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Thermal Conductivities of Two Specimens of  
Ferrous Alloys at Temperatures from 100°C to 700°C

by

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for

Lebanon Steel Foundry  
Lebanon, Pennsylvania.

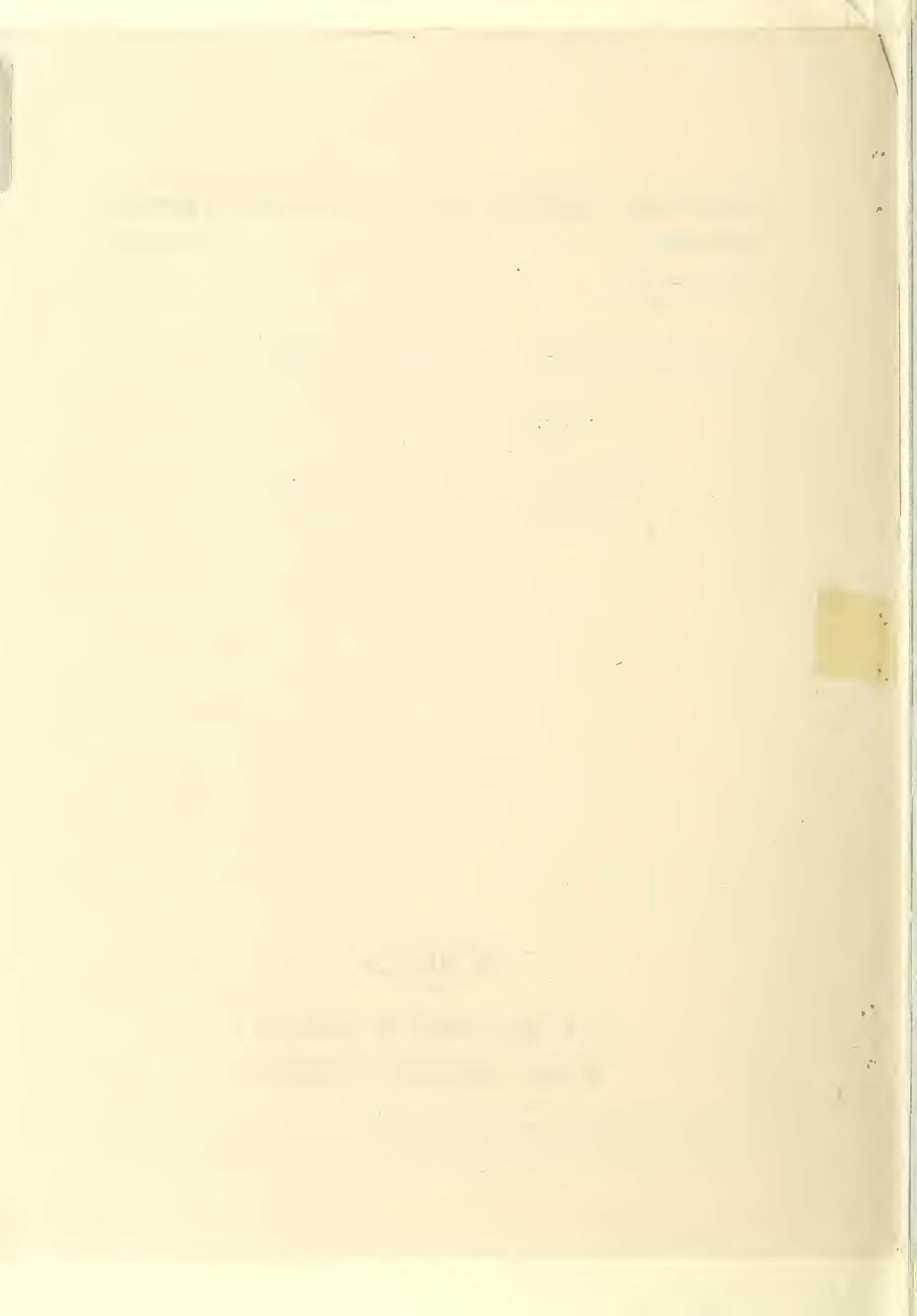


U. S. DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS

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# Thermal Conductivities of Two Specimens of Ferrous Alloys at Temperatures from 100°C to 700°C

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H. E. Robinson  
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## I. INTRODUCTION

Two specimens, referred to as No. E-4528 (L205A) and No. C-8507 (L23), were submitted by the Lebanon Steel Foundry, Lebanon, Pennsylvania, for calibration measurements of thermal conductivity in the temperature range from 100°C to 700°C.

