VIII. SPECIFIC HEAT OF SOME SOLIDS

CONTENTS

Additional Reference to Entire Chapter: NBS Monograph 21.

SPECIFIC HEAT, ENTHALPY of ALUMINUM

Sources of Data:

Giauque, W. F. and Meads, P. F., J. Am. Chem. Soc. 63, 1897-1901 (1941)
Maier, C. G. and Anderson, C. T., J. Chem. Phys. 2, 513-27 (1934)
Phillips, N. E., Low Temperature Physics and Chemistry, Univ. Wisconsin Press (1958)

Other References:

Behn, U., Ann. Physik Beiblätter 25, 178 (1901)
Goodman, B. B., Compt. rend. 244, 2899 (1957)
Griffiths, E. G. and Griffiths, E., Phil. Trans. Roy. Soc. London A90, 557 (1914)
Kok, J. A. and Keesom, W. H., Physica 4, 835 (1937)
Koref, F., Ann. Physik (4) 36, 49 (1911)
Nernst, W., Ann. Physik (4) 36, 395 (1911)
Nernst, W. and Lindemann, F. A., Z. Elektrochem. 17, 817 (1911)
Nernst, W. and Schwers, F., Sitzber. kgl. preuss. Akad. Wiss. 355 (1914)
Richards, T. W. and Jackson, F. G., Z. physik. Chem. 70, 414 (1910)
Schmitz, H. E., Proc. Roy. Soc. (London) 72, 177 (1903)
Tilden, W. A., Proc. Roy. Soc. (London) 71, 220 (1903)

Table of Selected Values

Temp. °K	C_p j/gm-°K	H j/gm	Temp. °K	C_p j/gm-°K	H j/gm
1	0.000 10*		60	0.214	3.64
1	.000 051	0.000 025	70	.287	6.15
2	.000 108	.000 105	80	.357	9.37
3	.000 176	.000 246	90	.422	13.25
4	.000 261	.000 463	100	.481	17.76
6	.000 50	.001 21	120	.580	28.4
8	.000 88	.002 6	140	.654	40.7
10	.001 4	.004 9	160	.713	54.4
15	.004 0	.018	180	.760	69.2
20	.008 9	.048	200	.797	84.8
25	.017 5	.112	220	.826	101.0
30	.031 5	.232	240	.849	117.8
35	.051 5	.436	260	.869	135.0
40	.077 5	.755	280	.886	152.5
50	.142	1.85	300	.902	170.4

* Superconducting

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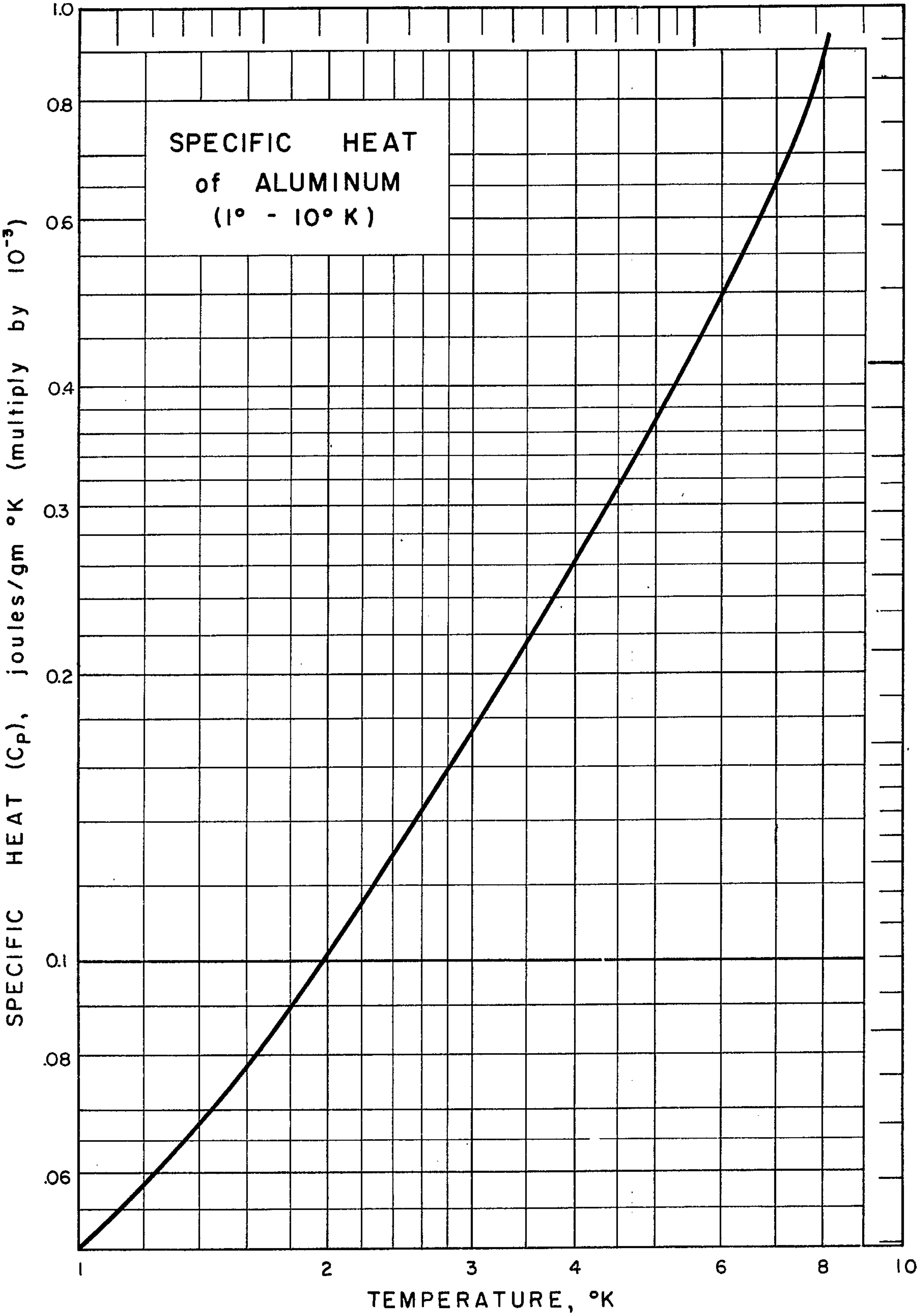
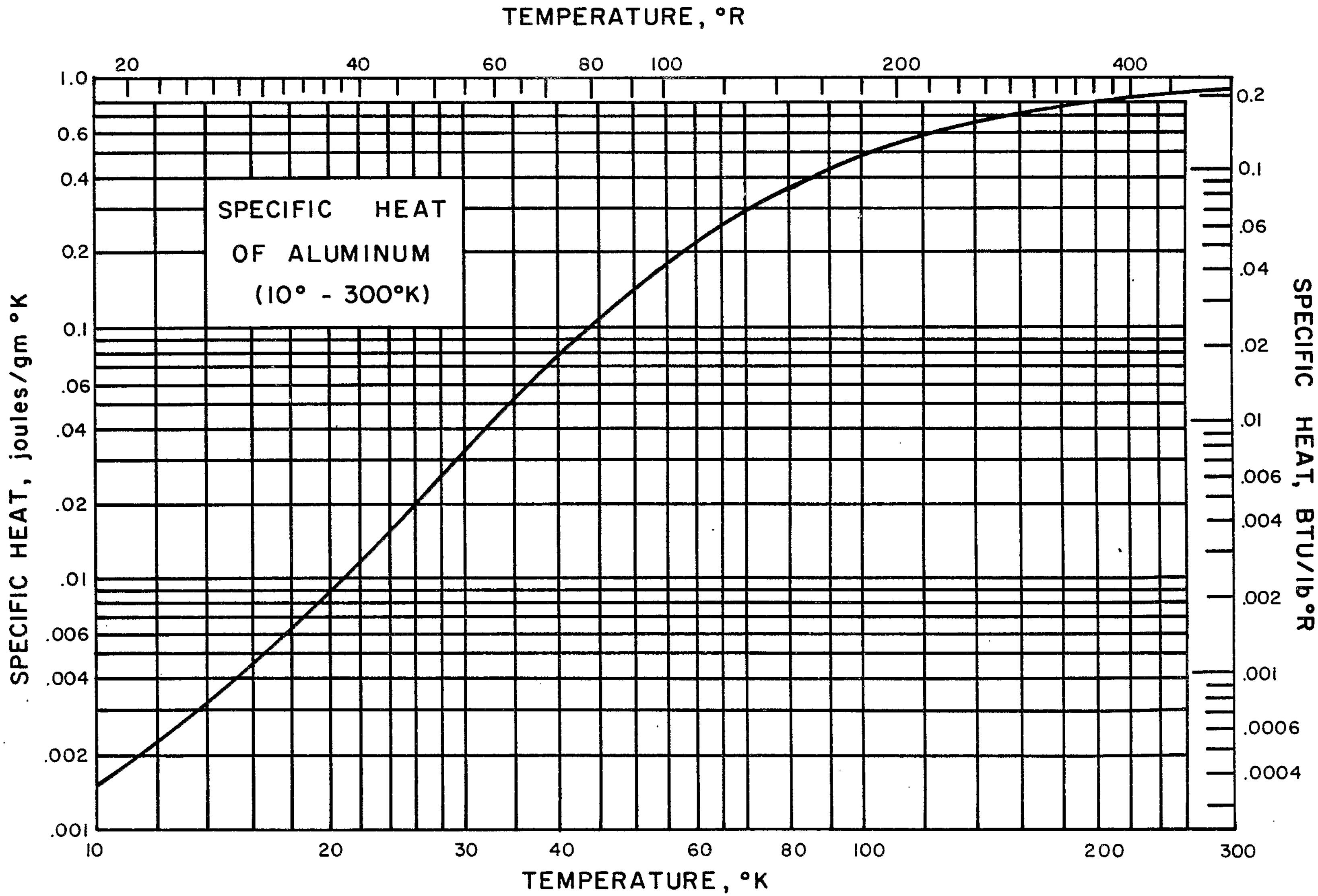
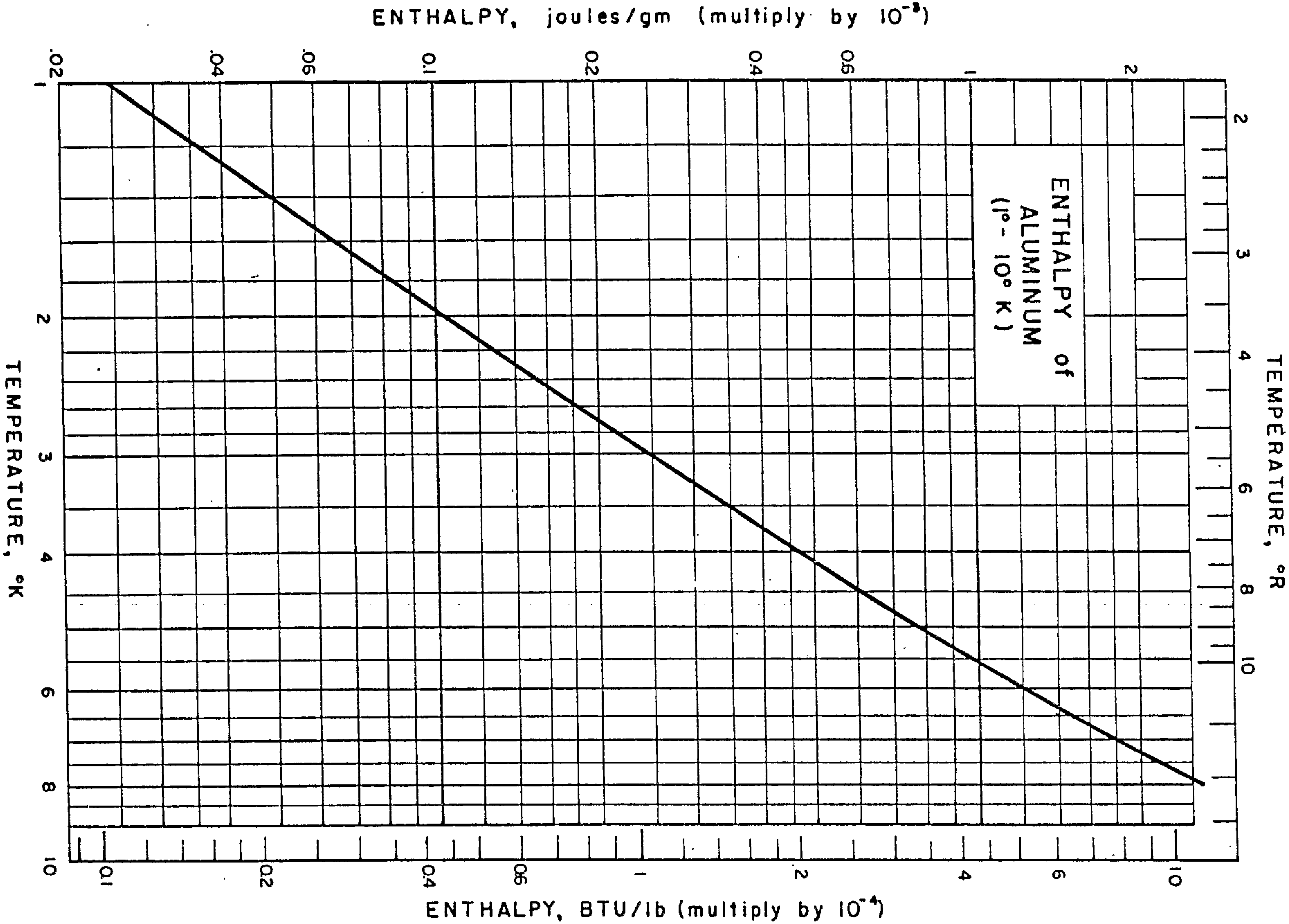
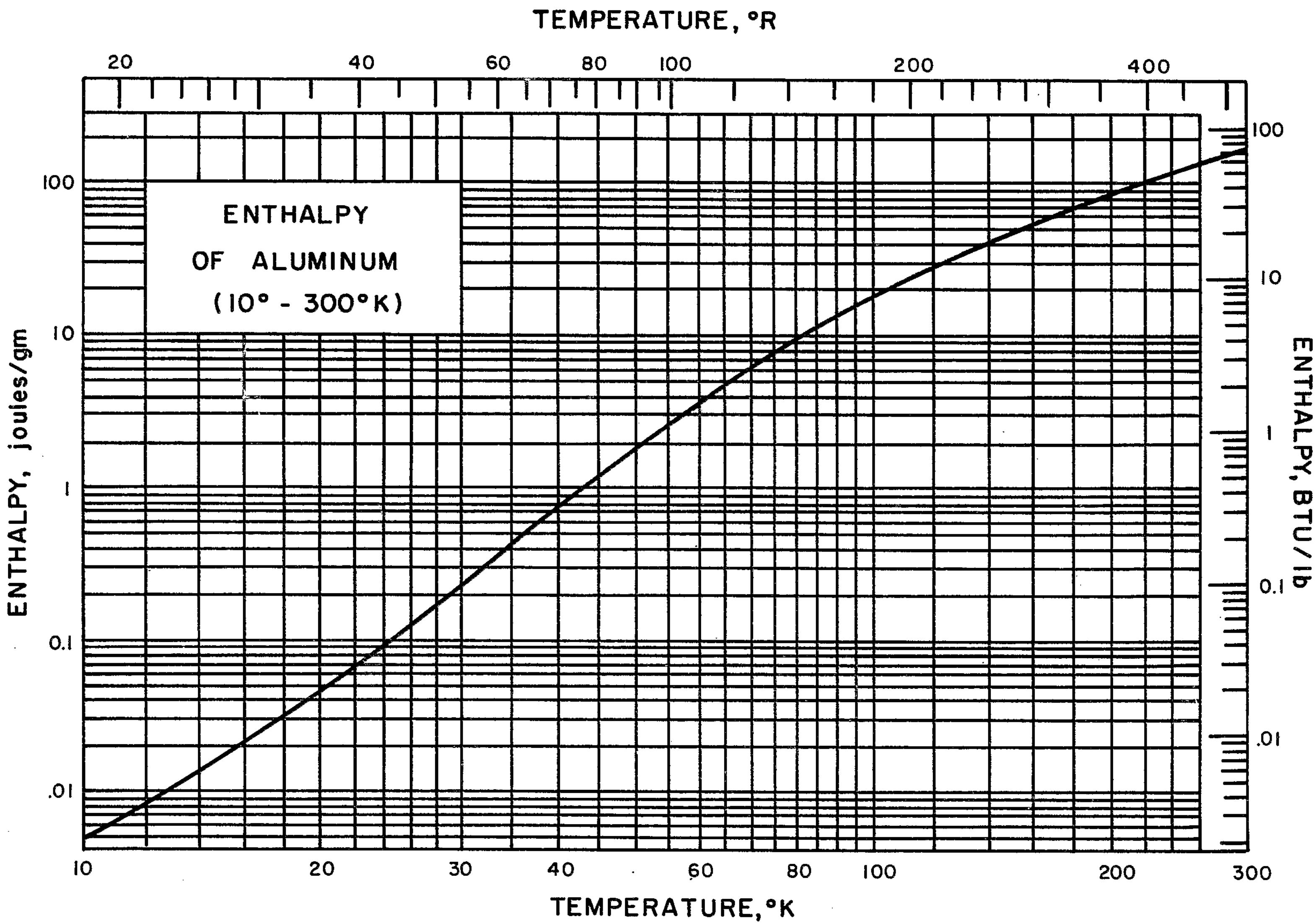

SPECIFIC HEAT
of ALUMINUM
(1° - 10° K)
SPECIFIC HEAT (C_p), joules/gm °K (multiply by 10^{-3})
1.0
0.8
0.6
0.4
0.3
0.2
0.1
.08
.06
1
2
3
4
6
8
10
TEMPERATURE, °K



TEMPERATURE, °R
20
40
60
80
100
200
400
SPECIFIC HEAT
OF ALUMINUM
(10° - 300°K)
1.0
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
.001
SPECIFIC HEAT, joules/gm °K
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
.001
.0006
.0004
SPECIFIC HEAT, BTU/lb°R
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K


ENTHALPY, joules/gm (multiply by 10^-3)
ENTHALPY of ALUMINUM (1° - 10° K)
TEMPERATURE, °K
TEMPERATURE, °R
ENTHALPY, BTU/lb (multiply by 10^-4)
.02
.04
.06
0.1
0.2
0.4
0.6
1
2
0.1
0.2
0.4
0.6
1
2
4
6
10
1
2
3
4
6
8
10
2
3
4
6
8
10


TEMPERATURE, °R
20
40
60
80
100
200
400
ENTHALPY
OF ALUMINUM
(10° - 300°K)
ENTHALPY, joules/gm
100
10
1
0.1
.01
ENTHALPY, BTU/lb
100
10
1
0.1
.01
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

SPECIFIC HEAT OF COPPER

T °K	C_p, cal g^{-1} K^{-1}	T °K	C_p, cal g^{-1} K^{-1}
0.1	2.70×10^{-7}	300	9.23×10^{-2}
0.2	5.30	400	9.46
0.3	7.95	500	9.71
0.4	1.05×10^{-6}	600	9.95
0.5	1.32	700	1.02×10^{-1}
0.6	1.59	800	1.04
0.7	1.88	900	1.07
0.8	2.15	1000	1.09
0.9	2.46	1100	1.11
1	2.75	1200	1.14
2	6.59	1300	1.16
3	1.26×10^{-5}	(s) 1356	1.18
4	2.17	(l) 1356	(1.18)†
5	3.45	1400	(1.18)
6	5.45	1500	(1.18)
7	8.00	1600	(1.18)
8	1.14×10^{-4}	1700	(1.18)
9	1.56	1800	(1.18)
10	2.05	1900	(1.18)
15	6.63	2000	(1.18)
20	1.76×10^{-3}	2100	(1.18)
30	6.53	2200	(1.18)
40	1.42×10^{-2}	2300	(1.18)
50	2.36	2400	(1.18)
60	3.45	2500	(1.18)
70	4.10	2600	(1.18)
80	4.35	2700	(1.18)
90	5.50	2800	(1.18)
100	6.06	2900	(1.18)
200	8.55	3000	(1.18)

Investigators: Avramescu, A. (34) [373-1273K]; Bell, I.P. (35) [288-701K]; Booker, J., et al (36) [727-1210K]; Butler, C.P., and Inn, E.C.Y. (37) [337-946K]; Dockerty, S.M. (38) [201-389K]; Dockerty, S.M. (39) [28-194K]; Eder, F.X. (40) [30-300K]; Esterman, I., et al (41) [2.2-3.6K]; Eucken, A., and Werth, H. (42) [94-219K]; Fieldhouse, I.B., et al (43) [811-1311K]; Fieldhouse, I.B., et al (44) [1366-1922K]; Giauque, W.F., and Meads, P.F. (45) [15-300K]; Howse, P.T., et al (46) [366-544K]; Jaeger, F.M., et al (47) [573-1173K];

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†Estimated (5)

SPECIFIC HEAT, ENTHALPY of COPPER

(1° to 10°K)

Sources of Data:

Corak, W. S., Garfunkel, M. P., Satterthwaite, C. B. and Wexler, A., Phys. Rev. 98, 1699-1707 (1955)

Rayne, J. A., Australian J. Phys. 9, 189-97 (1956)

Other References:

Estermann, I., Friedberg, S. A., and Goldman, J. E., Phys. Rev. 87, 582 (1952)

Kok, J. A. and Keesom, W. H., Physica 3, 1035-45 (1936)

Phillips, N. E., Low Temperature Physics and Chemistry, Univ. Wisconsin Press (1958) pp. 414-7

Comments:

For the temperature range 0° to 10°K, the specific heat follows the equation:

$$C_p = 10.8 \times 10^{-6}\, T + 30.6 \left[\frac{T}{344.5}\right]^3 \text{ j/gm-°K}$$

Table of Selected Values

Temp. °K	C_p j/gm-°K	H * j/gm
1	0.000 012	0.000 006
2	.000 028	.000 025
3	.000 053	.000 064
4	.000 091	.000 13
6	.000 23	.000 44
8	.000 47	.001 12
10	.000 86	.002 4

$$* \; H = \int_0^T C_p \, dT$$

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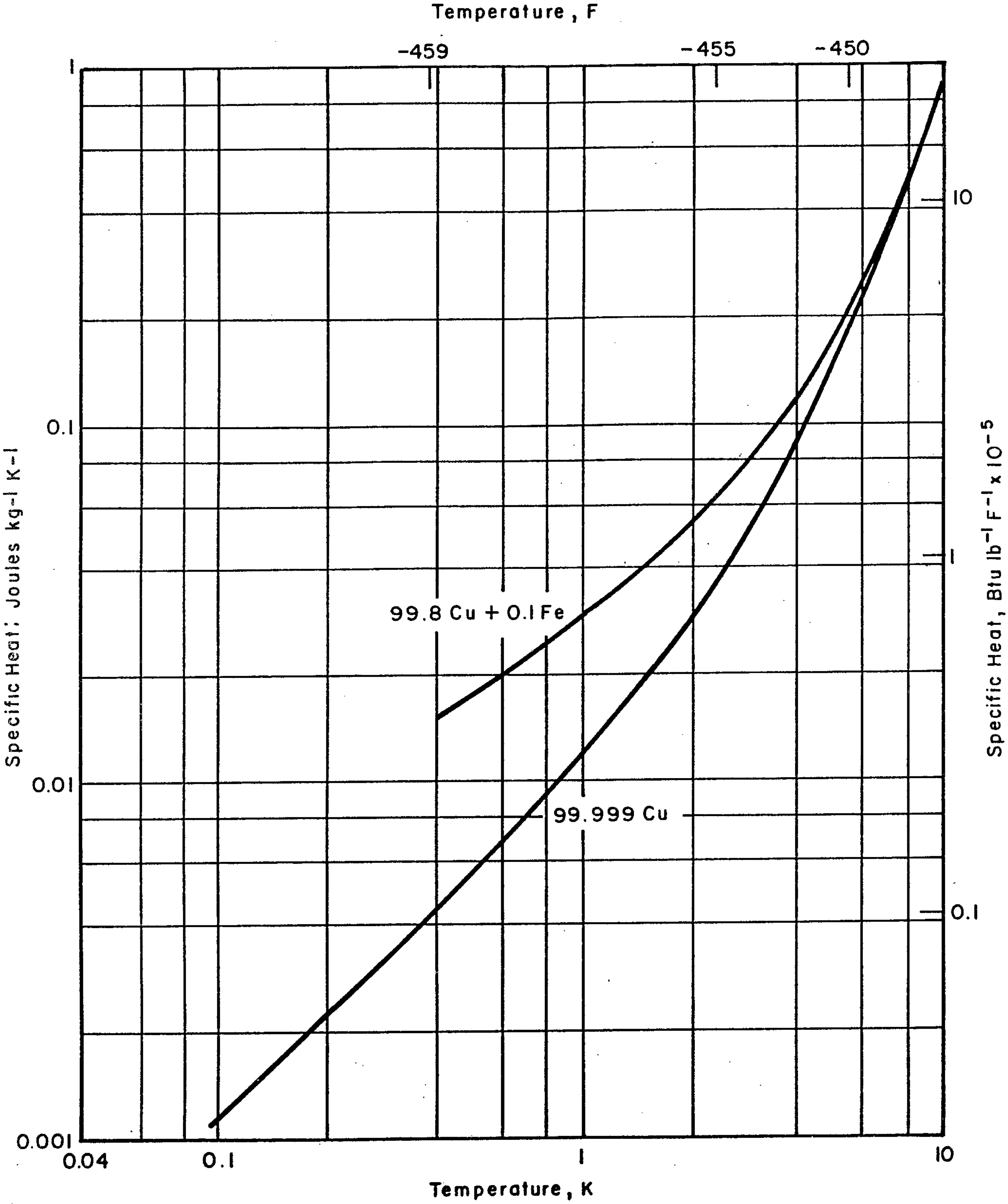
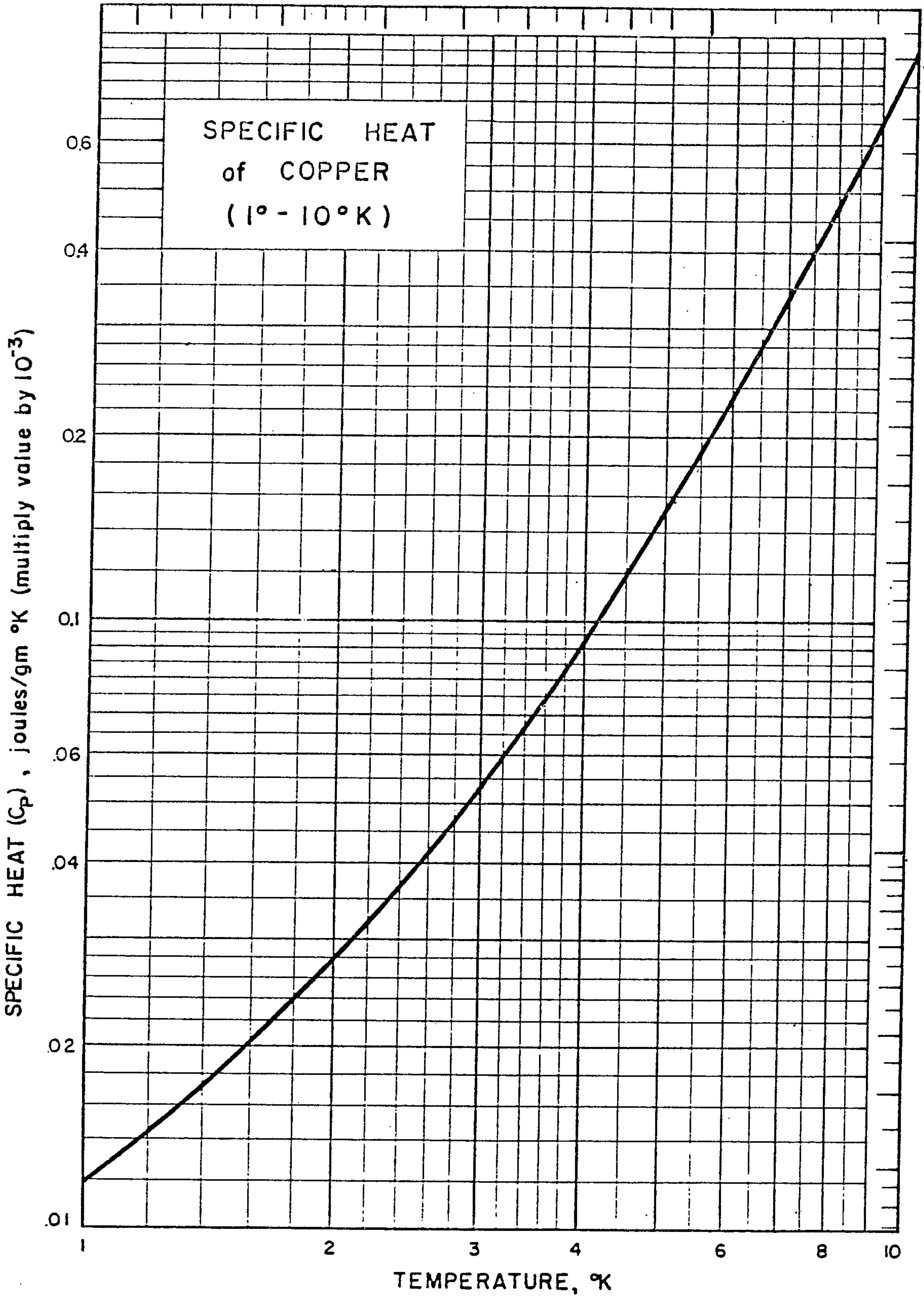


SPECIFIC HEAT VERSUS TEMPERATURE FOR COPPER


SPECIFIC HEAT
of COPPER
(1° - 10° K)
SPECIFIC HEAT (C_p), joules/gm °K (multiply value by 10^{-3})
0.6
0.4
0.2
0.1
.06
.04
.02
.01
1
2
3
4
6
8
10
TEMPERATURE, °K

SPECIFIC HEAT, ENTHALPY of COPPER

(10° to 300°K)

Sources of Data:

Dockerty, S. M., Can. J. Research 15A, 59-66 (1937)

Other References:

Aoyama, S. and Kanda, E., J. Chem. Soc. Japan 62, 312-15 (1941)

Behn, U., Ann. Physik u. Chem. (3) 66, 237-44 (1898)

Bronson, H. L., Chisholm, H. M. and Dockerty, S. M., Can. J. Research 8, 282-303 (1933)

Eucken, A. and Werth, H., Z. anorg. allgem. Chem. 188, Schenck Festschrift, 152-72 (1930)

Giauque, W. F. and Meads, P. F., J. Am. Chem. Soc. 63, 1897-1901 (1941)

Keesom, W. H. and Onnes, H. K., Communs. Phys. Lab. Univ. Leiden No. 147a, 3 (1915)

Koref, F., Ann. Physik 36, 49-73 (1911)

Nernst, W., Sitzber. kgl. preuss. Akad. Wiss. 262 (1910)

Nernst, W., Sitzber. kgl. preuss. Akad. Wiss. 306 (1911)

Nernst, W. and Lindemann, F. A., Z. Elektrochem. 17, 817 (1911)

Schimpff, H., Z. physik. Chem. 71, 257 (1910)

Table of Selected Values

Temp. °K	C_p j/gm-°K	H* j/gm	Temp. °K	C_p j/gm-°K	H* j/gm
10	0.000 86	0.0024	100	0.254	10.6
15	.002 7	.0107	120	.288	16.1
20	.007 7	.034	140	.313	22.1
25	.016	.090	160	.332	28.5
30	.027	.195	180	.346	35.3
40	.060	.61	200	.356	42.4
50	.099	1.40	220	.364	49.6
60	.137	2.58	240	.371	56.9
70	.173	4.13	260	.376	64.4
80	.205	6.02	280	.381	72.0
90	.232	8.22	300	.386	79.6

