Section 4

HEAT

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CONTENTS

4a. Temperature Scales, Thermocouples, and Resistance Thermometers[1]

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The National Bureau of Standards

The Comité International des Poids et Mesures (CIPM) in October, 1968, agreed to adopt the International Practical Temperature Scale of 1968[2] (IPTS-68) in accordance with the decision of the 13th General Conference of Weights and Measures, Resolution 8, of October, 1967. IPTS-68 has replaced IPTS-48 (amended edition of 1960). It was formulated in such a way that temperature measured on it closely approximates the thermodynamic temperature, and extends the range of definition down to 13.81 kelvins. (The previous scale, IPTS-48, terminated at −183°C.)

The basic temperature is the thermodynamic temperature, symbol T, the unit of which is the kelvin, symbol K. The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.[3] The Celsius temperature, symbol t, is defined by

$$t = T - T_0$$

where $T_0 = 273.15$ K (the ice point). The unit employed to express a Celsius temperature is the degree Celsius, symbol °C, which is equal to the kelvin. A difference of temperature is expressed in kelvins; it may also be expressed in degrees Celsius.

The International Practical Temperature Scale of 1968 distinguishes between the International Practical Kelvin Temperature with the symbol T_{68} and the International Practical Celsius Temperature with the symbol t_{68}. The relation between T_{68} and t_{68} is

$$t_{68} = T_{68} - 273.15 \text{ K}$$

The units of T_{68} and t_{68} are the kelvin, symbol K, and degree Celsius, symbol °C, as in the case of the thermodynamic temperature T and the Celsius temperature t.

The IPTS-68 is based on the assigned values of the temperatures of a number of reproducible equilibrium states (defining fixed points) and on standard instruments calibrated at those temperatures. Interpolation between the fixed-point temperatures is provided by formulas used to establish the relation between indications of the standard instruments and values of the International Practical Temperature. The defining fixed points are given in Table 4a-1.

[1] Acknowledgment is made of the previous contributions to this section in the second edition of the Handbook by H. F. Stimson, J. F. Swindells, and R. E. Wilson. Data on optical pyrometry and thermal radiation are given in Sec. 6.

[2] The text in French of this scale is published in *Compt. rend. 13ème conf. gén. poids mesures*, 1967–1968, Annexe 2, and Comité Consultatif de Thermométrie, 8e session, 1967, Annexe 18. The English text is published in *Metrologia* **5**(2), 35 (1969).

[3] 13th General Conference of Weights and Measures, 1967, Resolutions 3 and 4.

TABLE 4a-1. DEFINING FIXED POINTS OF THE IPTS-68*

Equilibrium state	Assigned value of International Practical Temperature	
	T_{68} K	t_{68} °C
Equilibrium between the solid, liquid, and vapor phases of equilibrium hydrogen (triple point of equilibrium hydrogen)	13.81	−259.34
Equilibrium between the liquid and vapor phases of equilibrium hydrogen at a pressure of 33 330.6 N/m² (25/76 standard atmosphere)	17.042	−256.108
Equilibrium between the liquid and vapor phases of equilibrium hydrogen (boiling point of equilibrium hydrogen)	20.28	−252.87
Equilibrium between the liquid and vapor phases of neon (boiling point of neon)	27.402	−246.048
Equilibrium between the solid, liquid, and vapor phases of oxygen (triple point of oxygen)	54.361	−218.789
Equilibrium between the liquid and vapor phases of oxygen (boiling point of oxygen)	90.188	−182.962
Equilibrium between the solid, liquid, and vapor phases of water (triple point of water)†	273.16	0.01
Equilibrium between the liquid and vapor phases of water (boiling point of water)†‡	373.15	100
Equilibrium between the solid and liquid phases of zinc (freezing point of zinc)	692.73	419.58
Equilibrium between the solid and liquid phases of silver (freezing point of silver)	1235.08	961.93
Equilibrium between the solid and liquid phases of gold (freezing point of gold)	1337.58	1064.43

* Except for the triple points and one equilibrium hydrogen point (17.042 K) the assigned values of temperature are for equilibrium states at a pressure p_0 = 1 standard atmosphere (101 325 N/m²). In the realization of the fixed points small departures from the assigned temperatures will occur as a result of the differing immersion depths of thermometers or the failure to realize the required pressure exactly. If due allowance is made for these small temperature differences, they will not affect the accuracy of realization of the Scale.

† The water used should have the isotopic composition of ocean water.

‡ The equilibrium state between the solid and liquid phases of tin (freezing point of tin) has the assigned value of t_{68} = 231.9681 °C and may be used as an alternative to the boiling point of water.

In the range 13.81 to 273.15 K, the interpolating instrument is a platinum thermometer and T_{68} is defined by the relation

$$W(T_{68}) = W_{CCT\text{-}68}(T_{68}) + \Delta W(T_{68}) \qquad (4a\text{-}1)$$

where $W(T_{68})$ is the resistance ratio of the platinum thermometer as defined by

$$W(T_{68}) = \frac{R(T_{68})}{R(273.15\text{ K})}$$

and $W_{CCT\text{-}68}(T_{68})$ is the resistance ratio as given by the reference function in Table 4a-2.

The deviations $\Delta W(T_{68})$ at the temperatures of the defining fixed points are the differences between the measured values of $W(T_{68})$ and the corresponding values of $W_{CCT\text{-}68}(T_{68})$.

Table 4a-2. The Reference Function $W_{CCT\text{-}68}(T_{68})$ for Platinum Resistance Thermometers for the Range from 13.81 to 273.15 K*

$$T_{68} = \left\{ A_0 + \sum_{i=1}^{20} A_i [\ln W_{CCT\text{-}68}(T_{68})]^i \right\} \text{ K}$$

Coefficients A_i:

i	A_i	i	A_i
0	$0.273\,15 \times 10^3$	11	$0.767\,976\,358\,170\,845\,8 \times 10$
1	$0.250\,846\,209\,678\,803\,3 \times 10^3$	12	$0.213\,689\,459\,382\,850\,0 \times 10$
2	$0.135\,099\,869\,964\,999\,7 \times 10^3$	13	$0.459\,843\,348\,928\,069\,3$
3	$0.527\,856\,759\,008\,517\,2 \times 10^2$	14	$0.763\,614\,629\,231\,648\,0 \times 10^{-1}$
4	$0.276\,768\,548\,854\,105\,2 \times 10^2$	15	$0.969\,328\,620\,373\,121\,3 \times 10^{-2}$
5	$0.391\,053\,205\,376\,683\,7 \times 10^2$	16	$0.923\,069\,154\,007\,007\,5 \times 10^{-3}$
6	$0.655\,613\,230\,578\,069\,3 \times 10^2$	17	$0.638\,116\,590\,952\,653\,8 \times 10^{-4}$
7	$0.808\,035\,868\,559\,866\,7 \times 10^2$	18	$0.302\,293\,237\,874\,619\,2 \times 10^{-5}$
8	$0.705\,242\,118\,234\,052\,0 \times 10^2$	19	$0.877\,551\,391\,303\,760\,2 \times 10^{-7}$
9	$0.447\,847\,589\,638\,965\,7 \times 10^2$	20	$0.117\,702\,613\,125\,477\,4 \times 10^{-8}$
10	$0.212\,525\,653\,556\,057\,8 \times 10^2$		

* The reference function $W_{CCT\text{-}68}(T_{68})$ is continuous at $T_{68} = 273.15$ K in its first and second derivatives with the function $W(t_{68})$ given by Eqs. (4a-6) and (4a-7) for $\alpha = 3.9259668 \times 10^{-3}(°\text{C})^{-1}$ and $\delta = 1.496334$°C. A tabulation of this reference function, sufficiently detailed to allow interpolation to an accuracy of 0.0001 K, is available from the Bureau International des Poids et Mesures, 92-Sèvres, France.