From information furnished by the Lebanon Steel Foundry, the compositions of these ferrous alloy specimens were as follows:

	<u>No. E-4528</u> <u>(L 205A)</u>	<u>No. C-8507</u> <u>(L 23)</u>
Carbon	.30	.11
Silicon	.35	1.20
Manganese	.69	.74
Chromium	.80	20.38
Nickel	.75	9.43
Molybdenum	.25	.07
Copper	.08	.10
Phosphorous	.026	.020
Sulphur	.036	.025

## II. PREPARATION OF THE SPECIMENS

The general arrangement of the test apparatus is shown in Figure 1, as amended to show an internal heater in the bar specimens in place of the external heater previously used.

The upper end of each specimen was drilled to provide a well for circulation of the coolant and the lower end was drilled to accommodate the heater. The internal heating element was made by winding nichrome wire on a grooved porcelain cylinder, which was then covered with alundum for electrical insulation. Chromel-alumel thermocouples were attached at intervals of about 4 cm. along the length of the bar. One thermocouple was attached to the lower end

General description of the specimens  
 from the collection of the University of  
 Toronto, Ontario, Canada, 1927-1928

by  
 J. S. Hildebrand  
 1928

I. Introduction

The specimens, numbered 1 to 100, were collected by the author in the  
 Province of Ontario, Canada, during the summer of 1927. The collection was  
 made at several localities in the Province of Ontario, Canada, and  
 was deposited in the collection of the University of Toronto, Ontario,  
 Canada, 1927-1928.

For information of those interested in the collection, the  
 following is a list of the specimens and their localities:  
 names were as follows:

Specimen No.	Locality	Remarks
1	1000	Carbon
2	1000	Silver
3	1000	Lead
4	1000	Copper
5	1000	Iron
6	1000	Gold
7	1000	Platinum
8	1000	Palladium
9	1000	Rhodium
10	1000	Ruthenium
11	1000	Mercury
12	1000	Antimony
13	1000	Strontium
14	1000	Barium
15	1000	Calcium
16	1000	Magnesium
17	1000	Zinc
18	1000	Aluminum
19	1000	Silicon
20	1000	Boron
21	1000	Fluorine
22	1000	Chlorine
23	1000	Bromine
24	1000	Iodine
25	1000	Phosphorus
26	1000	Sulfur
27	1000	Carbon
28	1000	Silver
29	1000	Lead
30	1000	Copper
31	1000	Iron
32	1000	Gold
33	1000	Platinum
34	1000	Palladium
35	1000	Rhodium
36	1000	Ruthenium
37	1000	Mercury
38	1000	Antimony
39	1000	Strontium
40	1000	Barium
41	1000	Calcium
42	1000	Magnesium
43	1000	Zinc
44	1000	Aluminum
45	1000	Silicon
46	1000	Boron
47	1000	Fluorine
48	1000	Chlorine
49	1000	Bromine
50	1000	Iodine
51	1000	Phosphorus
52	1000	Sulfur
53	1000	Carbon
54	1000	Silver
55	1000	Lead
56	1000	Copper
57	1000	Iron
58	1000	Gold
59	1000	Platinum
60	1000	Palladium
61	1000	Rhodium
62	1000	Ruthenium
63	1000	Mercury
64	1000	Antimony
65	1000	Strontium
66	1000	Barium
67	1000	Calcium
68	1000	Magnesium
69	1000	Zinc
70	1000	Aluminum
71	1000	Silicon
72	1000	Boron
73	1000	Fluorine
74	1000	Chlorine
75	1000	Bromine
76	1000	Iodine
77	1000	Phosphorus
78	1000	Sulfur
79	1000	Carbon
80	1000	Silver
81	1000	Lead
82	1000	Copper
83	1000	Iron
84	1000	Gold
85	1000	Platinum
86	1000	Palladium
87	1000	Rhodium
88	1000	Ruthenium
89	1000	Mercury
90	1000	Antimony
91	1000	Strontium
92	1000	Barium
93	1000	Calcium
94	1000	Magnesium
95	1000	Zinc
96	1000	Aluminum
97	1000	Silicon
98	1000	Boron
99	1000	Fluorine
100	1000	Chlorine

II. Description of the specimens

The general appearance of the specimens is shown in  
 Figure 1, an attempt to show an average specimen in the  
 collection in terms of the various metals mentioned  
 above.