$$* \; H = \int_0^T C_p \, dT$$

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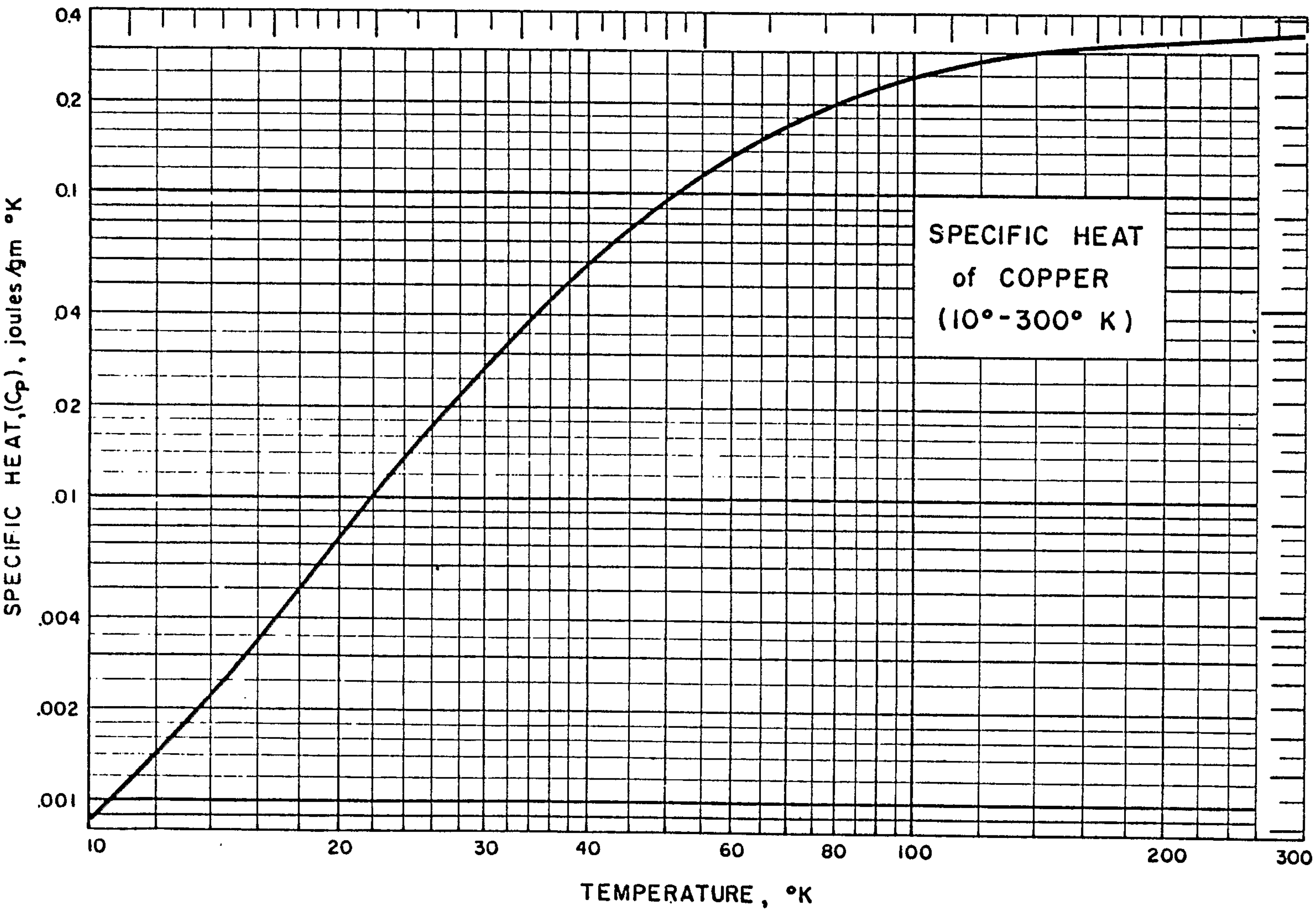
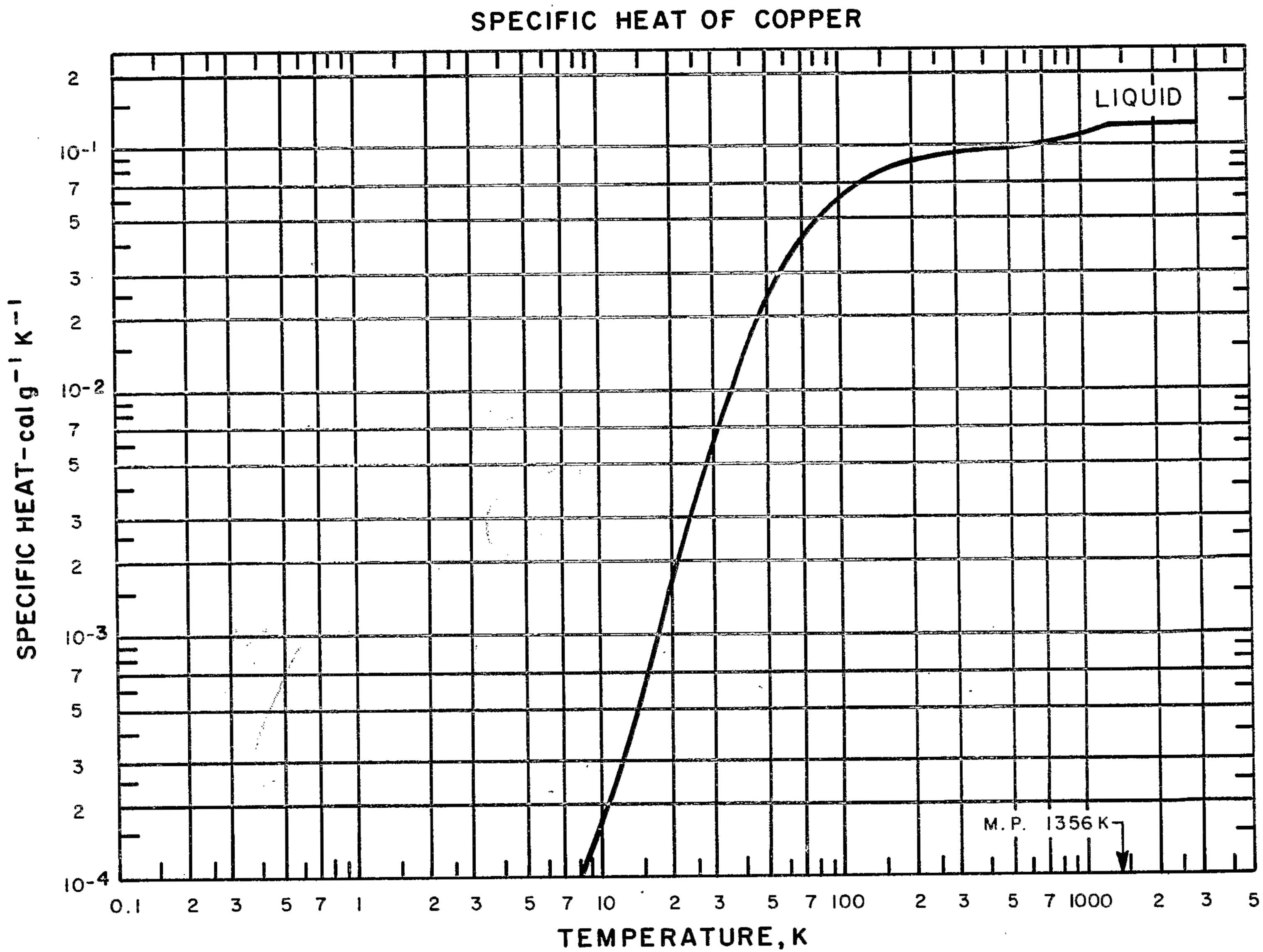
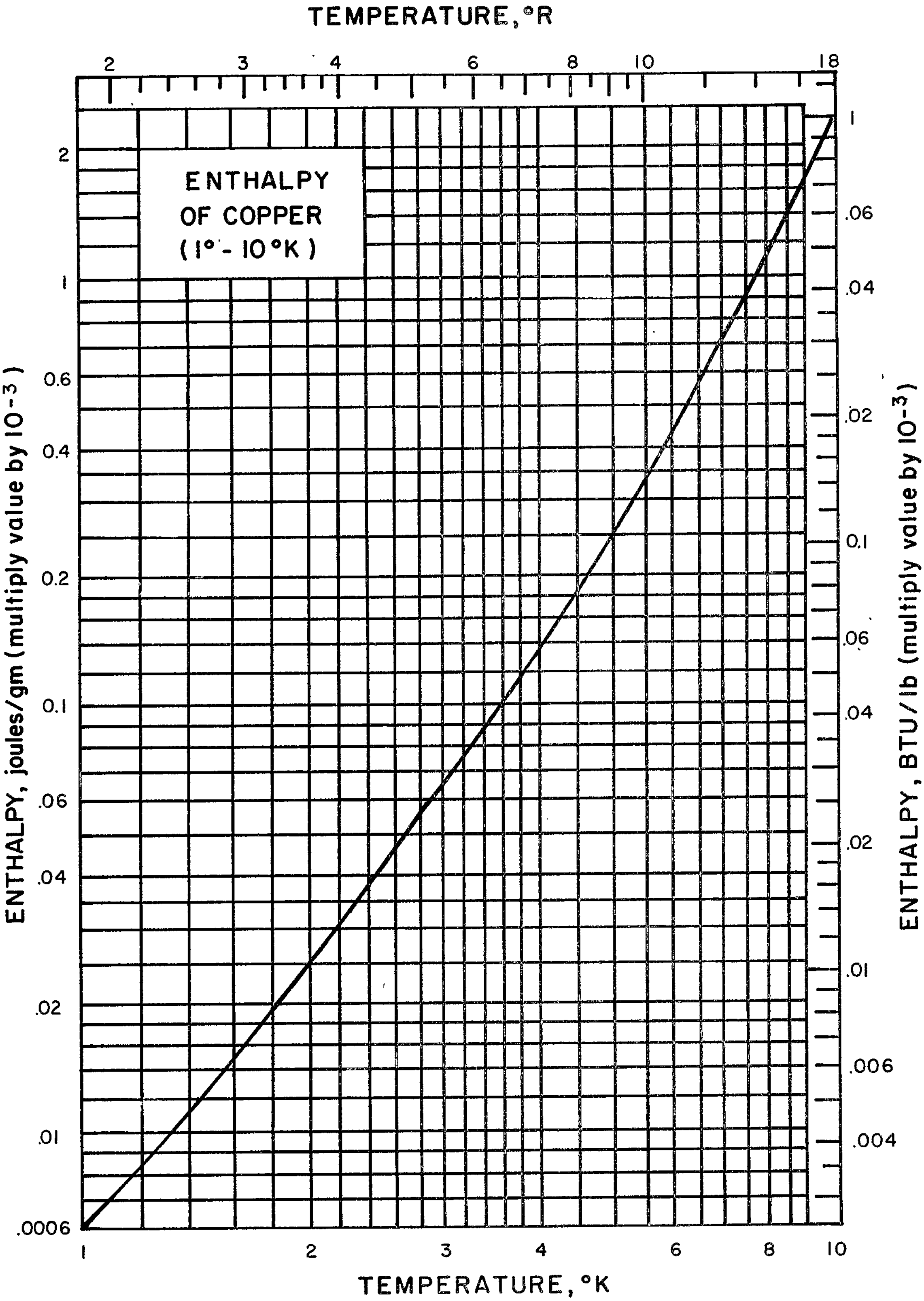
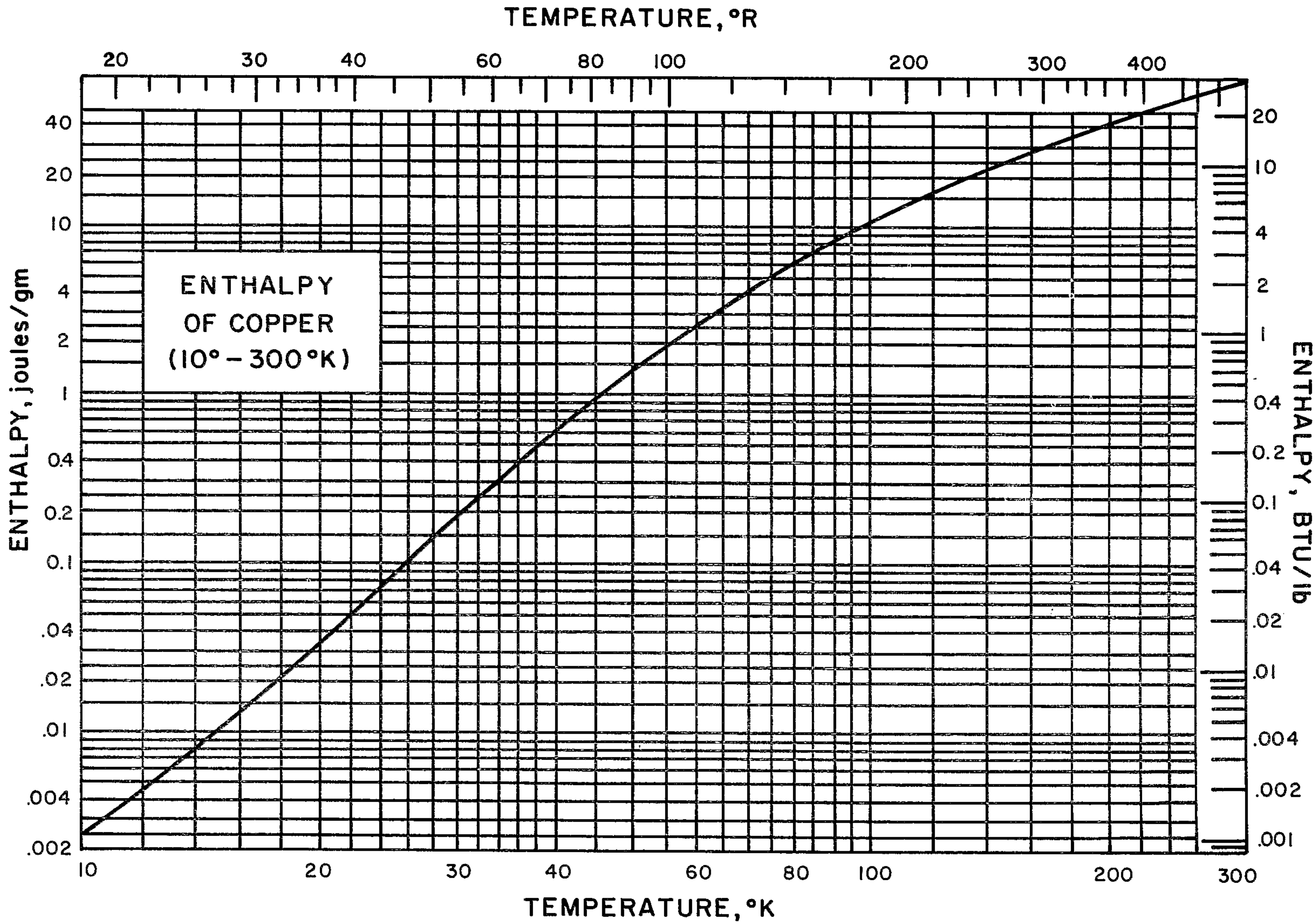
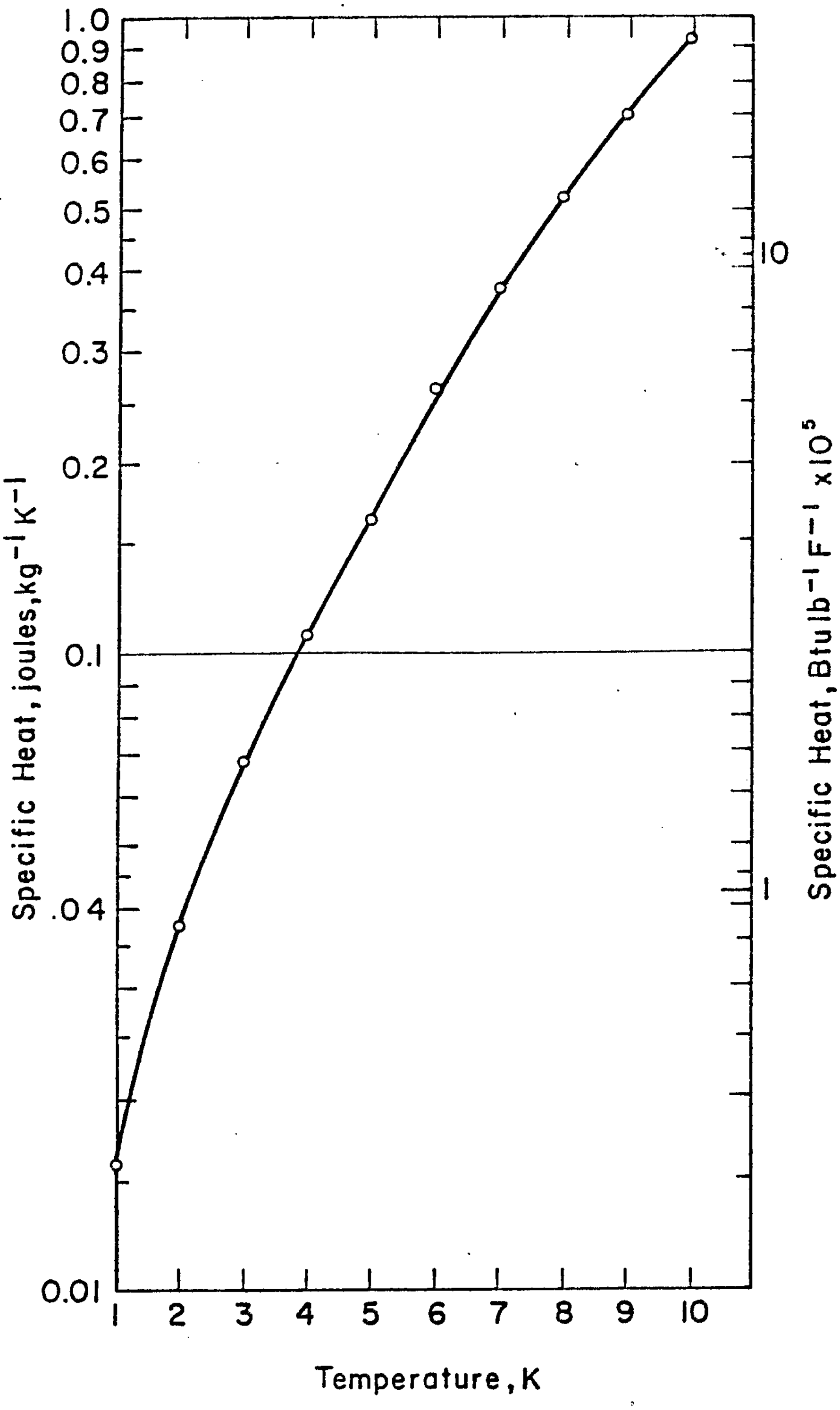

SPECIFIC HEAT
of COPPER
(10°-300° K)
SPECIFIC HEAT, (C_p), joules/gm °K
0.4
0.2
0.1
.04
.02
.01
.004
.002
.001
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K


SPECIFIC HEAT OF COPPER
SPECIFIC HEAT-cal g⁻¹ K⁻¹
TEMPERATURE, K
LIQUID
M.P. 1356 K
2
10⁻¹
7
5
3
2
10⁻²
7
5
3
2
10⁻³
7
5
3
2
10⁻⁴
0.1 2 3 5 7 1 2 3 5 7 10 2 3 5 7 100 2 3 5 7 1000 2 3 5


TEMPERATURE, °R
2
3
4
6
8
10
18
ENTHALPY
OF COPPER
(1° - 10°K)
ENTHALPY, joules/gm (multiply value by 10-3)
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.0006
ENTHALPY, BTU/lb (multiply value by 10-3)
1
.06
.04
.02
0.1
.06
.04
.02
.01
.006
.004
1
2
3
4
6
8
10
TEMPERATURE, °K


ENTHALPY
OF COPPER
(10° – 300°K)
TEMPERATURE, °R
20 30 40 60 80 100 200 300 400
TEMPERATURE, °K
10 20 30 40 60 80 100 200 300
ENTHALPY, joules/gm
.002 .004 .01 .02 .04 0.1 0.2 0.4 1 2 4 10 20 40
ENTHALPY, BTU/lb
.001 .002 .004 .01 .02 .04 0.1 0.2 0.4 1 2 4 10 20



SPECIFIC HEAT VERSUS TEMPERATURE FOR COPPER ALLOY 90 CU-10 NI

SPECIFIC HEAT and ENTHALPY of INDIUM

Sources of Data:

Clement, J. R. and Quinnell, E. H., Phys. Rev. 92, 258 (1953)

Clusius, K. and Schachinger, L., Z. Naturforsch. A7, 185 (1952)

Other References:

Clement, J. R. and Quinnell, E. H., Nat. Bur. Standards Circ. 519, 89 (1952) and Phys. Rev. 79, 1028 (1950)

Table of Selected Values

T °K	Cp j/gm-°K	H j/gm
1	0.000 029	0.000 011
1	.000 019*	.000 006*
2	.000 138	.000 085
2	.000 141*	.000 073*
3	.000 410	.000 341
3	.000 464*	.000 357*
3.40**	.000 584	.000 537
3.40	.000 669*	.000 581*
4	.000 95	.000 99
6	.003 59	.005 20
8	.008 55	.017 0
10	.015 5	.040 8
15	.036 7	.170
20	.060 8	.413
25	.085 7	.778
30	.108	1.265
40	.141	2.52
50	.162	4.04
60	0.176	5.73
70	.186	7.53
80	.193	9.42
90	.198	11.38
100	.203	13.39
120	.211	17.53
140	.217	21.81
160	.220	26.18
180	.223	30.61
200	.225	35.08
220	.227	39.59
240	.229	44.14
260	.230	48.72
280	.232	53.34
300	.233	58.0

* Superconducting

** Superconducting transition temperature

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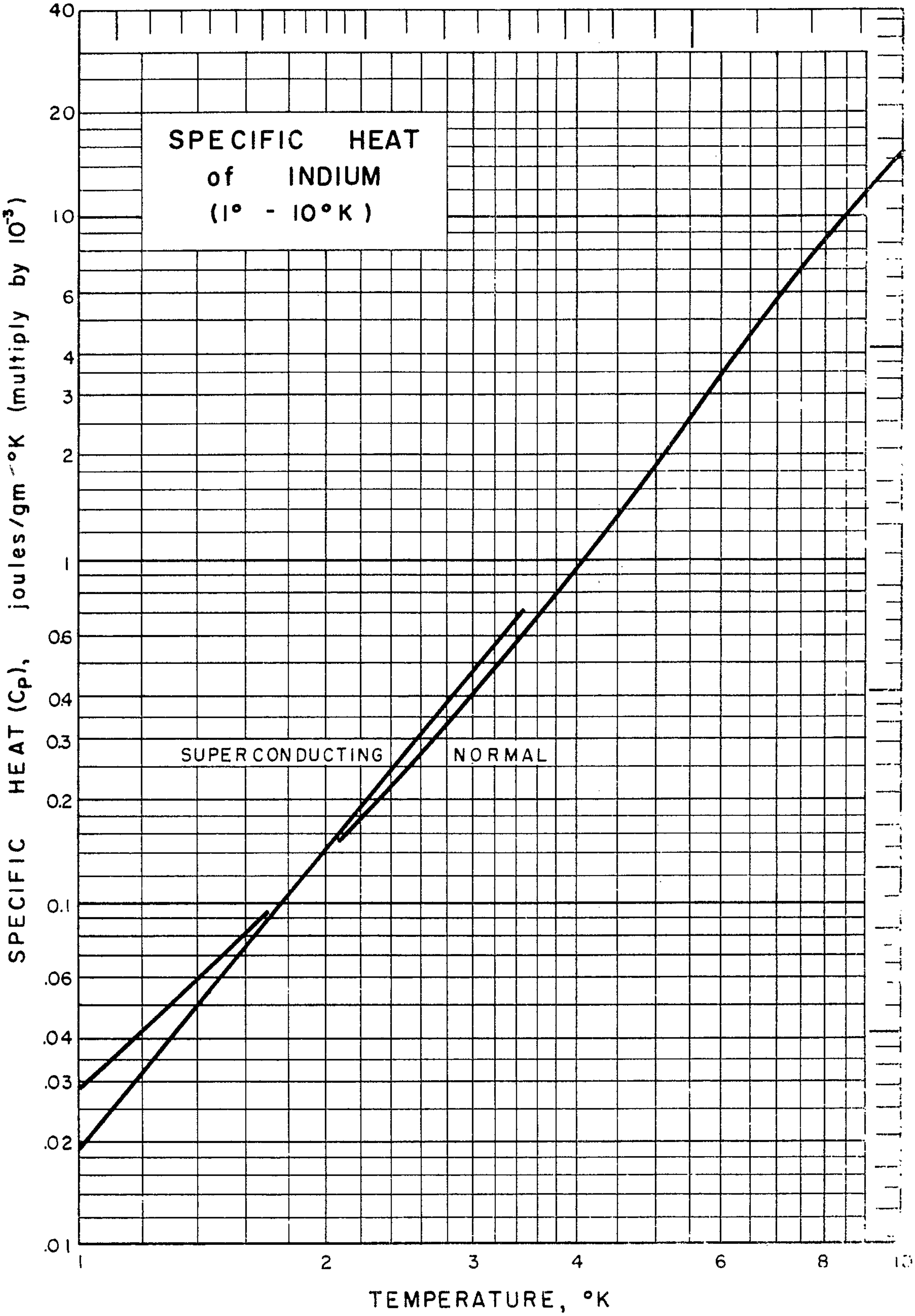
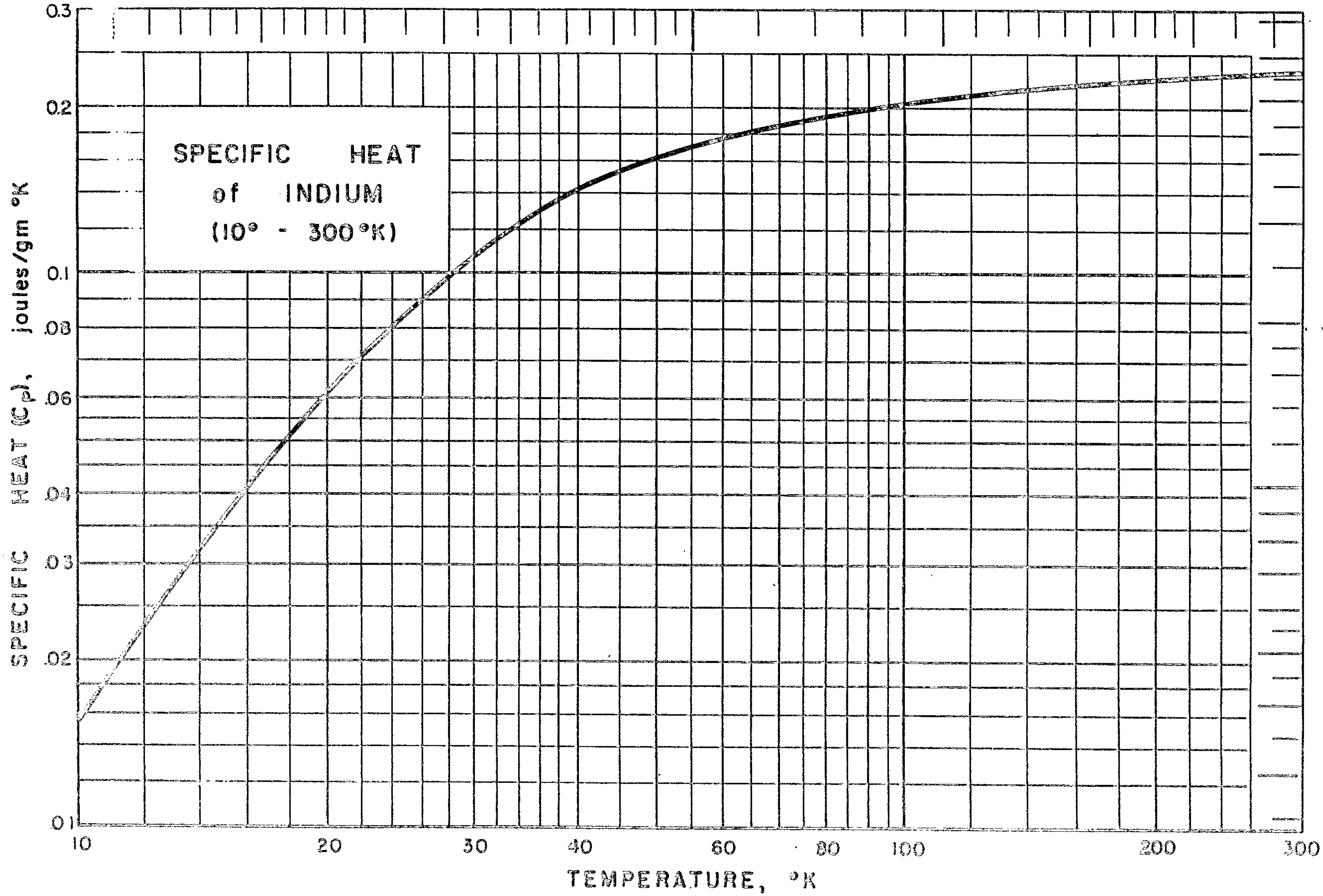
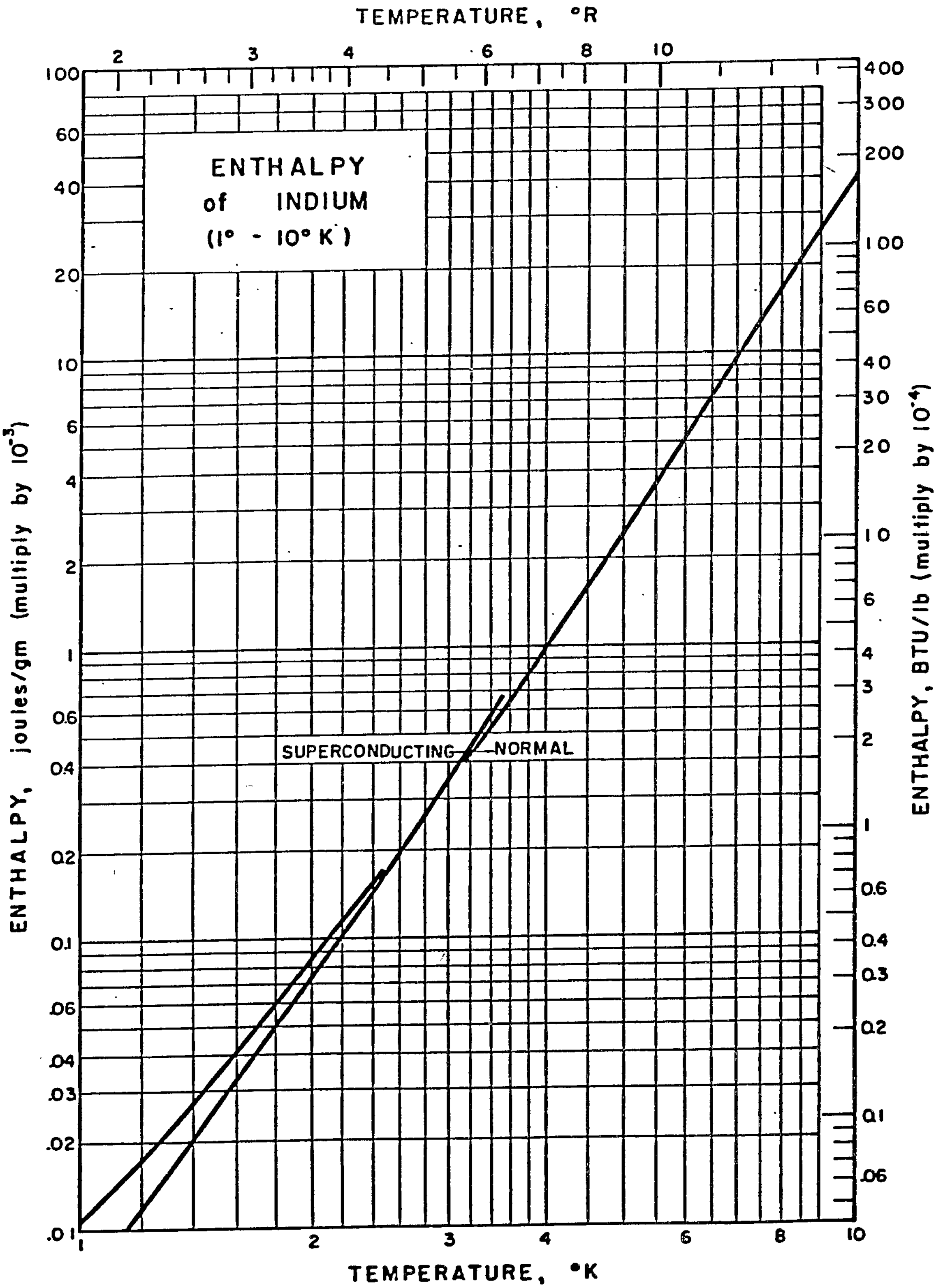
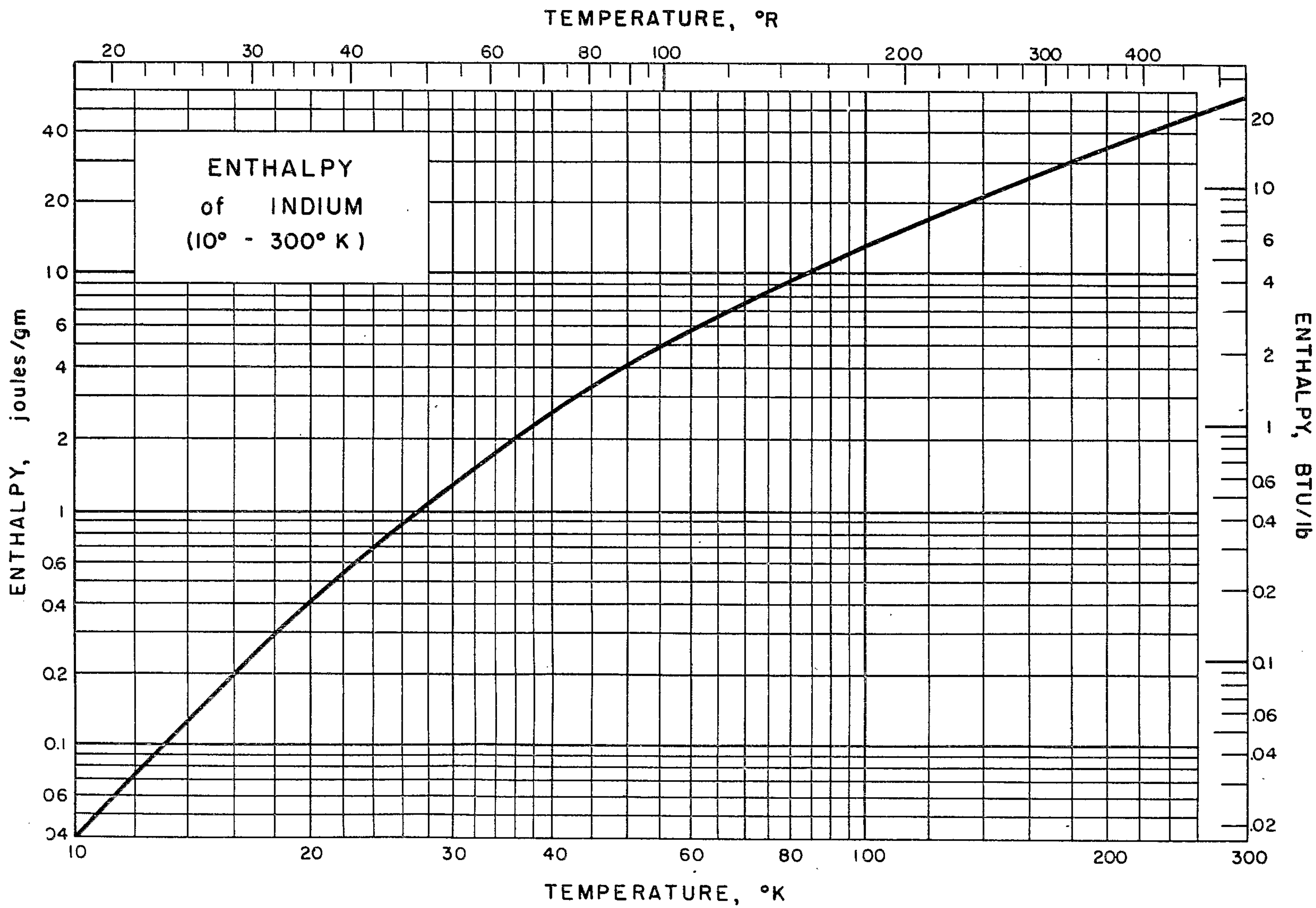

SPECIFIC HEAT
of INDIUM
(1° - 10°K)
SPECIFIC HEAT (C_p), joules/gm-°K (multiply by 10^{-3})
40
20
10
6
4
3
2
1
0.6
0.4
0.3
0.2
0.1
.06
.04
.03
.02
.01
SUPERCONDUCTING
NORMAL
1
2
3
4
6
8
10
TEMPERATURE, °K


SPECIFIC HEAT
of INDIUM
(10° - 300°K)
SPECIFIC HEAT (C_p), joules/gm °K
0.3
0.2
0.1
.08
.06
.04
.03
.02
0.01
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K



TEMPERATURE, °R
ENTHALPY
of INDIUM
(1° - 10° K)
SUPERCONDUCTING
NORMAL
ENTHALPY, joules/gm (multiply by 10^-3)
ENTHALPY, BTU/lb (multiply by 10^-4)
TEMPERATURE, °K


ENTHALPY
of INDIUM
(10° - 300° K)
TEMPERATURE, °R
20
30
40
60
80
100
200
300
400
ENTHALPY, joules/gm
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
06
04
ENTHALPY, BTU/lb
20
10
6
4
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

SPECIFIC HEAT and ENTHALPY of α-IRON

Sources of Data:

Duyckaerts, G., Physica 6, 401-8 (1939)

Keesom, W. H. and Kurrelmayer, B., Physica 6, 633 (1939)

Kelley, K. K., J. Chem. Phys. 11, 16-8 (1943)

Other References:

Austin, J. B., Ind. Eng. Chem. 24, 1225 (1932)

Behn, U., Ann. Physik (3) 66, 237 (1898)

Duyckaerts, G., Mem. soc. roy. sci. Liege 6, 193 (1945)

Eucken, A. and Werth, H., Z. anorg. u. allgem. Chem. 188, 152 (1930)

Griffiths, E. G. and Griffiths, E., Phil. Trans. Roy. Soc. London A214, 319 (1914) and Proc. Roy. Soc. (London) A90, 557 (1914)

Gunther. P., Ann. Physik (4) 51, 828 (1916)

Richards, T. W. and Jackson, F. G., Z. physik. Chem. 70, 414 (1910)

Rodebush, W. H. and Michalek, J. C., J. Am. Chem. Soc. 47, 2117 (1925)

Schmitz, H. E., Proc. Roy. Soc. (London) 72, 177 (1903)

Simon, F., Z. angew. Chem. 41, 1113 (1928)

Simon, F. and Swain, R. C., Z. physik. Chem. B28, 189 (1935)

Comments:

α -Iron is the form that is stable up to the Curie point at 760°C. It has a body-centered cubic lattice.

T °K	C_p j/gm-°K	H j/gm	T °K	C_p j/gm-°K	H j/gm
1	0.000 090	0.000 045	70	0.121	2.46
2	.000 183	.000 181	80	.154	3.84
3	.000 279	.000 412	90	.186	5.55
4	.000 382	.000 742	100	.216	7.56
6	.000 615	.001 73	120	.267	12.40
8	.000 90	.003 23	140	.307	18.16
10	.001 24	.005 37	160	.339	24.63
15	.002 49	.014 5	180	.364	31.67
20	.004 5	.031 6	200	.384	39.2
25	.007 5	.061	220	.401	47.0
30	.012 4	.110	240	.415	55.2
40	.029	.31	260	.428	63.6
50	.055	.73	280	.439	72.3
60	.087	1.43	300	.447	81.1