The following interpolation formulas are used to determine $\Delta W(T_{68})$ at intermediate temperatures:

13.81 to 20.28 K:	$\Delta W(T_{68}) = A_1 + B_1 T_{68} + C_1 T_{68}^2 + D_1 T_{68}^3$	(4a-2)[1]
20.28 to 54.361 K:	$\Delta W(T_{68}) = A_2 + B_2 T_{68} + C_2 T_{68}^2 + D_2 T_{68}^3$	(4a-3)[2]
54.361 to 90.188 K:	$\Delta W(T_{68}) = A_3 + B_3 T_{68} + C_3 T_{68}^2$	(4a-4)[3]
90.188 to 273.15 K:	$\Delta W(T_{68}) = A_4 t_{68} + C_4 t_{68}^3 (t_{68} - 100°\text{C})$	(4a-5)[4]

In the range 0°C (273.15 K) to 630.74°C, t_{68} is defined by

$$t_{68} = t' + 0.045 \frac{t'}{100°\text{C}} \left(\frac{t'}{100°\text{C}} - 1 \right) \left(\frac{t'}{419.58°\text{C}} - 1 \right) \left(\frac{t'}{630.74°\text{C}} - 1 \right) °\text{C} \qquad (4a\text{-}6)$$

where t' is defined as

$$t' = \frac{1}{\alpha} [W(t') - 1] + \delta \left(\frac{t'}{100°\text{C}} \right) \left(\frac{t'}{100°\text{C}} - 1 \right) \qquad (4a\text{-}7)$$

[1] Constants for Eq. (4a-2) are determined by the three measured deviations—at the triple point of equilibrium hydrogen, the temperature of 17.042 K, and the boiling point of equilibrium hydrogen—and by the derivative of the deviation function at the boiling point of equilibrium hydrogen as derived from Eq. (4a-3).

[2] Constants for Eq. (4a-3) are determined by the three measured deviations—at the boiling point of equilibrium hydrogen, the boiling point of neon, and the triple point of oxygen—and by the derivative of the deviation function at the triple point of oxygen as derived from Eq. (4a-4).

[3] Constants for Eq. (4a-4) are determined by the two measured deviations—at the triple point and the boiling point of oxygen and by the derivative of the deviation function at the boiling point of oxygen as derived from Eq. (4a-5).

[4] Constants for Eq. (4a-5) are determined by the two measured deviations at the boiling point of oxygen and the boiling point of water.

The resistance ratio $W(t') = R(t')/R(0°C)$ and the constants $R(0°C)$, α and δ are determined by measurement of three resistances—at the triple point of water, the boiling point of water (or the freezing point of tin), and the freezing point of zinc. Equation (4a-7) is equivalent to

$$W(t') = 1 + At' + Bt'^2 \tag{4a-8}$$

when $A = \alpha\left(1 + \frac{\delta}{100°C}\right)$ and $B = -10^{-4}\,\alpha\delta(°C)^{-2}$

From 630.74 to 1064.43°C, t_{68} is defined by

$$E(t_{68}) = a + bt_{68} + ct_{68}^2 \tag{4a-9}$$

where $E(t_{68})$ is the electromotive force of a standard thermocouple of rhodium-platinum alloy and platinum, when one junction is at the temperature $t_{68} = 0°C$ and the other junction is at temperature t_{68}. The constants a, b, and c are calculated from the values of E at $630.74 \pm 0.2°C$, as determined by a platinum resistance thermometer, and at the freezing points of silver and gold.

Above 1337.58 K (1064.43°C) the temperature T_{68} is defined by

$$\frac{L_\lambda(T_{68})}{L_\lambda(T_{68}(\text{Au}))} = \frac{\exp\,[c_2/\lambda T_{68}(\text{Au})] - 1}{\exp\,[c_2/\lambda T_{68}] - 1} \tag{4a-10}$$

where $L_\lambda(T_{68})$ and $L_\lambda(T_{68}(\text{Au}))$ are the spectral concentrations at temperature T_{68} and at the freezing point of gold, $T_{68}(\text{Au})$ of the radiance of a black body at the wavelength[1] λ; $c_2 = 0.014388$ meter kelvin.

Table 4a-3 (p. 4–6) lists the approximate differences between the IPTS-68 and IPTS-48 and should prove to be a utility for many references to this section.

To avoid creating conflicting statements, the preceding description of IPTS-68 has for the most part been taken from the English language version of the International Practical Temperature Scale of 1958 as it appeared in *Metrologia*. For a more complete description of the IPTS-68 and pertinent supplementary information the reader should refer to the defining text.[2]

In Tables 4a-4, 4a-5, and 4a-6 which follow, values have been adjusted to agree with IPTS-68.

[1] Since $T_{68}(\text{Au})$ is close to the thermodynamic temperature of the freezing point of gold, and c_2 is close to the second radiation constant of the Planck equation, it is not necessary to specify the value of the wavelength to be employed in the measurements [see *Metrologia* **3**, 28 (1967)].

[2] *Metrologia* **5** (2), 35 (1969).

TABLE 4a-3. APPROXIMATE DIFFERENCES ($t_{68} - t_{48}$), IN KELVINS, BETWEEN THE VALUES OF TEMPERATURE GIVEN BY THE IPTS OF 1968 AND THE IPTS OF 1948

t_{48}°C	0	−10	−20	−30	−40	−50	−60	−70	−80	−90	−100
−100	0.022	0.013	0.003	−0.006	−0.013	−0.013	−0.005	0.007	0.012		
0	0.000	0.006	0.012	0.018	0.024	0.029	0.032	0.034	0.033	0.029	0.022
t_{68}°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	−0.004	−0.007	−0.009	−0.010	−0.010	−0.010	−0.008	−0.006	−0.003	0.000
100	0.000	0.004	0.007	0.012	0.016	0.020	0.025	0.029	0.034	0.038	0.043
200	0.043	0.047	0.051	0.054	0.058	0.061	0.064	0.067	0.069	0.071	0.073
300	0.073	0.074	0.075	0.076	0.077	0.077	0.077	0.077	0.077	0.076	0.076
400	0.076	0.075	0.075	0.075	0.074	0.074	0.074	0.075	0.076	0.077	0.079
500	0.079	0.082	0.085	0.089	0.094	0.100	0.108	0.116	0.126	0.137	0.150
600	0.150	0.165	0.182	0.200	0.23	0.25	0.28	0.31	0.34	0.36	0.39
700	0.39	0.42	0.45	0.47	0.50	0.53	0.56	0.58	0.61	0.64	0.67
800	0.67	0.70	0.72	0.75	0.78	0.81	0.84	0.87	0.89	0.92	0.95
900	0.95	0.98	1.01	1.04	1.07	1.10	1.12	1.15	1.18	1.21	1.24
1000	1.24	1.27	1.30	1.33	1.36	1.39	1.42	1.44			
t_{68}°C	0	100	200	300	400	500	600	700	800	900	1000
1000		1.5	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
2000	3.2	3.5	3.7	4.0	4.2	4.5	4.8	5.0	5.3	5.6	5.9
3000	5.9	6.2	6.5	6.9	7.2	7.5	7.9	8.2	8.6	9.0	9.3

TABLE 4a-4. THERMAL EMF OF CHEMICAL ELEMENTS RELATIVE TO PLATINUM*

Temp., °C	Lithium, mV	Sodium, mV	Potassium, mV	Rubidium, mV	Cesium, mV	Calcium, mV	Cerium, mV
−200	−1.12	+1.00	+1.61	+1.09	+0.22		
−100	−1.00	+0.29	+0.78	+0.46	−0.13		
0	0	0	0	0	0	0	0
+100	+1.82	....	....	......	......	−0.51	+1.14
200	......	....	....	......	......	−1.13	2.46
300	......	....	....	......	......	−1.85	

Temp., °C	Magnesium, mV	Zinc, mV	Cadmium, mV	Mercury, mV	Indium, mV	Thallium, mV	Aluminum, mV
−200	+0.37	−0.07	−0.04	......	......	......	+0.45
−100	−0.09	−0.33	−0.31	......	......	......	+0.06
0	0	0	0	0	0	0	0
+100	+0.44	+0.76	+0.90	−0.60	+0.69	+0.58	+0.42
200	+1.10	1.89	2.35	−1.33	......	1.30	1.06
300	......	3.42	4.24	......	......	2.16	1.88
400	......	5.29	....	......	......	......	2.84
500	......	....	....	......	......	......	3.93
600	......	....	....	......	......	......	5.15

Temp. °C	Carbon, mV	Silicon, mV	Germanium, mV	Tin, mV	Lead, mV	Antimony, mV	Bismuth, mV
−200	......	+63.13	−46.00	+0.26	+0.24	......	+12.39
−100	......	+37.17	−26.62	−0.12	−0.13	......	+7.54
0	0	0	0	0	0	0	0
+100	+0.70	−41.56	+33.9	+0.42	+0.44	+4.89	−7.34
200	1.54	−80.57	72.4	1.07	1.09	10.14	−13.57
300	2.55	−110.07	91.8	......	1.91	15.44	
400	3.72	....	82.3	......	......	20.53	
500	5.15	....	63.5	......	......	25.10	
600	6.79	....	43.9	......	......	28.87	
700	8.82	....	27.9				
800	10.98						
900	13.55						
1000	16.46						
1100	19.46						