The upper end of each specimen was drilled in order  
 to allow for circulation of the metal and the lower end  
 was drilled to accommodate the metal. The internal  
 diameter was made as wide as possible and the  
 specimen drilled, which was then covered with a  
 thin layer of metal. The internal diameter was  
 the same as the diameter of the metal. The  
 specimen was drilled in order to allow for  
 circulation of the metal. The internal  
 diameter was made as wide as possible and  
 the specimen drilled, which was then covered  
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 the same as the diameter of the metal.

of the specimen. The completed specimen was supported on a thin nichrome pin located in the bottom of a thick-walled stainless steel guard cylinder. The guard cylinder was also equipped with thermocouples and a heater element, and at the top with a copper coil through which the coolant was circulated. The specimen-guard assembly was suspended in a large sheet metal container and the entire system insulated with a fine granular insulation.

### III. TEST METHOD

Electrical energy was supplied to the heater elements and adjusted so that a minimum temperature difference between bar and guard existed at the thermocouples just above the heaters. Cooling water at constant temperature was pumped through the well in the specimen and through the coil on the guard cylinder. When steady temperature conditions had been attained the emfs of the thermocouples (reference junctions at 0C) and the current through and voltage drop across the bar heater were measured by means of standard resistors and a precision potentiometer. Thermocouple readings were subsequently converted to degrees Centigrade, using data determined by a calibration of the thermocouple wire.

To calculate the thermal conductivity, observed temperatures of the bar and guard were plotted versus position along the bar as abscissae and smooth curves were drawn through the points along the bar and along the guard. Corrections to the measured heat input to the bar to account for heat interchange between the bar and guard were made on the basis of the temperature differences between them determined from the curves and using the conductivity of the granular insulation at the appropriate mean temperature. The corrections were made for the heat interchange (a) between the lower end of the bar and the guard cylinder (b) between the bar and guard at the heater region and (c) between bar and guard for each thermocouple span. The average rate of heat flow between any two thermocouples on the bar was thus computed and used, together with the measured distance and temperature difference between them, and the cross-sectional area of the specimen, to calculate the average thermal conductivity for that span. The calculated heat loss from the bar below the first span was less than 10 percent of the heat input; the total heat loss for all six spans was from -9 to +6 percent of the heat input in the various tests. It is believed

of the specimen. The specimen was supported  
on a thin aluminum rod which is the center of a thick  
solid stainless steel support cylinder. The rod and  
bar was also supported with longitudinal and a  
element, and at the top with a support and  
the column was attached. The specimen was  
was supported in a large steel support and  
cooling system insulated with a low-conductivity insulation.

III. EXPERIMENTAL

Electrical power was supplied to the heater elements  
and adjusted to heat a specimen continuously. The  
specimen was held in the center of the support  
above the heater. The heater was supported  
that was supported above the specimen and  
around the coil on the support cylinder. The  
temperature distribution was measured at the  
the thermocouple locations at 1/2 and 1  
current through and voltage over current and  
were measured by means of standard resistance and a  
ratio potentiometer. The thermocouple voltage was  
electrically converted to current by means of a  
resistance of a calibration of the thermocouple.

To calculate the current distribution, the  
temperature of the bar was measured at various  
positions along the bar as specimens and small  
were drawn through the center of the bar and  
the guard. Corrections to the measured values  
the bar to account for heat loss from the  
bar and guard were made on the basis of the  
difference between the measured and  
value the conductivity of the specimen. The  
the specimen was measured. The conductivity was  
made for the heat loss from the specimen and  
of the bar and the guard cylinder. The  
and heat at the heater region and at the  
heat for each specimen's case. The heat loss  
heat loss between the specimen and the bar was  
time constant and heat transfer rate the  
heat loss from the specimen to the bar was  
cross-sectional area of the specimen. The  
specimen thermal conductivity for the bar was  
heat loss from the specimen to the bar was  
loss from the specimen to the bar was  
loss from the specimen to the bar was  
loss from the specimen to the bar was



that the various corrections could be evaluated with an uncertainty of not more than about 20 percent, consequently the uncertainty in the rates of heat flow used in computing the conductivities is of the order of not more than 2 percent.