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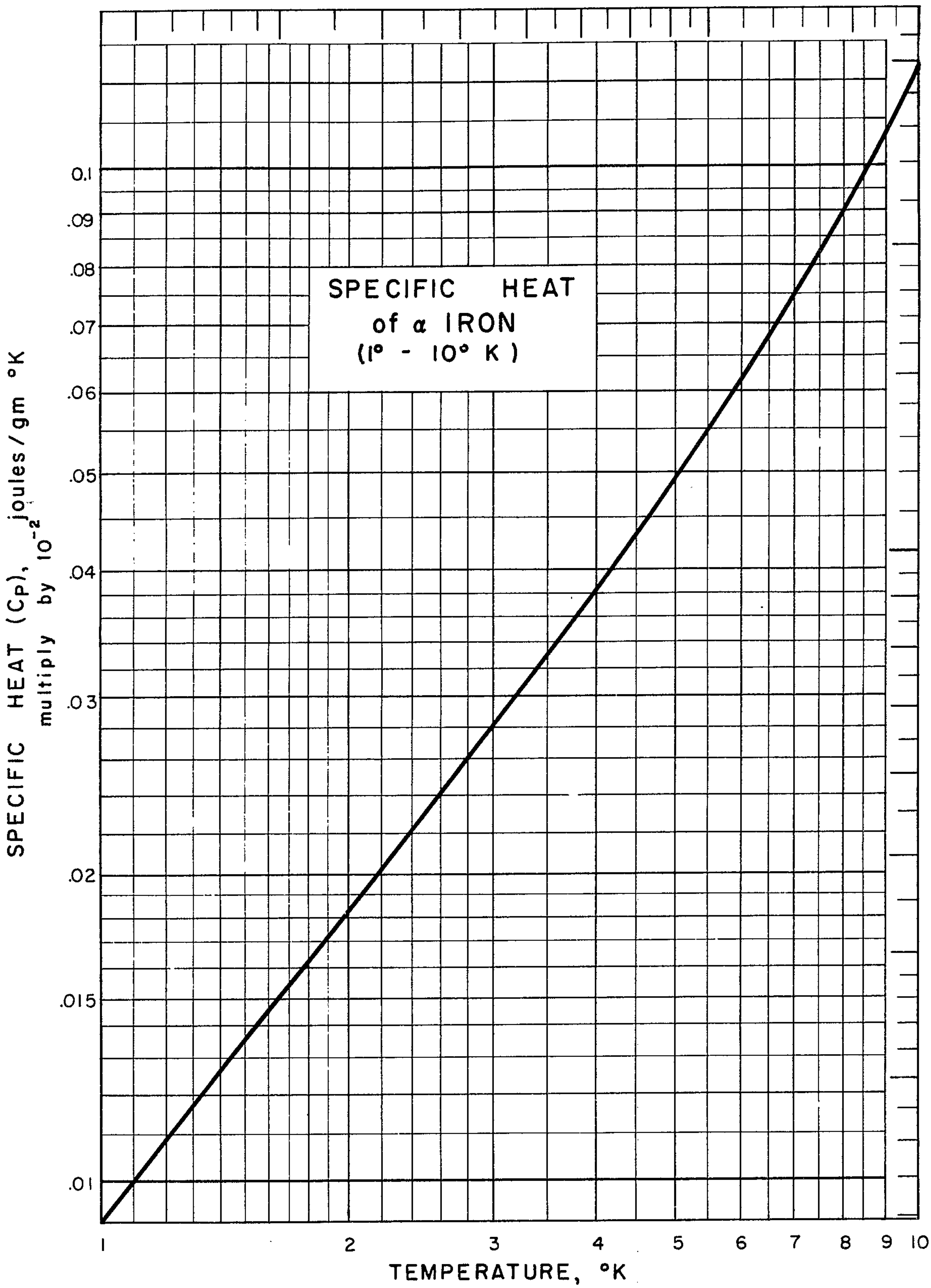
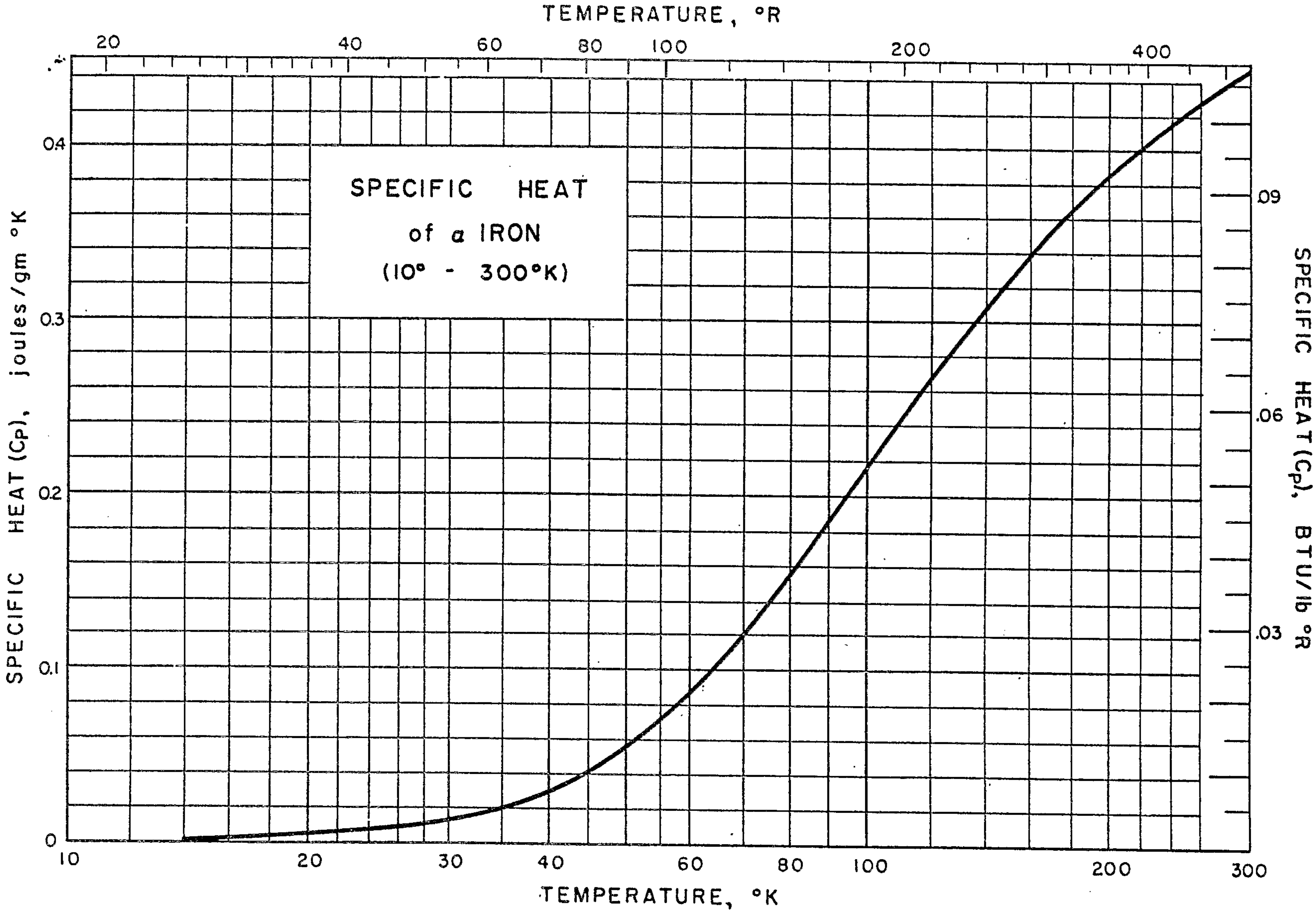
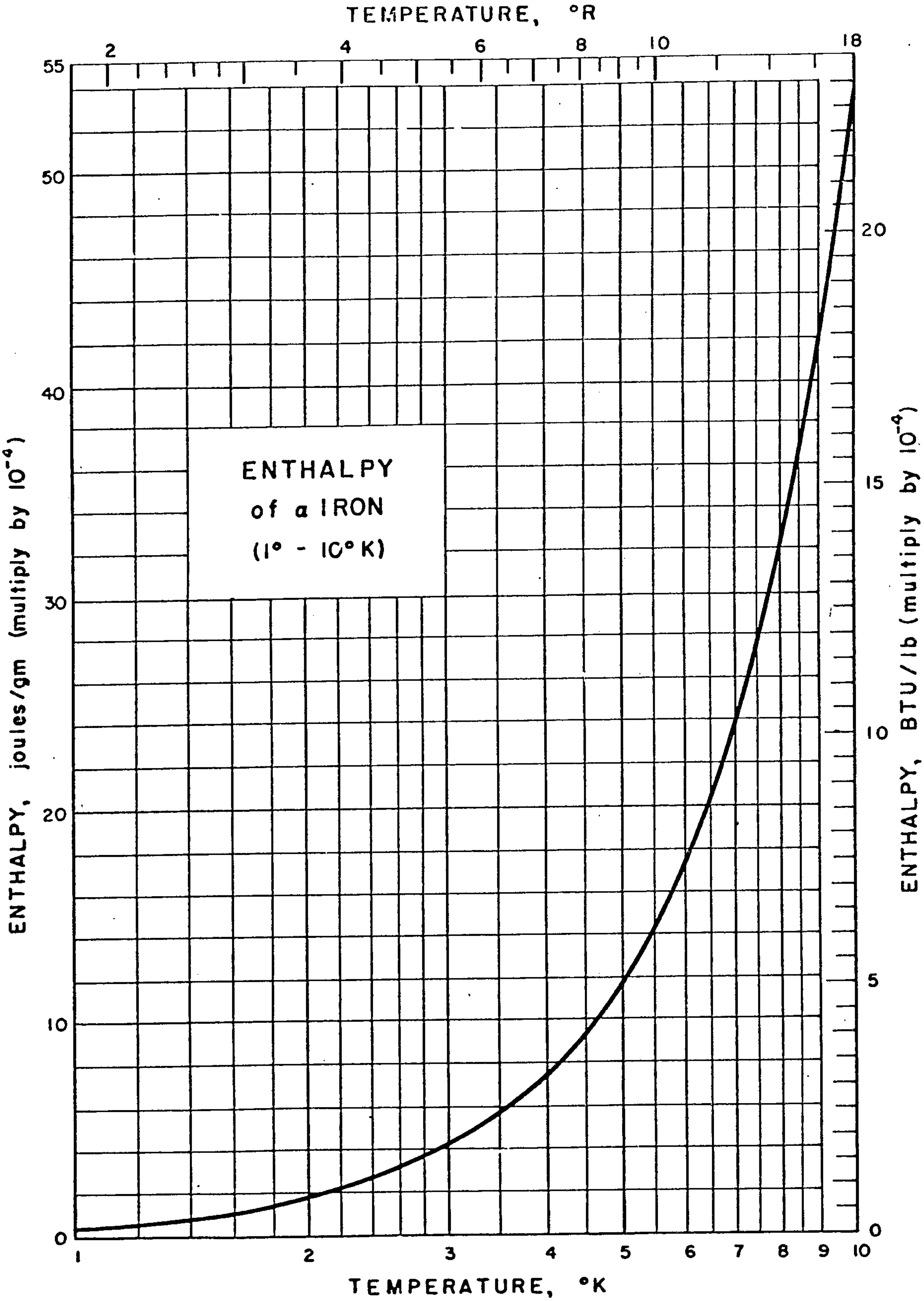
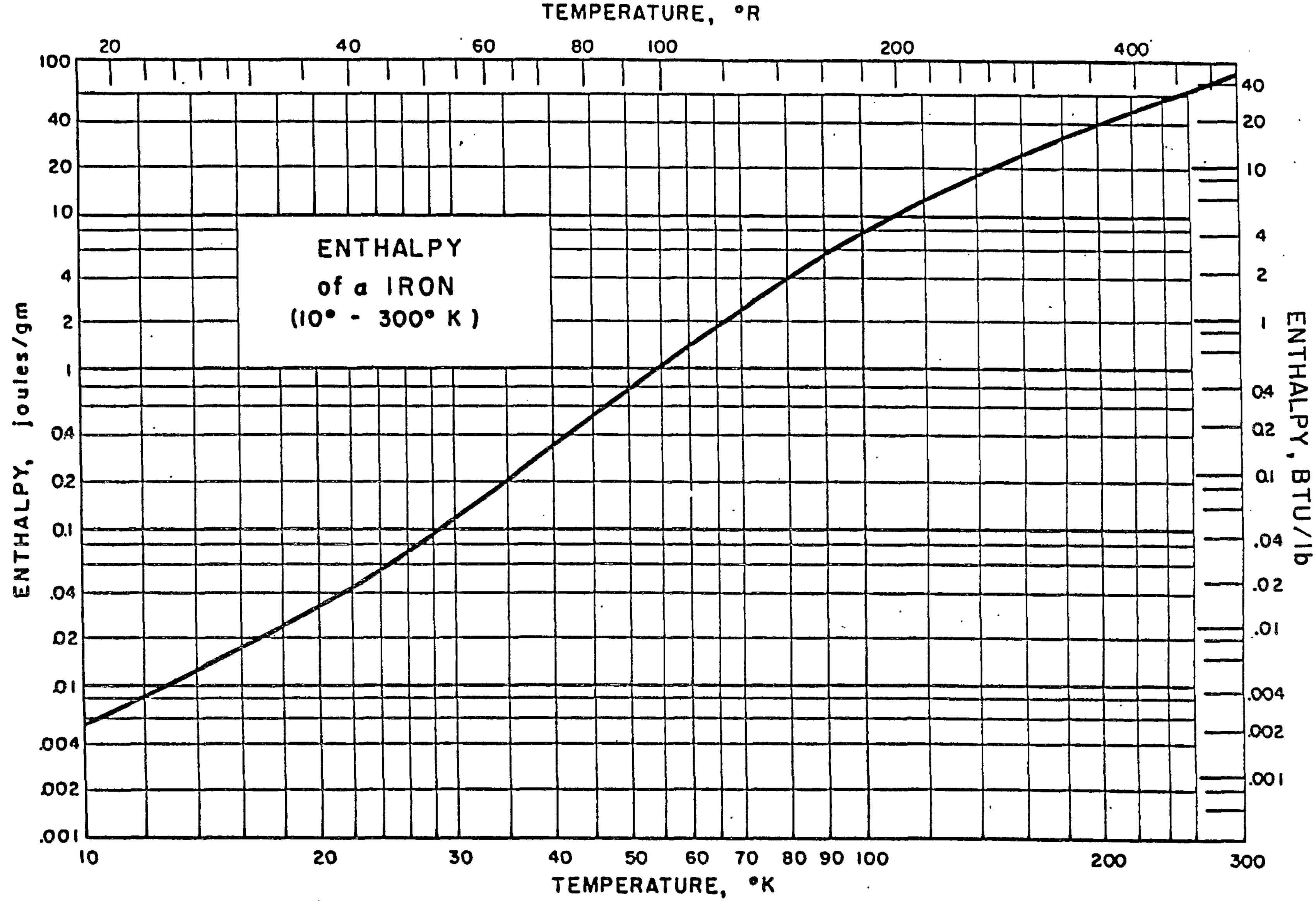

SPECIFIC HEAT
of α IRON
(1° - 10° K)
SPECIFIC HEAT (C_P), joules/gm °K
multiply by 10^{-2}
0.1
.09
.08
.07
.06
.05
.04
.03
.02
.015
.01
1
2
3
4
5
6
7
8
9
10
TEMPERATURE, °K



TEMPERATURE, °R
20
40
60
80
100
200
400
SPECIFIC HEAT
of α IRON
(10° - 300°K)
0.4
0.3
0.2
0.1
0
SPECIFIC HEAT (C_p), joules/gm °K
.09
.06
.03
SPECIFIC HEAT (C_p), BTU/lb °R
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K


TEMPERATURE, °R
2
4
6
8
10
18
55
50
40
30
20
10
0
ENTHALPY, joules/gm (multiply by 10^{-4})
ENTHALPY
of α IRON
(1° - 10° K)
20
15
10
5
0
ENTHALPY, BTU/lb (multiply by 10^{-4})
1
2
3
4
5
6
7
8
9
10
TEMPERATURE, °K


TEMPERATURE, °R
20
40
60
80
100
200
400
ENTHALPY
of α IRON
(10° - 300° K)
ENTHALPY, Joules/gm
100
40
20
10
4
2
1
0.4
0.2
0.1
.04
.02
.01
.004
.002
.001
ENTHALPY, BTU/lb
40
20
10
4
2
1
0.4
0.2
0.1
.04
.02
.01
.004
.002
.001
10
20
30
40
50
60
70
80
90
100
200
300
TEMPERATURE, °K

SPECIFIC HEAT, ENTHALPY of γ - IRON

<u>Sources of Data</u>:

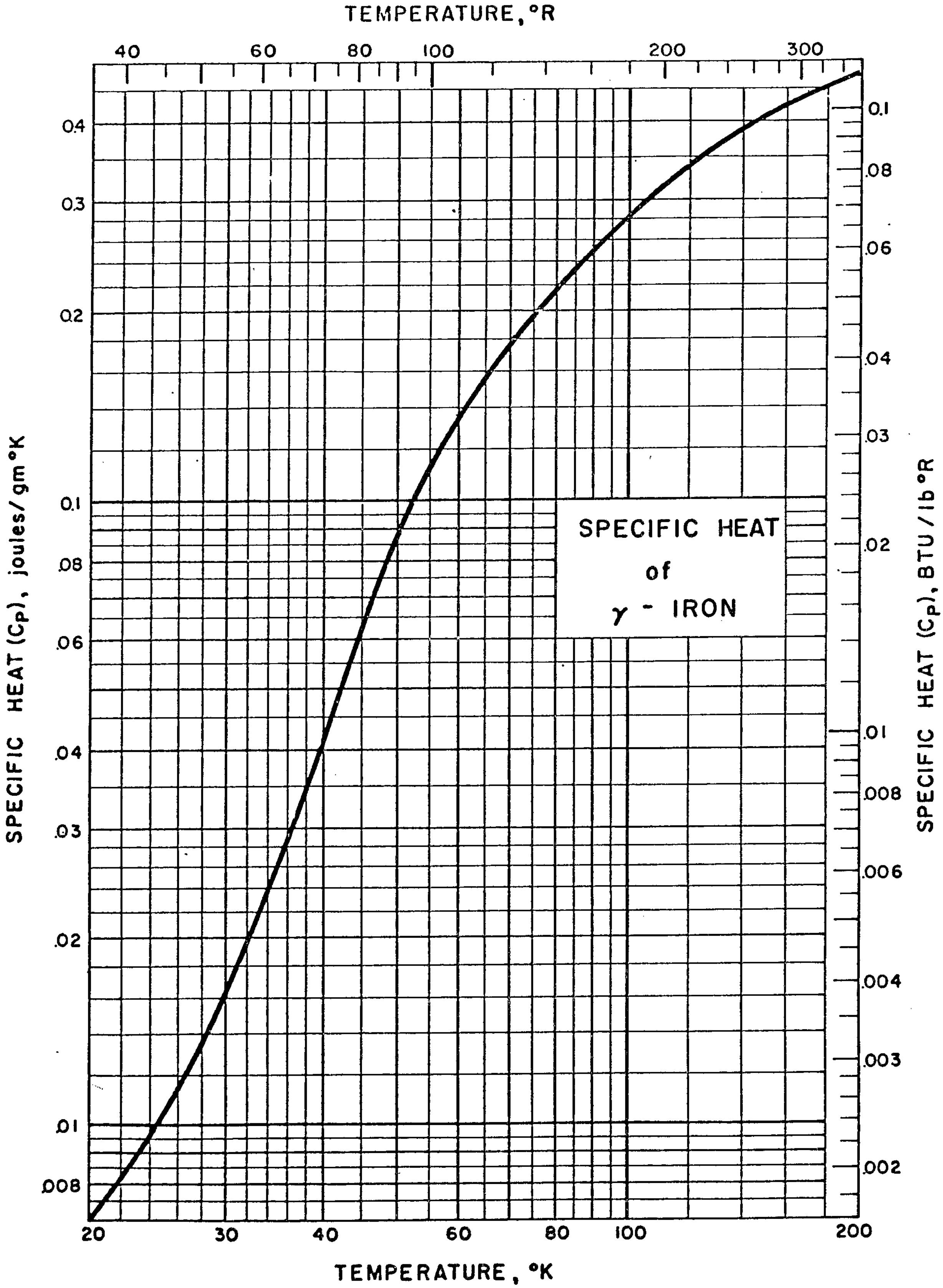
Eucken A. and Werth, H., Z. anorg. u. allgem. Chem. <u>188</u>, 152-72 (1930).

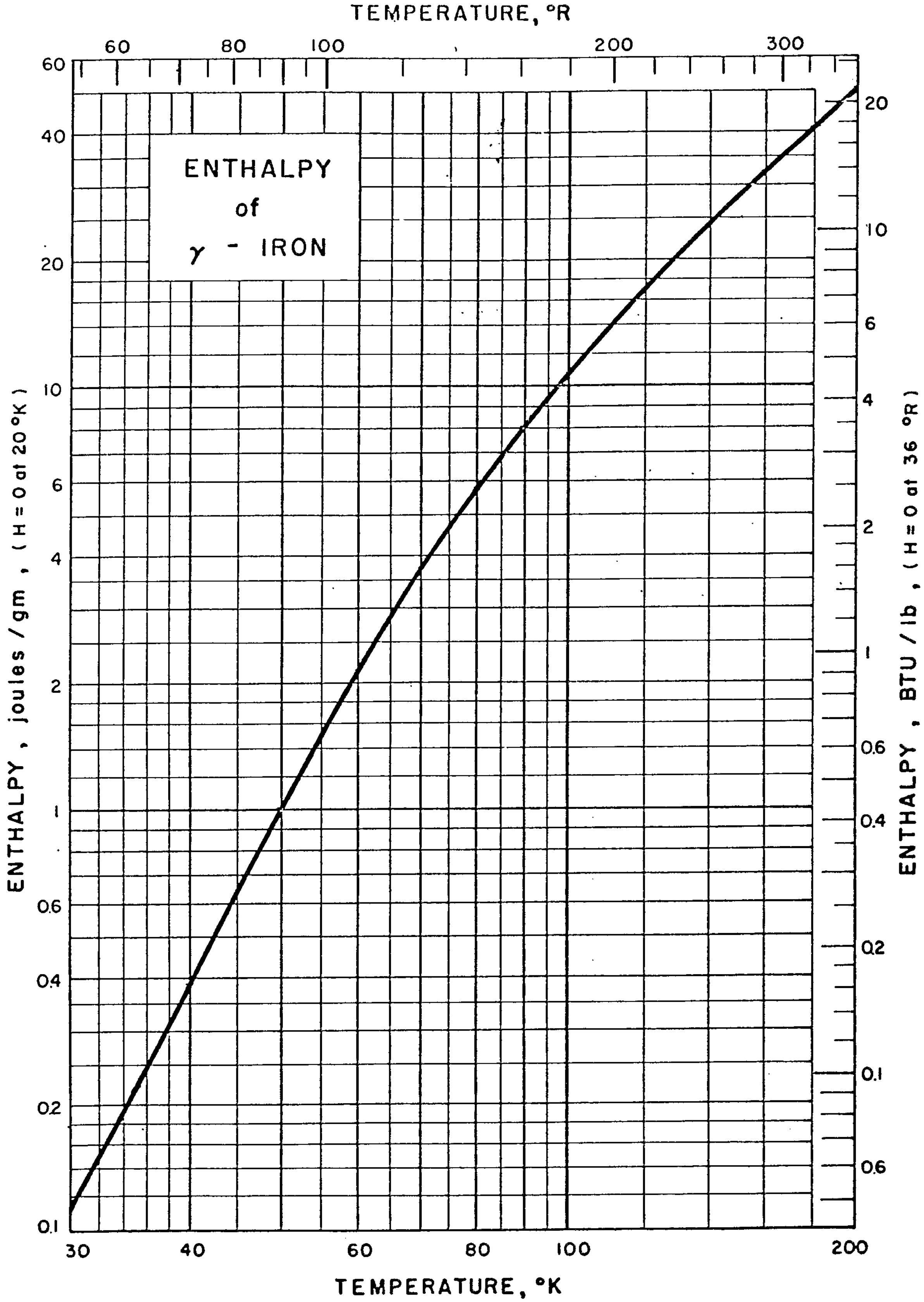
Comments:

The values of specific heat for pure γ iron were calculated by Eucken and Werth by application of the Kopp-Neumann principle to their specific heat measurements on a 30% Mn-Fe alloy and 19.4% Mn-Fe alloy. In view of this procedure, the values tabulated below should be regarded as an approximation only.

T °K	C_p j/gm-°K	$H-H_{20}$ j/gm
20	0.007	
30	.016	0.11
40	.041	0.39
50	.090	1.0_2
60	$.13_7$	2.1_6
70	$.18_0$	3.7_5
80	$.21_8$	5.7_4
90	.255	8.1_1
100	$.28_8$	10.8
120	$.34_5$	17.1
140	$.38_9$	24.4
160	$.42_7$	32.6
180	$.45_0$	41.4
200	$.47_0$	50.6

RJC/JJG Issued: 9-2-59


TEMPERATURE, °R
40
60
80
100
200
300
0.4
0.3
0.2
0.1
.08
.06
.04
.03
.02
.01
.008
SPECIFIC HEAT (Cp), joules/gm °K
0.1
.08
.06
.04
.03
.02
.01
.008
.006
.004
.003
.002
SPECIFIC HEAT (Cp), BTU/lb °R
SPECIFIC HEAT
of
γ - IRON
20
30
40
60
80
100
200
TEMPERATURE, °K


TEMPERATURE, °R
60
80
100
200
300
ENTHALPY
of
γ - IRON
ENTHALPY, joules /gm, (H = 0 at 20 °K)
60
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
ENTHALPY, BTU / lb, (H = 0 at 36 °R)
20
10
6
4
2
1
0.6
0.4
0.2
0.1
0.6
30
40
60
80
100
200
TEMPERATURE, °K

SPECIFIC HEAT, ENTHALPY of TANTALUM

Sources of Data:

Kelley, K. K., J. Chem. Phys. 8, 316-22 (1940)

White, D., Chou, C. and Johnston, H. L., Phys. Rev. 109, 797-802 (1958)

Other References:

Clusius, K. and Losa, G. L., Z. Naturforsch. 10A, 939-43 (1955)

Desirant, M., Rept. Intern. Conf. Fundamental Particles and Low Temp. 2, 124 (1947)

Keesom, W. H. and Desirant, M., Physica 8, 273 (1941)

Mendlesohn, K., Nature 148, 316 (1941)

Wolcott, N. M., Conf. Physique Bases Temp., Paris (1955)

Worley, R. D., Zemansky, M. W. and Boorse, H. A., Phys. Rev. 91, 1567-8 (1953); Phys. Rev. 99, 447-58 (1955)

Comments:

For temperatures less than 4°K, the normal specific heat C_p follows the equation:

$$C_p = (31.7 \pm 0.9) \times 10^{-6} T + 10.74 \left(\frac{T}{248 \pm 6}\right)^3 \text{ j/gm-°K}$$

Table of Selected Values

Temp. °K	C_p, j/gm-°K normal	C_p, j/gm-°K super-conducting	H, j/gm normal	H, j/gm super-conducting
1	0.000 032	0.000 0063	0.000 016	0.000 0021
2	.000 068	.000 054	.000 065	.000 026
3	.000 112	.000 178	.000 155	.000 138
4	.000 171	.000 352	.000 295	.000 400
4.39	.000 201	.000 433	.000 368	.000 553
6	.000 333		.000 776	
8	.000 648		.001 73	
10	.001 17		.003 52	
15	.003 60		.014 5	
20	.008 23		.043 2	
25	.015 3		.102	
30	.024 0		.202	
40	.043 0		.540	
50	.060 4		1.06	
60	.075 4		1.74	

Temp. °K	C_p j/gm-°K	H j/gm
70	0.0879	2.56
80	.0976	3.49
90	.105	4.50
100	.111	5.58
120	.119	7.88
140	.125	10.4
160	.128	12.9
180	.131	15.5
200	.134	18.1
220	.136	20.8
240	.137	23.6
260	.138	26.3
280	.139	29.1
300	.140	31.9

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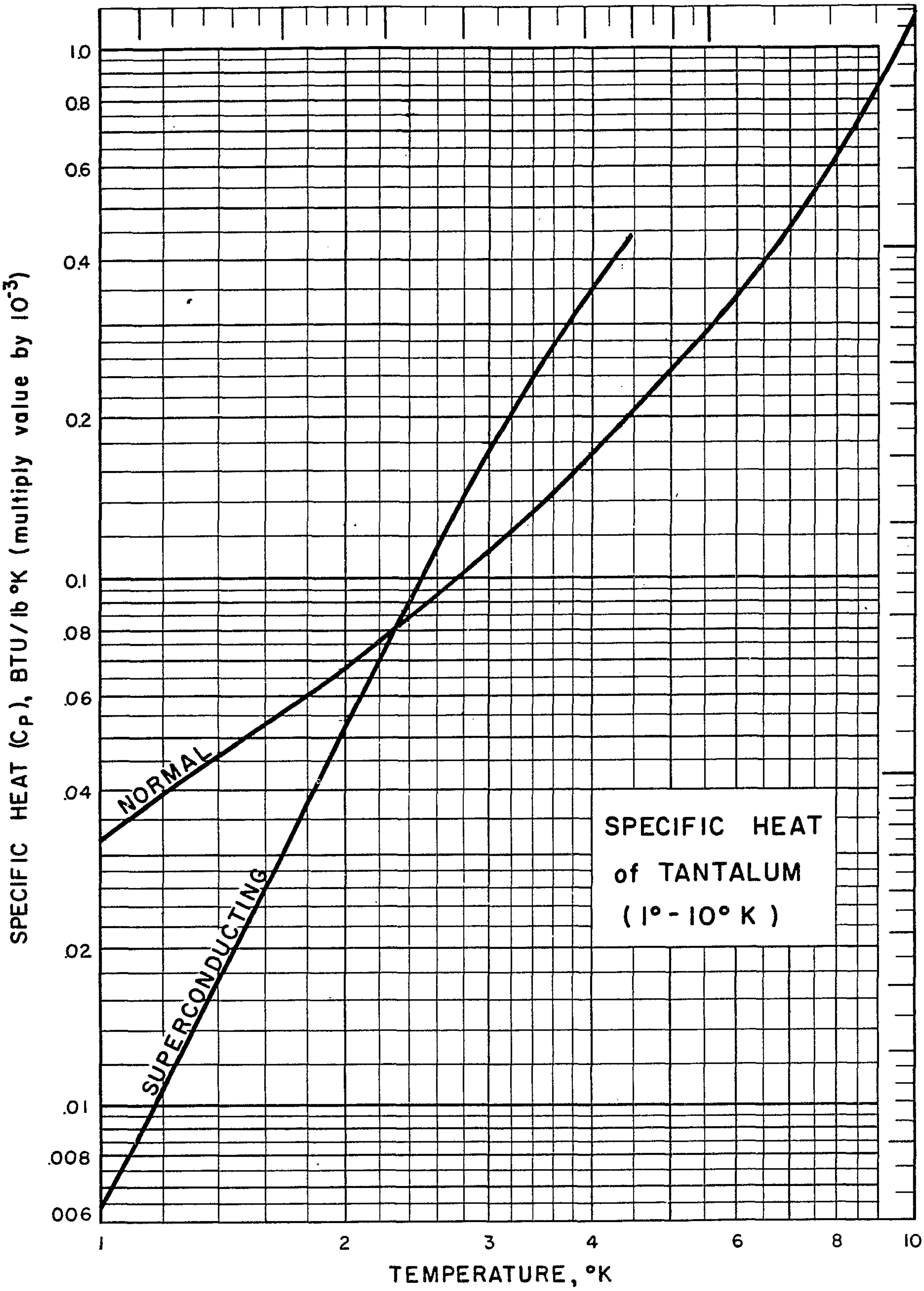
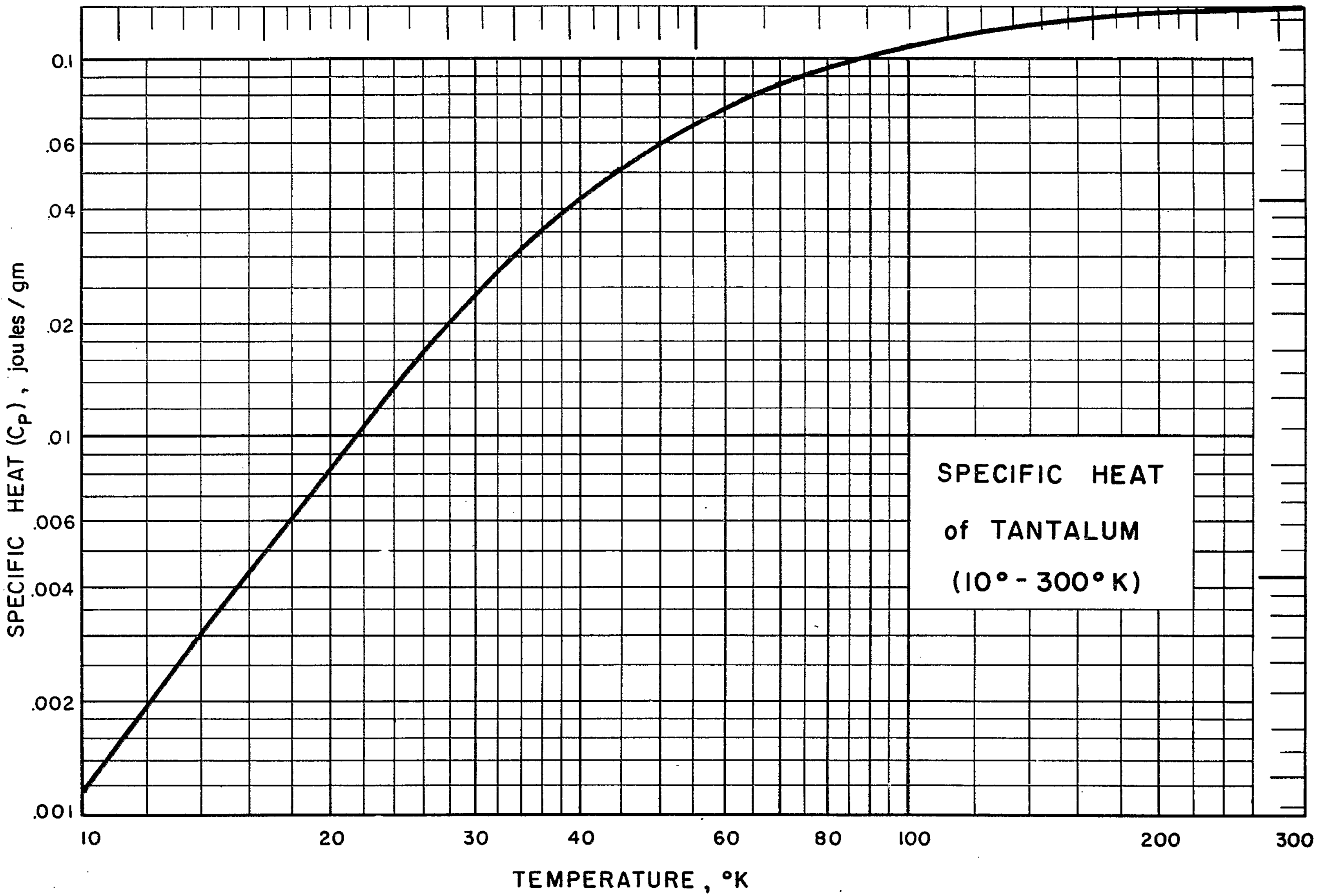

SPECIFIC HEAT of TANTALUM (1° - 10° K)
NORMAL
SUPERCONDUCTING
SPECIFIC HEAT (Cp), BTU/lb °K (multiply value by 10^-3)
TEMPERATURE, °K
1.0
0.8
0.6
0.4
0.2
0.1
.08
.06
.04
.02
.01
.008
006
1
2
3
4
6
8
10


SPECIFIC HEAT
of TANTALUM
(10° - 300° K)
SPECIFIC HEAT (C_p), joules / gm
0.1
.06
.04
.02
.01
.006
.004
.002
.001
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

SPECIFIC HEAT, ENTHALPY of ACTIVATED CHARCOAL

Source of Data:

Simon, F. and Swain, R. C., Z. physik. Chem. B28, 189-98 (1935)

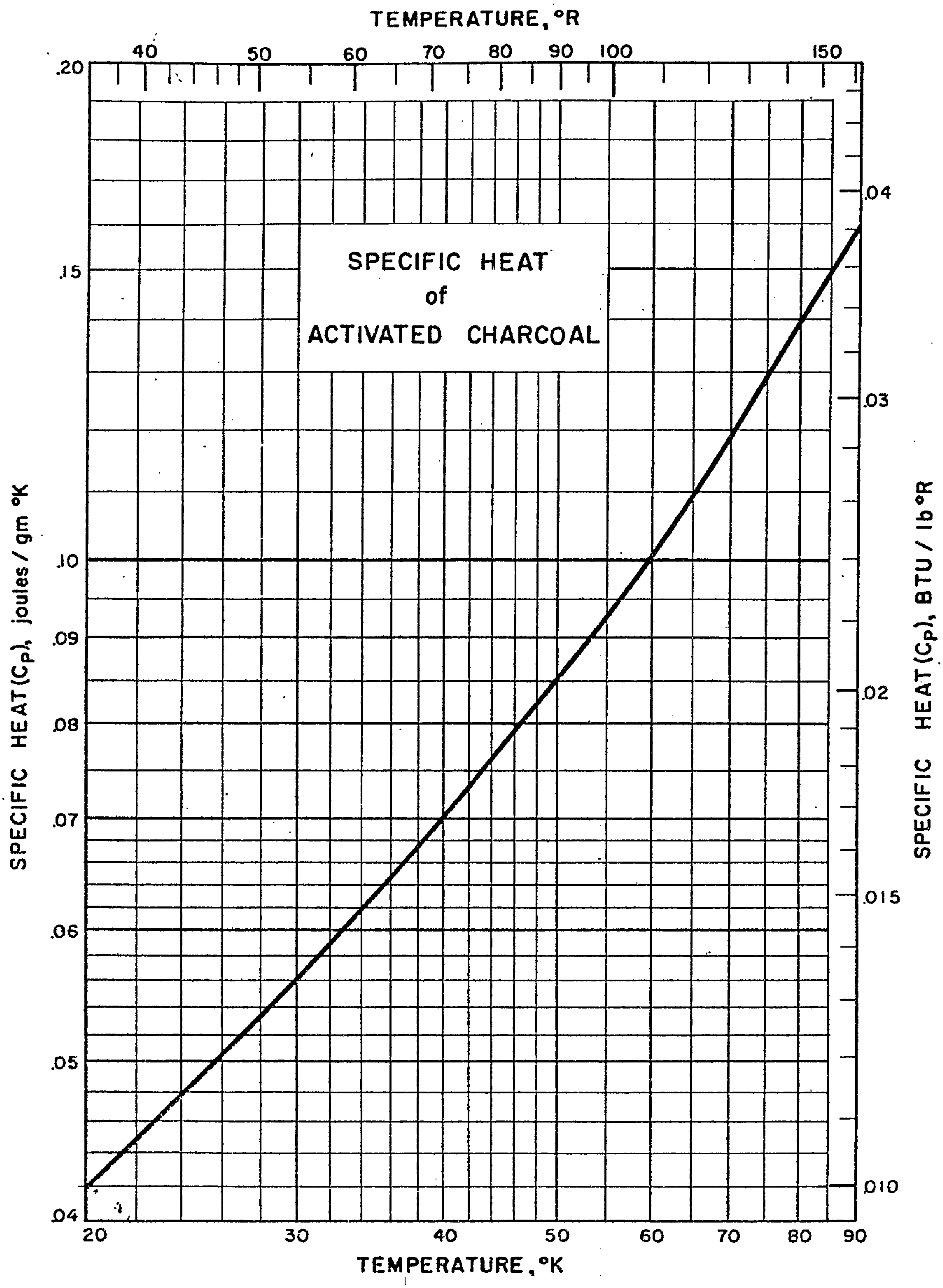
Comments:

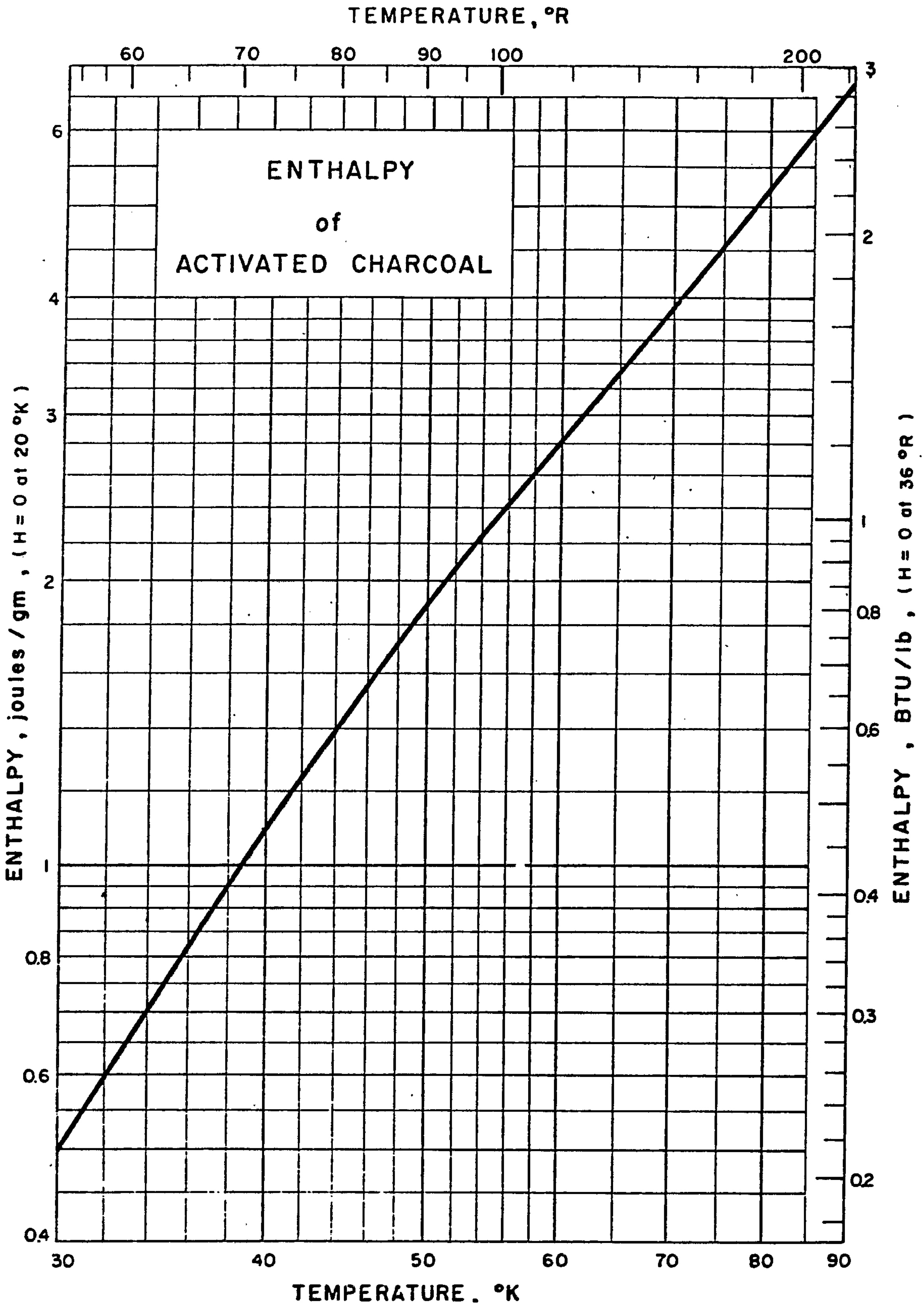
The values in the table below do not represent precise measurements and were made on a sample not fully characterized. The values are much higher than those for graphite. Since activated charcoal varies in structure and area, one may infer that the specific heat might also vary considerably from sample to sample.