TABLE 4a-4. THERMAL EMF OF CHEMICAL ELEMENTS RELATIVE TO PLATINUM*
(Continued)

Temp., °C	Copper, mV	Silver, mV	Gold, mV	Cobalt, mV	Nickel, mV
−200	−0.19	−0.21	−0.21	......	+2.28
−100	−0.37	−0.39	−0.39	......	+1.22
0	0	0	0	0	0
+100	+0.76	+0.74	+0.78	−1.33	−1.48
200	1.83	1.77	1.84	−3.08	−3.10
300	3.15	3.05	3.14	−5.10	−4.59
400	4.68	4.57	4.63	−7.24	−5.45
500	6.41	6.36	6.29	−9.35	−6.16
600	8.34	8.41	8.12	−11.28	−7.04
700	10.47	10.73	10.11	−12.87	−8.10
800	12.81	13.33	12.26	−13.99	−9.33
900	15.37	16.16	14.58	−14.49	−10.67
1000	18.16	......	17.05	−14.21	−12.11
1100	......	......	......	−13.01	−13.60
1200	......	......	......	−10.70	

Temp., °C	Iridium, mV	Rhodium, mV	Palladium, mV	Molybdenum, mV	Tungsten, mV	Tantalum, mV	Thorium, mV
−200	−0.25	−0.20	+0.81	......	+0.43	+0.21	
−100	−0.35	−0.34	+0.48	......	−0.15	−0.10	
0	0	0	0	0	0	0	0
+100	+0.65	+0.70	−0.57	+1.45	+1.12	+0.33	−0.13
200	1.49	1.61	−1.23	3.19	2.62	0.93	−0.26
300	2.47	2.68	−1.99	5.23	4.48	1.79	−0.40
400	3.55	3.91	−2.82	7.57	6.70	2.91	−0.50
500	4.78	5.28	−3.84	10.20	9.30	4.30	−0.53
600	6.10	6.77	−5.03	13.13	12.26	5.95	−0.45
700	7.55	8.39	−6.40	16.33	15.58	7.86	−0.21
800	9.10	10.14	−7.96	19.83	19.25	10.02	+0.22
900	10.77	12.01	−9.69	23.63	23.30	12.45	+0.86
1000	12.57	14.02	−11.61	27.74	27.73	15.15	+1.72
1100	14.45	16.15	−13.67	32.15	32.53	18.13	+2.78
1200	16.45	18.39	−15.86	36.86	37.72	21.37	+4.03
1300	18.45	20.69	−18.11	......	......	......	+5.41
1400	20.47	22.99	−20.40				
1500	22.51	25.36	−22.75				

* A positive sign means that in a simple thermoelectric circuit the resultant emf given is in such a direction as to produce a current from the element to the platinum at the reference junction (0°C).

The values below 0°C, in most cases, have not been determined on the same samples as the values above 0°C.

Based upon the original table in American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," pp. 1309–1310, Reinhold Book Corporation, New York, 1941. Values of the emf have been adjusted to correspond to temperatures expressed on the International Practical Temperature Scale of 1968.

TABLE 4a-5. THERMAL EMF OF IMPORTANT THERMOCOUPLE MATERIALS RELATIVE TO PLATINUM*

Temp., °C	Chromel P, mV	Alumel, mV	Copper, mV	Iron, mV	Constantan, mV
−200	−3.36	+2.39	−0.19	−2.92	+5.35
−100	−2.20	+1.29	−0.37	−1.84	+2.98
0	0	0	0	0	0
+100	+2.81	−1.29	+0.76	+1.89	−3.51
200	5.96	−2.17	1.83	3.54	−7.45
300	9.32	−2.89	3.15	4.85	−11.71
400	12.75	−3.64	4.68	5.88	−16.19
500	16.21	−4.43	6.41	6.79	−20.79
600	19.61	−5.28	8.34	7.80	−25.46
700	22.94	−6.18	10.47	9.11	−30.15
800	26.20	−7.07	12.81	10.84	−34.81
900	29.37	−7.94	15.37	12.82	−39.39
1000	32.47	−8.78	18.16	14.28	−43.85
1100	35.52	−9.57			
1200	38.48	−10.33			
1300	41.38	−11.06			
1400	44.04	−11.77			

* American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," p. 1308, Reinhold Book Corporation, New York, 1941. Values of the emf have been adjusted to correspond to temperatures expressed on the International Practical Temperature Scale of 1968.

TABLE 4a-6. THERMAL EMF OF SOME ALLOYS RELATIVE TO PLATINUM*

Temp., °C	Manganin, mV	Gold-chromium, mV	Copper-beryllium, mV	Yellow brass, mV	Phosphor bronze, mV	Solder 50 Sn–50 Pb, mV	Solder 96.5 Sn–3.5 Ag, mV
0	0	0	0	0	0	0	0
+100	+0.61	−0.17	+0.67	+0.60	+0.55	+0.46	+0.45
200	1.55	−0.32	1.62	1.49	1.34		
300	2.77	−0.44	2.81	2.58	2.34		
400	4.25	−0.55	4.19	3.85	3.50		
500	5.95	−0.63	......	5.30	4.81		
600	7.84	−0.66	......	6.96	6.30		

TABLE 4a-6. THERMAL EMF OF SOME ALLOYS RELATIVE TO PLATINUM* (*Continued*)

Temp., °C	18-8 stainless steel, mV	Spring steel, mV	80 Ni–20 Cr, mV	60 Ni–24 Fe–16 Cr, mV	Copper coin (95 Cu–4 Sn–1 Zn), mV	Nickel coin (75 Cu–25 Ni), mV	Silver coin (90 Ag–10 Cu), mV
0	0	0	0	0	0	0	0
+100	+0.44	+1.32	+1.14	+0.85	+0.60	−2.76	+0.80
200	1.04	2.63	2.62	2.01	1.48	−6.01	1.90
300	1.76	3.81	4.34	3.41	2.60	−9.71	3.25
400	2.60	4.84	6.25	5.00	3.91	−13.78	4.81
500	3.56	5.80	8.31	6.76	5.44	−18.10	6.59
600	4.67	6.86	10.53	8.68	7.14	−22.59	8.64
700	5.92	......	12.89	10.76			
800	7.35	......	15.41	13.03			
900	8.96	......	18.07	15.47			
1000	......	......	20.87	18.06			

* American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry, p. 1310, Reinhold Book Corporation, New York, 1941. Values of the emf have been adjusted to correspond to temperatures expressed on the International Practical Temperature Scale of 1968.

Thermocouple Reference Tables. Tables 4a-7 through 4a-12 contain abbreviated data on the thermoelectric voltages of six thermocouple combinations, two noble-metal types S and R and four base-metal types E, J, K, and T. The full tables, functional representations, approximations, and material descriptions appear in NBS Monograph 125, "Thermocouple Reference Tables Based on the IPTS-68" by R. L. Powell, W. J. Hall, C. H. Hyink, L. L. Sparks, G. W. Burns, and H. H. Plumb, U.S. Government Printing Office, Washington, D.C., 1972.