#### IV. TEST RESULTS

The values of thermal conductivity obtained in the tests were plotted against mean temperature (Figures 2 and 3) and a straight line, determined by the method of least squares, was drawn through the points. In the case of specimen No. E-4528 two straight lines were drawn because of a sharp change in the thermal conductivity at a mean temperature of about 200°C. Table I lists thermal conductivities taken from these lines.

#### V. DISCUSSION OF RESULTS

The plotted points show some scatter from the least mean square lines drawn through them over a range of mean temperatures. The scattering about the straight line evidenced by the points obtained for the same test condition is an inverse measure of the precision of the measurements. Several factors may have contributed to the scattering, namely, small random inaccuracies in measuring the thermocouple locations on the bar, slight heat conduction along the thermocouple wires near the hot junctions and possible slight inhomogenities of the thermocouple wires.

To minimize heat conduction effects, No. 26 A.W. gage thermocouple wires were used, and the wires were led away for a distance of a few centimeters in the plane of the cross-section at the junction, in which the temperature should be fairly uniform. However, since the temperature gradients along the bar ranged from 5 to 38 degrees C per centimeter in different tests, some conduction effect on individual thermocouple readings probably could not be avoided. The plot of bar temperatures versus position indicates some slight departures from a smooth curve, of magnitude not greater than one degree C in the extreme case. Since all of these factors were random in nature, their effect was probably to decrease the precision of the measurements rather than to affect the overall results in any one direction.

The various experiments which have been conducted with the  
purpose of determining the effect of the various factors  
mentioned above upon the rate of the reaction are  
summarized in the following table.

#### TABLE I

The values of the rate constants,  $k_1$ ,  $k_2$ , and  $k_3$ ,  
obtained from the experiments described in the  
preceding section, are given in the following table.  
The values of  $k_1$  and  $k_2$  are given in units of  
liters per mole per second, and the value of  $k_3$  is  
given in units of liters per mole per second squared.

#### TABLE II

The values of the rate constants,  $k_1$ ,  $k_2$ , and  $k_3$ ,  
obtained from the experiments described in the  
preceding section, are given in the following table.  
The values of  $k_1$  and  $k_2$  are given in units of  
liters per mole per second, and the value of  $k_3$  is  
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liters per mole per second, and the value of  $k_3$  is  
given in units of liters per mole per second squared.

