Titanium Alloy 6Al-4V

No data were uncovered from a limited search of literature. Estimated value may be obtained from values of the constituent elements using empirical relations and/or the Kopp-Neumann rule.

e. Magnesium + Aluminum Alloys

Experimental data are available for only one alloy [5]. The values for the other alloys may be estimated from values of the constituent elements using empirical relations and/or the Kopp-Neumann rule.

f. Stainless Steels 304 and 347

No data were uncovered from a limited search of literature. Estimated values may be obtained from values of the constituent elements using empirical relations and/or the Kopp-Neumann rule.

g. References

- | Ref.
No. | TPRC
No. | |
|-------------|-------------|---|
| 1 | | Hultgren, R., Desai, P.D., Hawkins, D.T., Gleiker, M., Kelley, K.K., and Wagman, D.D., "Selected Values of the Thermodynamic Properties of Elements," American Society for Metals, 636 pp., 1973. |
| 2 | 64418 | Treverton, J.A. and Margrave, J.L., "Enthalpies of Fusion and Heat Capacities for the Liquid Phases of Iron, Titanium, and Vanadium," J. Chem. Thermodyn., <u>3</u> (4), 473-81, 1971. |

Ref. No.	TPRC No.	
3	7006	Glassner, A., "The Thermochemical Properties of the Oxides, Fluorides, and Chlorides to 2500 K," Supt. of Documents, U.S. Government Printing Office Rept. ANL-5750, 70 pp., 1957.
4	16952	Douglas, T.B. and Victor, A.C., "High Temperature Heat Contents," From Preliminary Report on the Thermodynamic Properties of Selected Light-Element Compounds, " NBS Rept. 6645, 19-31, 1960.
5	24547	McDonald, R.A. and Stull, D.R., "Heat Content, Specific Heat, and Heat of Melting of Magnesium Alloy AZ-80 From 280 to 1080 K," J. Chem. Eng. Data, <u>6</u> , 609-10, 1966.