Table of Selected Values

Temp. °K	C_p j/gm-°K	$H-H_{20}$ j/gm
20	0.042	
30	.056	0.49
40	.070	1.1
50	.087	1.9
60	.10	2.8
70	.12	3.9
80	.14	5.2
90	.16	6.7

JJG/JRC Issued: 9/2/59
Revised: 1/20/60


TEMPERATURE, °R
40
50
60
70
80
90
100
150
SPECIFIC HEAT
of
ACTIVATED CHARCOAL
.20
.15
.10
.09
.08
.07
.06
.05
.04
SPECIFIC HEAT (Cp), joules / gm °K
.04
.03
.02
.015
.010
SPECIFIC HEAT (Cp), BTU / lb °R
20
30
40
50
60
70
80
90
TEMPERATURE, °K


TEMPERATURE, °R
60
70
80
90
100
200
ENTHALPY
of
ACTIVATED CHARCOAL
ENTHALPY, joules / gm, (H = 0 at 20 °K)
6
4
3
2
1
0.8
0.6
0.4
ENTHALPY, BTU/lb, (H = 0 at 36 °R)
3
2
1
0.8
0.6
0.4
0.3
0.2
30
40
50
60
70
80
90
TEMPERATURE, °K

SPECIFIC HEAT, ENTHALPY of ICE

Sources of Data:

Giauque, W. F. and Stout, J. W., J. Am. Chem. Soc. 58, 1144 (1936)

Simon, F., unpublished (1923). Data reproduced in Giauque and Stout (see above).

Other References:

Barnes, W. H. and Maas, O., Can. J. Research 3, 205 (1930)

Duyckaerts, G., Mem. soc. roy. sci. Liege 6, 325 (1945)

Nernst, W., Ann. physik, ser. 4, 36, 395 (1911)

Pollitzer, F., Z. Elektrochem. 19, 513 (1913)

Table of Selected Values

Temp. °K	C_p j/gm-°K	H j/gm	Temp. °K	C_p j/gm-°K	H j/gm
1	0.000 015	0.000 004	60	0.535	13.97
2	0.000 12	0.000 061	70	0.627	19.78
3	0.000 41	0.000 31	80	0.716	26.49
4	0.000 98	0.000 98	90	0.801	34.06
6	0.003 3	0.004 9	100	0.882	42.47
8	0.007 8	0.015 6	120	1.03	61.6
10	0.015 2	0.038	140	1.16	83.5
12	0.026 5	0.079	160	1.29	108.0
14	0.043	0.148	180	1.43	135.2
16	0.065	0.255	200	1.57	165.1
18	0.090	0.410	220	1.72	197.9
20	0.114	0.615	240	1.86	233.7
30	0.229	2.33	260	2.01	272.4
40	0.340	5.18	270	2.08	292.8
50	0.440	9.09	273.15	2.10	299.4

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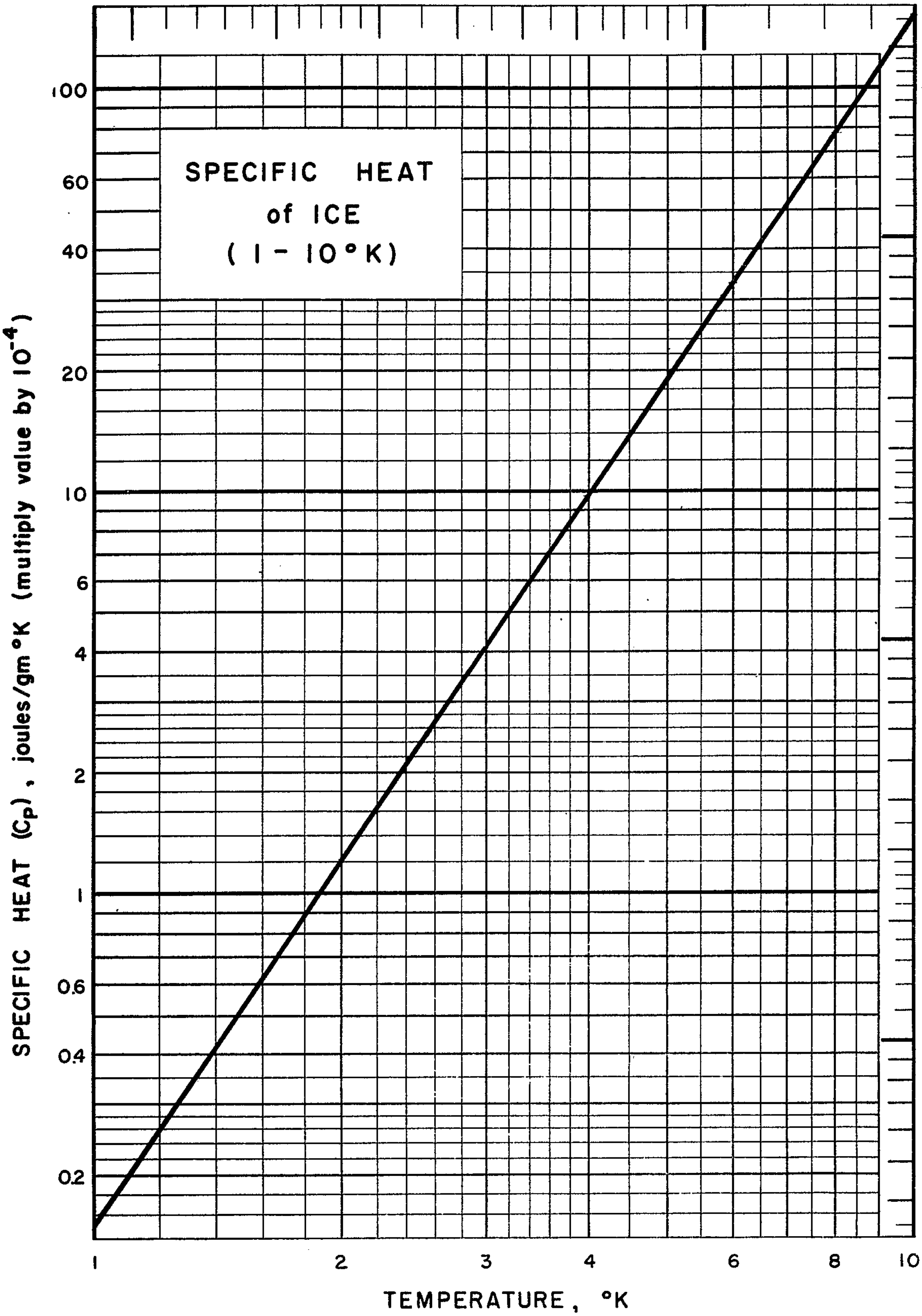
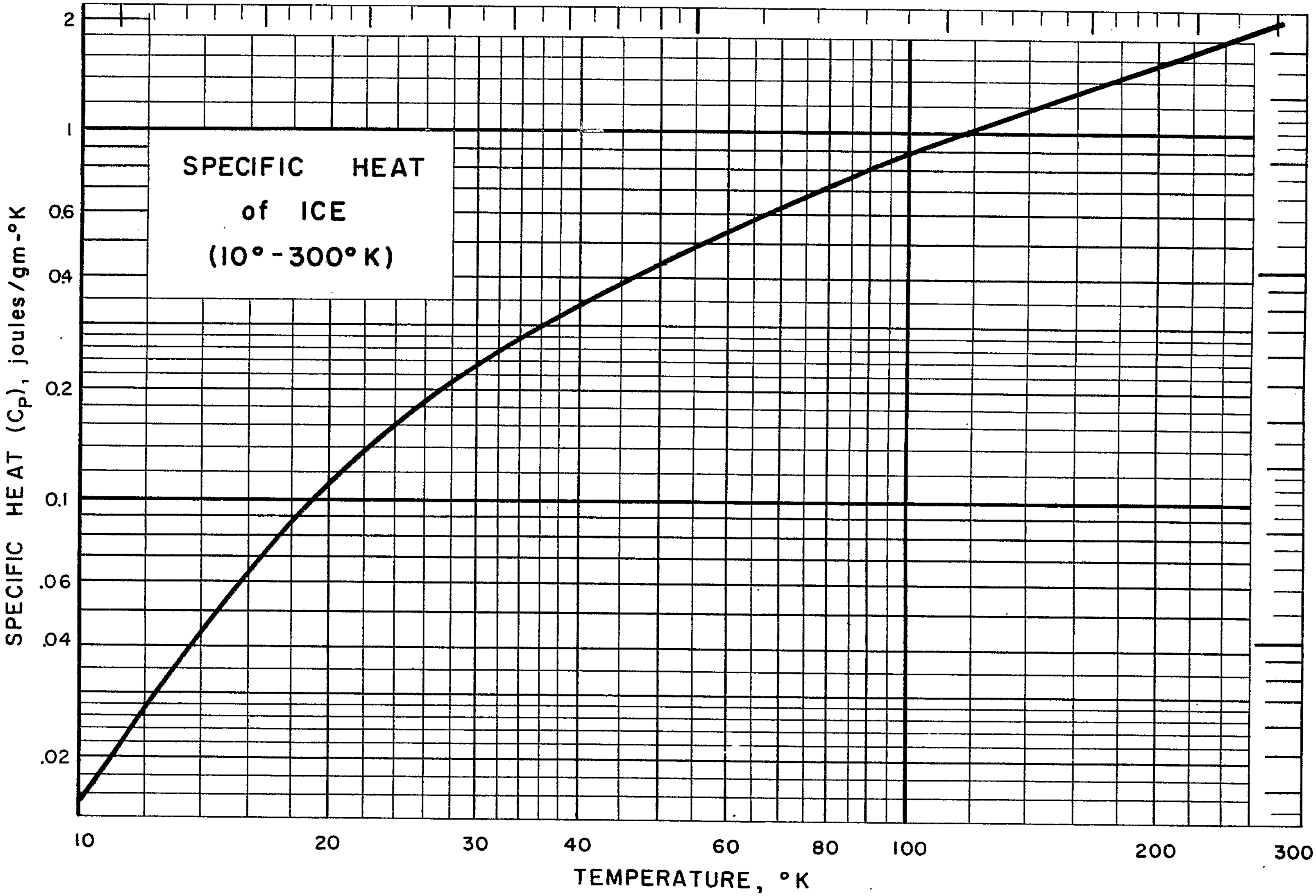

SPECIFIC HEAT
of ICE
(1 - 10 °K)
SPECIFIC HEAT (C_p), joules/gm °K (multiply value by 10^{-4})
100
60
40
20
10
6
4
2
1
0.6
0.4
0.2
1
2
3
4
6
8
10
TEMPERATURE, °K


SPECIFIC HEAT
of ICE
(10° - 300° K)
SPECIFIC HEAT (C_p), joules/gm-°K
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

SPECIFIC HEAT, ENTHALPY of POLYETHYLENE

Source of Data:

Sochava, I. V. and Trapeznikova, O. N., Sov. Phys. Doklady 2, 164-6 (1957).

Comments:

Since no specific heat measurements existed below 60°K, enthalpy values are given referenced to this temperature.

Table of Selected Values

T °K	C_p j/gm-°K	$H-H_{60}$ j/gm
60	0.418	
70	.496	4.57
80	.561	9.84
90	.619	15.7
100	.676	22.2
120	.778	36.8
140	.872	53.2
160	.971	71.7
180	1.07	92.1
200	1.17	114
220	1.28	139
240	1.43	166
260	1.63	196

$$H - H_{60} = \int_{60}^{T} C_p \, dT$$

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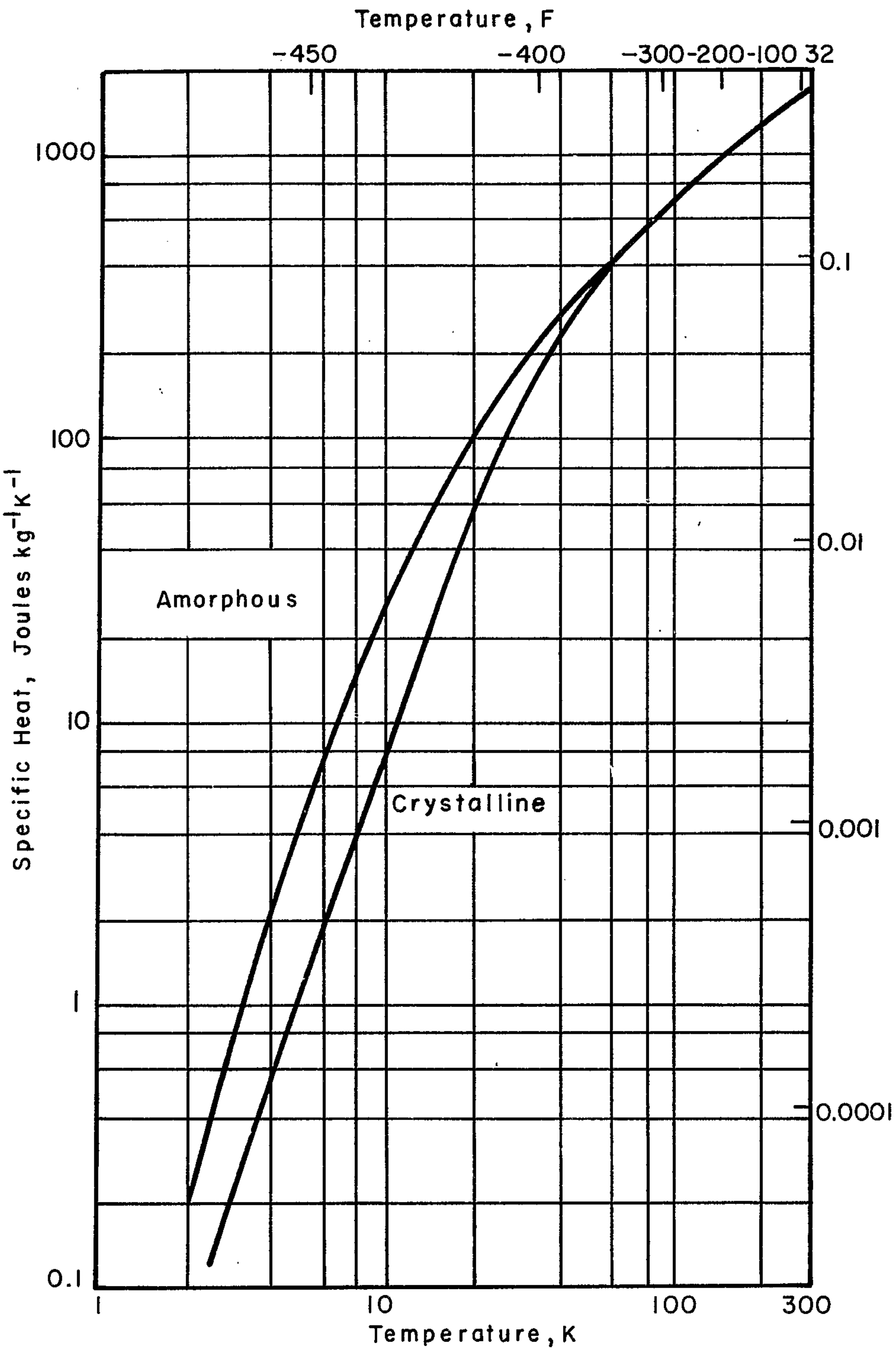
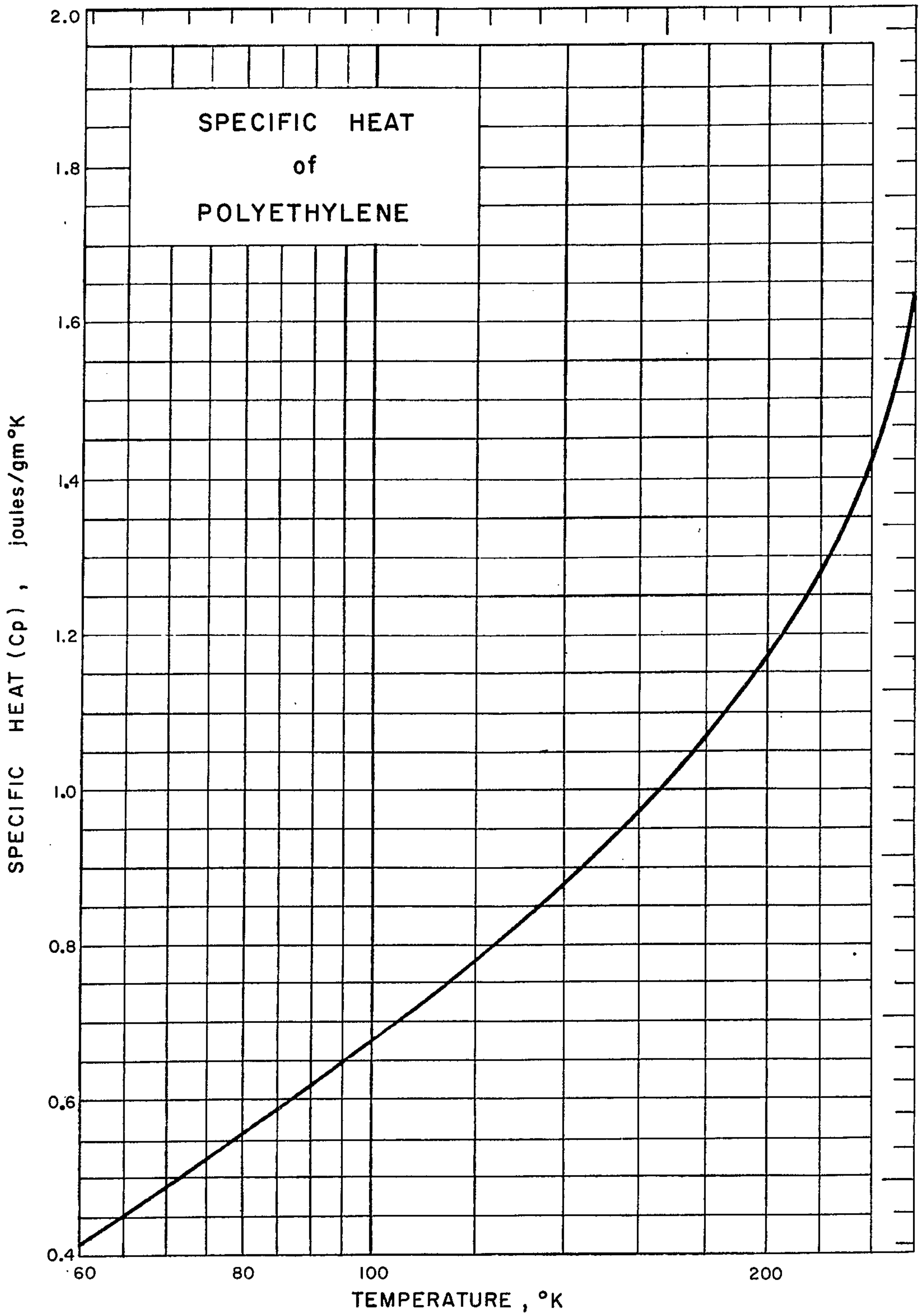


SPECIFIC HEAT VERSUS TEMPERATURE FOR CRYSTALLINE AND AMORPHOUS POLYETHYLENE


SPECIFIC HEAT
of
POLYETHYLENE
SPECIFIC HEAT (Cp), joules/gm°K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
60
80
100
200
TEMPERATURE, °K

SPECIFIC HEAT and ENTHALPY of TEFLON (MOLDED)

Source of Data:

Furukawa, G. T., McCoskey, R. E. and King, G. J., J. Research Natl. Bur. Standards 49, 273 (1952)

Other References:

Noer, R. J., Dempsey, C. W. and Gordon, J. E., Bull. Am. Phys. Soc. 4, 108 (1959)

Comments:

The above reference (Furukawa, et al.), also gives data on molded and annealed, molded and quenched, and powdered teflon. The effects of heat treatment do not exceed 3% and are not significant below 150°K. The data indicate a second-order transition at about 160°K and two first-order transitions between 280°K and 310°K. Thermal hysteresis occurs in these regions. Because of this effect, data are not presented for the region 280°K to 310°K. Specific heat values at 5°K and 10°K were obtained through computation involving the Debye temperature, Θ_0 values extrapolated from the 15-30°K range.

Noer, et al. report an approximate formula for the specific heat of teflon between 1.4°K and 4.2°K which is not in good agreement with the extrapolated value of Furukawa, et al. tabulated below. Their approximate formula is given as

$$C \cong 4 \times 10^{-5} T^3 \text{ j/gm-°K}$$

Temp. °K	C_p j/gm °K	H j/gm	Temp. °K	C_p j/gm °K	H j/gm
5	0.0024	0.003	100	0.386	19.51
10	.018	0.047	120	0.457	27.9
15	.048	0.21	140	0.525	37.7
20	.076	0.52	160	0.598	49.0
25	.102	0.97	180	0.677	61.7
30	.125	1.54	200	0.741	75.9
40	.165	2.99	220	0.798	91.3
50	.202	4.83	240	0.853	107.8
60	.238	7.02	260	0.193	125.5
70	.274	9.59	280	1.01	144.6
80	.312	12.52	310	1.02	179.3
90	.350	15.83			

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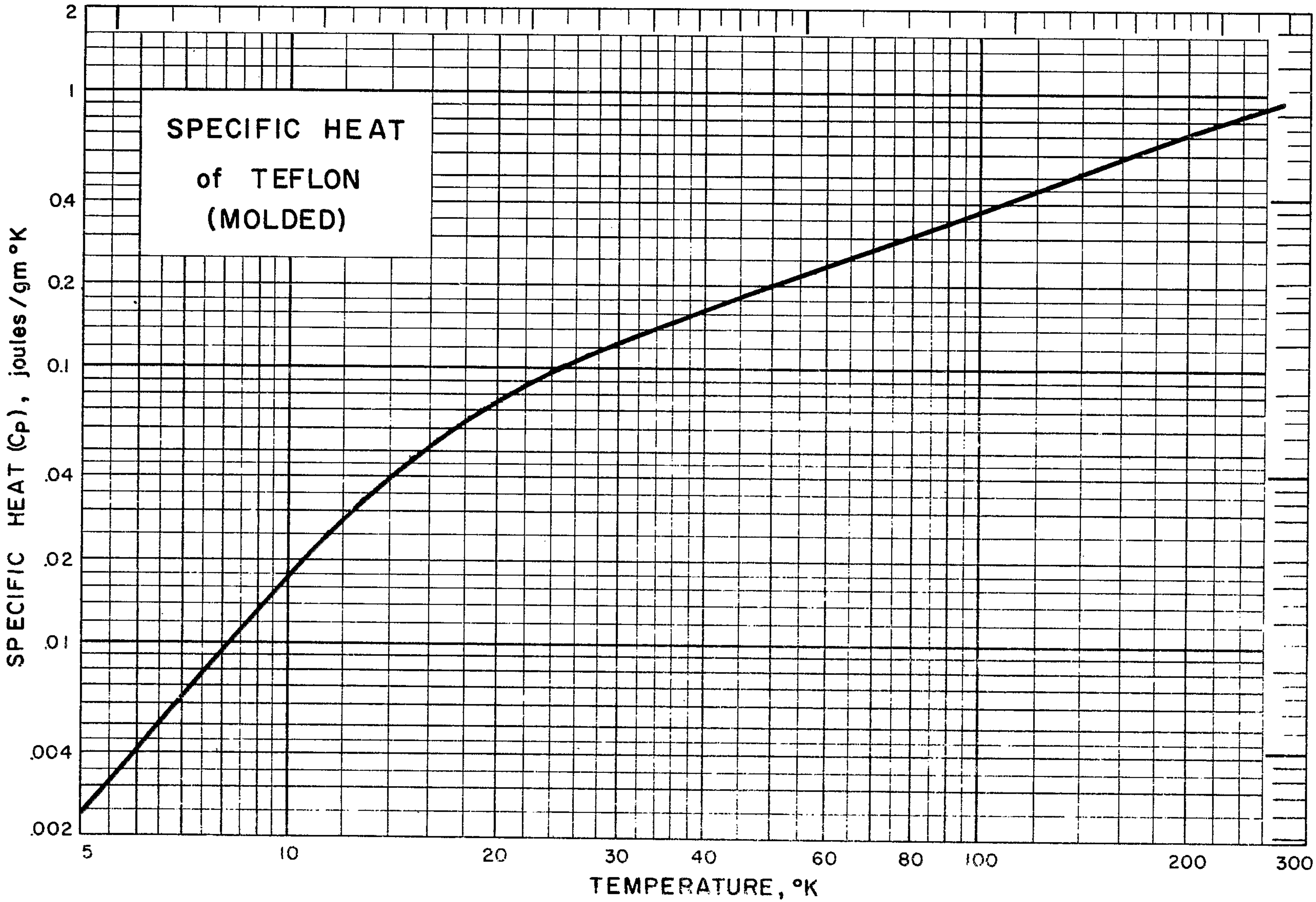
SPECIFIC HEAT
of TEFLON
(MOLDED)
SPECIFIC HEAT (Cp), joules / gm °K
2
1
0.4
0.2
0.1
.04
.02
.01
.004
.002
5
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

SPECIFIC HEAT AND ENTHALPY OF

GR-S (BUNA S) RUBBER (1-3 BUTADIENE, 25 WT. % STYRENE)

Source of Data:

Rands, R. D. Jr., Ferguson, W. T. and Prather, J. L., J. Research Natl. Bur. Standards 33, 63-70 (1944)

Comments:

A second-order transition which indicates a change of slope occurs at about 212 °K. Hysteresis occurs in the region immediately below this transition.

Table of Selected Values

Temp. °K	C_p j/gm-°K	H j/gm	Temp. °K	C_p j/gm-°K	H j/gm
5	0.004	0.005	120	0.711	45.0
10	.028	.07	140	.811	60.2
15	.070	.31	160	.911	77.4
20	.113	.77	180	1.01	96.7
25	.155	1.44	200	1.12	118.0
30	.196	2.32	210	1.34	130.0
40	.272	4.66	212	1.66	133.3
50	.338	7.72	220	1.68	146.1
60	.399	11.40	240	1.73	180.1
70	.455	15.68	260	1.78	215.2
80	.509	20.50	280	1.84	251.4
90	.562	25.86	300	1.90	288.7
100	.612	31.74			

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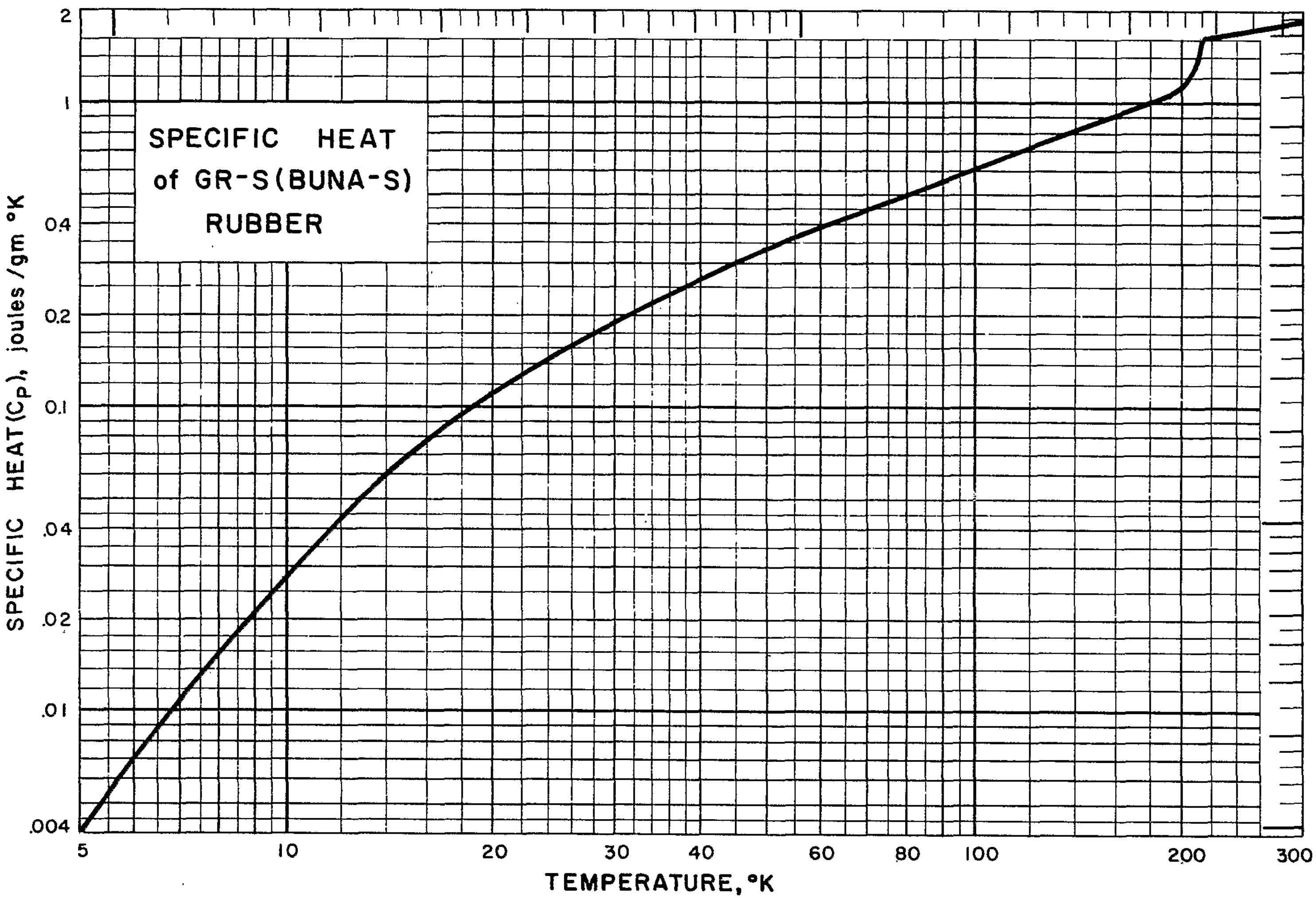
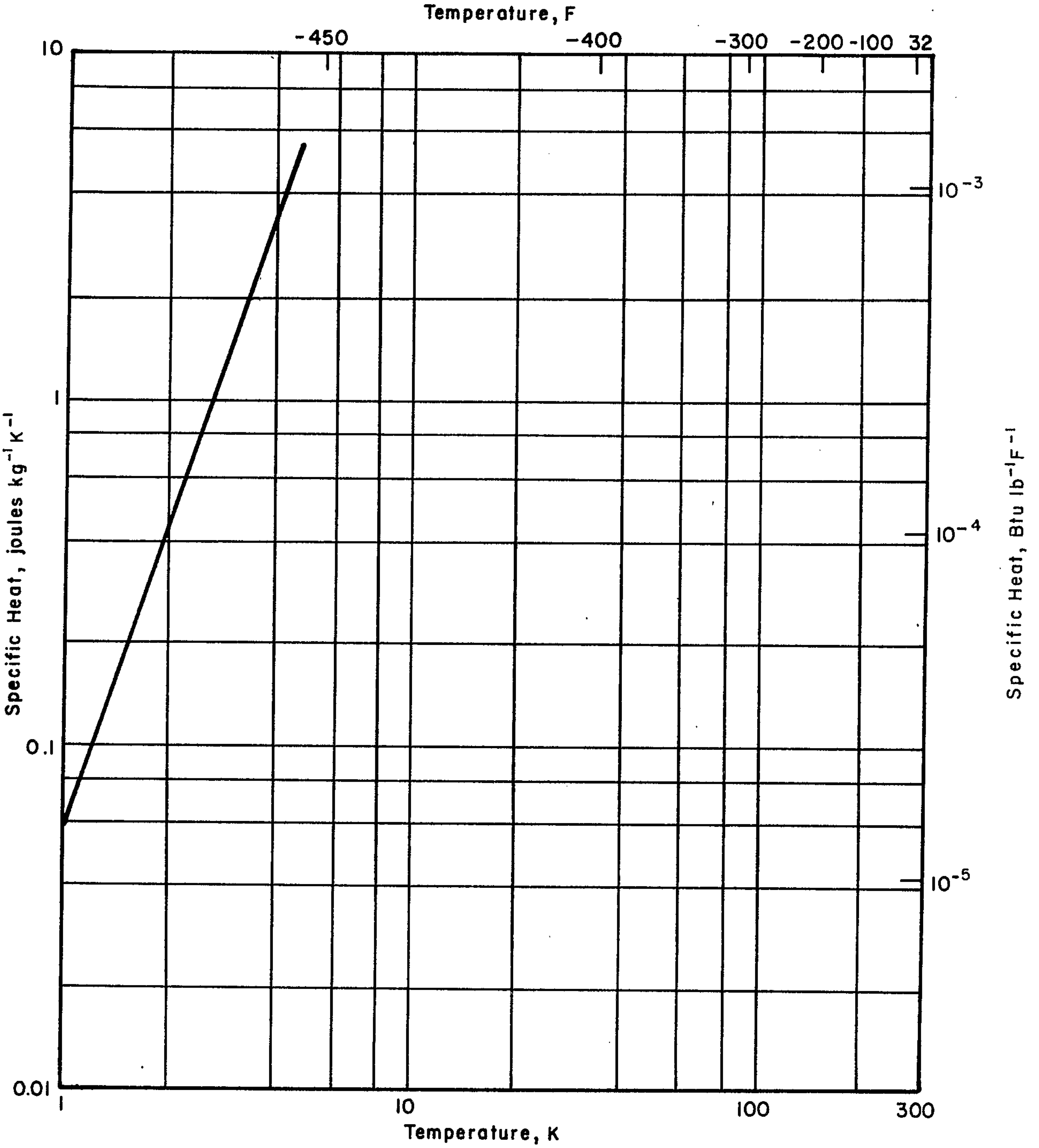

SPECIFIC HEAT
of GR-S (BUNA-S)
RUBBER
SPECIFIC HEAT (C_p), joules /gm °K
2
1
0.4
0.2
0.1
.04
.02
.01
.004
5
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K



SPECIFIC HEAT VERSUS TEMPERATURE FOR
POLYCHLOROTRIFLUOROETHYLENE (KEL-F)

SPECIFIC HEAT and ENTHALPY of NATURAL RUBBER HYDROCARBON (Amorphous)

Source of Data:

Bekkedahl, N., and Matheson, H. J., Research Nat. Bur. Standards 15, 503 (1934)

Comments:

These data apply to pure hydrocarbon polymer extracted from latex. Commerical natural rubber differs from this by containing various additives and having been vulcanized. No low-temperature data for vulcanized rubber have been found, and the data on this sheet are presented as being the closest available approximation thereto. A second-order transformation (glass transformation) occurs at about 200°K. The data in this region are the least applicable to other forms of rubber since the temperature and shape of the transition in C_p will be rather strongly affected by vulcanization and additives.