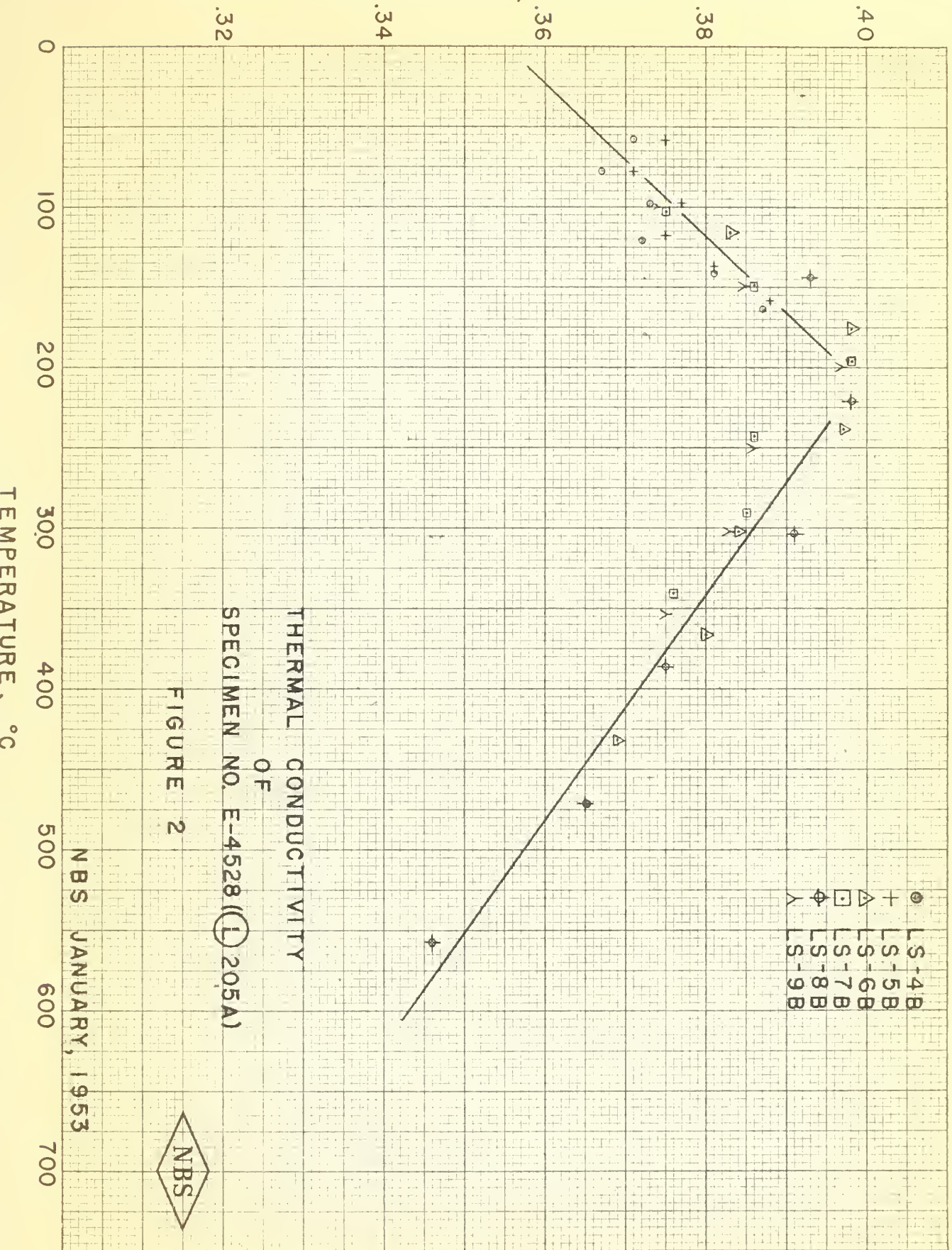
Table 1

<u>Mean Temperature</u> °C	<u>Thermal Conductivity, watts/cm(degC)</u>	
	<u>No. E-4528</u>	<u>No. C-8507</u>
50	0.366	0.132
100	.376	.140
150	.387	.149
200	.397	.157
(200)	(.400)	-
300	.386	.173
400	.372	.190
500	.357	.206
600	.343	.223
700	-	.239