TABLE 4a-7. TYPE S. PLATINUM–10% RHODIUM VS. PLATINUM THERMOCOUPLES
[Emf, absolute millivolts; temp., °C (IPTS-68); reference junctions at 0°C]

°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.055	0.113	0.173	0.235	0.299	0.365	0.432	0.502	0.573	0.645
100	0.645	0.719	0.795	0.872	0.950	1.029	1.109	1.190	1.273	1.356	1.440
200	1.440	1.525	1.611	1.698	1.785	1.873	1.962	2.051	2.141	2.232	2.323
300	2.323	2.414	2.506	2.599	2.692	2.786	2.880	2.974	3.069	3.164	3.260
400	3.260	3.356	3.452	3.549	3.645	3.743	3.840	3.938	4.036	4.135	4.234
500	4.234	4.333	4.432	4.532	4.632	4.732	4.832	4.933	5.034	5.136	5.237
600	5.237	5.339	5.442	5.544	5.648	5.751	5.855	5.960	6.064	6.169	6.274
700	6.274	6.380	6.486	6.592	6.699	6.805	6.913	7.020	7.128	7.236	7.345
800	7.345	7.454	7.563	7.672	7.782	7.892	8.003	8.114	8.225	8.336	8.448
900	8.448	8.560	8.673	8.786	8.899	9.012	9.126	9.240	9.355	9.470	9.585
1000	9.585	9.700	9.816	9.932	10.048	10.165	10.282	10.400	10.517	10.635	10.754
1100	10.754	10.872	10.991	11.110	11.229	11.348	11.467	11.587	11.707	11.827	11.947
1200	11.947	12.067	12.188	12.308	12.429	12.550	12.671	12.792	12.913	13.034	13.155
1300	13.155	13.276	13.397	13.519	13.640	13.761	13.883	14.004	14.125	14.247	14.368
1400	14.368	14.489	14.610	14.731	14.852	14.973	15.094	15.215	15.336	15.456	15.576
1500	15.576	15.697	15.817	15.937	16.057	16.176	16.296	16.415	16.534	16.653	16.771
1600	16.771	16.890	17.008	17.125	17.243	17.360	17.477	17.594	17.711	17.826	17.942
1700	17.942	18.056	18.170	18.282	18.394	18.504	18.612				

TABLE 4a-8. TYPE R. PLATINUM–13% RHODIUM VS. PLATINUM THERMOCOUPLES
[Emf, absolute millivolts; temp., °C (IPTS-68); reference junctions at 0°C]

°C	0	10	20	30	40	50	60	70	80	90	100
0	0.00	0.054	0.111	0.171	0.232	0.296	0.363	0.431	0.501	0.573	0.647
100	0.647	0.723	0.800	0.879	0.959	1.041	1.124	1.208	1.294	1.380	1.468
200	1.468	1.557	1.647	1.738	1.830	1.923	2.017	2.111	2.207	2.303	2.400
300	2.400	2.498	2.596	2.605	2.705	2.806	2.907	3.099	3.201	3.304	3.407
400	3.407	3.511	3.616	3.721	3.826	3.933	4.039	4.146	4.254	4.362	4.471
500	4.471	4.580	4.689	4.799	4.910	5.021	5.132	5.244	5.356	5.469	5.582
600	5.582	5.696	5.810	5.925	6.040	6.155	6.272	6.388	6.505	6.623	6.741
700	6.741	6.860	6.979	7.098	7.218	7.339	7.460	7.582	7.703	7.826	7.949
800	7.949	8.072	8.196	8.320	8.445	8.570	8.696	8.822	8.949	9.076	9.203
900	9.203	9.331	9.460	9.589	9.718	9.848	9.978	10.109	10.240	10.371	10.503
1000	10.503	10.636	10.768	10.902	11.035	11.170	11.304	11.439	11.574	11.710	11.846
1100	11.846	11.983	12.119	12.257	12.394	12.532	12.669	12.808	12.946	13.085	13.224
1200	13.224	13.363	13.502	13.642	13.782	13.922	14.062	14.202	14.343	14.483	14.624
1300	14.624	14.765	14.906	15.047	15.188	15.329	15.470	15.611	15.752	15.893	16.035
1400	16.035	16.176	16.317	14.458	16.599	16.741	16.882	17.022	17.163	17.304	17.445
1500	17.445	17.585	17.726	17.866	18.006	18.146	18.286	18.425	18.564	18.703	18.842
1600	18.842	18.981	19.119	19.257	19.395	19.533	19.670	19.807	19.944	20.080	20.215
1700	20.215	20.350	20.483	20.616	20.748	20.878	21.006				

TABLE 4a-9. TYPE E. CHROMEL VS. CONSTANTAN THERMOCOUPLES
[Emf, absolute millivolts; temp., °C (IPTS-68); reference junctions at 0°C]

°C	0	10	20	30	40	50	60	70	80	90	100
−200	−8.824	−9.063	−9.274	−9.455	−9.604	−9.719	−9.797	−9.835			
−100	−5.237	−5.680	−6.167	−6.516	−6.907	−7.279	−7.631	−7.963	−8.273	−8.561	−8.824
(−)0	0.00	−0.581	−1.151	−1.709	−2.254	−2.787	−3.306	−3.811	−4.301	−4.777	−5.237
(+)0	0.00	0.591	1.192	1.801	2.419	3.047	3.683	4.329	4.983	5.646	6.317
100	6.317	6.996	7.683	8.377	9.078	9.787	10.501	11.222	11.949	12.681	13.419
200	13.419	14.161	14.909	15.661	16.417	17.178	17.942	18.710	19.481	20.256	21.033
300	21.033	21.814	22.597	23.383	24.171	24.961	25.754	26.549	27.345	28.143	28.943
400	28.943	20.744	30.546	31.350	32.155	32.960	33.767	34.574	35.382	36.190	36.999
500	36.999	37.808	38.617	39.426	40.236	41.045	41.853	42.662	43.470	44.278	45.085
600	45.085	45.891	46.697	47.502	48.306	49.109	49.911	50.713	51.513	52.312	53.110
700	53.110	53.907	45.703	55.498	56.291	57.083	57.873	58.663	59.451	60.237	61.022
800	61.022	61.806	62.588	63.368	64.147	64.924	65.700	66.473	67.245	68.015	68.783
900	68.783	69.549	70.313	71.075	71.835	72.593	73.350	74.104	74.857	75.608	76.358
1000	76.358										

TABLE 4a-10. TYPE J. IRON VS. CONSTANTAN THERMOCOUPLES
[Emf, absolute millivolts; temp., °C (IPTS-68); reference functions at 0°C]

°C	0	10	20	30	40	50	60	70	80	90	100
−200	−7.890	−8.096									
−100	−4.632	−5.036	−5.426	−5.801	−6.159	−6.499	−6.821	−7.122	−7.402	−7.659	−7.890
(−)0	0.00	−0.501	−0.995	−1.481	−1.960	−2.431	−2.892	−3.344	−3.785	−4.215	−4.632
(+)0	0.00	0.507	1.019	1.536	2.058	2.585	3.115	3.649	4.186	4.725	5.268
100	5.268	5.812	6.359	6.907	7.457	8.008	8.560	9.113	9.667	10.222	10.777
200	10.777	11.332	11.887	12.442	12.998	13.553	14.108	14.663	15.217	15.771	16.325
300	16.325	16.879	17.432	17.984	18.537	19.089	19.640	20.192	20.743	21.295	21.846
400	21.846	22.397	22.949	23.501	24.054	24.607	25.161	25.716	26.272	26.829	27.388
500	27.388	27.949	28.511	29.075	29.642	30.210	30.782	31.356	31.933	32.513	33.096
600	33.096	33.683	34.273	34.867	35.464	36.066	36.671	37.280	37.893	38.510	39.130
700	39.130	39.754	40.382	41.013	41.647	42.283	42.922				

TABLE 4a-11. TYPE K. CHROMEL VS. ALUMEL THERMOCOUPLES
[Emf, absolute millivolts; temp., °C (IPTS-68); reference junctions at 0°C]

°C	0	10	20	30	40	50	60	70	80	90	100
−200	−5.891	−6.035	−6.158	−6.262	−6.344	−6.404	−6.441	−6.458			
−100	−3.553	−3.852	−4.138	−4.410	−4.669	−4.912	−5.141	−5.354	−5.550	−5.730	−5.891
(−)0	0.00	−0.392	−0.777	−1.156	−1.527	−1.889	−2.243	−2.586	−2.920	−3.242	−3.553
(+)0	0.00	0.397	0.798	1.203	1.611	2.022	2.436	2.850	3.266	3.681	4.095
100	4.095	4.508	4.919	5.327	5.733	6.137	6.539	6.939	7.338	7.737	8.137
200	8.137	8.537	8.938	9.341	9.745	10.151	10.560	10.969	11.381	11.793	12.207
300	12.207	12.623	13.039	13.456	13.874	14.292	14.712	15.132	15.552	15.974	16.395
400	16.395	16.818	17.241	17.664	18.088	18.513	18.938	19.363	19.788	20.214	20.640
500	20.640	21.066	21.493	21.919	22.346	22.772	23.198	23.624	24.050	24.476	24.902
600	24.902	25.327	25.751	26.176	26.599	27.022	27.445	27.867	28.288	28.709	29.128
700	29.128	29.547	29.965	30.383	30.799	31.214	31.629	32.042	32.455	32.866	33.277
800	33.277	33.686	34.095	34.502	34.909	35.314	35.718	36.121	36.524	36.925	37.325
900	37.325	37.724	38.122	38.519	38.915	39.310	39.703	40.096	40.488	40.879	41.269
1000	41.269	41.657	42.045	42.432	42.817	43.202	43.585	43.968	44.349	44.729	45.108
1100	45.108	45.486	45.863	46.238	46.612	46.985	47.356	47.726	48.095	48.462	48.828
1200	48.828	49.192	49.555	49.916	50.276	50.633	50.990	51.344	51.697	52.049	52.398
1300	52.398	52.747	53.093	53.439	53.782	54.125	54.466	54.807			