Table of Selected Values

T °K	Cp j/gm-°K	H j/gm
15	0.073	0.32
20	.117	0.80
30	.204	2.41
40	.282	4.84
50	.352	8.01
60	.418	11.87
70	.480	16.36
80	.537	21.45
90	.596	27.12
100	.646	33.34
120	.75	47.3
140	.84	63.2
160	.94	81.0

T °K	Cp j/gm-°K	H j/gm
180	1.03	100.7
190	1.08	
195	1.10	
200*	1.44	
205	1.60	
210	1.61	
220	1.64	155.0
240	1.70	188.4
260	1.75	222.9
280	1.81	258.4
290	1.84	276.6
300	1.89	295.3

* Second-order transition

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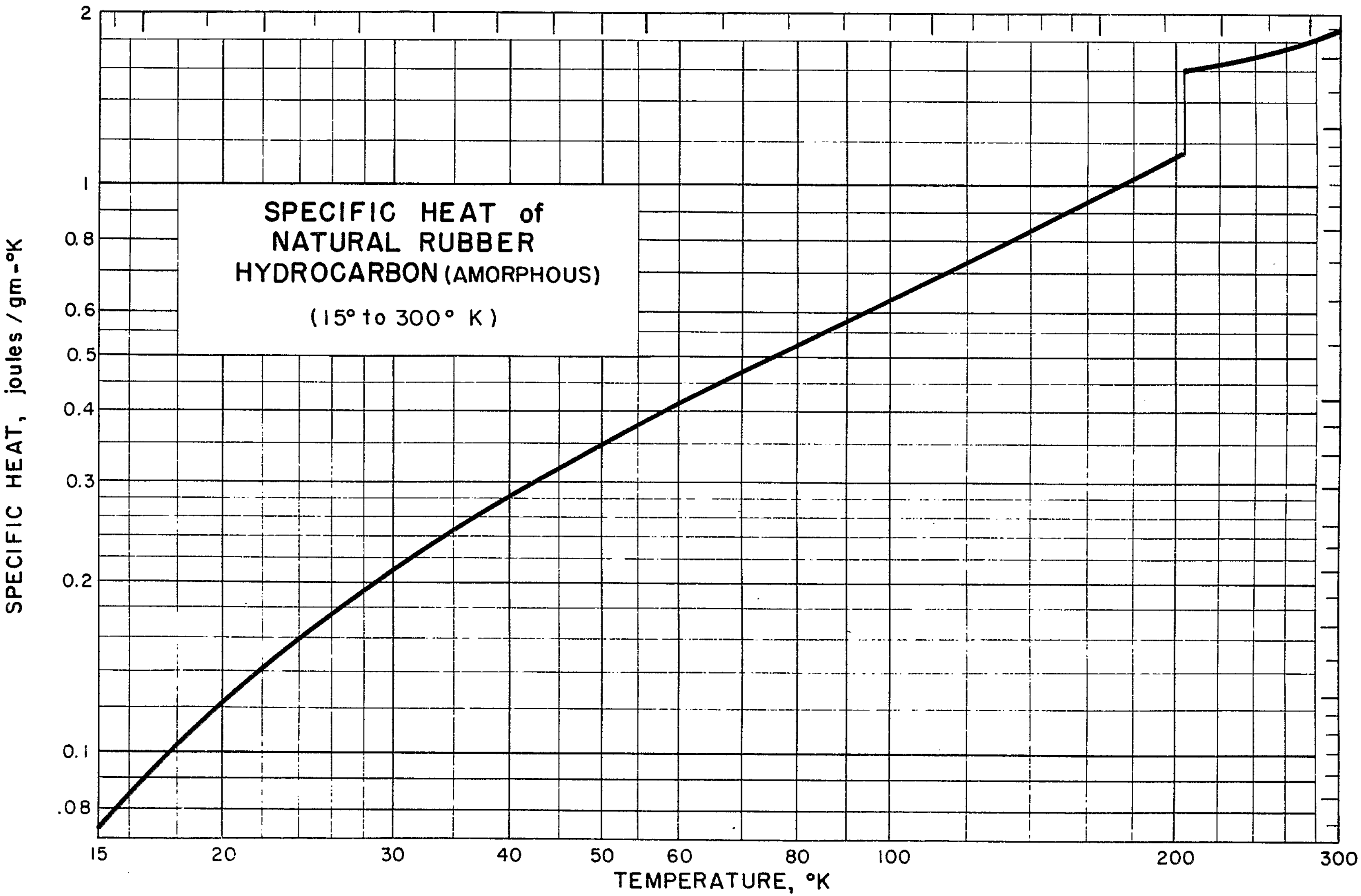

SPECIFIC HEAT of
NATURAL RUBBER
HYDROCARBON (AMORPHOUS)
(15° to 300° K)
SPECIFIC HEAT, joules / gm-°K
TEMPERATURE, °K
2
1
0.8
0.6
0.5
0.4
0.3
0.2
0.1
.08
15
20
30
40
50
60
80
100
200
300

SPECIFIC HEAT and ENTHALPY of QUARTZ

Sources of Data:

Anderson, C. T., J. Am. Chem. Soc. 58, 568 (1936)

Westrum, E. F.; data reproduced in Lord, R.C. and Morrow, J. C., J. Chem. Phys. 26, 230 (1957)

Other References:

Gunther, P., Z. anorg. u allgem. Chem. 116, 71 (1921)

Nernst, W., Ann. Physik (4) 36, 395 (1911)

Table of Selected Values

T °K	Cp j/gm-°K	H j/gm	T °K	Cp j/gm-°K	H j/gm
10	0.0007	0.001	100	0.261	10.51
15	.0040	0.012	120	.325	16.37
20	.0113	0.049	140	.385	23.48
25	.0221	0.131	160	.441	31.75
30	.0353	0.273	180	.494	41.1
40	.0653	0.773	200	.543	51.5
50	.0969	1.583	220	.588	62.8
60	.129	2.71	240	.631	75.0
70	.162	4.17	260	.671	88.0
80	.195	5.95	280	.709	101.8
90	.228	8.07	300	.745	116.4

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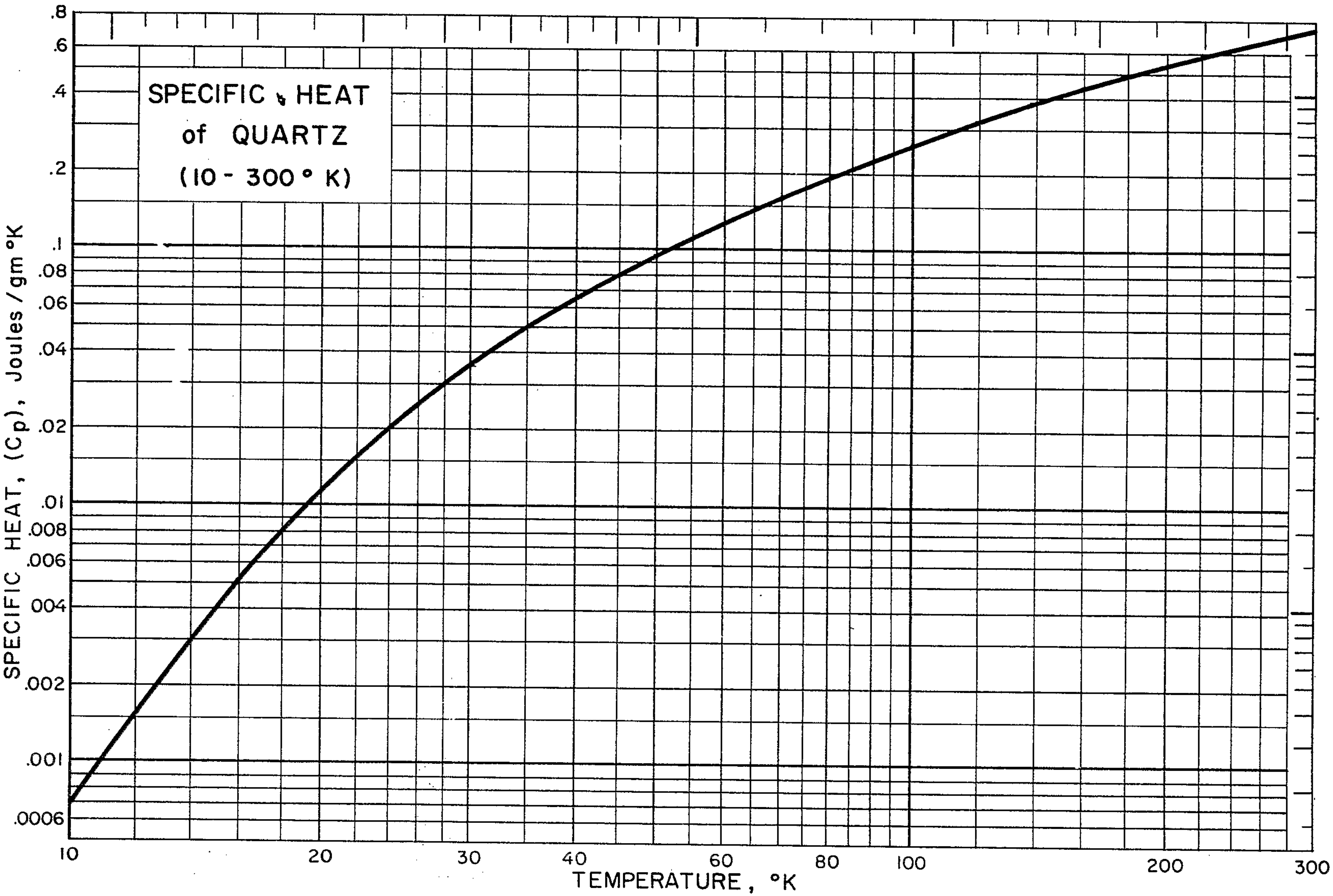
SPECIFIC HEAT
of QUARTZ
(10 - 300° K)
SPECIFIC HEAT, (Cp), Joules / gm °K
.8
.6
.4
.2
.1
.08
.06
.04
.02
.01
.008
.006
.004
.002
.001
.0006
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

ISABELLE Project

Technical Note No. 327

THERMAL CONDUCTIVITY INTEGRALS FOR FIBERGLASS-REINFORCED EPOXY AND AISI 304 STAINLESS STEEL

S.R. Plate

November 10, 1981

I. INTRODUCTION

G-10, a glass-filled epoxy composite, and AISI 304 stainless steel, are materials which are used extensively in the ISABELLE cryogenic transfer system. To calculate reasonably accurate heat leaks at G-10 spacers and stainless steel vacuum breaks where large temperature gradients occur, the integrated thermal conductivities for the materials in question, over various temperature ranges, were required. Since the desired values were not readily available, the integrated conductivities were calculated. These are shown in Tables 1 and 2.

G-10 is a woven cloth/epoxy composite; however, thermal conductivity data could not be obtained for this particular material construction. Conductivity data was found for uniaxial glass-filled epoxy resin material, both parallel to the glass fibers and perpendicular (through material thickness). Refer to Figs. 1a and 1b. The parallel direction is a reasonably accurate analog of G-10 conductivity longitudinally and transversely; the perpendicular direction probably gives somewhat lower heat leak values than would actually be realized through the thickness of a G-10 sheet. These differences must be kept in mind when using the thermal conductivity values to approximate G-10 behavior.

II. METHOD

The computer was programmed to perform an integral approximation by summation of areas under the curves of conductivity for the respective materials. A trapezoid approximation method was considered adequate. Data fed to the computer were obtained by visual inspection of the graphs of thermal conductivity taken from the references.[1,2] The glass-reinforced epoxy resin material was chosen as representative of G-10.

Concerning those original conductivity plots cited, the glass-epoxy curve required extrapolation from 277°K to 300°K and from 50°K down to 4°K. For the 304 stainless steel curve, extrapolation was necessary only from 277°K to 300°K, the lower limit remaining at 4°K.

The information is presented in a form compatible with that presented in the Cryogenic Data Notebook, Vol. I, Section VII.

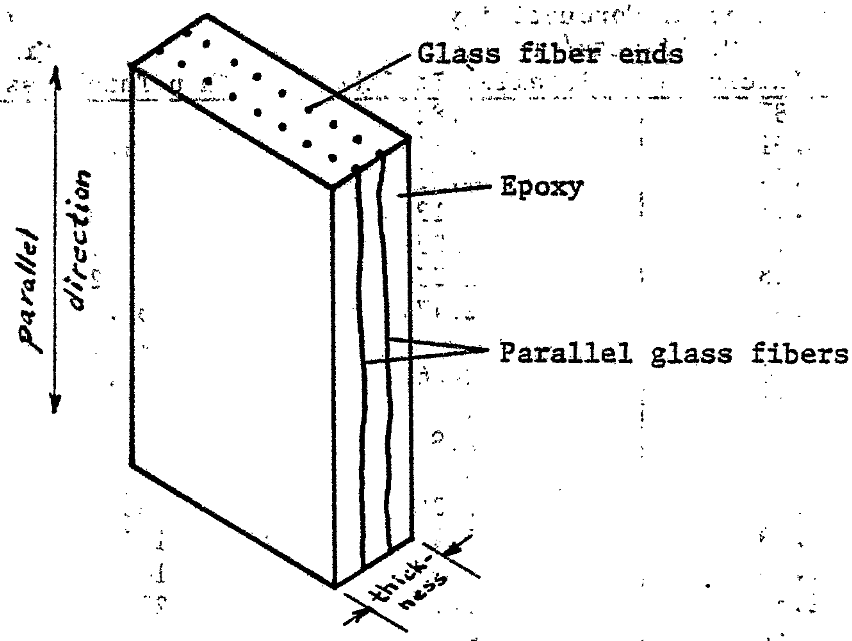

Fig. 1a.

Uniaxial glass/epoxy matrix.

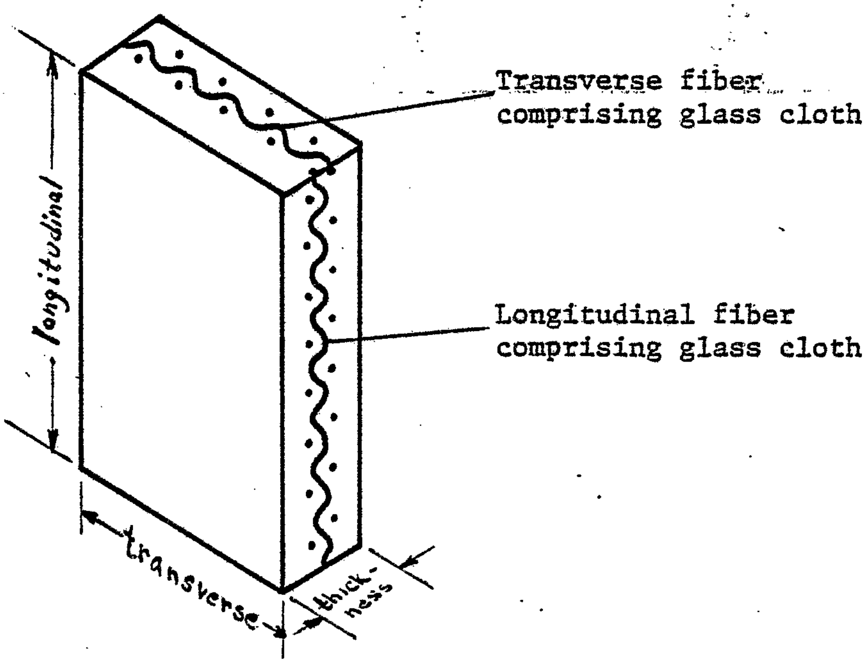

Fig. 1b.

Glass cloth/epoxy matrix.

Table 1. Thermal conductivity integrals for uniaxial glass-filled epoxy.

Temp. °K	Thermal Conductivity Milliwatts/cm-°K		$\int_{4°K}^{T_L} \lambda\, dT$ Milliwatts/cm	
	Thru Thickness	Parallel To Fibers	Thru Thickness	Parallel To Fibers
4.0	0.87	1.82		
5.6	0.91	1.87	1.42	2.95
11.1	1.04	1.99	6.80	13.6
16.7	1.18	2.13	13.0	25.0
22.2	1.28	2.25	19.8	37.2
27.8	1.38	2.35	27.2	50.0
33.3	1.49	2.47	35.1	63.4
38.9	1.61	2.56	43.8	77.3
44.4	1.70	2.66	53.0	91.8
50.0	1.73	2.75	62.5	107
61.1	1.96	2.94	82.9	139
72.2	2.09	3.11	105	172
83.3	2.25	3.29	130	208
94.4	2.39	3.46	155	245
100.0	2.44	3.55	169	265
122.2	2.66	3.84	226	347
144.4	2.87	4.10	287	435
161.1	2.99	4.31	336	505
183.3	3.17	4.55	404	603
200.0	3.25	4.72	458	680
227.8	3.41	5.00	551	816
250.0	3.51	5.19	628	929
277.8	3.63	5.38	727	1076
300.0	3.70	5.51	809	1197

Table II. Thermal conductivity integrals for AISI 304 stainless steel.

Temp. °K	Thermal Conductivity Milliwatts/cm-°K	$\int_{4°K}^{T_L} \lambda dT$ Milliwatts/cm
4	3.10	
6	4.85	7.98
8	6.75	19.6
10	8.75	35.1
13	12.2	66.5
20	20.0	179
24	24.0	267
27	28.0	345
30	33.0	437
35	39.0	617
40	46.5	830
45	53.5	1080
50	59.2	1360
60	70.0	2010
70	80.0	2760
80	86.0	3580
100	95.0	5400
120	103	7370
140	110	9490
160	117	11750
180	124	14200
200	130	16700
230	141	20800
260	152	25200
300	168	31600

REFERENCES

1. Brunswick Corp., Technical Products Div., J. Gray; "Thermal Conductivity of Fiberglass Laminates as a Function of Temperature", curves E(T) and E(||).

2. National Bureau of Standards, NBS Monograph 131, Sept. 1973, G. Childs, L. Ericks, and R. Powell; "Thermal Conductivity of Solids at Room Temperature and Below", p. 257, Fig. 40A.

<u>Bldg. 911</u>
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H. Fadem
S. Ghoshroy
J.W. Glenn
C. Goodzeit
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J. Grisoli
J. Jackson
A. Kaam
J. Keohane
D. Lazarus
Y. Lee
D. Lowenstein
Y. Makdisi
P. Montemuro
R. Nawrocky
M. Smith (1) plus
one for each author(s) file
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S. Ozaki
R.B. Palmer
S. Protopopescu
D. Rahm
M. Sakitt
R. Fernow 510-C
I. Stumer
T.L. Trueman

/dv

SPECIFIC HEAT and ENTHALPY of VITREOUS SILICA
(Silica Glass, Quartz Glass)

Sources of Data:

Simon, F., Ann. Physik (4) 68, 241-80 (1922)

Simon, F. and Lange, F., Z. physik. 38, 227-36 (1926)

Westrum, E. F., data reproduced in Lord, R. C. and Morrow, J. C., J. Chem. Phys. 26, 230 (1957)

Other References:

Nernst, W., Sitzber. kgl. preuss. Akad. Wiss., 306 (1911)

Table of Selected Values

Temp. °K	C_p j/gm-°K	H j/gm	Temp. °K	C_p j/gm-°K	H j/gm
10	0.0045	0.011	100	0.268	11.57
15	.0126	0.052	120	.331	17.56
20	.0244	0.143	140	.391	24.77
25	.0379	0.299	160	.446	33.14
30	.0519	0.524	180	.497	42.6
40	.0808	1.186	200	.544	53.0
50	.111	2.15	220	.588	64.3
60	.141	3.41	240	.629	76.5
70	.172	4.97	260	.668	89.5
80	.204	6.85	280	.704	103.2
90	.236	9.05	300	.738	117.6

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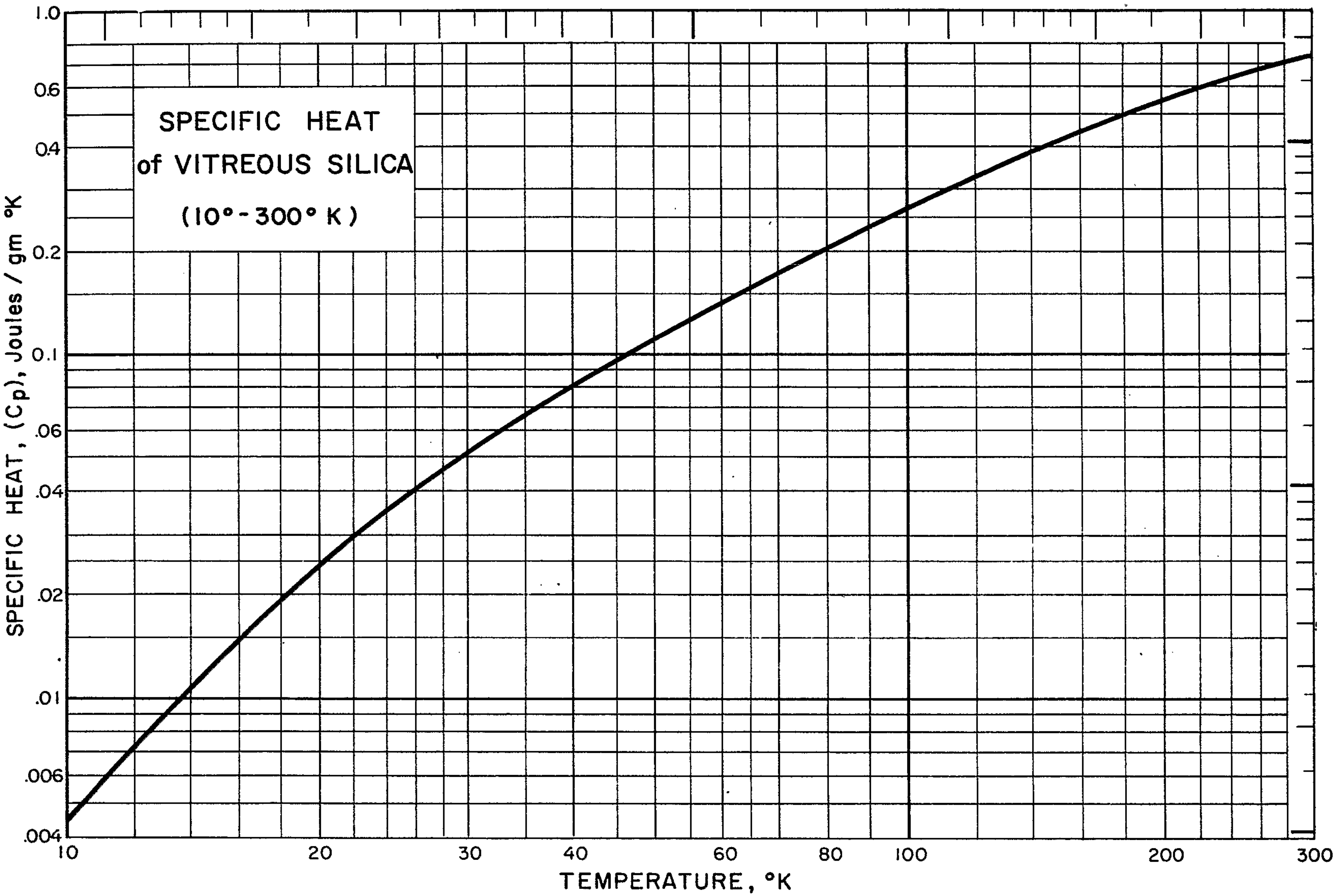
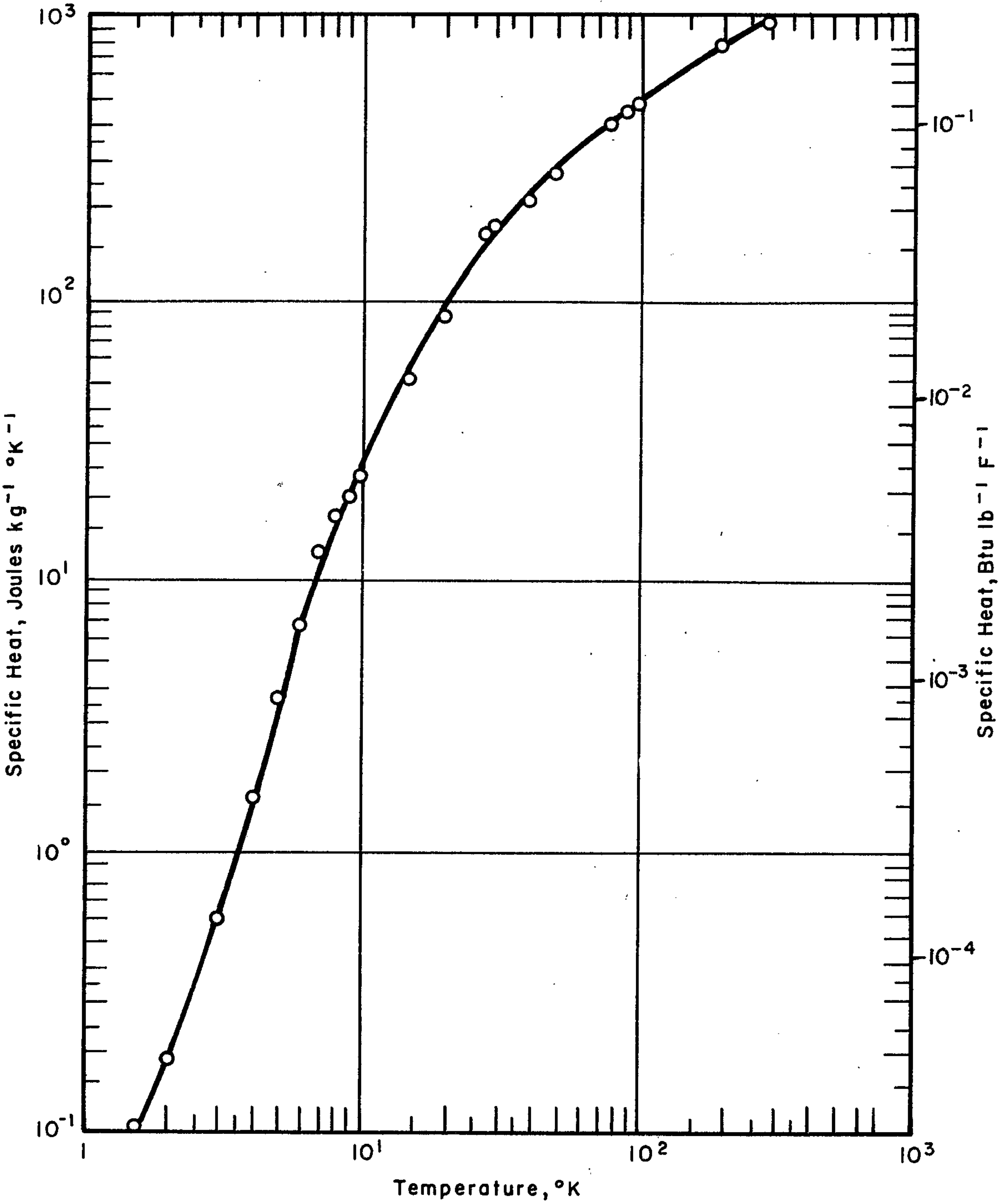
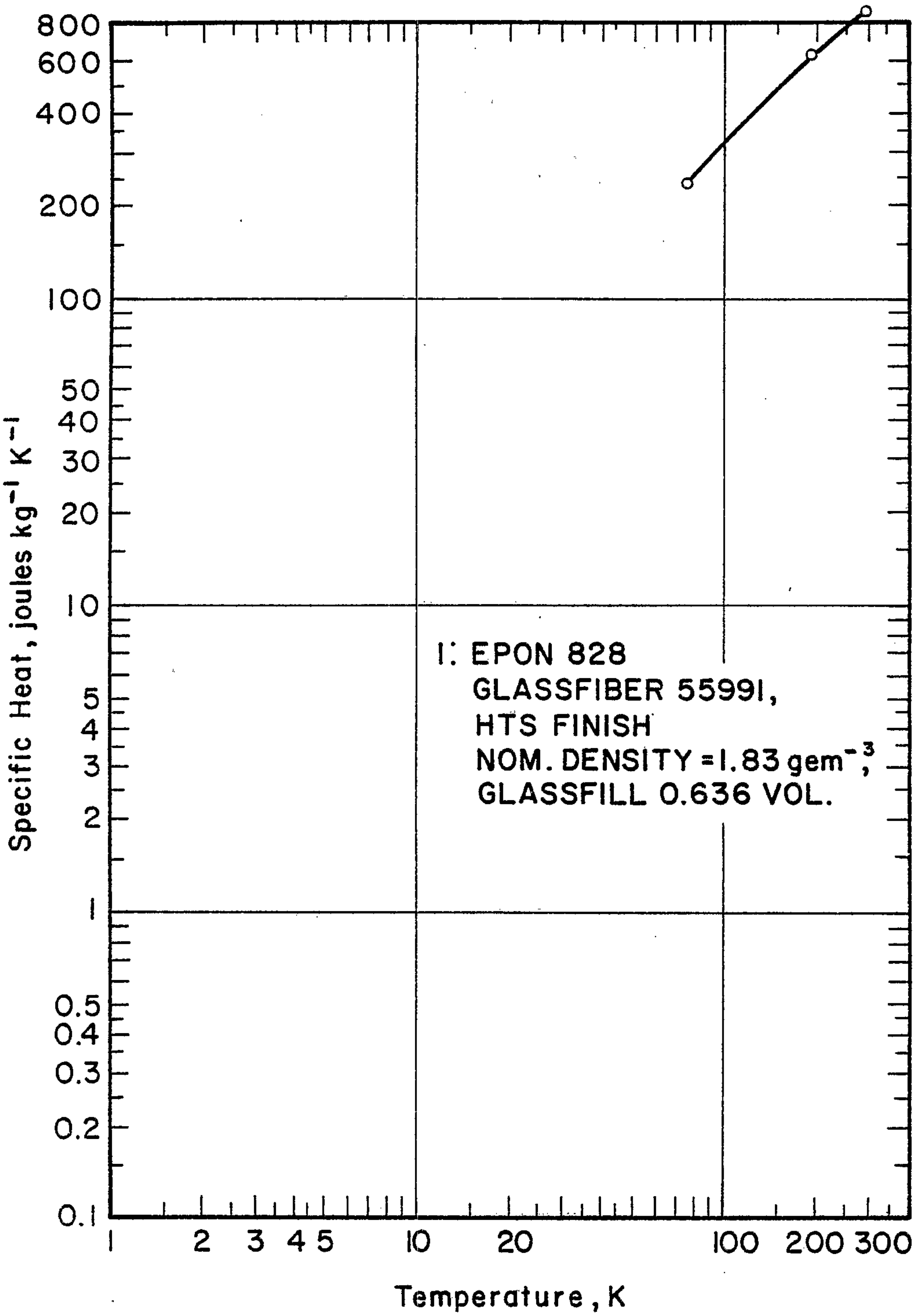

SPECIFIC HEAT
of VITREOUS SILICA
(10° - 300° K)
SPECIFIC HEAT, (Cp), Joules / gm °K
1.0
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.006
.004
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

VIII-M-2



SPECIFIC HEAT OF UNFILLED EPOXY RESINS



SPECIFIC HEAT VERSUS TEMPERATURE FOR GLASSFIBER REINFORCED EPOXIES

SPECIFIC HEAT, ENTHALPY of ARALDITE

(TYPE I)

Source of Data:

Parkinson, D. H. and Quarrington, J. E., Brit. J. Appl. Phys. 5, 219-20 (1954)

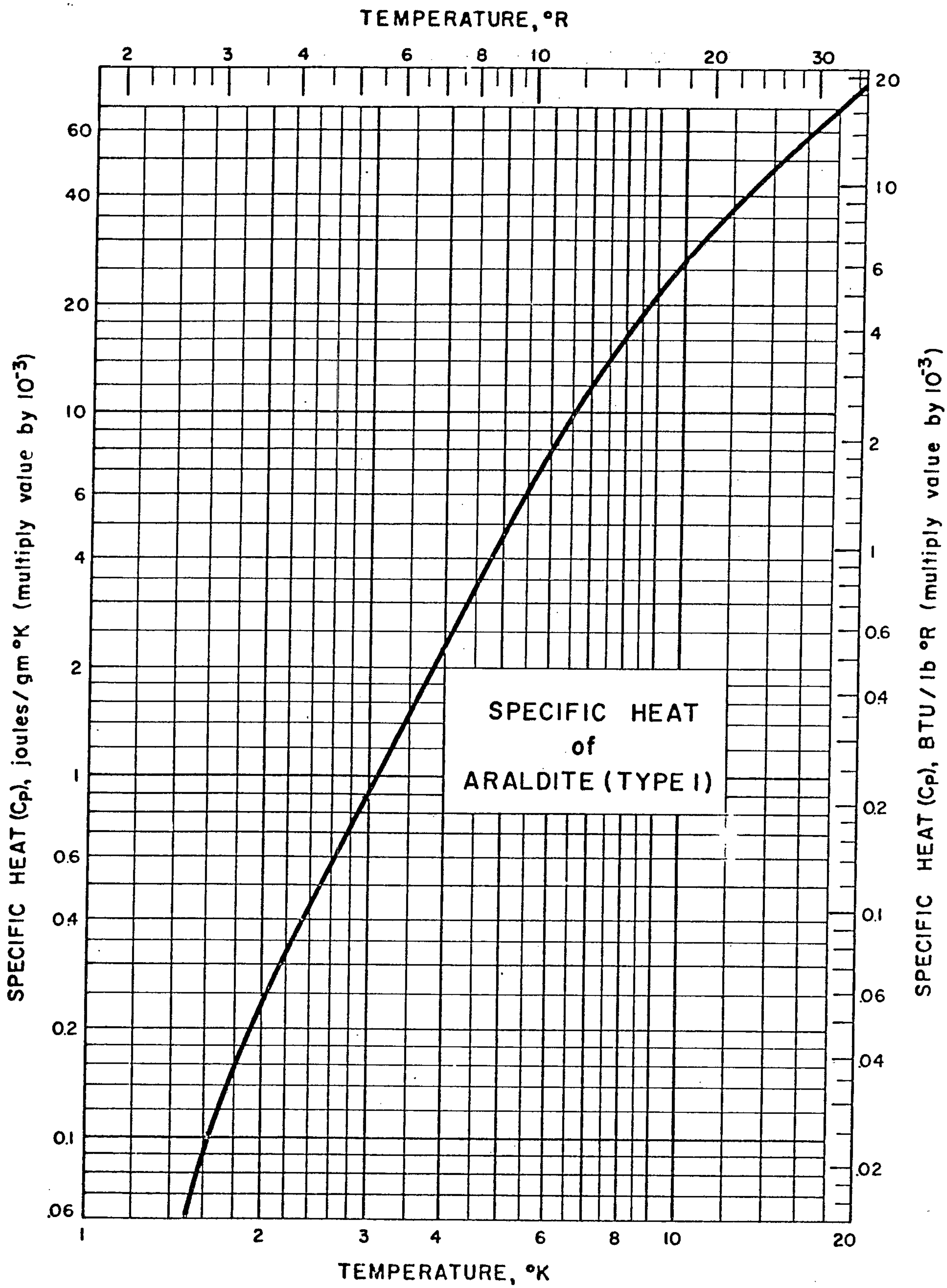
Comments:

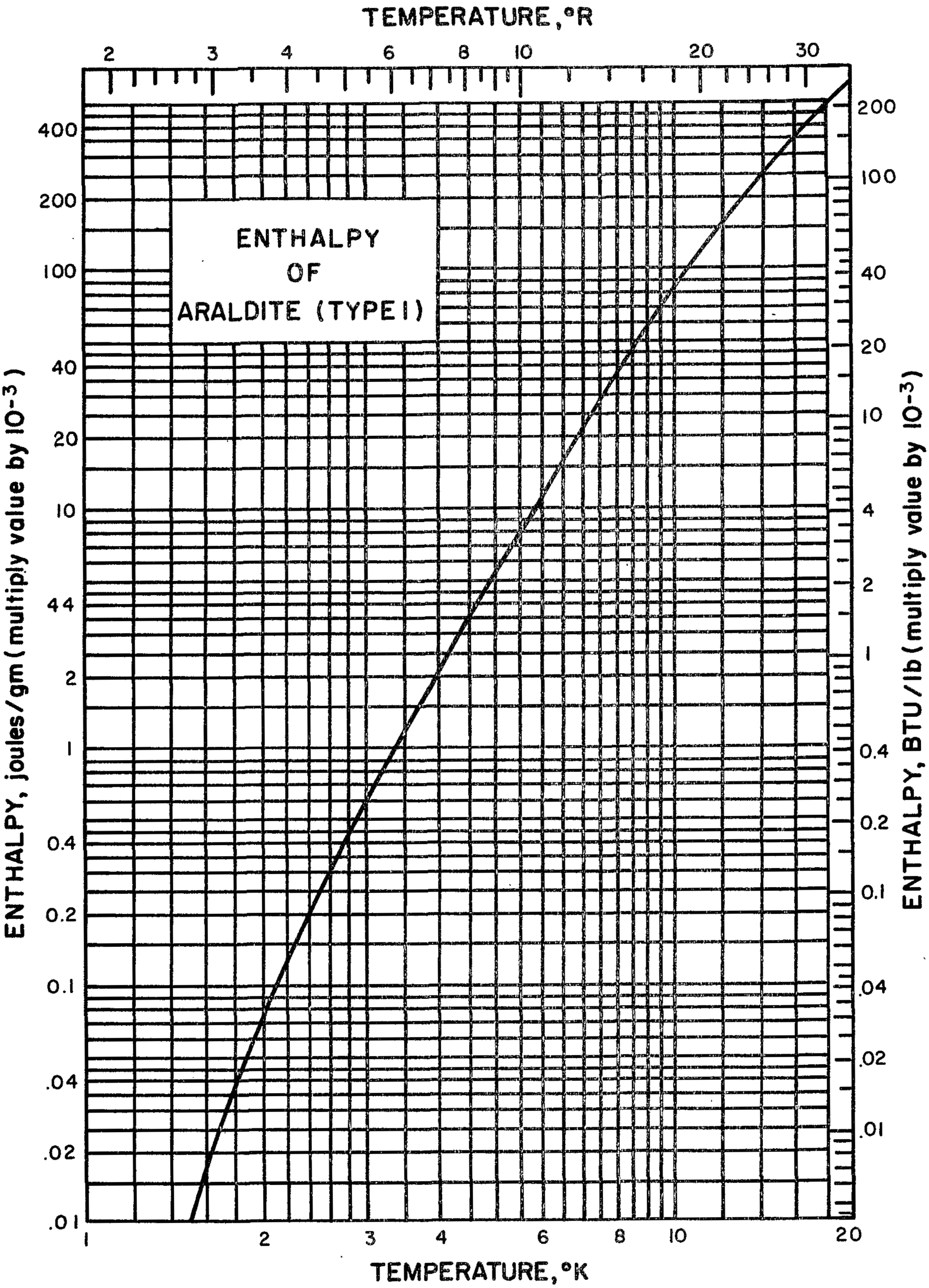
Sample prepared according to manufacturer's directions.