Table I

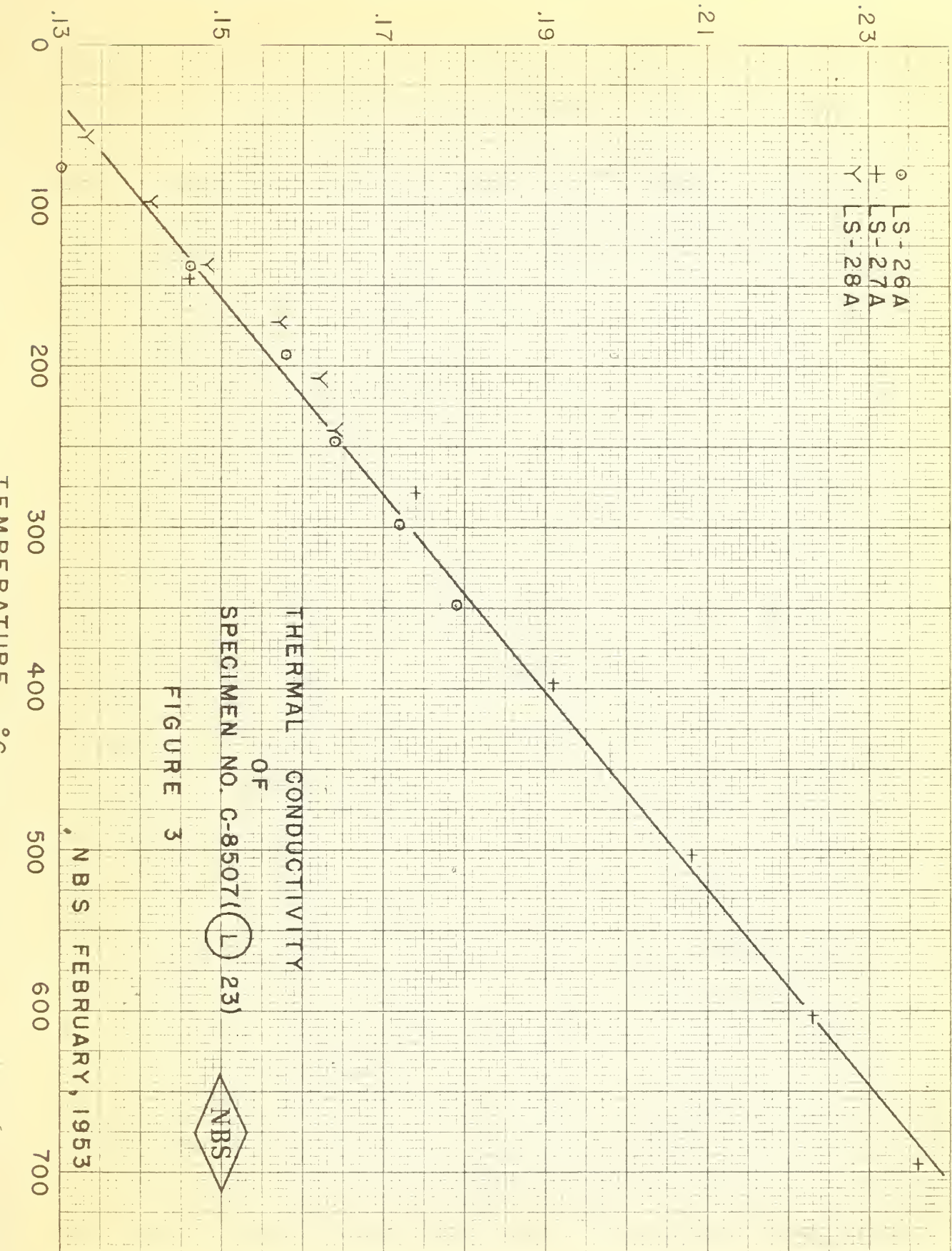
<u>Year</u>	<u>Value</u>	<u>Index</u>
1910	100	100
1911	105	105
1912	110	110
1913	115	115
1914	120	120
1915	125	125
1916	130	130
1917	135	135
1918	140	140
1919	145	145
1920	150	150
1921	155	155
1922	160	160
1923	165	165
1924	170	170
1925	175	175
1926	180	180
1927	185	185
1928	190	190
1929	195	195
1930	200	200
1931	205	205
1932	210	210
1933	215	215
1934	220	220
1935	225	225
1936	230	230
1937	235	235
1938	240	240
1939	245	245
1940	250	250
1941	255	255
1942	260	260
1943	265	265
1944	270	270
1945	275	275
1946	280	280
1947	285	285
1948	290	290
1949	295	295
1950	300	300
1951	305	305
1952	310	310
1953	315	315
1954	320	320
1955	325	325
1956	330	330
1957	335	335
1958	340	340
1959	345	345
1960	350	350
1961	355	355
1962	360	360
1963	365	365
1964	370	370
1965	375	375
1966	380	380
1967	385	385
1968	390	390
1969	395	395
1970	400	400
1971	405	405
1972	410	410
1973	415	415
1974	420	420
1975	425	425
1976	430	430
1977	435	435
1978	440	440
1979	445	445
1980	450	450
1981	455	455
1982	460	460
1983	465	465
1984	470	470
1985	475	475
1986	480	480
1987	485	485
1988	490	490
1989	495	495
1990	500	500
1991	505	505
1992	510	510
1993	515	515
1994	520	520
1995	525	525
1996	530	530
1997	535	535
1998	540	540
1999	545	545
2000	550	550
2001	555	555
2002	560	560
2003	565	565
2004	570	570
2005	575	575
2006	580	580
2007	585	585
2008	590	590
2009	595	595
2010	600	600
2011	605	605
2012	610	610
2013	615	615
2014	620	620
2015	625	625
2016	630	630
2017	635	635
2018	640	640
2019	645	645
2020	650	650
2021	655	655
2022	660	660
2023	665	665
2024	670	670
2025	675	675
2026	680	680
2027	685	685
2028	690	690
2029	695	695
2030	700	700