TABLE 4a-12. TYPE T. COPPER VS. CONSTANTAN THERMOCOUPLES
[Emf, absolute millivolts; temp., °C (IPTS-68); reference junctions at 0°C]

°C	0	10	20	30	40	50	60	70	80	90	100
−200	−5.603	−5.753	−5.889	−6.007	−6.105	−6.181	−6.232	−6.258			
−100	−3.378	−3.656	−3.923	−4.177	−4.419	−4.648	−4.865	−5.069	−5.261	−5.439	−5.603
(−)0	0.00	−0.383	−0.757	−1.121	−1.475	−1.819	−2.152	−2.475	−2.788	−3.089	−3.378
(+)0	0.00	0.391	0.789	1.196	1.611	2.035	2.467	2.908	3.357	3.813	4.277
100	4.277	4.749	5.227	5.712	6.204	6.702	7.207	7.718	8.235	8.757	9.286
200	9.286	9.820	10.360	10.905	11.456	12.011	12.572	13.137	13.707	14.281	14.860
300	14.860	15.443	16.030	16.621	17.217	17.816	18.420	19.027	19.638	20.252	20.869
400	20.869										

TABLE 4a-13. ELECTRICAL RESISTIVITY OF SOME ELEMENTS AND ALLOYS AS A FUNCTION OF TEMPERATURE*
[At 0°C both the relative R_t/R_0 and actual resistivity (microhm cm) are given]

Temp., °C	Platinum (R_t/R_0)	Copper (R_t/R_0)	Nickel (R_t/R_0)	Iron (R_t/R_0)	Silver (R_t/R_0)	90 Pt–10 Rh (R_t/R_0)	87 Pt–13 Rh (R_t/R_0)
−200	0.177	0.117	.....	......	0.176		
−100	0.599	0.557	.....	......	0.596		
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(9.83)	(1.56)	(6.38)	(8.57)	(1.50)	(18.4)	(19.0)
+100	1.392	1.431	1.663	1.650	1.408	1.166	1.156
200	1.773	1.862	2.501	2.464	1.827	1.330	1.308
300	2.142	2.299	3.611	3.485	2.256	1.490	1.456
400	2.499	2.747	4.847	4.716	2.698	1.646	1.601
500	2.844	3.210	5.398	6.162	3.150	1.798	1.744
600	3.178	3.695	5.882	7.839	3.616	1.947	1.885
700	3.499	4.207	6.326	9.785	4.093	2.093	2.023
800	3.809	4.750	6.749	12.003	4.584	2.233	2.156
900	4.108	5.332	7.154	12.788	5.089	2.369	2.286
1000	4.395	5.959	7.541	13.070	.....	2.503	2.414
1100	4.672	.....	.....	......	.....	2.633	2.538
1200	4.937	.....	.....	......	.....	2.762	2.661
1300	5.190	.....	.....	......	.....	2.888	2.781
1400	5.431	.....	.....	......	.....	3.013	2.900
1500	5.660	.....	.....	......	.....	3.136	3.017

* American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," p. 1312, Reinhold Book Corporation, New York, 1941. The values below 0°C, in most cases, were not determined on the same samples as the values above 0°C.

TABLE 4a-14. ELECTRICAL RESISTIVITY OF SOME ALLOYS AS A FUNCTION OF TEMPERATURE*

[At 0°C both the relative (R_t/R_0) and actual resistivity (microhm cm) are given]

Temp., °C	80 Ni–20 Cr (R_t/R_0)	60 Ni–24 Fe–16 Cr (R_t/R_0)	50 Fe–30 Ni–20 Cr (R_t/R_0)	Chromel P (90 Ni–10 Cr) (R_t/R_0)	Alumel (95 Ni–bal. Al, Si, and Mn) (R_t/R_0)	Constantan (55 Cu–45 Ni) (R_t/R_0)	Manganin (R_t/R_0)
0	1.000 (107.6)	1.000 (111.6)	1.000 (99.0)	1.000 (70.0)	1.000 (28.1)	1.000 (48.9)	1.000 (48.2)
100	1.021	1.025	1.037	1.041	1.239	0.999	1.002
200	1.041	1.048	1.073	1.086	1.428	0.996	0.996
300	1.056	1.071	1.107	1.134	1.537	0.994	0.991
400	1.068	1.092	1.137	1.187	1.637	0.994	0.983
500	1.073	1.108	1.163	1.222	1.726	1.007	
600	1.071	1.115	1.185	1.248	1.814	1.024	
700	1.067	1.119	1.204	1.275	1.899	1.040	
800	1.066	1.127	1.221	1.304	1.982	1.056	
900	1.071	1.138	1.237	1.334	2.066	1.074	
1000	1.077	1.149	1.251	1.365	2.150	1.092	
1100	1.083	.....	.....	1.397	2.234	1.110	
1200	.....	.....	.....	1.430	2.318		

* American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," p. 1312, Reinhold Book Corporation, New York, 1941. The values below 0°C, in most cases, were not determined on the same samples as the values above 0°C.

Tables 4a-15, 4a-16, and 4a-17 give the thermoelectric voltage E and Seebeck coefficient dE/dT, for the three thermocouple combinations that are most useful between liquid helium temperatures and the ice point: ANSI types E, T, and EP vs. Au-0.07 at.% Fe (often referred to as Chromel vs. constantan, copper vs. constantan, and Chromel vs. Au-0.07 at.% Fe, respectively). Type E thermocouples are recommended for general use above the normal boiling point of hydrogen (20 K). Both components of this thermocouple combination have low thermal conductivity and reasonably good homogeneity. For operation below 20 K, the combination EP vs. Au-0.07 at.% Fe is the most sensitive combination commonly available for which there is a standard table. The values given for the last combination are interim: the *gold*-iron material is not yet standardized. Additional details and discussion for these three types of thermocouples have been published.[1,2] Seebeck coefficients for each type are shown in Fig. 4a-1.

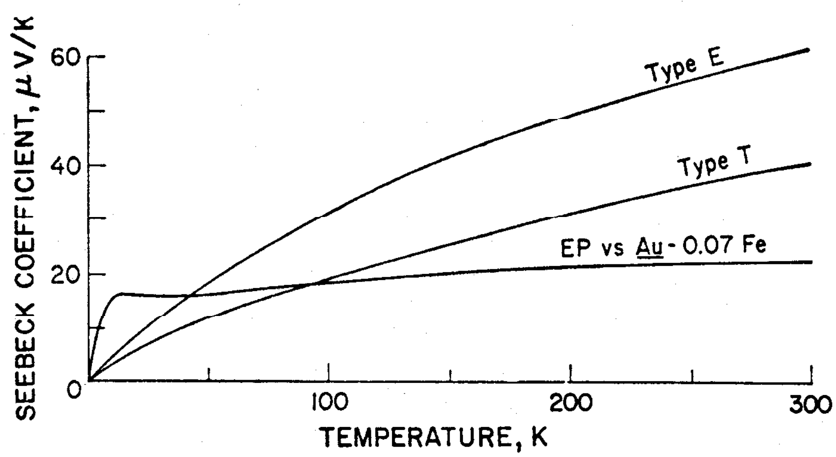

FIG. 4a-1. Seebeck coefficients for USASI thermocouple types E, T, and EP vs. Au-0.07 at.% Fe.

[1] For standardized thermocouples: NBS Monograph 124, "Reference Tables for Low Temperature Thermocouples," by L. L. Sparks, R. L. Powell, and W. J. Hall, U.S. Government Printing Office, Washington, D.C., 1972.

[2] For nonstandardized combinations: L. L. Sparks and R. L. Powell, *J. Res. Nat. Bur. Stand.* (*U.S.*) **76 A**, No. 3, 1972.