Table of Selected Values

Temp. °K	C_p j/gm-°K	H j/gm
1.5	0.000 06	0.000 01
2	.000 24	.000 08
3	.000 89	.000 60
4	.002 25	.002 10
6	.008 2	.011 7
8	.016 9	.036 7
10	.027 2	.080 7
15	.054 2	.284
20	.081 1	.623

RJC/JJG Issued: 12-18-59


TEMPERATURE, °R
2
3
4
6
8
10
20
30
SPECIFIC HEAT (Cp), joules/gm °K (multiply value by 10^-3)
60
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
.06
SPECIFIC HEAT (Cp), BTU/lb °R (multiply value by 10^-3)
20
10
6
4
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
SPECIFIC HEAT
of
ARALDITE (TYPE I)
1
2
3
4
6
8
10
20
TEMPERATURE, °K


TEMPERATURE, °R
2
3
4
6
8
10
20
30
ENTHALPY
OF
ARALDITE (TYPE I)
400
200
100
40
20
10
44
2
1
0.4
0.2
0.1
.04
.02
.01
ENTHALPY, joules/gm (multiply value by 10-3)
200
100
40
20
10
4
2
1
0.4
0.2
0.1
.04
.02
.01
ENTHALPY, BTU/lb (multiply value by 10-3)
1
2
3
4
6
8
10
20
TEMPERATURE, °K

SPECIFIC HEAT, ENTHALPY of NIOBIUM

Source of Data:

Chou, C., White, P. and Johnston, H. L., Phys. Rev. 109, 788-796 (1958)

Other References:

Brown, A., Zemansky, M. W. and Boorse, H. A., Phys. Rev. 86, 134 (1952)

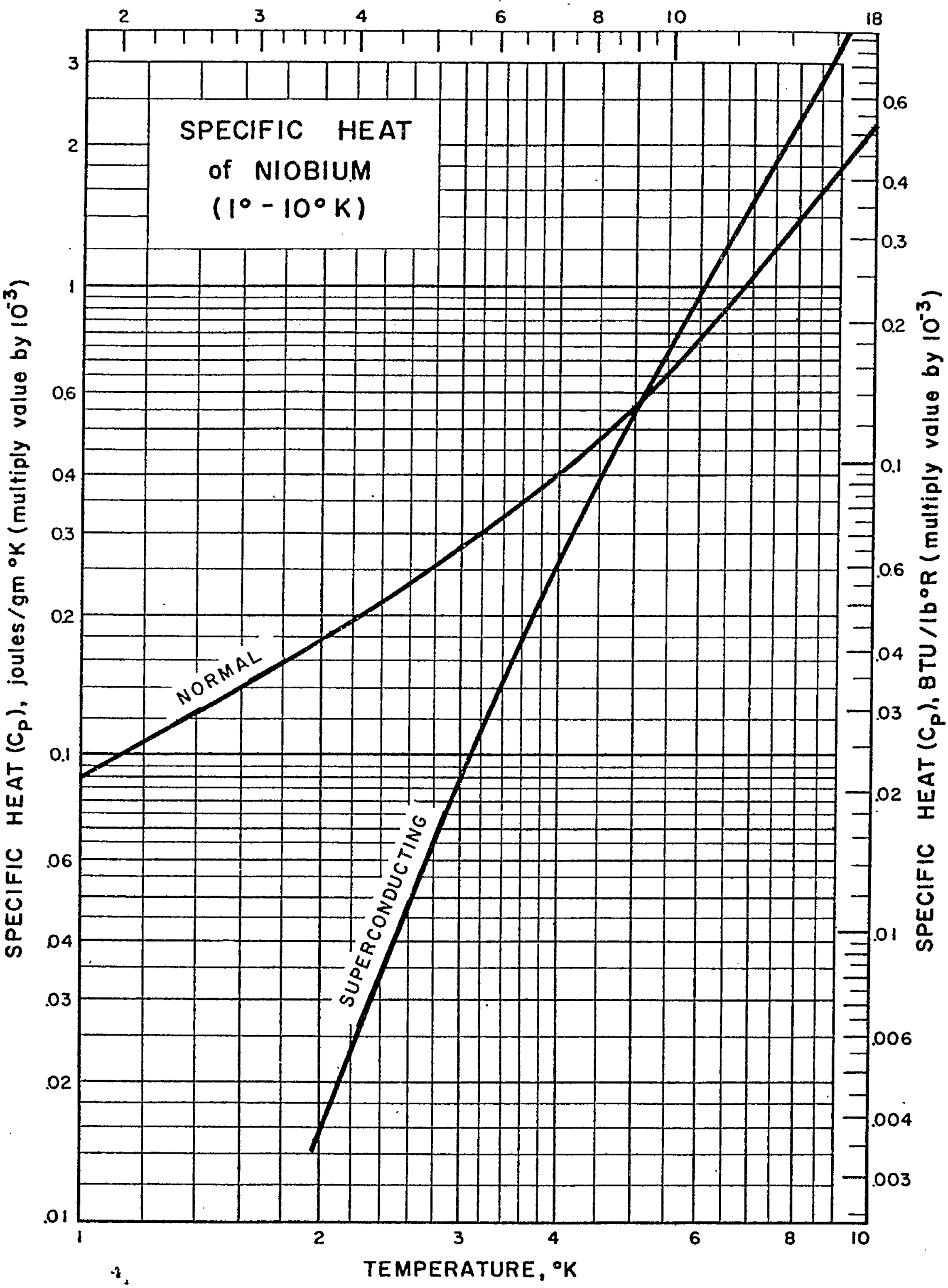
Richards, T. W. and Jackson, F. G., Z. physik. Chem. 70, 414 (1910)

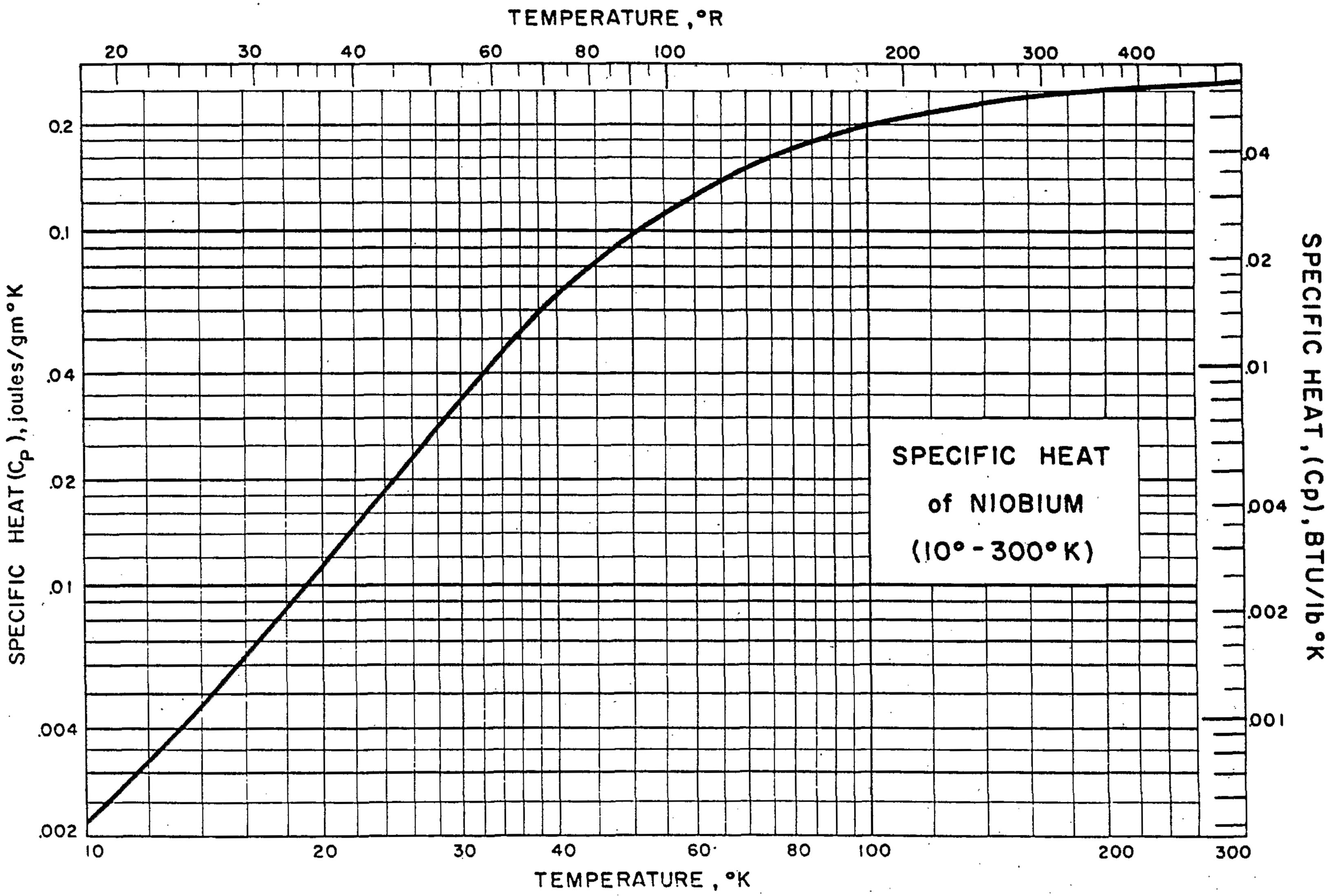
Comments:

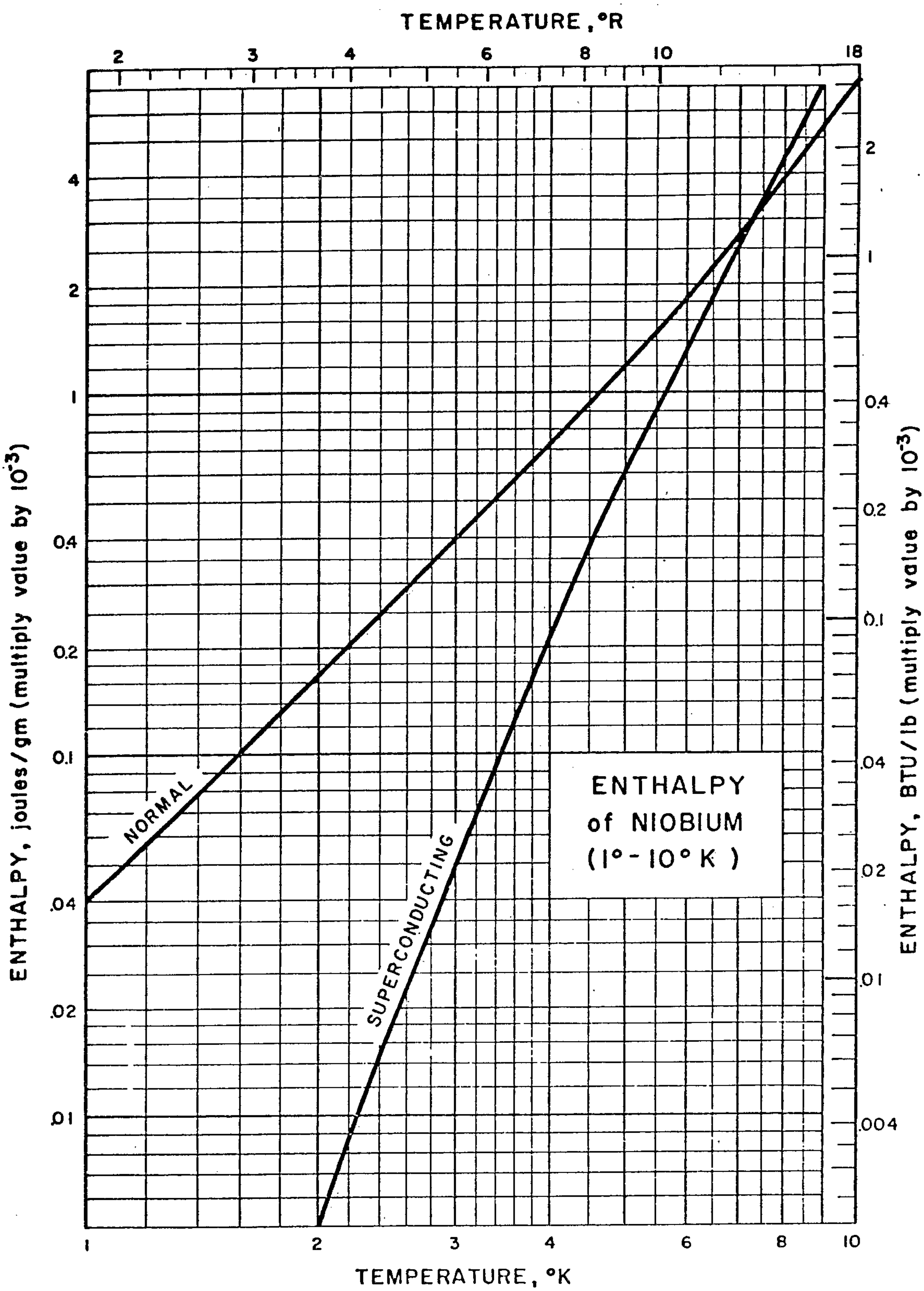
The data of Chou, White and Johnston cover the range, 1.5° to 30°K while the compilation of Kelley (1949) gives best values for room temperature and above. Between 30° and room temperature no modern experimental data are to be found. The values in this region given here are estimates. While the accuracy at 2 to 30° and at 300°K is of order 1%, the estimated values between 30° and 300°K are more uncertain and may be in error by as much as 10% in the region 40° to 100°K.

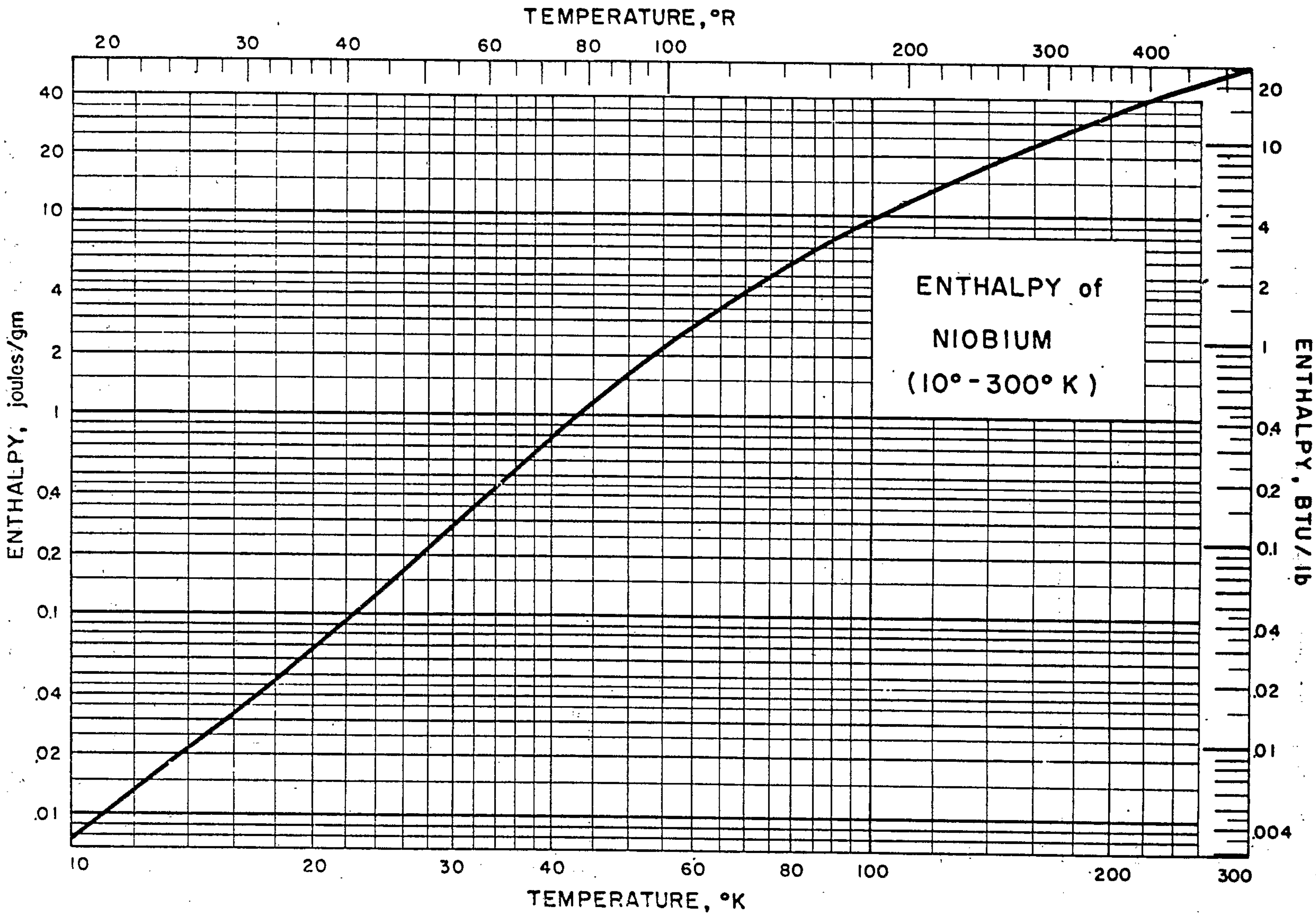
Temp. °K	C_p joules/gram-°K Normal	C_p joules/gram-°K Supercond.	H joules/gram Normal	H joules/gram Supercond.	Temp. °K	C_p j/gm-°K Normal	H j/gm Normal
1	.09 x10^{-3}		.04 x10^{-3}		60	.127	2.76
2	.18 "	.015 x10^{-3}	.17 "	.005 x10^{-3}	70	.152	4.2
3	.28 "	.088 "	.40 "	.049 "	80	.173	5.8
4	.40 "	.27 "	.73 "	.22 "	90	.189	7.6
5	.56 "	.56 "	1.20 "	.62 "	100	.202	9.6
6	.77 "	.98 "	1.86 "	1.38 "	120	.221	13.8
7	1.02 "	1.5 "	2.75 "	2.6 "	140	.234	18.3
8	1.4 "	2.3 "	3.93 "	4.5 "	160	.243	23.1
9	1.7 "	3.2 "	5.5 "	7.2 "	180	.249	28.0
10	2.2 "		7.4 "		200	.254	33.1
15	.0055		.026		220	.258	38.2
20	.0113		.066		240	.261	43.4
25	.021		.145		260	.264	48.6
30	.035		.28		280	.266	53.9
40	.068		.80		300	.268	59.2
50	.099		1.63				

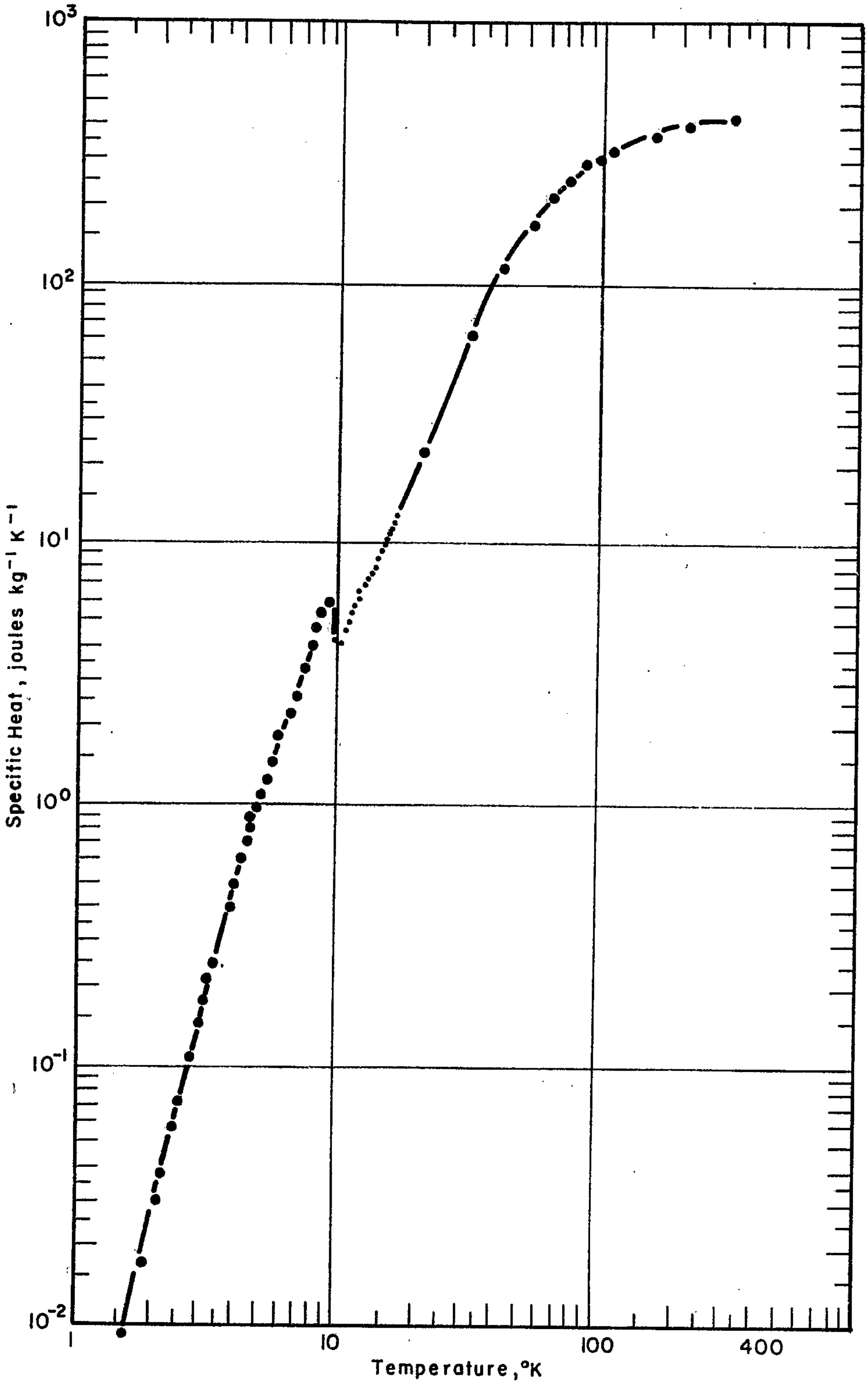
RJC/JJG Issued: 10-21-59


SPECIFIC HEAT
of NIOBIUM
(1° - 10° K)
NORMAL
SUPERCONDUCTING
SPECIFIC HEAT (C_p), joules/gm °K (multiply value by 10^{-3})
SPECIFIC HEAT (C_p), BTU/lb°R (multiply value by 10^{-3})
TEMPERATURE, °K
.01
.02
.03
.04
.06
0.1
0.2
0.3
0.4
0.6
1
2
3
.003
.004
.006
.01
.02
.03
.04
.06
0.1
0.2
0.3
0.4
0.6
1
2
3
4
6
8
10
18


TEMPERATURE, °R
20
30
40
60
80
100
200
300
400
SPECIFIC HEAT (C_p), joules/gm°K
0.2
0.1
.04
.02
.01
.004
.002
SPECIFIC HEAT, (Cp), BTU/lb°K
.04
.02
.01
.004
.002
.001
SPECIFIC HEAT
of NIOBIUM
(10° - 300°K)
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K


TEMPERATURE, °R
2
3
4
6
8
10
18
ENTHALPY, joules/gm (multiply value by 10^{-3})
4
2
1
0.4
0.2
0.1
.04
.02
.01
ENTHALPY, BTU/lb (multiply value by 10^{-3})
2
1
0.4
0.2
0.1
.04
.02
.01
.004
NORMAL
SUPERCONDUCTING
ENTHALPY
of NIOBIUM
(1° - 10° K)
1
2
3
4
6
8
10
TEMPERATURE, °K


TEMPERATURE, °R
20
30
40
60
80
100
200
300
400
ENTHALPY, joules/gm
40
20
10
4
2
1
0.4
0.2
0.1
.04
.02
.01
ENTHALPY, BTU/lb
20
10
4
2
1
0.4
0.2
0.1
.04
.02
.01
.004
ENTHALPY of
NIOBIUM
(10° - 300° K)
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K



SPECIFIC HEAT VERSUS TEMPERATURE FOR NB 51 TI 49

SPECIFIC HEAT, ENTHALPY of TITANIUM

Sources of Data:

Aven, M. H., Craig, R. S., Waite, T. R. and Wallace, W. E., Phys. Rev. 102, 1263 (1956)

Kothen, C. W. and Johnston, H. L., J. Am. Chem. Soc. 75, 3101 (1953)

Wolcott, N. M., Conf. de Physique des Basses Temperatures, Paris (1955)

Other References:

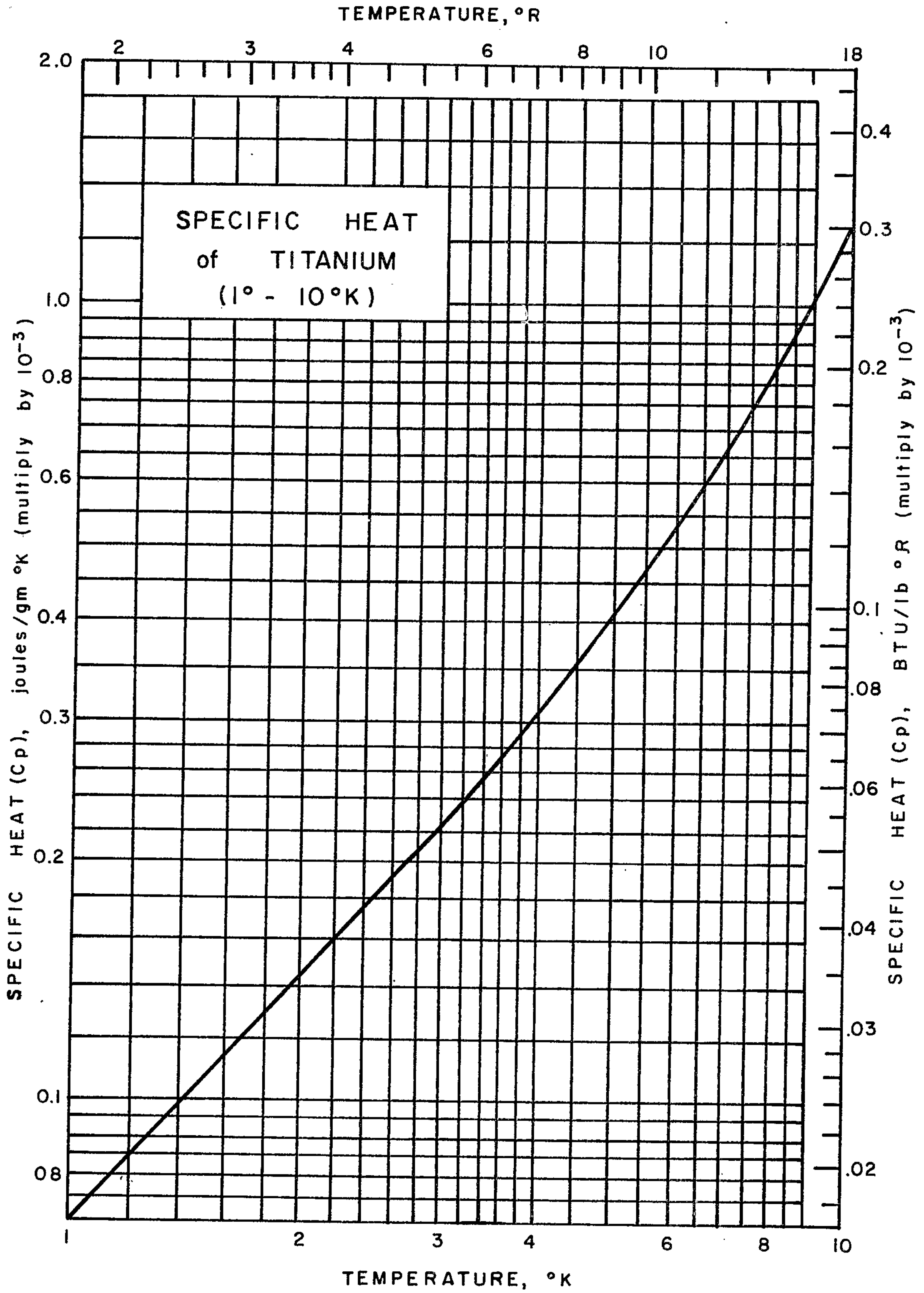
Estermann, I., Friedberg, S. A. and Goldman, J. E., Phys. Rev. 87, 582 (1952)

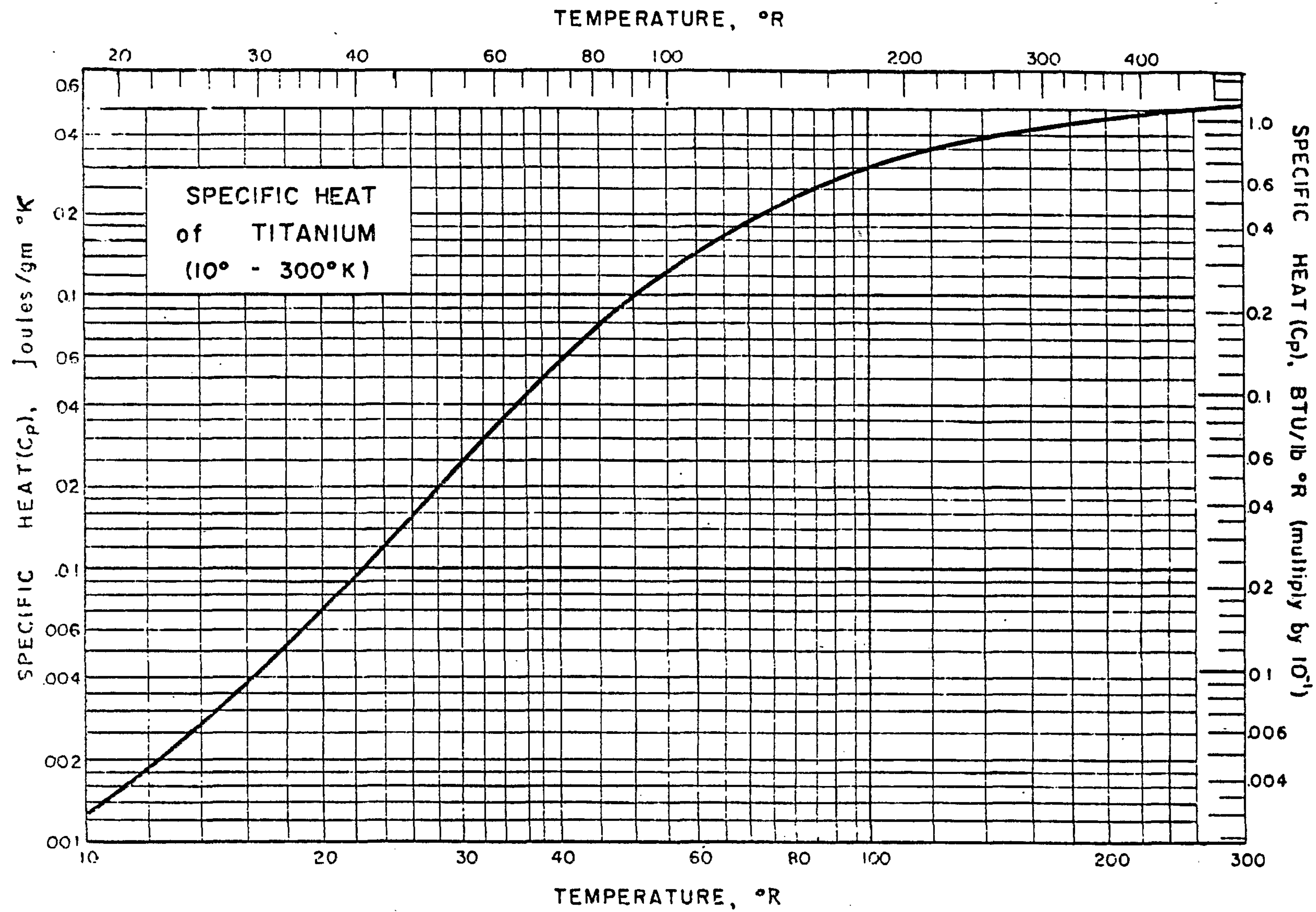
Kelley, K. K., Ind. Eng. Chem. 36, 865 (1944)

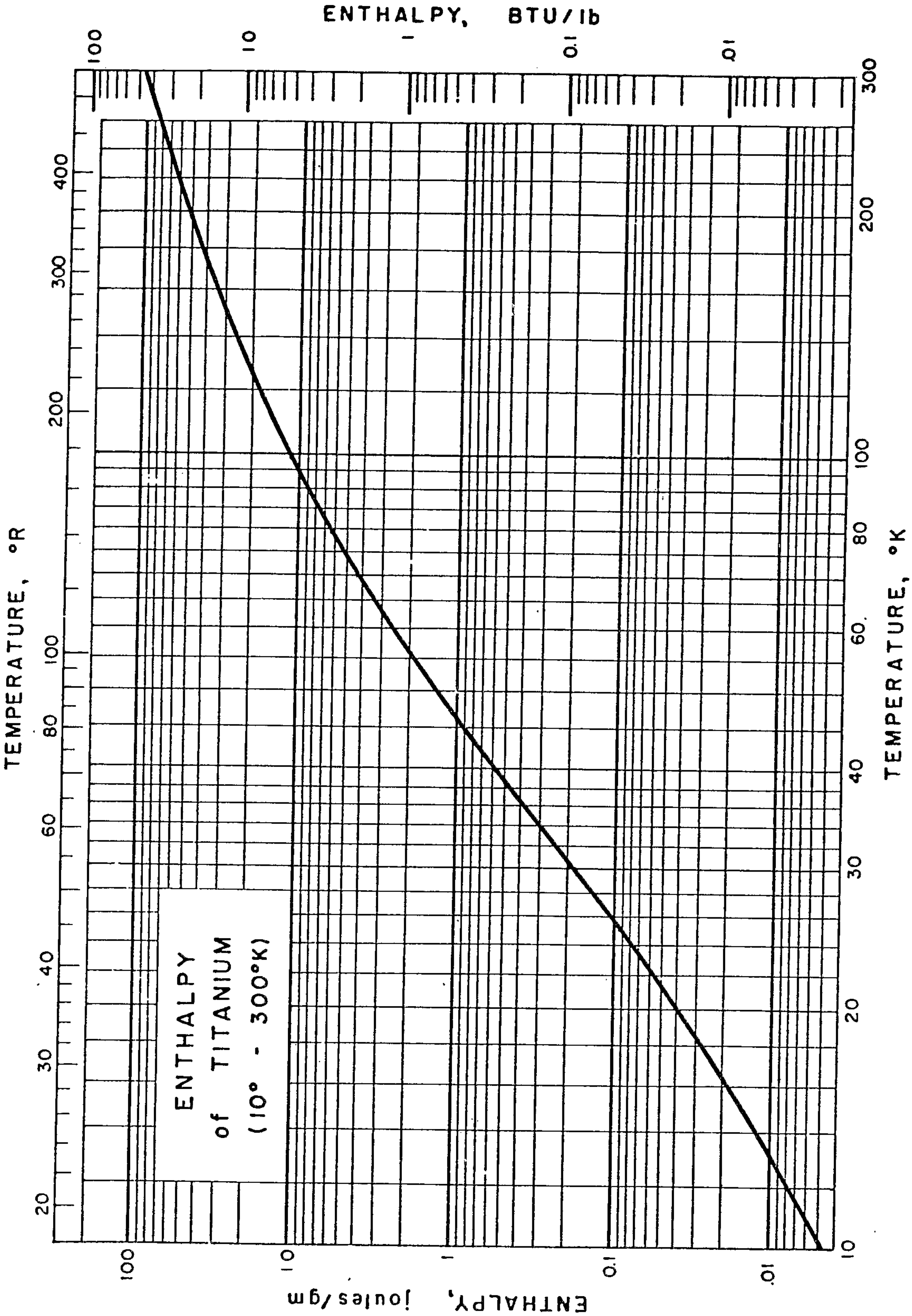
Table of Selected Values

Temp. °K	C_p j/gm-°K	H j/gm	Temp. °K	C_p j/gm-°K	H j/gm
1	0.000 071	0.000 035	70	0.189	4.27
2	.000 146	.000 143	80	.230	6.37
3	.000 226	.000 329	90	.267	8.86
4	.000 317	.000 599	100	.300	11.69
6	.000 54	.001 45	120	.352	18.24
8	.000 84	.002 81	140	.391	25.69
10	.001 26	.004 89	160	.422	33.84
15	.003 3	.015 6	180	.446	42.54
20	.007 0	.040	200	.465	51.66
25	.013 4	.090	220	.480	61.11
30	.024 5	.182	240	.493	70.84
40	.057 1	.581	260	.504	80.82
50	.099 2	1.358	280	.514	91.01
60	.146 7	2.592	300	.522	101.39

RJC Issued: 12-16-59


TEMPERATURE, °R
2
3
4
6
8
10
18
2.0
1.0
0.8
0.6
0.4
0.3
0.2
0.1
08
0.4
0.3
0.2
0.1
.08
.06
.04
.03
.02
SPECIFIC HEAT
of TITANIUM
(1° - 10°K)
SPECIFIC HEAT (Cp), joules/gm °K (multiply by 10⁻³)
SPECIFIC HEAT (Cp), BTU/lb °R (multiply by 10⁻³)
1
2
3
4
6
8
10
TEMPERATURE, °K


TEMPERATURE, °R
20
30
40
60
80
100
200
300
400
SPECIFIC HEAT
of TITANIUM
(10° - 300°K)
SPECIFIC HEAT (C_p), Joules/gm °K
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
.001
SPECIFIC HEAT (C_p), BTU/lb °R (multiply by 10^{-1})
1.0
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.006
.004
10
20
30
40
60
80
100
200
300
TEMPERATURE, °R


ENTHALPY of TITANIUM (10° - 300°K)
ENTHALPY, BTU/lb
ENTHALPY, joules/gm
TEMPERATURE, °R
TEMPERATURE, °K
100
10
1
.1
.01
20
30
40
60
80
100
200
300
400
10
20
30
40
60
80
100
200
300

SPECIFIC HEAT, ENTHALPY of CARBON (GRAPHITE)

Sources of Data:

Keesom, P. H. and Pearlman, N.; Phys. Rev. 99, 1119-24 (1955)

De Sorbo, W. and Tyler, W., J. Chem. Phys. 21, 1660-3 (1953)

Other References:

Bergenlid, V., Hill, R. W., Webb, F. J. and Wilks, J., Phil. Mag. 45, 851-4 (1954)

Dewar, J., Proc. Roy. Soc. (London) A76, 325 (1904)

Ewald, R., Ann. phys. (4) 1213 (1914)

Jacobs, C. J. and Parks, G. S., J. Am. Chem. Soc. 56, 1513 (1934)

Koref, F., Ann. Phys. (4) 36, 49 (1911)

Richards, T. W. and Jackson, F. G., Z. physik. Chem. 70, 414 (1910)

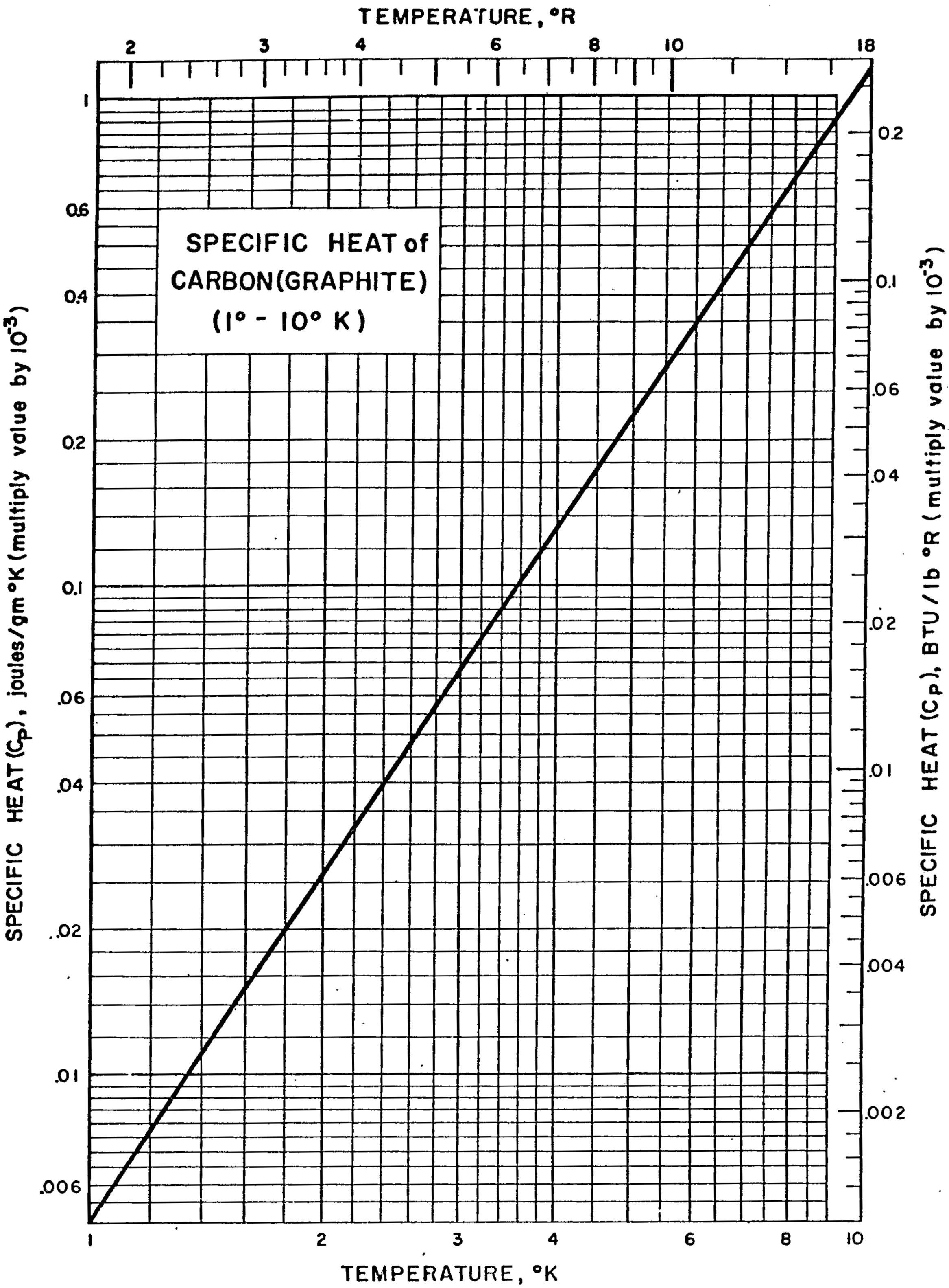
Comments:

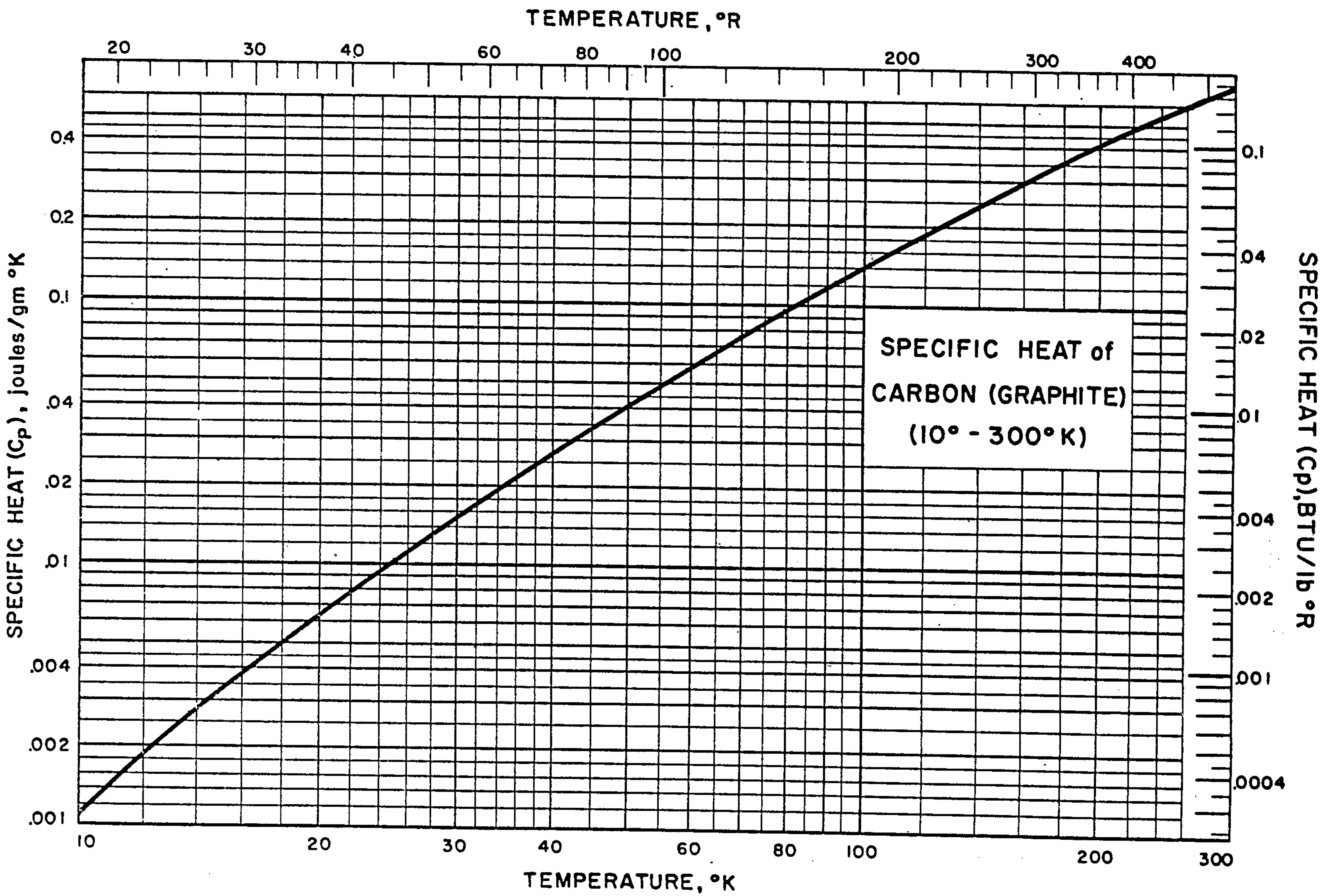
For $0 < T < 2°K$

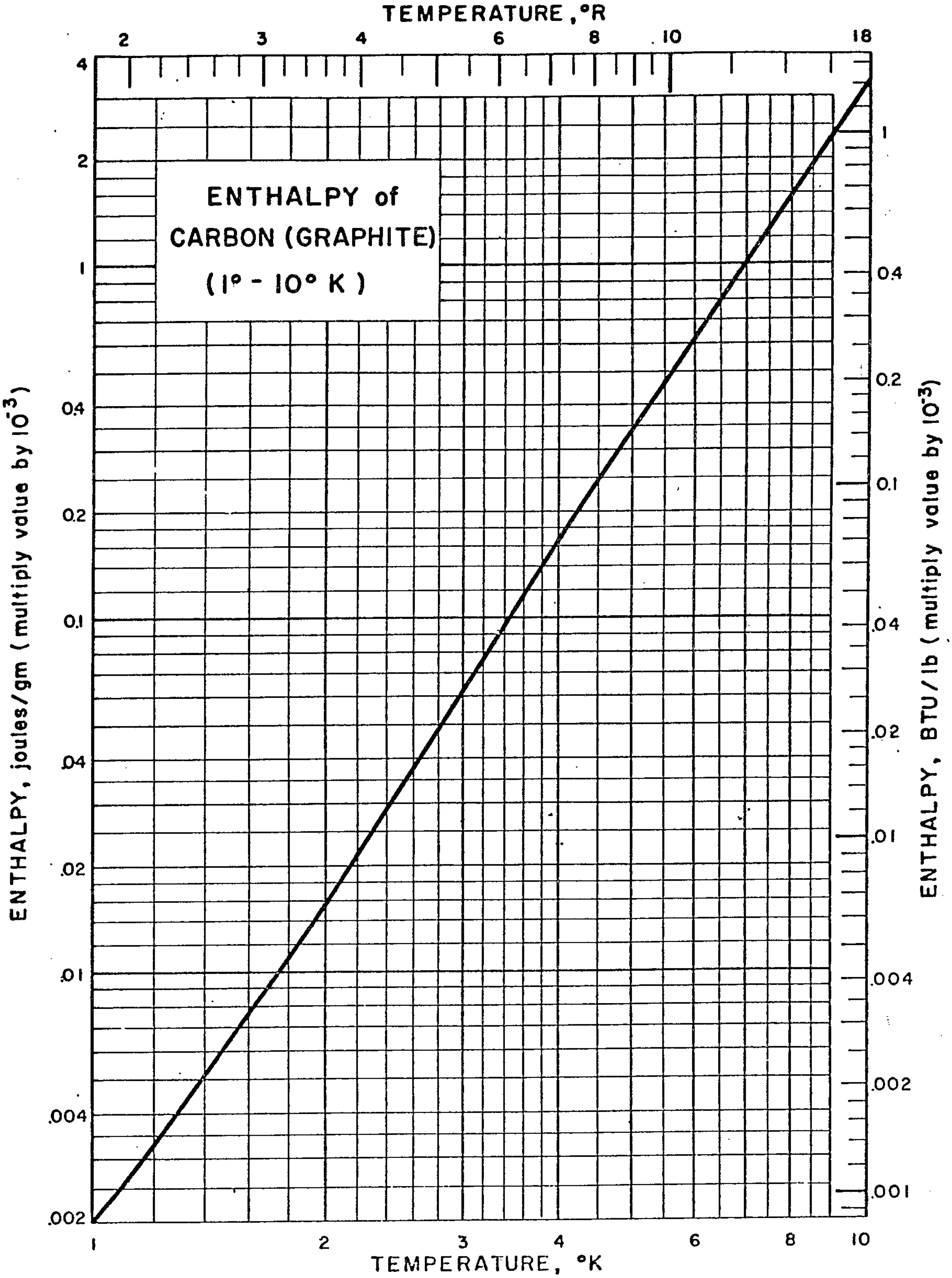
$$C_p = 162\ (T/391)^3 + 2.6 \times 10^{-6}\ T\ \text{j/gm-°K}$$

Temp. °K	C_p j/gm-°K	H j/gm	Temp. °K	C_p j/gm-°K	H j/gm
1	.000 005	.000 002	70	.077	1.87
2	.000 027	.000 016	80	.097	2.74
3	.000 070	.000 062	90	.118	3.81
4	.000 144	.000 168	100	.140	5.10
6	.000 33	.000 61	120	.188	8.37
8	.000 64	.001 56	140	.240	12.65
10	.001 14	.003 3	160	.296	18.0
15	.003 3	.014 2	180	.355	24.5
20	.006 3	.038	200	.414	32.2
25	.010 3	.079	220	.474	41.1
30	.015 5	.143	240	.535	51.2
40	.027	.36	260	.595	62.5
50	.042	.70	280	.656	75.0
60	.058	1.20	300	.716	88.7

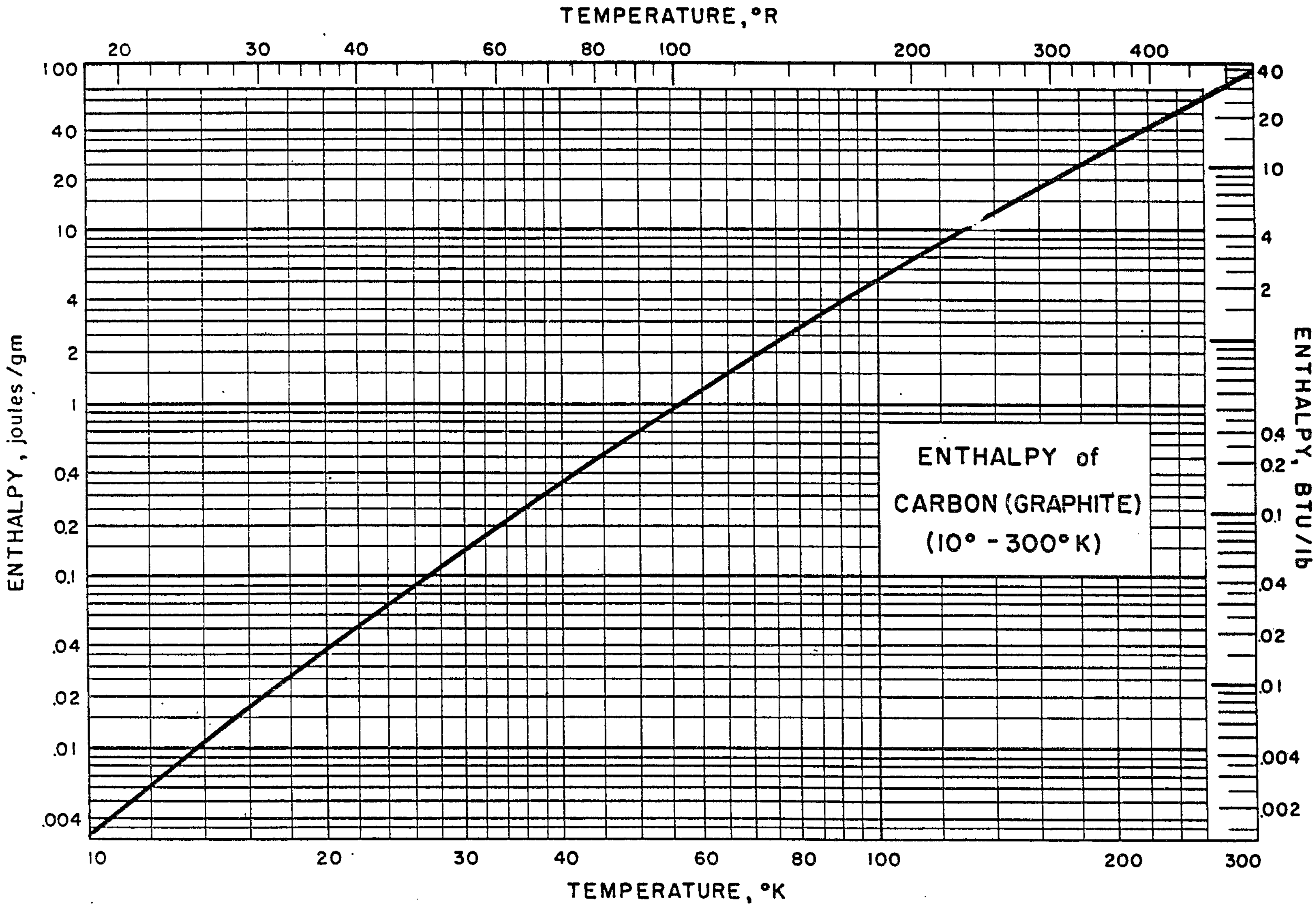
RJC/JJG Issued: 12-16-59
Revised: 5-20-60

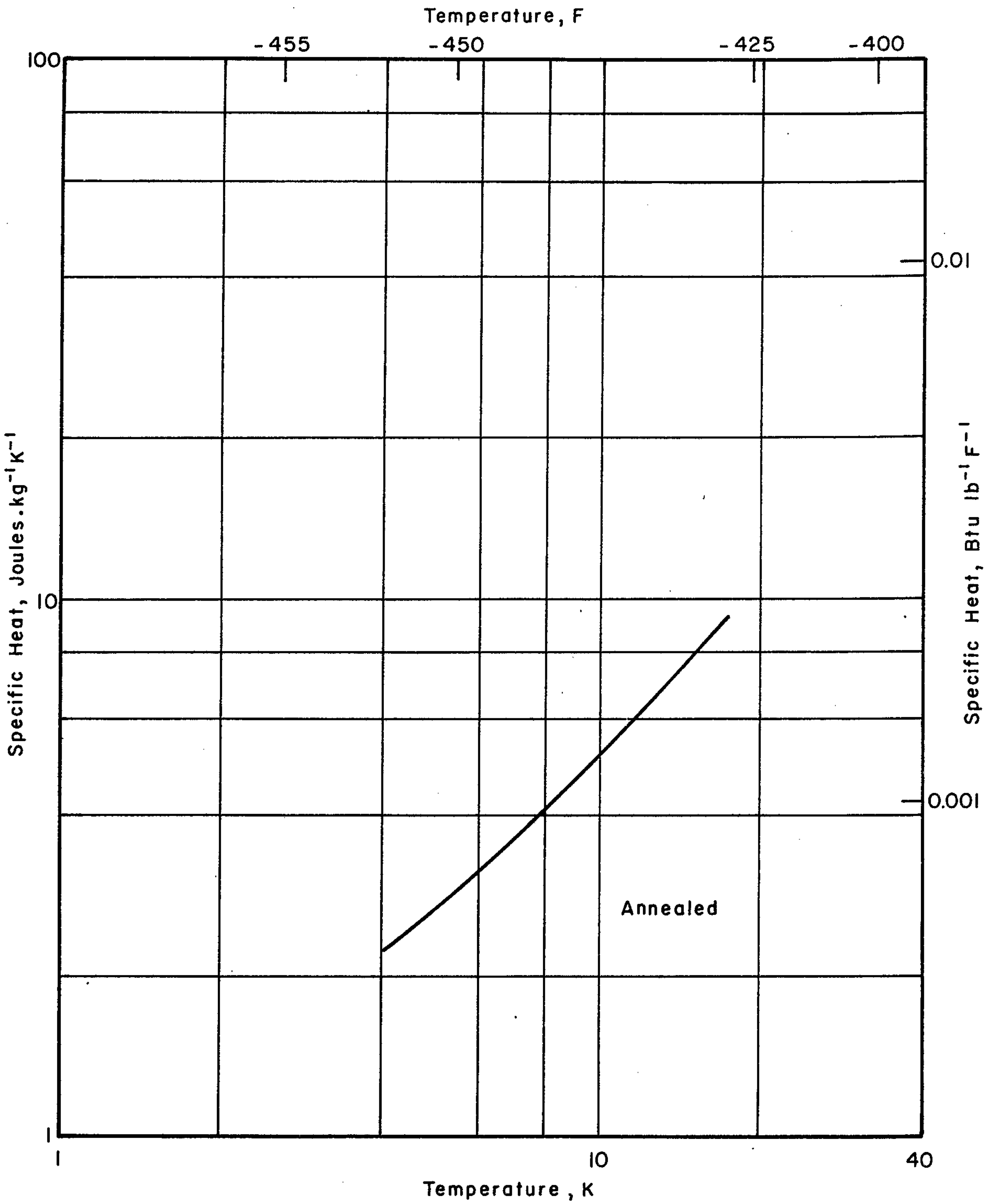

TEMPERATURE, °R
2
3
4
6
8
10
18
SPECIFIC HEAT of
CARBON(GRAPHITE)
(1° - 10° K)
1
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.006
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
1
2
3
4
6
8
10
TEMPERATURE, °K
SPECIFIC HEAT (C_p), joules/gm °K (multiply value by 10^{-3})
SPECIFIC HEAT (C_p), BTU/lb °R (multiply value by 10^{-3})


TEMPERATURE, °R
20
30
40
60
80
100
200
300
400
SPECIFIC HEAT (Cp), joules/gm °K
0.4
0.2
0.1
.04
.02
.01
.004
.002
.001
SPECIFIC HEAT (Cp),BTU/lb °R
0.1
.04
.02
.01
.004
.002
.001
.0004
SPECIFIC HEAT of CARBON (GRAPHITE) (10° - 300° K)
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K

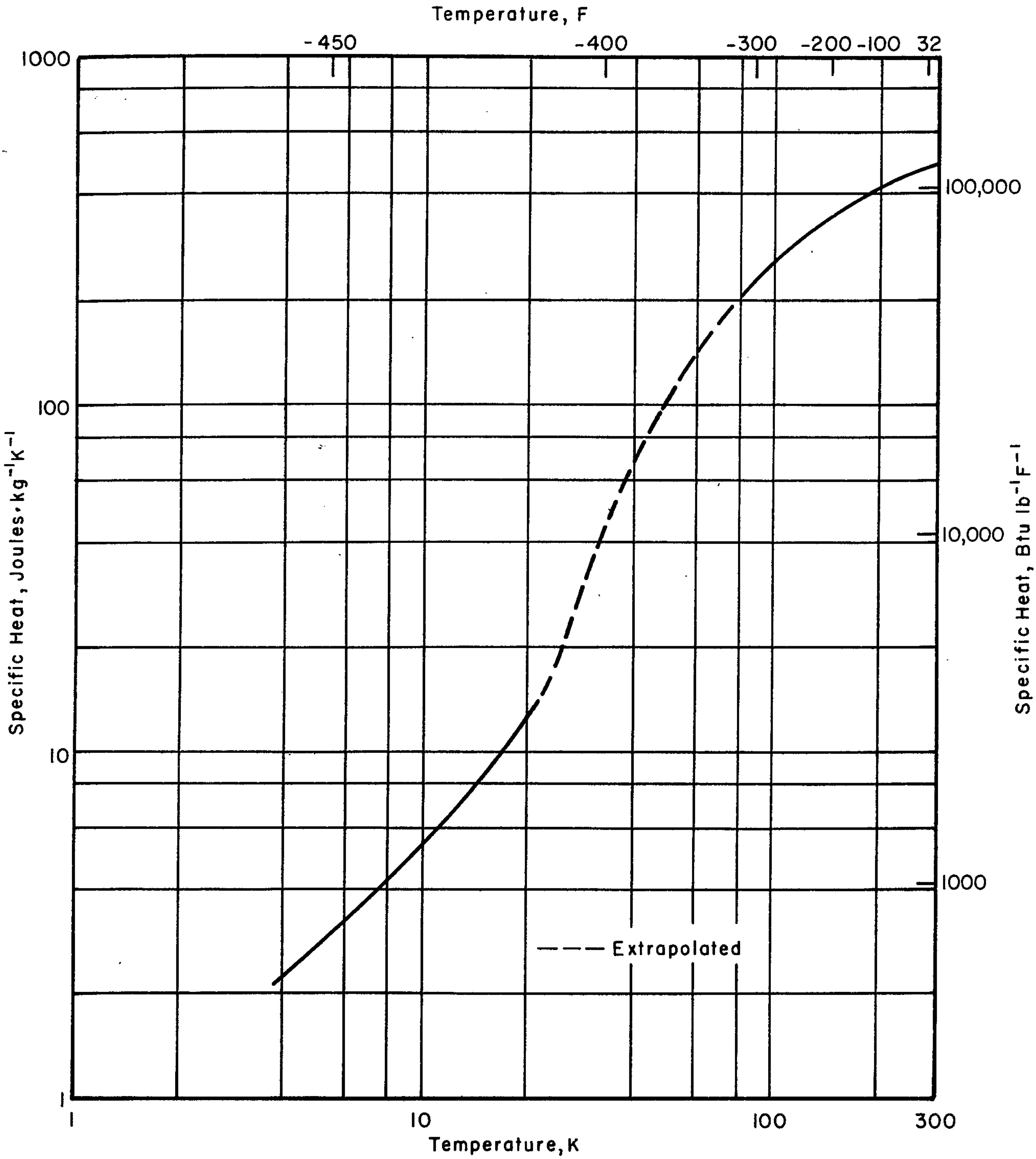


TEMPERATURE, °R
2
3
4
6
8
10
18
ENTHALPY of
CARBON (GRAPHITE)
(1° - 10° K)
4
2
1
0.4
0.2
0.1
.04
.02
.01
.004
.002
ENTHALPY, joules/gm (multiply value by 10^-3)
1
0.4
0.2
0.1
.04
.02
.01
.004
.002
.001
ENTHALPY, BTU/lb (multiply value by 10^-3)
1
2
3
4
6
8
10
TEMPERATURE, °K


TEMPERATURE, °R
ENTHALPY, joules/gm
ENTHALPY, BTU/lb
TEMPERATURE, °K
ENTHALPY of
CARBON (GRAPHITE)
(10° - 300° K)



SPECIFIC HEAT VERSUS TEMPERATURE FOR TYPE 310S STAINLESS STEEL



SPECIFIC HEAT VERSUS TEMPERATURE FOR TYPE 310S STAINLESS STEEL

SPECIFIC HEAT, ENTHALPY of BERYLLIUM

Source of Data:

Hill, R. W. and Smith, P. L., Phil. Mag. 44, 636-44 (1953)

Other References:

Cristescu, S. and Simon, F., Z. physik. Chem. B25, 273 (1934)

Kelley, K. K., U.S. Bur. Mines Bull. No. 476 (1949)

Lewis, E. J., Phys. Rev. (2) 34, 1575 (1929)

Simon, F. and Ruhemann, M., Z. physik. Chem. 129, 321 (1927)

Comments:

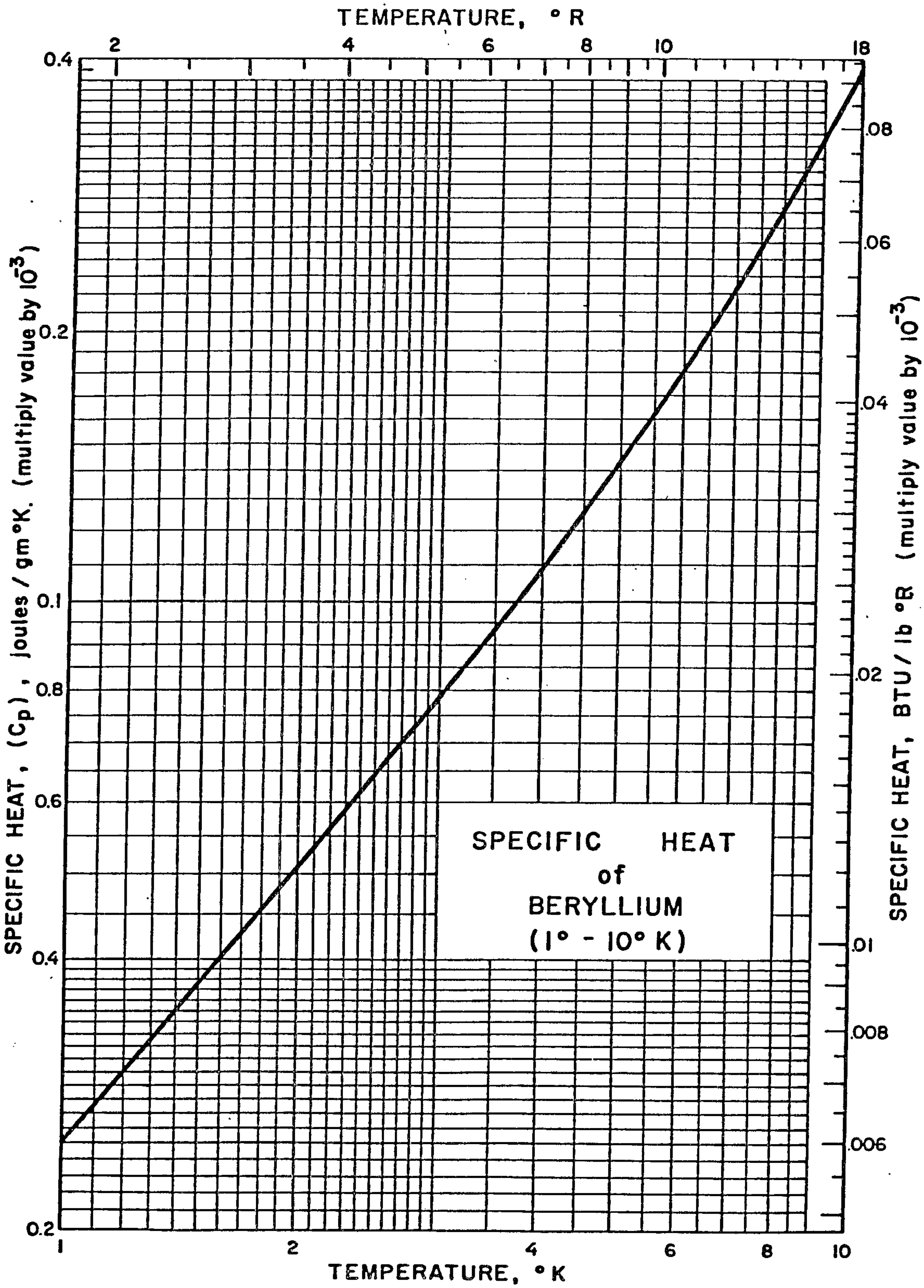
For the temperature range from 0° to 20°K, the specific heat C_p follows the equation:

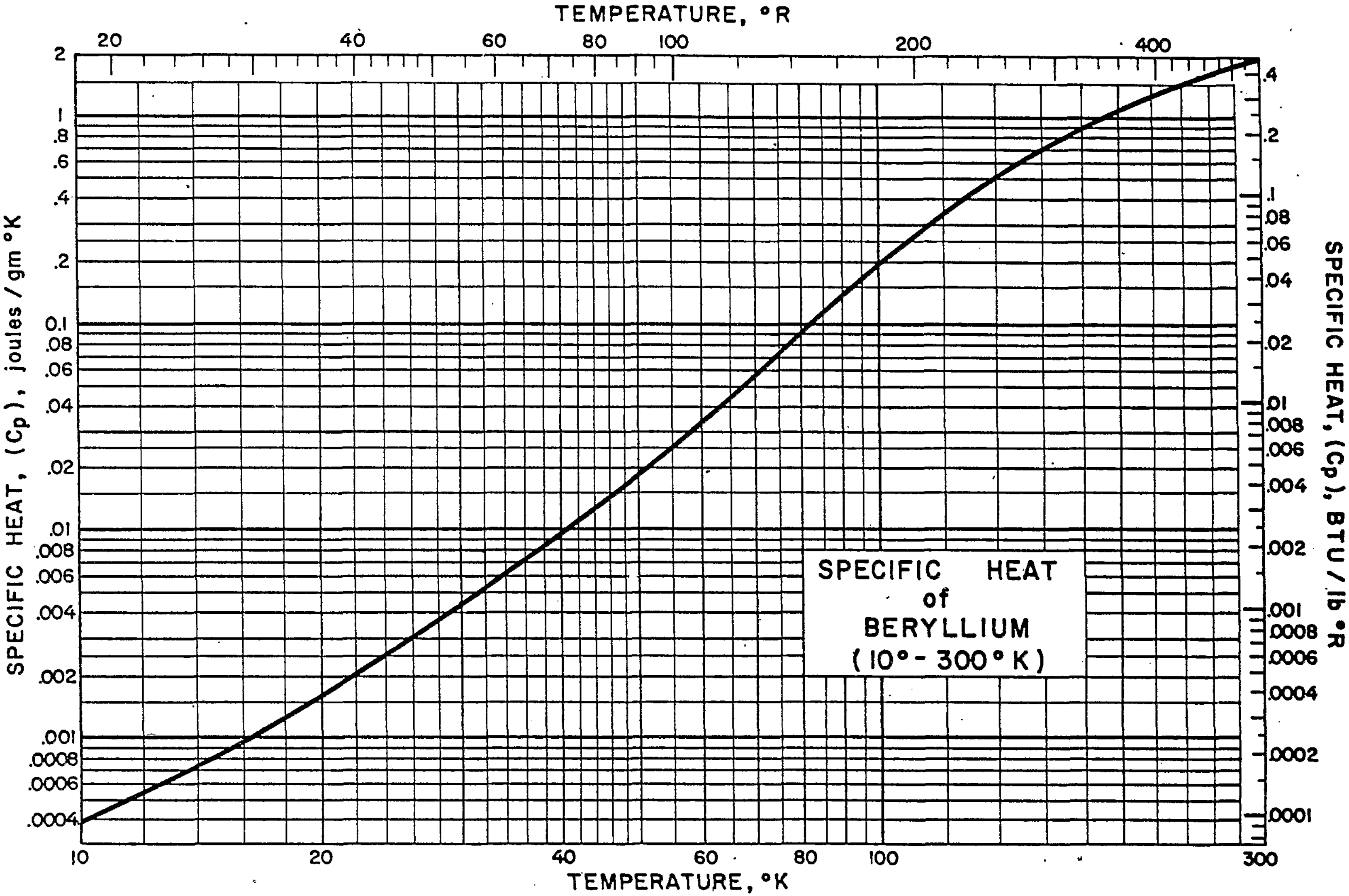
$$C_p = (2.5 \pm 0.4) \times 10^{-5} T + 215.7 \left(\frac{T}{1160 \pm 5} \right)^3 \text{ j/gm-°K}$$

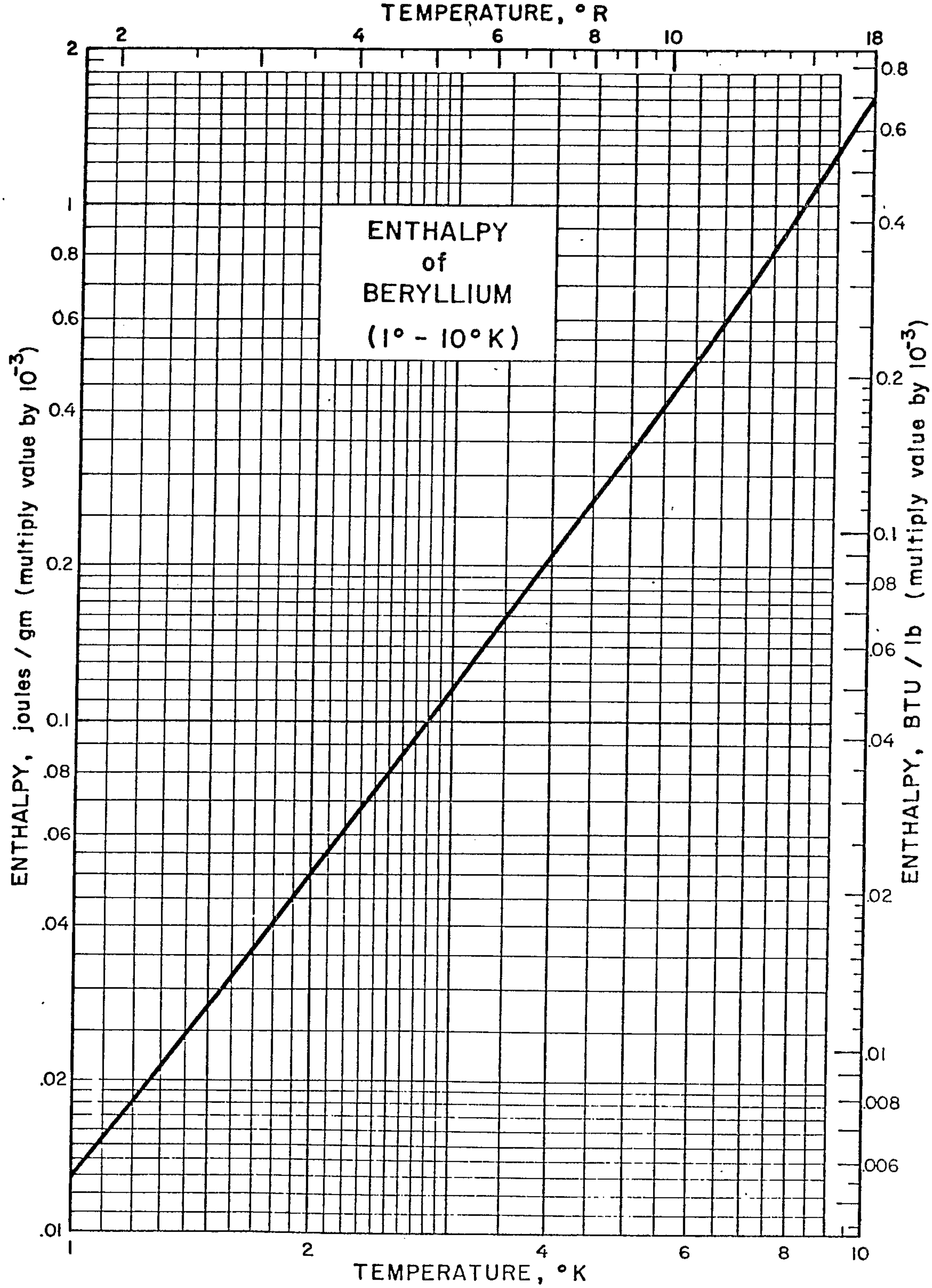
Table of Selected Values

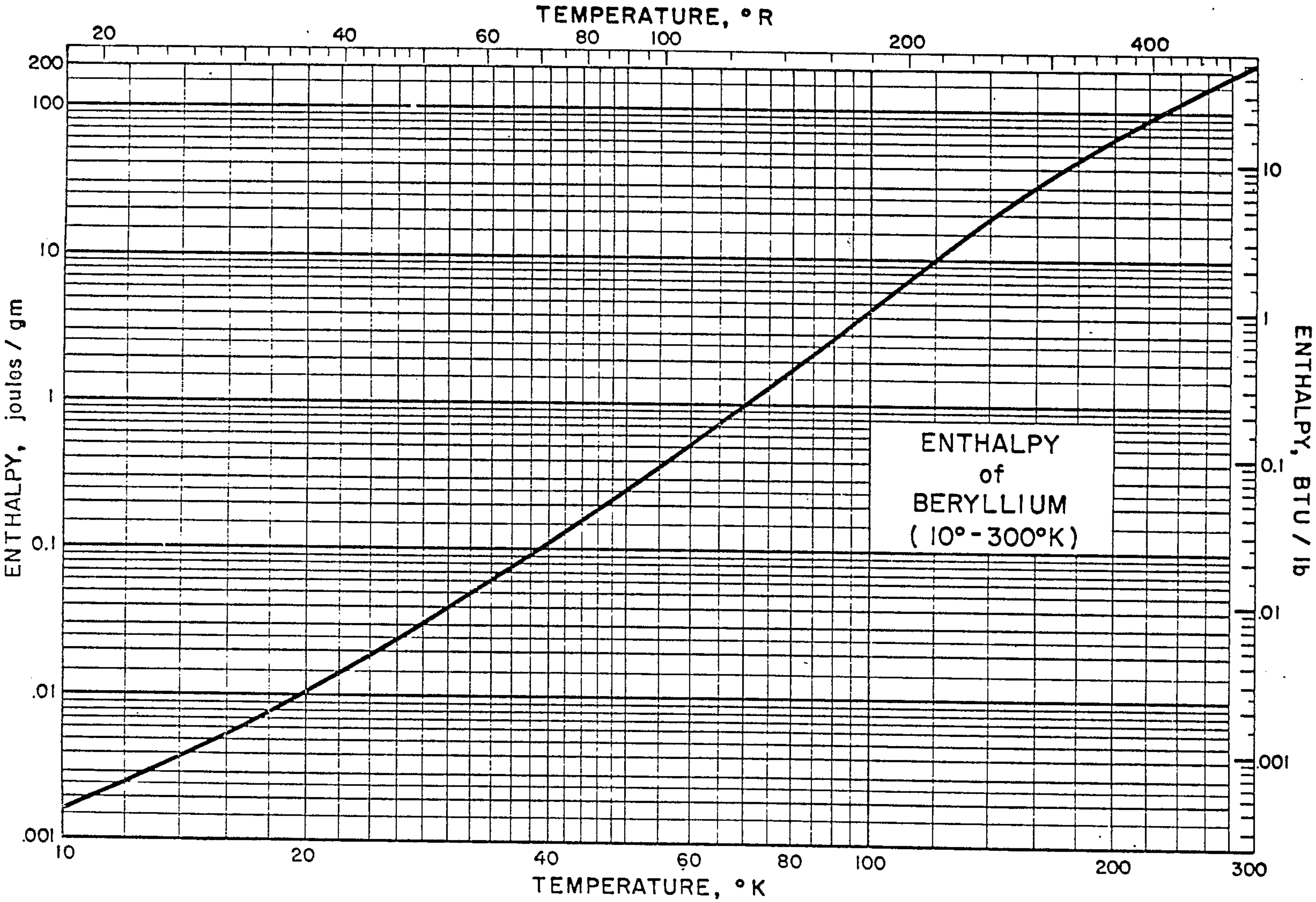
Temp. °K	C_p j/gm-°K	H j/gm	Temp. °K	C_p j/gm-°K	H j/gm
1	0.000 025	0.000 013	70	0.0562	0.971
2	.000 051	.000 051	80	.0906	1.69
3	.000 079	.000 116	90	.139	2.82
4	.000 109	.000 209	100	.199	4.51
6	.000 180	.000 496	120	.345	9.87
8	.000 271	.000 944	140	.525	18.5
10	.000 389	.001 60	160	.723	31.0
15	.000 842	.004 57	180	.921	47.4
20	.001 61	.010 5	200	1.11	67.8
25	.002 79	.021 2	220	1.29	91.8
30	.004 50	.039 2	240	1.47	120
40	.009 96	.109	260	1.64	151
50	.019 2	.253	280	1.81	185
60	.034 1	.523	300	1.97	223