THERMAL CONDUCTIVITY, WATTS / CM. (DEG. C)





THERMAL CONDUCTIVITY, WATTS / CM. (DEG. C)



○ LS-26A  
 + LS-27A  
 Y LS-28A

THERMAL CONDUCTIVITY  
 OF  
 SPECIMEN NO. C-8507(L23)

FIGURE 3

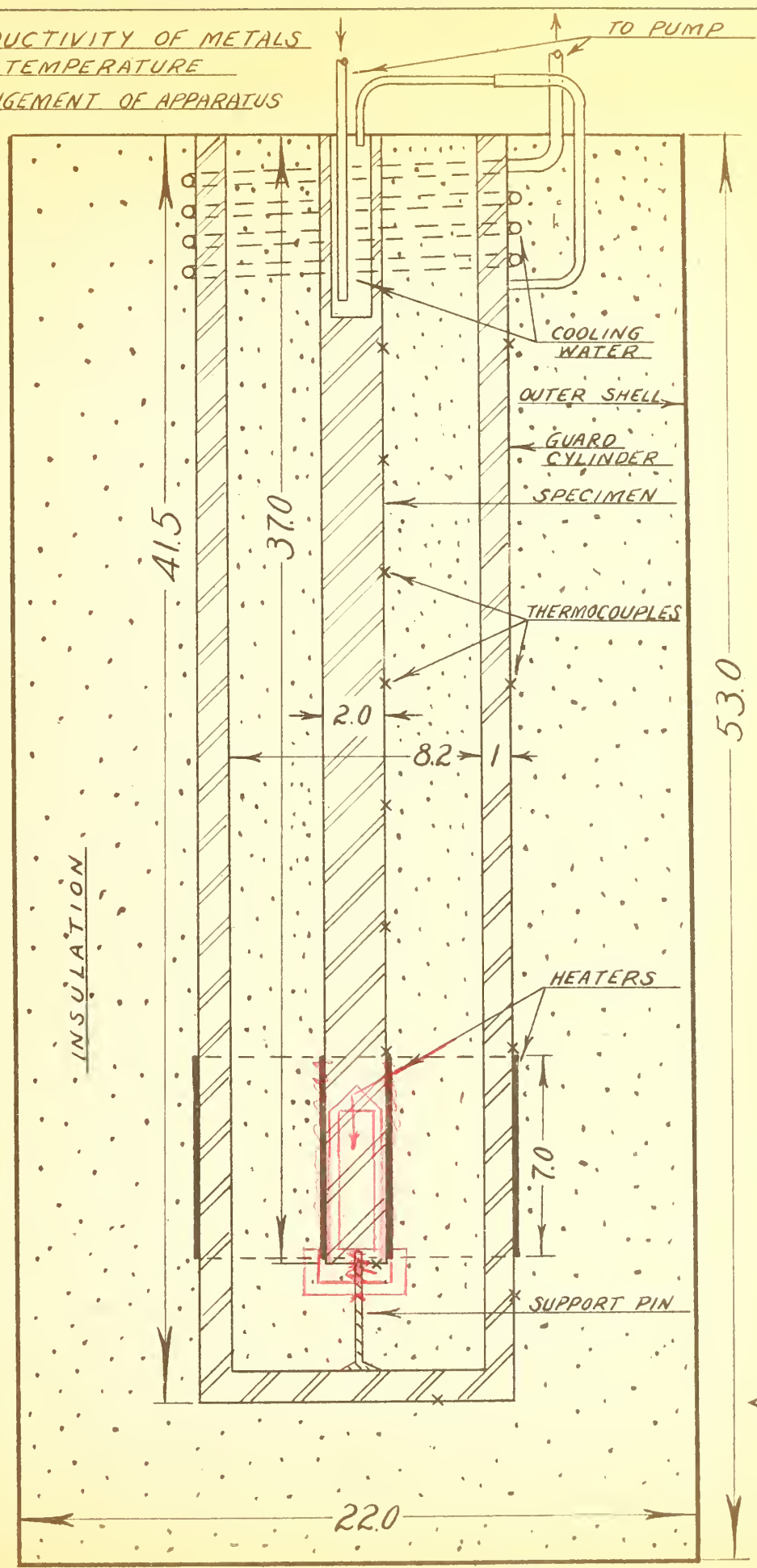


NBS FEBRUARY, 1953