TABLE 4a-15. TYPE E THERMOCOUPLES (CHROMEL VS. CONSTANTAN)

T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K
1	0.41	0.660	51	522.68	19.001	101	1,806.73	31.648
2	1.31	1.149	52	541.83	19.303	102	1,838.49	31.865
3	2.70	1.623	53	561.28	19.603	103	1,870.46	32.081
4	4.56	2.085	54	581.04	19.900	104	1,902.65	32.295
5	6.87	2.535	55	601.08	20.194	105	1,935.05	32.509
6	9.62	2.975	56	621.42	20.486	106	1,967.67	32.722
7	12.81	3.406	57	642.05	20.776	107	2,000.50	32.934
8	16.43	3.829	58	662.97	21.063	108	2,033.54	33.145
9	20.47	4.244	59	684.18	21.348	109	2,066.79	33.355
10	24.92	4.653	60	705.67	21.630	110	2,100.25	33.565
11	29.77	5.057	61	727.44	21.911	111	2,133.92	33.773
12	35.03	5.455	62	749.49	22.188	112	2,167.79	33.981
13	40.68	5.848	63	771.82	22.464	113	2,201.88	34.187
14	46.72	6.238	64	794.42	22.737	114	2,236.17	34.393
15	53.15	6.623	65	817.29	23.008	115	2,270.66	34.598
16	59.97	7.005	66	840.43	23.277	116	2,305.36	34.802
17	67.16	7.385	67	863.84	23.544	117	2,340.27	35.005
18	84.74	7.761	68	887.52	23.809	118	2,375.37	35.207
19	82.69	8.135	69	911.46	24.072	119	2,410.68	35.408
20	91.01	8.506	70	935.66	24.333	120	2,446.19	35.609
21	99.70	8.876	71	960.13	24.592	121	2,481.90	35.809
22	108.76	9.243	72	984.85	24.849	122	2,517.81	36.007
23	118.18	9.608	73	1,009.82	25.104	123	2,553.91	36.205
24	127.97	9.971	74	1,035.05	25.357	124	2,590.22	36.402
25	138.12	10.332	75	1,060.54	25.608	125	2,626.72	36.599
26	148.64	10.691	76	1,086.27	25.858	126	2,663.41	36.794
27	159.51	11.049	77	1,112.25	26.106	127	2,700.30	36.989
28	170.73	11.404	78	1,138.48	26.353	128	2,737.39	37.182
29	182.31	11.758	79	1,164.96	26.598	129	2,774.67	37.375
30	194.25	12.110	80	1,191.68	26.841	130	2,812.14	37.567
31	206.53	12.460	81	1,218.64	27.083	131	2,859.80	37.759
32	219.17	12.808	82	1,245.84	27.323	132	2,887.66	37.949
33	232.15	13.154	83	1,273.28	27.562	133	2,925.70	38.139
34	245.47	13.498	84	1,300.96	27.799	134	2,963.94	38.328
35	259.14	13.840	85	1,328.88	28.035	135	3,002.36	38.516
36	273.15	14.179	86	1,357.03	28.270	136	3,040.97	38.703
37	287.50	14.517	87	1,385.42	28.503	137	3,079.76	38.890
38	302.19	14.853	88	1,414.04	28.735	138	3,118.75	39.075
39	317.20	15.186	89	1,442.89	28.966	139	3,157.91	39.260
40	332.56	15.517	90	1,471.97	29.196	140	3,197.27	39.445
41	348.24	15.846	91	1,501.28	29.424	141	3,236.80	39.628
42	364.25	16.172	92	1,530.82	29.652	142	3,276.52	39.811
43	380.58	16.496	93	1,560.59	29.878	143	3,316.42	39.993
44	397.24	16.818	94	1,590.58	30.103	144	3,356.51	40.174
45	414.22	17.137	95	1,620.79	30.327	145	3,396.77	40.355
46	431.51	17.454	96	1,651.23	30.549	146	3,437.22	40.534
47	449.13	17.769	97	1,681.89	30.771	147	3,477.84	40.713
48	467.05	18.081	98	1,712.77	30.992	148	3,518.64	40.892
49	485.29	18.390	99	1,743.87	31.212	149	3,559.62	41.070
50	503.83	18.697	100	1,775.19	31.430	150	3,600.78	41.247

TABLE 4a-15. TYPE E THERMOCOUPLES (CHROMEL VS. CONSTANTAN) (*Continued*)

T, K	*E*, μV	*dE/dT*, μV/K	*T*, K	*E*, μV	*dE/dT*, μV/K	*T*, K	*E*, μV	*dE/dT*, μV/K
151	3,642.12	41.423	196	5,675.23	48.743	241	8,010.92	54.888
152	3,683.63	41.599	197	5,724.05	48.893	242	8,065.87	55.014
153	3,725.31	41.774	198	5,773.02	49.041	243	8,120.95	55.140
154	3,767.18	41.948	199	5,822.13	49.189	244	8,176.15	55.265
155	3,809.21	42.122	200	5,871.40	40.336	245	8,231.48	55.390
156	3,851.42	42.295	201	5,920.81	49.485	246	8,286.93	55.515
157	3,893.80	42.467	202	5,970.36	49.629	247	8,342.51	55.639
158	3,936.35	42.639	203	6,020.06	49.775	248	8,398.21	55.763
159	3,979.08	42.811	204	6,059.91	49.919	249	8,454.04	55.887
160	4,021.97	42.981	205	6,119.90	50.064	250	8,509.99	56.010
161	4,065.04	43.151	206	6,170.04	50.207	251	8,566.06	56.133
162	4,108.28	43.321	207	6,220.32	50.350	252	8,622.25	56.255
163	4,151.68	43.490	208	6,270.74	50.492	253	8,678.57	56.377
164	4,195.26	43.658	209	6,321.30	50.634	254	8,735.01	56.498
165	4,239.00	43.825	210	6,372.01	50.775	255	8,791.56	56.619
166	4,282.91	43.993	211	6,422.85	50.915	256	8,848.24	56.739
167	4,326.98	44.159	212	6,473.84	51.055	257	8,905.04	56.858
168	4,371.22	44.325	213	6,524.96	51.194	258	8,961.96	56.977
169	4,415.63	44.591	214	6,576.22	51.333	259	9,019.00	57.095
170	4,460.21	44.655	215	6,627.63	51.471	260	9,076.15	57.212
171	4,504.94	44.820	216	6,679.17	51.608	261	9,133.42	57.329
172	4,549.84	44.984	217	6,730.84	51.745	262	9,190.81	57.445
173	4,594.91	45.147	218	6,782.66	51.882	263	9,248.31	57.559
174	4,640.14	45.309	219	6,834.61	52.017	264	9,305.93	57.673
175	4,685.53	45.471	220	6,886.69	52.152	265	9,363.66	57.786
176	4,731.08	45.633	221	6,938.91	52.287	266	9,421.50	57.898
177	4,776.79	45.794	222	6,991.27	52.421	267	9,479.45	58.009
178	4,822.67	45.954	223	7,043.75	52.555	268	9,537.51	58.119
179	4,868.70	46.114	224	7,096.38	52.688	269	9,595.69	58.227
180	4,914.90	46.274	225	7,149.13	52.821	270	9,653.97	58.335
181	4,961.25	46.432	226	7,202.02	52.953	271	9,712.36	58.442
182	5,007.76	46.590	227	7,255.04	53.085	272	9,770.85	58.547
183	5,054.43	46.748	228	7,308.19	53.216	273	9,829.45	58.651
184	5,101.26	46.905	229	7,361.47	53.347	274	9,888.15	58.755
185	5,148.24	47.061	230	7,414.88	53.477	275	9,946.96	58.857
186	5,195.38	47.217	231	7,468.42	53.607	276	10,005.87	58.958
187	5,242.67	47.373	232	7,522.09	53.737	277	10,064.88	59.059
188	5,290.12	47.527	233	7,575.89	53.866	278	10,123.98	59.159
189	5,337.73	47.681	234	7,629.83	53.995	279	10,183.19	59.258
190	5,385.49	47.835	235	7,683.88	54.125	280	10,242.50	59.356
191	5,433.40	47.988	236	7,738.07	54.252			
192	5,481.46	48.140	237	7,792.39	54.380			
193	5,529.68	48.292	238	7,846.83	54.507			
194	5,578.05	48.443	239	7,901.40	54.634			
195	5,626.56	48.593	240	7,956.10	54.761			