RJC/JJG Issued: 10-13-59


TEMPERATURE, °R
2
4
6
8
10
18
0.4
0.2
0.1
0.8
0.6
0.4
0.2
SPECIFIC HEAT, (Cp), Joules / gm °K. (multiply value by 10-3)
.08
.06
.04
.02
.01
.008
.006
SPECIFIC HEAT, BTU / lb °R (multiply value by 10-3)
SPECIFIC HEAT
of
BERYLLIUM
(1° - 10° K)
1
2
4
6
8
10
TEMPERATURE, °K


TEMPERATURE, °R
20 40 60 80 100 200 400
SPECIFIC HEAT, (Cp), joules / gm °K
2 1 .8 .6 .4 .2 0.1 .08 .06 .04 .02 .01 .008 .006 .004 .002 .001 .0008 .0006 .0004
SPECIFIC HEAT, (Cp), BTU / lb °R
.4 .2 .1 .08 .06 .04 .02 .01 .008 .006 .004 .002 .001 .0008 .0006 .0004 .0002 .0001
SPECIFIC HEAT of BERYLLIUM (10° - 300° K)
10 20 40 60 80 100 300
TEMPERATURE, °K


TEMPERATURE, °R
ENTHALPY
of
BERYLLIUM
(1° - 10° K)
ENTHALPY, joules / gm (multiply value by 10^{-3})
ENTHALPY, BTU / lb (multiply value by 10^{-3})
TEMPERATURE, °K


TEMPERATURE, °R
20
40
60
80
100
200
400
200
100
10
1
0.1
.01
.001
ENTHALPY, joules / gm
10
20
40
60
80
100
200
300
TEMPERATURE, °K
10
1
0.1
.01
.001
ENTHALPY, BTU / lb
ENTHALPY
of
BERYLLIUM
(10°-300°K)

SPECIFIC HEAT, ENTHALPY of TIN (white)

Sources of Data:

Corak, W. S. and Satterwaite, C. B., Phys. Rev. 102, 662 (1956)
Goodman, B. B., Compt. rend. 244, 2899 (1957)
Keesom, W. H. and Van den Ende, J. N., Proc. Acad. Sci. Amsterdam 35, 143 (1932)
Lange, F., Z. physik. Chem. 110, 343 (1924)
Rodebush, W. H., J. Am. Chem. Soc. 45, 1413 (1923)

Other References:

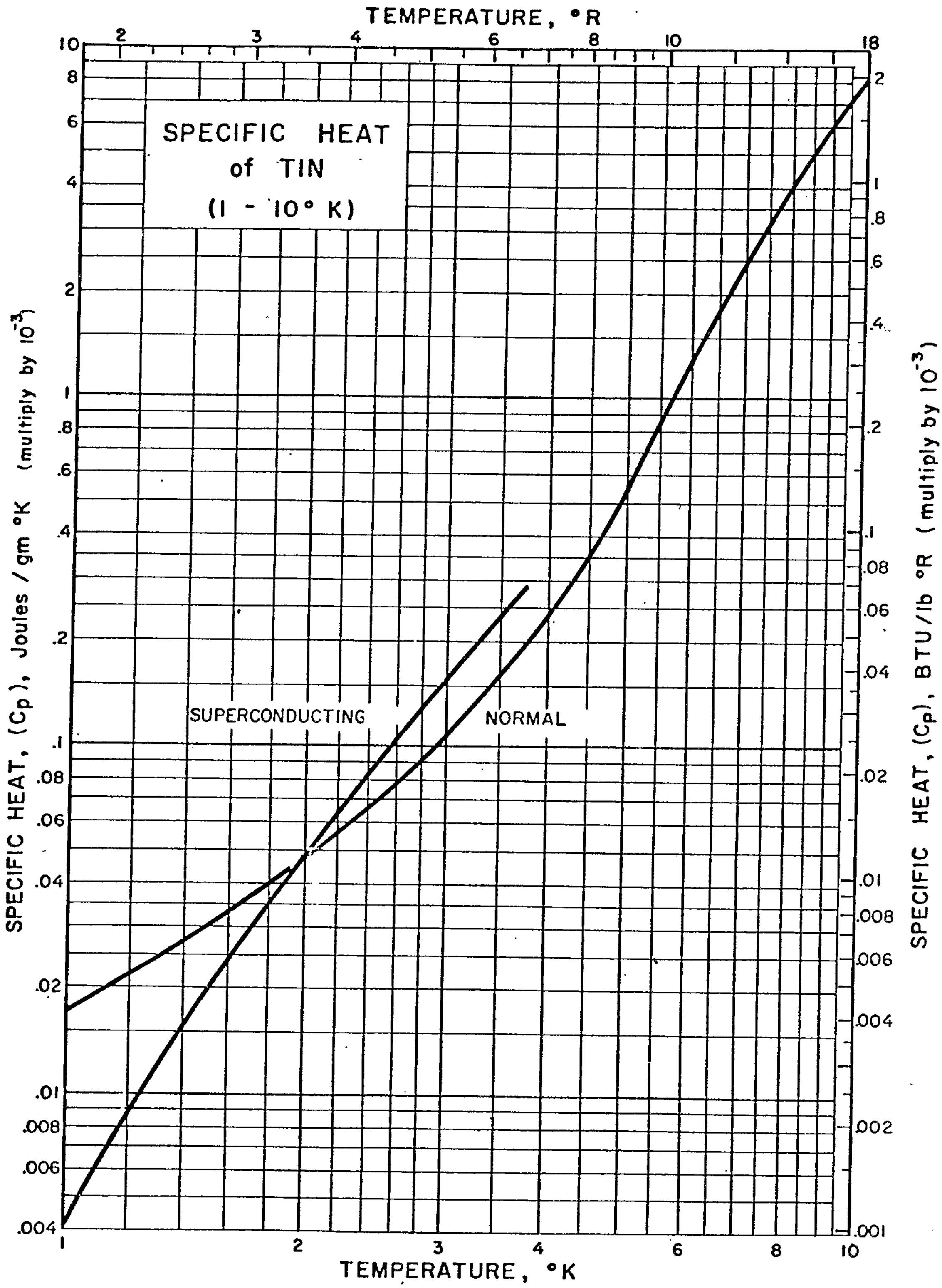
Brönsted, J. N., Z. physik. Chem. 88, 479 (1914)
Keesom, W. H. and Kok, J. A., Proc. Acad. Sci. Amsterdam 35, 743 (1932)
Keesom, W. H. and Van Laer, P. H., Physica 3, 371 (1936)
Keesom, W. H. and Van Laer, P. H., Physica 4, 487 (1937)
Keesom, W. H. and Van Laer, P. H., Physica 5, 193 (1938)
Ramanathan, K. G. and Srinivasan, T. M., Phil. Mag. 46, 338 (1955)
Richards, T. W. and Jackson, R. G., Z. physik. Chem. 70, 414 (1910)
Schmitz, H. E., Proc. Roy. Soc. (London) 72, 177 (1903)

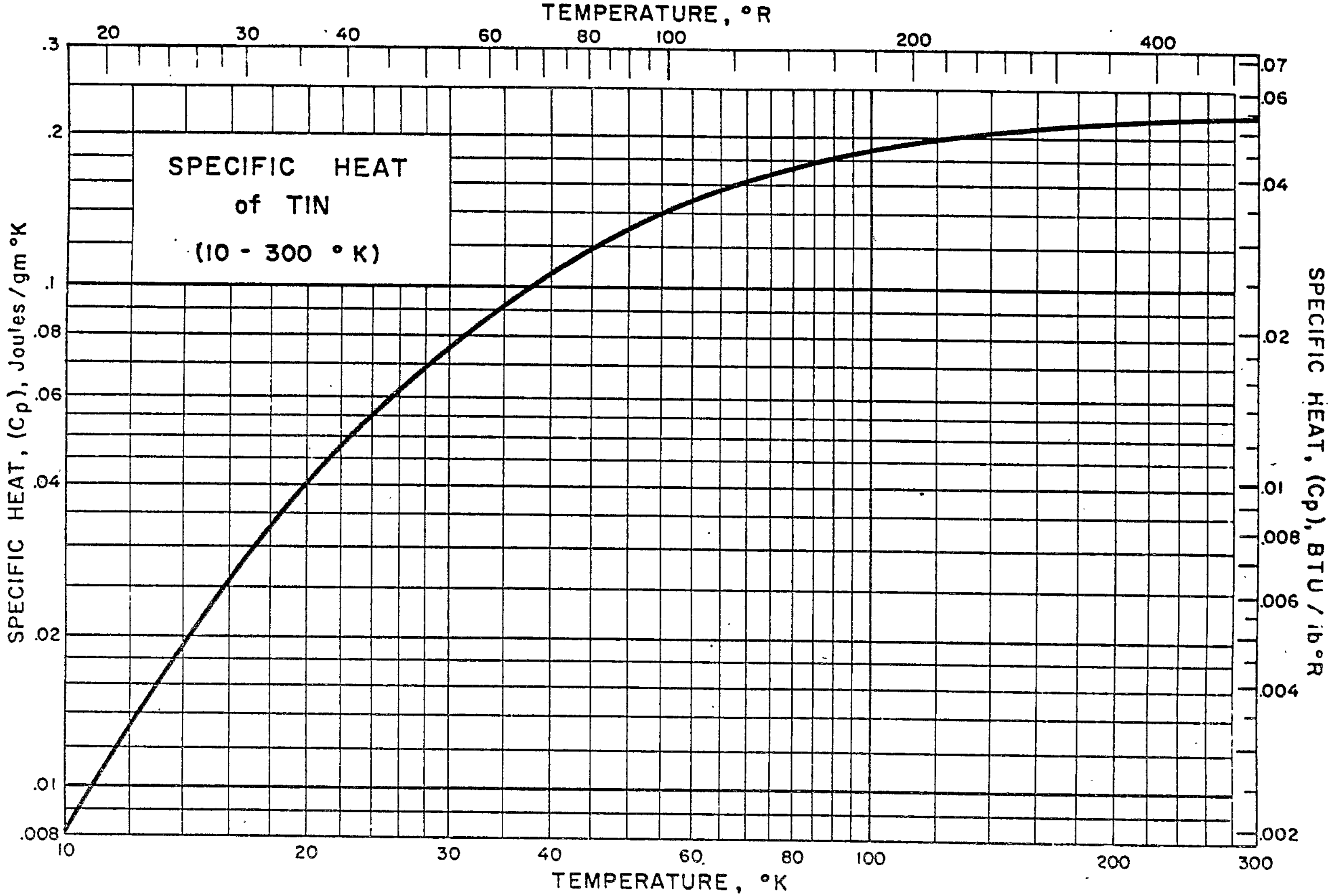
Table of Selected Values

Temp.	C_p, j/gm-°K		H, j/gm		Temp.	C_p, j/gm-°K	H, j/gm
°K	Normal	Super-conducting	Normal	Super-conducting	°K	Normal	Normal
1	0.000 0170	0.000 0041	0.000 0079	0.000 0009	60	0.148	4.33
2	.000 047	.000 048	.000 0383	.000 0228	70	.162	5.88
3	.000 109	.000 151	.000 113	.000 116	80	.173	7.55
*3.72	.000 198	.000 285	.000 221	.000 270	90	.182	9.33
4	.000 245		.000 283		100	.189	11.18
5	.000 54		.000 65		120	.198	15.05
6	.001 27		.001 51		140	.204	19.1
8	.004 2		.006 8		160	.208	23.2
10	.008 1		.019 0		180	.212	27.4
15	.022 6		.093		200	.214	31.7
20	.040		.251		220	.216	36.0
25	.058		.498		240	.218	40.3
30	.076		.834		260	.220	44.7
40	.106		1.75		280	.221	49.1
50	.130		2.93		300	.222	53.6

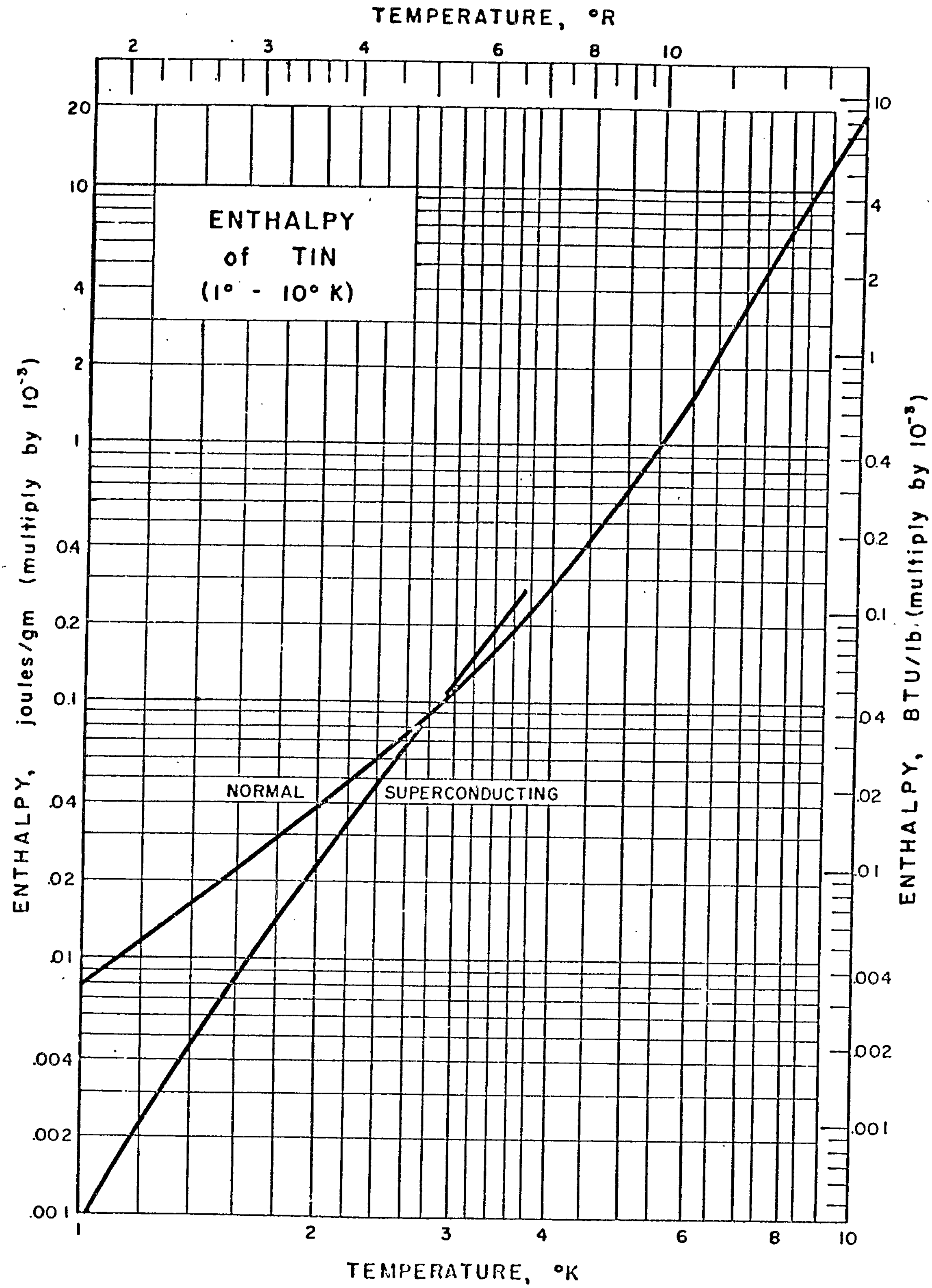
* Superconducting transition temperature

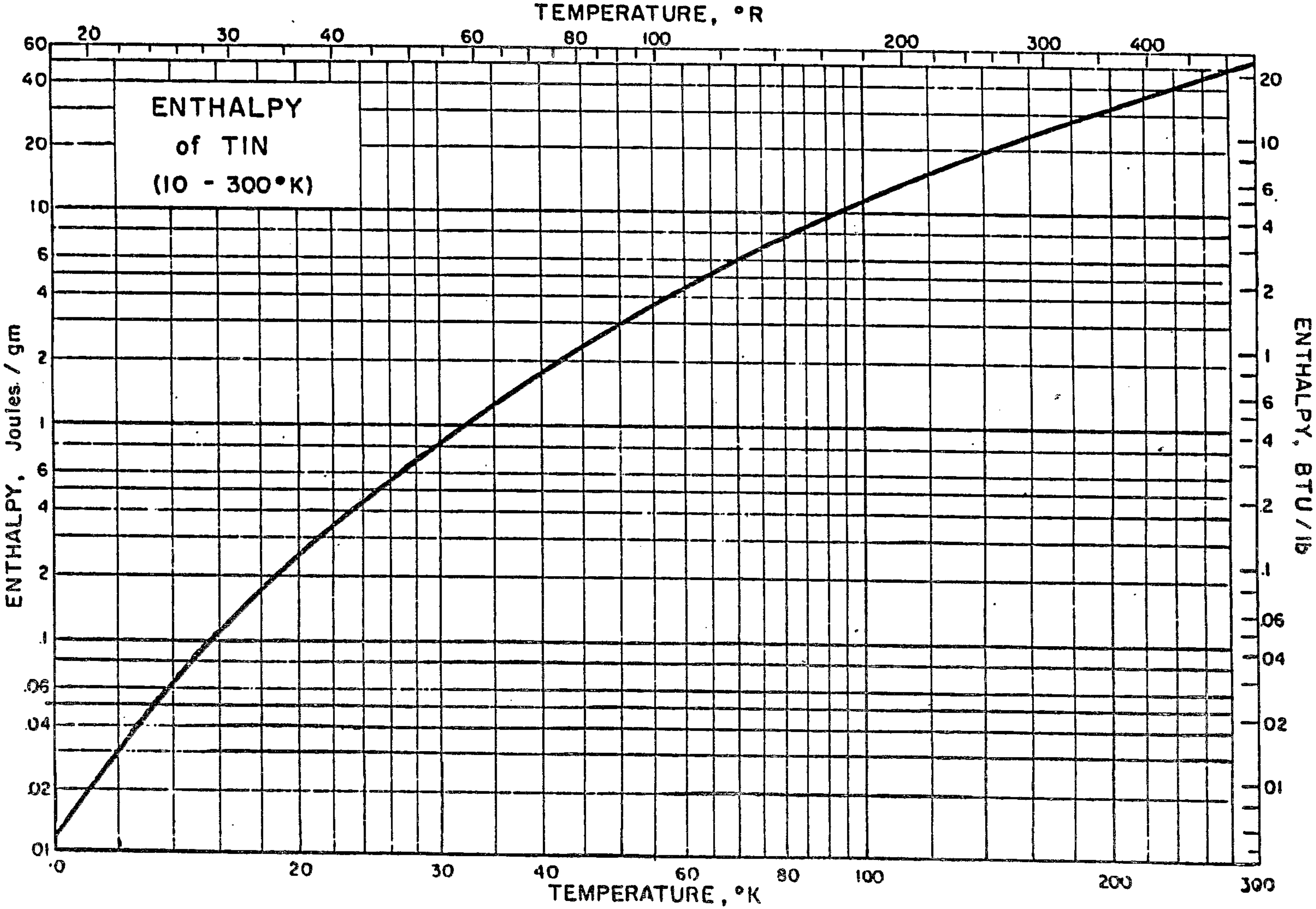
RJC Issued: 6-5-59
Revised: 5-20-60

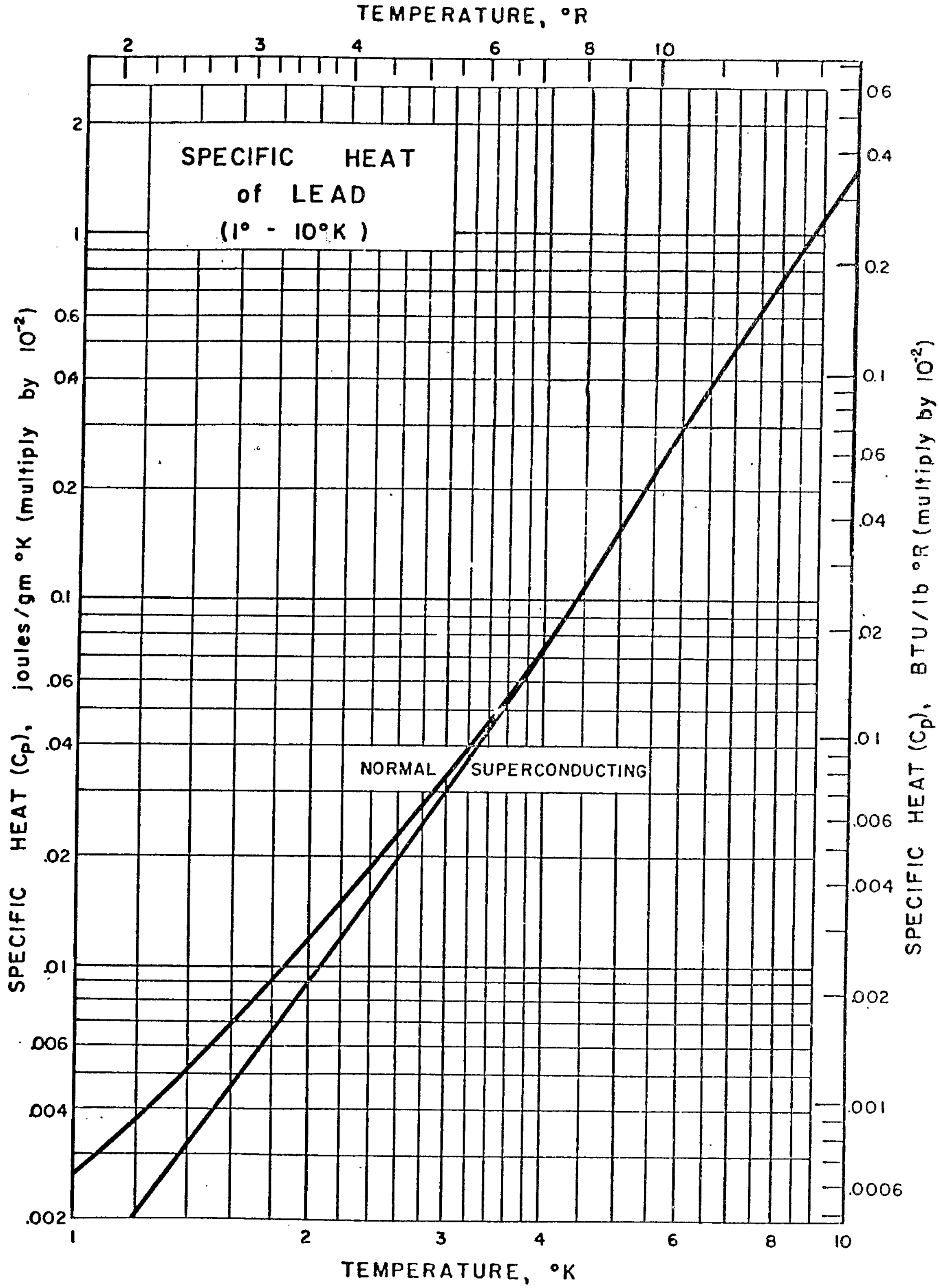

TEMPERATURE, °R
SPECIFIC HEAT
of TIN
(1 - 10° K)
SUPERCONDUCTING
NORMAL
SPECIFIC HEAT, (Cp), Joules / gm °K (multiply by 10-3)
SPECIFIC HEAT, (Cp), BTU/lb °R (multiply by 10-3)
TEMPERATURE, °K



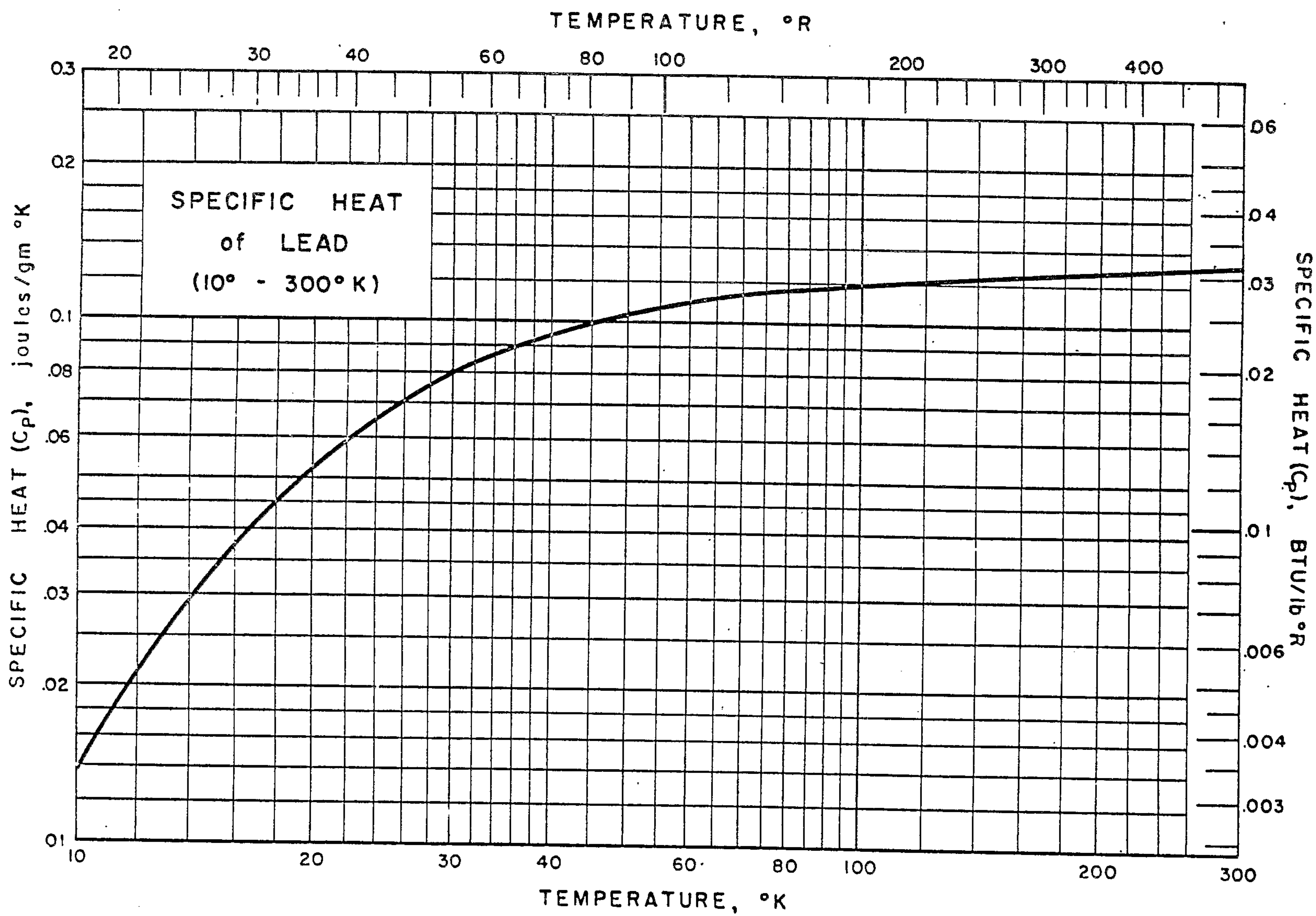
SPECIFIC HEAT
of TIN
(10 - 300 °K)
TEMPERATURE, °R
20
30
40
60
80
100
200
400
TEMPERATURE, °K
10
20
30
40
60
80
100
200
300
SPECIFIC HEAT, (Cp), Joules/gm °K
.3
.2
.1
.08
.06
.04
.02
.01
.008
SPECIFIC HEAT, (Cp), BTU/lb °R
.07
.06
.04
.02
.01
.008
.006
.004
.002


TEMPERATURE, °R
2
3
4
6
8
10
ENTHALPY
of TIN
(1° - 10° K)
ENTHALPY, joules/gm (multiply by 10⁻³)
20
10
4
2
1
0.4
0.2
0.1
.04
.02
.01
.004
.002
.001
ENTHALPY, BTU/lb (multiply by 10⁻³)
10
4
2
1
0.4
0.2
0.1
.04
.02
.01
.004
.002
.001
NORMAL
SUPERCONDUCTING
1
2
3
4
6
8
10
TEMPERATURE, °K

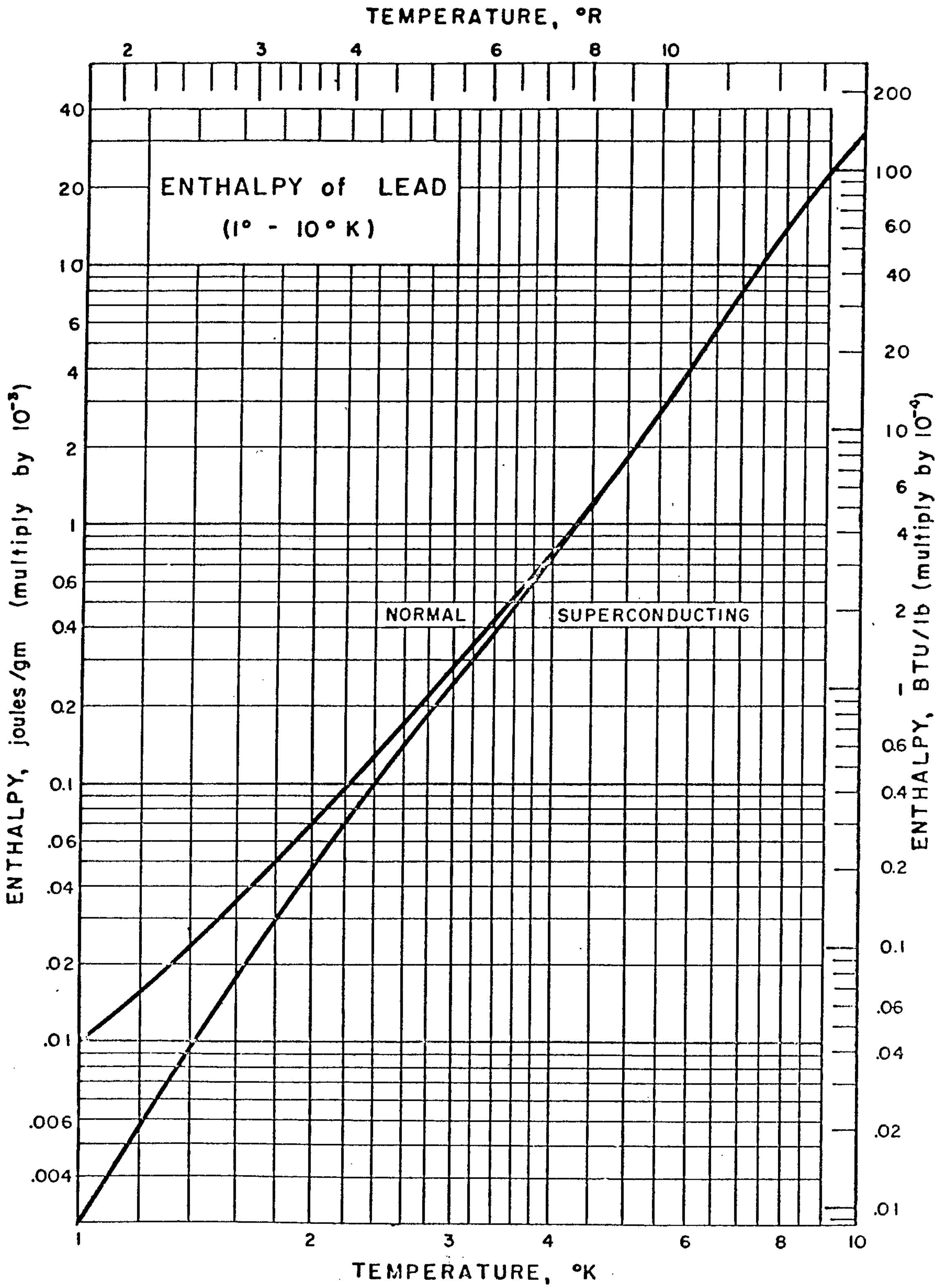

ENTHALPY
of TIN
(10 - 300°K)
TEMPERATURE, °R
20 30 40 60 80 100 200 300 400
ENTHALPY, Joules / gm
60 40 20 10 6 4 2 1 .6 .4 .2 .1 .06 .04 .02 .01
ENTHALPY, BTU / lb
20 10 6 4 2 1 .6 .4 .2 .1 .06 .04 .02 .01
TEMPERATURE, °K
10 20 30 40 60 80 100 200 300

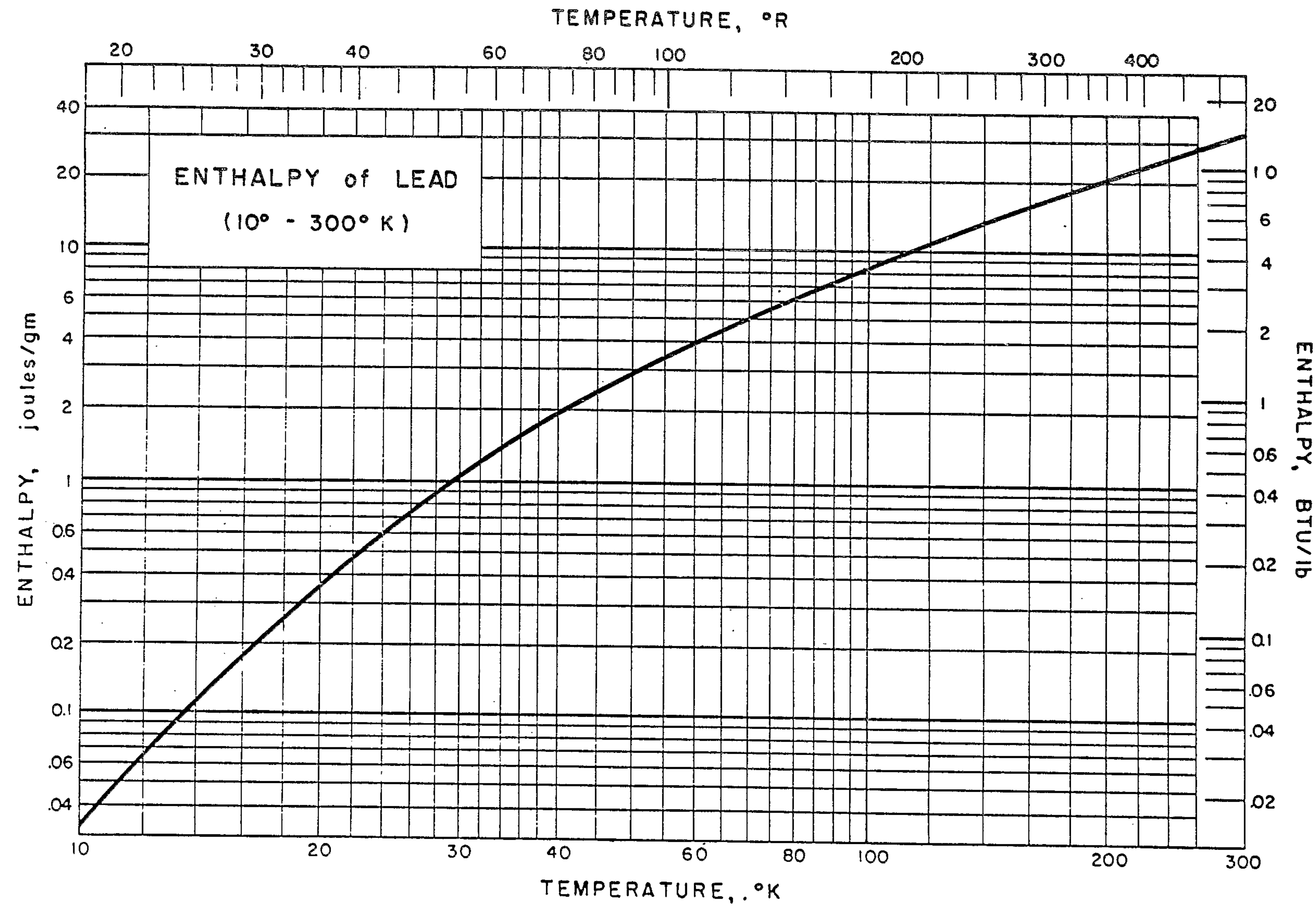


TEMPERATURE, °R
2
3
4
6
8
10
SPECIFIC HEAT
of LEAD
(1° - 10°K)
NORMAL
SUPERCONDUCTING
SPECIFIC HEAT (C_p), joules/gm °K (multiply by 10^{-2})
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
SPECIFIC HEAT (C_p), BTU/lb °R (multiply by 10^{-2})
.06
0.4
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
.001
.0006
1
2
3
4
6
8
10
TEMPERATURE, °K


SPECIFIC HEAT
of LEAD
(10° - 300° K)
TEMPERATURE, °R
20
30
40
60
80
100
200
300
400
TEMPERATURE, °K
10
20
30
40
60
80
100
200
300
SPECIFIC HEAT (C_p), joules/gm °K
0.3
0.2
0.1
.08
.06
.04
.03
.02
0.1
SPECIFIC HEAT (C_p), BTU/lb °R
.06
.04
.03
.02
.01
.006
.004
.003

VIII-T-2


TEMPERATURE, °R
ENTHALPY of LEAD
(1° - 10° K)
NORMAL
SUPERCONDUCTING
ENTHALPY, joules/gm (multiply by 10⁻³)
ENTHALPY, BTU/lb (multiply by 10⁻⁴)
TEMPERATURE, °K


ENTHALPY of LEAD
(10° - 300° K)
TEMPERATURE, °R
20
30
40
60
80
100
200
300
400
ENTHALPY, joules/gm
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
.06
.04
ENTHALPY, BTU/lb
20
10
6
4
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
10
20
30
40
60
80
100
200
300
TEMPERATURE, °K