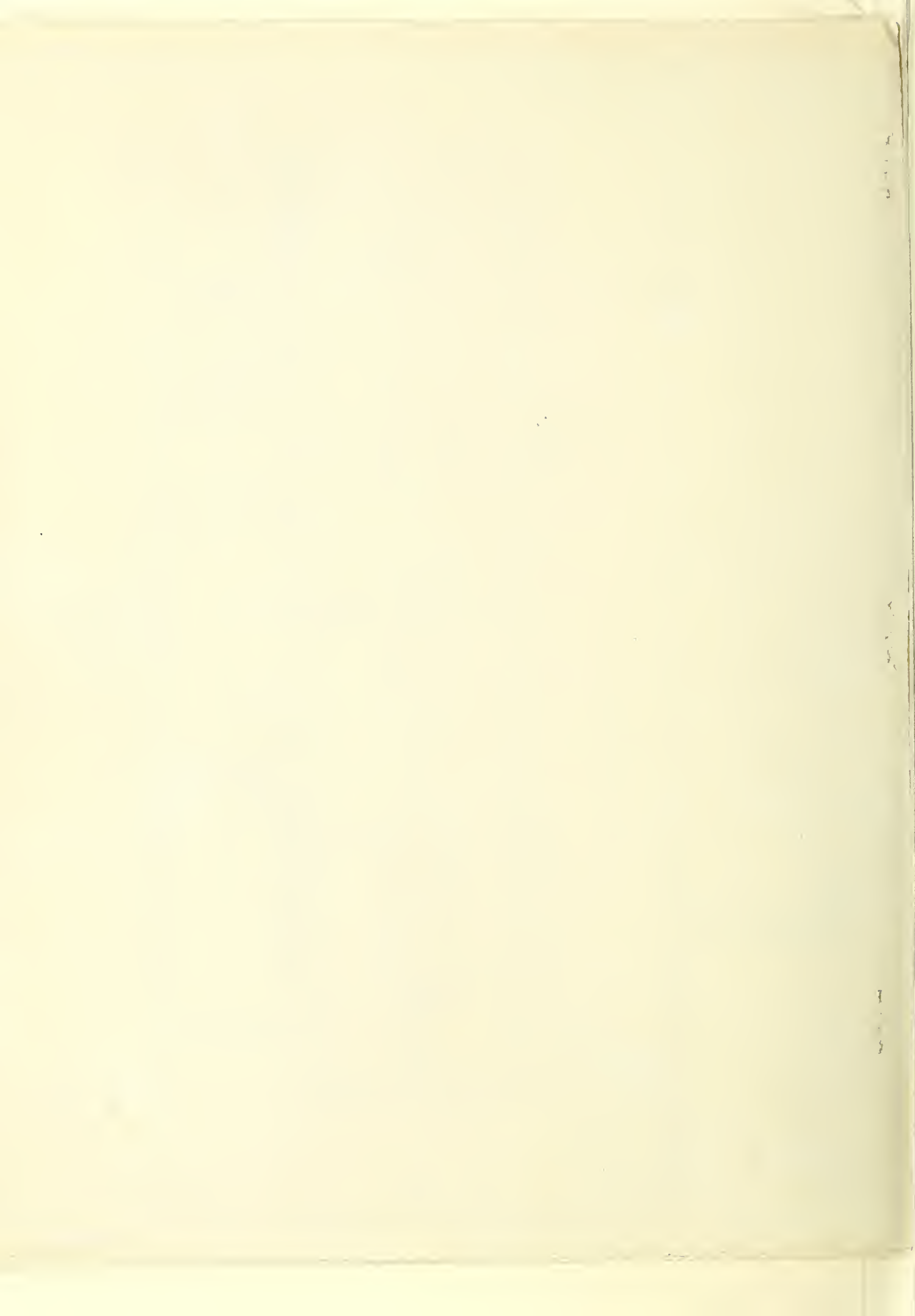
THERMAL CONDUCTIVITY OF METALS  
AT HIGH TEMPERATURE  
GENERAL ARRANGEMENT OF APPARATUS



NOTE:  
ALL DIMENSIONS  
IN CENTIMETERS

NBS

FIGURE 1



**STAPLES**

Jul 26, 2016

U.S. District Court  
District of Columbia