Table 4a-16. Type T Thermocouples (Copper vs. Constantan)

T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K
1	−0.09	0.147	51	343.30	12.345	101	1,147.25	19.498
2	0.28	0.586	52	355.73	12.519	102	1,166.81	19.629
3	1.07	0.985	53	368.33	12.690	103	1,186.51	19.758
4	2.24	1.351	54	381.11	12.859	104	1,206.33	19.888
5	3.76	1.690	55	394.05	13.025	105	1,226.28	20.017
6	5.61	2.006	56	407.16	13.189	106	1,246.37	20.147
7	7.77	2.304	57	420.43	13.350	107	1,266.58	20.275
8	10.21	2.587	58	433.86	13.510	108	1,286.92	20.404
9	12.94	2.859	59	447.44	13.668	109	1,307.38	20.532
10	15.93	3.121	60	461.19	13.824	110	1,327.98	20.660
11	19.18	3.377	61	475.09	13.978	111	1,348.71	20.788
12	22.68	3.628	62	489.15	14.130	112	1,369.56	20.916
13	26.43	3.876	63	503.35	14.281	113	1,390.54	21.043
14	30.43	4.120	64	517.71	14.431	114	1,411.64	21.170
15	34.67	4.364	65	532.21	14.579	115	1,432.88	21.297
16	39.16	4.606	66	546.86	14.726	116	1,454.24	21.424
17	43.89	4.848	67	561.66	14.872	117	1,475.73	21.551
18	48.85	5.091	68	576.61	15.017	118	1,497.34	21.677
19	54.07	5.333	69	591.70	15.160	119	1,519.08	21.803
20	59.52	5.576	70	606.93	15.303	120	1,540.95	21.929
21	65.22	5.818	71	622.30	15.445	121	1,562.94	22.055
22	71.16	6.062	72	637.82	15.587	122	1,585.06	22.181
23	77.34	6.305	73	653.48	15.727	123	1,607.30	22.306
24	83.77	6.548	74	669.27	15.868	124	1,629.67	22.431
25	90.44	6.791	75	685.21	16.007	125	1,652.16	22.557
26	97.35	7.033	76	701.29	16.146	126	1,674.78	22.682
27	104.50	7.274	77	717.50	16.284	127	1,697.53	22.807
28	111.90	7.515	78	733.86	16.422	128	1,720.39	22.932
29	119.53	7.754	79	750.35	16.559	129	1,743.39	23.056
30	127.40	7.991	80	766.97	16.696	130	1,766.51	23.181
31	135.51	8.227	81	783.74	16.833	131	1,789.75	23.305
32	143.86	8.461	82	800.64	16.969	132	1,813.12	23.430
33	152.43	8.692	83	817.68	17.105	133	1,836.61	23.554
34	161.24	8.921	84	834.85	17.241	134	1,860.23	23.678
35	170.27	9.147	85	852.16	17.376	135	1,883.97	23.802
36	179.53	9.371	86	869.60	17.511	136	1,907.83	23.926
37	189.01	9.591	87	887.18	17.645	137	1,931.82	24.050
38	198.72	9.809	88	904.89	17.779	138	1,955.93	24.174
39	208.63	10.023	89	922.74	17.913	139	1,980.17	24.297
40	218.76	10.234	90	940.72	18.047	140	2,004.52	24.420
41	229.10	10.442	91	958.83	18.180	141	2,029.01	24.544
42	239.64	10.647	92	977.08	18.314	142	2,053.61	24.667
43	250.39	10.848	93	995.46	18.446	143	2,078.34	24.790
44	261.34	11.046	94	1,013.97	18.579	144	2,103.19	24.913
45	272.48	11.241	95	1,032.62	18.711	145	2,128.17	25.035
46	283.82	11.433	96	1,051.39	18.843	146	2,153.26	25.158
47	295.35	11.621	97	1,070.30	18.975	147	2,178.48	25.280
48	307.06	11.807	98	1,089.34	19.106	148	2,203.82	25.402
49	318.96	11.989	99	1,108.51	19.237	149	2,229.28	25.524
50	331.04	12.168	100	1,127.82	19.368	150	2,254.87	25.646

TABLE 4a-16. TYPE T THERMOCOUPLES (COPPER VS. CONSTANTAN) (*Continued*)

T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K
151	2,280.58	25.767	196	3,559.13	30.975	241	5,061.31	35.688
152	2,306.40	25.889	197	3,590.16	31.086	242	5,097.05	35.787
153	2,332.35	26.010	198	3,621.30	31.197	243	5,132.89	35.886
154	2,358.42	26.130	199	3,652.56	31.307	244	5,168.82	35.986
155	2,384.61	26.251	200	3,683.92	31.417	245	5,204.86	36.084
156	2,410.93	26.371	201	3,715.39	31.527	246	5,240.99	36.183
157	2,437.36	26.491	202	3,746.97	31.637	247	5,277.22	36.282
158	2,463.91	26.611	203	3,778.66	31.746	248	5,313.55	36.381
159	2,490.58	26.731	204	3,810.46	31.856	249	5,349.99	36.480
160	2,517.37	26.850	205	3,842.38	31.965	250	5,386.51	36.579
161	2,544.28	26.969	206	3,874.39	32.074	251	5,423.15	36.677
162	2,571.31	27.088	207	3,906.52	32.182	252	5,459.87	36.776
163	2,598.46	27.206	208	3,938.76	32.291	253	5,496.69	36.874
164	2,625.72	27.325	209	3,971.10	32.399	254	5,533.62	36.972
165	2,653.10	27.442	210	4,003.56	32.506	255	5,570.64	37.070
166	2,680.61	27.560	211	4,036.12	32.614	256	5,607.75	37.167
167	2,708.22	27.677	212	4,068.78	32.721	257	5,644.97	37.264
168	2,735.96	27.795	213	4,101.56	32.828	258	5,682.28	37.360
169	2,763.81	27.911	214	4,134.44	32.934	259	5,719.69	37.456
170	2,791.78	28.028	215	4,167.43	33.040	260	5,757.20	37.551
171	2,819.87	28.144	216	4,200.52	33.146	261	5,794.79	37.645
172	2,848.07	28.260	217	4,233.72	33.252	262	5,832.49	37.739
173	2,876.39	28.376	218	4,267.02	33.357	263	5,870.27	37.831
174	2,904.82	28.491	219	4,300.43	33.462	264	5,908.15	37.923
175	2,933.37	28.606	220	4,333.95	33.566	265	5,946.12	38.014
176	2,962.04	28.721	221	4,367.56	33.670	266	5,984.17	38.103
177	2,990.81	28.836	222	4,401.29	33.774	267	6,022.32	38.193
178	3,019.71	28.950	223	4,435.11	33.877	268	6,060.56	38.281
179	3,048.71	29.065	224	4,469.04	33.980	269	6,098.88	38.368
180	3,077.84	29.179	225	4,503.07	34.083	270	6,137.30	38.455
181	3,107.07	29.292	226	4,537.21	34.185	271	6,175.79	38.541
182	3,136.42	29.406	227	4,571.44	34.287	272	6,214.37	38.627
183	3,165.88	29.519	228	4,605.78	34.388	273	6,253.05	38.714
184	3,195.46	29.632	229	4,640.22	34.490	274	6,291.80	38.802
185	3,225.15	29.745	230	4,674.76	34.591	275	6,330.65	38.891
186	3,254.95	29.858	231	4,709.40	34.691	276	6,369.59	38.983
187	3,284.86	29.971	232	4,744.14	34.792	277	6,408.62	39.078
188	3,314.89	30.083	233	4,778.98	34.892	278	6,447.74	39.178
189	3,345.03	30.195	234	4,813.93	34.992	279	6,486.97	39.283
190	3,375.28	30.307	235	4,848.97	35.092	280	6,526.31	39.397
191	3,405.64	30.419	236	4,884.11	35.192			
192	3,436.12	30.531	237	4,919.35	35.291			
193	3,466.71	30.642	238	4,954.69	35.391			
194	3,497.40	30.753	239	4,990.13	35.490			
195	3,528.21	30.864	240	5,025.67	35.589			

TABLE 4a-17. TYPE EP VS. Au-0.07 Fe (CHROMEL VS. Au-0.07 AT.% Fe)
(INTERIM VALUES)

T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K	T, K	E, μV	dE/dT, μV/K
1	7.86	8.645	51	785.00	16.402	101	1,665.72	18.731
2	17.21	10.035	52	801.42	16.450	102	1,684.47	18.770
3	27.86	11.220	53	817.89	16.498	103	1,703.20	18.809
4	39.59	12.226	54	834.42	16.548	104	1,722.09	18.848
5	52.26	13.073	55	850.99	16.598	105	1,740.95	18.886
6	65.69	13.782	56	867.61	16.648	106	1,759.86	18.924
7	79.78	14.369	57	884.29	16.699	107	1,778.80	18.961
8	94.40	14.852	58	901.01	16.750	108	1,797.78	18.998
9	109.45	15.243	59	917.79	16.801	109	1,816.80	19.035
10	124.86	15.555	60	934.61	16.852	110	1,835.85	19.071
11	140.54	15.801	61	951.49	16.903	111	1,854.94	19.107
12	156.44	15.989	62	968.42	16.953	112	1,874.06	19.143
13	172.50	16.128	63	985.40	17.004	113	1,893.22	19.178
14	188.68	16.228	64	1,002.43	17.055	114	1,912.42	19.213
15	204.94	16.293	65	1,019.51	17.105	115	1,931.65	19.247
16	221.26	16.331	66	1,036.64	17.155	116	1,950.91	19.281
17	237.60	16.347	67	1,053.82	17.205	117	1,970.21	19.315
18	253.95	16.346	68	1,071.05	17.255	118	1,989.54	19.349
19	270.29	16.330	69	1,088.33	17.304	119	2,008.91	19.382
20	286.60	16.305	70	1,105.66	17.354	120	2,028.31	19.415
21	302.89	16.272	71	1,123.03	17.402	121	2,047.74	19.447
22	319.15	16.235	72	1,140.46	17.451	122	2,067.20	19.480
23	335.36	16.195	73	1,157.94	17.499	123	2,086.70	19.512
24	351.54	16.154	74	1,175.46	17.547	124	2,106.23	19.543
25	367.67	16.114	75	1,193.03	17.595	125	2,125.78	19.575
26	383.77	16.076	76	1,210.65	17.642	126	2,145.37	19.606
27	399.82	16.040	77	1,228.31	17.689	127	2,165.00	19.637
28	415.85	16.008	78	1,246.03	17.736	128	2,184.65	19.668
29	431.84	15.980	79	1,263.79	17.783	129	2,204.33	19.698
30	447.81	15.957	80	1,281.59	17.829	130	2,224.04	19.728
31	463.76	15.938	81	1,299.44	17.875	131	2,243.79	19.758
32	479.69	15.924	82	1,317.34	17.921	132	2,263.56	19.788
33	495.61	15.915	83	1,335.29	17.966	133	2,283.36	19.818
34	511.52	15.911	84	1,353.28	18.011	134	2,303.20	19.847
35	527.43	15.912	85	1,371.31	18.056	135	2,323.06	19.876
36	543.35	15.917	86	1,389.39	18.101	136	2,342.95	19.905
37	559.27	15.927	87	1,407.51	18.145	137	2,362.87	19.834
38	575.20	15.941	88	1,425.68	18.189	138	2,382.82	19.963
39	591.15	15.960	89	1,443.89	18.233	139	2,402.80	19.991
40	607.12	15.982	90	1,462.14	18.276	140	2,422.80	20.020
41	623.12	16.007	91	1,480.44	18.319	141	2,442.83	20.048
42	639.14	16.036	92	1,498.78	18.362	142	2,462.90	20.076
43	655.19	16.068	93	1,517.16	18.404	143	2,482.99	20.104
44	671.28	16.103	94	1,535.59	18.446	144	2,503.10	20.131
45	687.40	16.140	95	1,554.06	18.488	145	2,523.25	20.159
46	703.56	16.180	96	1,572.56	18.529	146	2,543.42	20.186
47	719.76	16.221	97	1,591.11	18.570	137	2,563.62	20.213
48	736.00	16.264	98	1,609.70	18.611	148	2,583.85	20.240
49	752.29	16.309	99	1,628.34	18.651	149	2,604.10	20.267
50	768.62	16.355	100	1,647.01	18.691	150	2,624.38	20.293

TABLE 4a-17. TYPE EP VS. AU–0.07 FE (CHROMEL VS. AU–0.07 AT.% FE) (INTERIM VALUES)
(Continued)

T, K	*E*, μV	*dE/dT*, μV/K	*T*, K	*E*, μV	*dE/dT*, μV/K	*T*, K	*E*, μV	*dE/dT*, μV/K
151	2,644.69	20.320	196	3,582.42	21.288	241	4,556.11	21.933
152	2,665.02	20.346	197	3,603.72	21.305	242	4,578.05	21.944
153	2,685.38	20.372	198	3,625.03	21.322	243	4,600.00	21.955
154	2,705.76	20.398	199	3,646.36	21.340	244	4,621.96	21.966
155	2,726.18	20.423	200	3,667.71	21.357	245	4,643.94	21.977
156	2,746.61	20.449	201	3,689.08	21.374	246	4,665.92	21.987
157	2,767.07	20.474	202	3,710.46	21.391	247	4,687.91	21.998
158	2,787.56	20.499	203	3,731.86	21.408	248	4,709.91	22.009
159	2,808.07	20.524	204	3,753.27	21.424	249	4,731.93	22.019
160	2,828.61	20.548	205	3,774.71	21.441	250	4,753.95	22.030
161	2,849.17	20.573	206	3,796.16	21.457	251	4,775.99	22.040
162	2,869.75	20.597	207	3,817.62	21.474	252	4,708.03	22.050
163	2,890.36	20.621	208	3,839.10	21.490	253	4,820.09	22.060
164	2,910.99	20.644	209	3,860.60	21.506	254	4,842.15	22.071
165	2,931.65	20.668	210	3,882.12	21.522	255	4,864.23	22.081
166	2,952.33	20.691	211	3,903.65	21.538	256	4,886.31	22.090
167	2,973.03	20.714	212	3,925.19	21.554	257	4,908.41	22.100
168	2,993.76	20.736	213	3,946.75	21.569	258	4,930.51	22.109
169	3,014.50	20.759	214	3,968.33	21.585	259	4,952.63	22.118
170	3,035.27	20.781	215	3,989.92	21.600	260	4,974.75	22.127
171	3,056.06	20.803	216	4,011.53	21.615	261	4,996.88	22.135
172	3,076.88	20.825	217	4,033.15	21.630	262	5,019.03	22.143
173	3,097.71	20.846	218	4,054.79	21.645	263	5,041.17	22.150
174	3,118.57	20.867	219	4,076.44	21.659	264	5,063.32	22.157
175	3,139.45	20.888	220	4,098.11	21.674	265	5,085.48	22.164
176	3,160.35	20.909	221	4,119.79	21.688	266	5,107.64	22.170
177	3,181.27	20.930	222	4,141.49	21.702	267	5,129.82	22.175
178	3,202.21	20.950	233	4,163.19	21.716	268	5,152.00	22.180
179	3,223.17	20.970	224	4,184.92	21.729	269	5,174.18	22.185
180	3,244.15	20.990	225	4,206.65	21.743	270	5,196.37	22.190
181	3,265.15	21.010	226	4,228.40	21.756	271	5,218.56	22.194
182	3,286.17	21.030	227	4,250.17	21.769	272	5,240.75	22.198
183	3,307.21	21.049	228	4,271.94	21.782	273	5,262.96	22.203
184	3,328.27	21.068	229	4,293.73	21.794	274	5,285.16	22.209
185	3,349.34	21.088	230	4,315.53	21.807	275	5,307.37	22.216
186	3,370.44	21.106	231	4,337.34	21.819	276	5,329.59	22.224
187	3,391.56	21.125	232	4,359.17	21.831	277	5,351.83	22.235
188	3,412.69	21.144	233	4,381.00	21.843	278	5,374.06	22.248
189	3,433.85	21.162	232	4,402.85	21.855	279	5,396.32	22.266
190	3,455.02	21.180	235	4,424.71	21.866	280	5,418.60	22.290
191	3,476.21	21.199	236	4,446.59	21.878			
192	3,497.41	21.217	237	4,468.47	21.889			
193	3,518.64	21.235	238	4,490.36	21.900			
194	3,539.88	21.252	239	4,512.27	21.911			
195	3,561.14	21.270	240	4,534.19	21.922			