REFERENCE TABLES FOR PLATINUM TO PLATINUM-
RHODIUM THERMOCOUPLES

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ABSTRACT

Reference tables for use with platinum to platinum-10 per cent rhodium and platinum to platinum-13 per cent rhodium thermocouples have been prepared. When these tables are used, the deviation curves obtained for individual couples, have no points of inflection and are, with few exceptions, linear. These tables are based on the International Temperature Scale, so that the indications of a thermocouple whose calibration is obtained by extrapolation of a deviation curve above the gold point will agree in this region with those of an optical pyrometer.

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I. INTRODUCTION

Although the platinum to platinum-10 per cent rhodium thermocouple is used to define the International Temperature Scale only in the range 660° to $1,063^{\circ}$ C., this couple, as well as the 13 per cent rhodium couple, is used extensively in measuring temperatures in the range 0° to $1,500^{\circ}$ C. Convenient and reliable means are required not only for calibrating these couples over this entire range but also for reducing readings of electromotive force to temperature.

Since the platinum resistance thermometer, in the range 0° to 660° C., and the optical pyrometer, in the range above $1,063^{\circ}$ C., are also used in defining the International Temperature Scale, it is necessary to compare thermocouples either directly or indirectly with these instruments in their respective temperature ranges. Since it is not convenient to compare thermocouples directly with the other types of instruments, it is necessary to resort to indirect methods.

The indirect comparison of thermocouples with resistance thermometers in the range 0° to 660° C. is easily carried out by employing thermometric fixed points defined by the temperature of equilibrium between the solid and liquid phases or the liquid and vapor phases of pure substances. There are a large number of such points in this temperature range. However, there are no metals having freezing points above the freezing point of copper ($1,083^{\circ}$ C.) with which conveniently to compare thermocouples and optical pyrometers. The freezing points of nickel ($1,455^{\circ}$ C.) and of palladium ($1,555^{\circ}$ C.) are near the upper useful limit of thermocouples, but both of these materials should be melted in vacuo to obtain the best results. It is therefore desirable in the routine calibration of thermocouples (ex-

cepting those cases where the highest possible accuracy is required) to employ a method which does not require the comparison of each thermocouple with the optical pyrometer.

The method of calibration employing standard reference tables with suitable deviation curves has been described by Sosman¹ and Adams.² As pointed out by these authors such reference curves are arbitrary but it is advisable, for the sake of accuracy, that they represent closely the actual form of the curve. If the reference table is properly constructed, the deviations of thermocouple calibrations from it will be small and the resulting deviation curve approximately linear, requiring comparatively few calibrations points to fix the curve.

Standard reference tables for use with platinum to platinum-10 per cent rhodium thermocouples are given by Sosman and by Adams in the references cited. The table given by Sosman is based upon the measurements made by Day and Sosman³ with the gas thermometer and thermocouples. The table given by Adams is essentially the same as that of Sosman above 650° C., but the values below 650° C. have been altered to agree with changes in the temperature scale.

The adoption of the International Temperature Scale⁴ defining temperatures above 1,063° C. in terms of Wien's law of radiation, with an assigned value of C_2 , raises the question as to whether, in this region, Adams's reference table represents the emf temperature relation on the international scale. Measurements at the Bureau of Standards⁵ of the temperatures on the international scale of several of the fixed points used by Day and Sosman have indicated fairly well the differences between this scale and that used by Day and Sosman. If it be taken for granted that the thermocouples used by these authors have the same characteristics as those now being used, the table of Adams may be modified by merely converting the temperatures in this table, above 1,063° C., to the international scale by applying the differences deduced. It seemed advisable, however, to adopt the sounder procedure of comparing the indications of thermocouples with those of the optical pyrometer above 1,063° C. and with those of platinum resistance thermometers in the range below 660° C.

II. EXPERIMENTAL PROCEDURE

Twenty standard thermocouples, platinum to platinum-10 per cent rhodium, from four different manufacturers were calibrated in the range 660° to 1,063° C. in accordance with the procedure specified for the International Temperature Scale. They were then calibrated in the range 0° to 420° C. at four thermometric fixed points which had been previously determined by the platinum resistance thermometer. Above 1,063° C. eight of the thermocouples were directly compared with an optical pyrometer by employing an electrically heated black body up to 1,450° C. The thermocouples were then heated until the platinum at the hot junction melted and the emf observed at the instant of melting was assigned to the temperature previously determined for the platinum point, 1,773° C.⁶

¹ Am. J. Sci. (4), vol. 50, p. 7, 1910.

² J. Am. Chem. Soc., vol. 36, p. 65, 1914, Pyrometry Symposium. A. I. M. M. E., p. 165, 1919.

³ Car. Inst. of Wash. Pub. No. 157, 1911. Am. J. Sci., vol. 33, p. 517, 1912.

⁴ Proc. Seventh General Conference of Weights and Measures. 1927, p. 56. Text in Annex IV, p. 94.

G. K. Burgess, B. S. Jour. Research, vol. 1, p. 635, 1928.

⁵ B. S. Jour. Research, vol. 5, p. 1309, 1930.

⁶ B. S. Jour. Research, vol. 6, p. 1119, 1931.

III. CONSTRUCTION OF TABLE

The alloy element of the standard platinum-rhodium thermocouple is specified as that alloy which develops between 10.2 and 10.4 mv against pure platinum at the gold point. This fixes the rhodium content of the alloy at 10 per cent as accurately as can be done by chemical analysis. Since the value given in Adams's table at the gold point (10.301 mv) is near the mean of these limits it was considered advisable to retain this value in the new table.

Since the average emf of the couples investigated differed by ΔE (about 4 μv) from Adams's table at the gold point, the emf at each calibration point was increased by an amount $\frac{E \text{ at calibration point}}{10,301} \times \Delta E$.

This yielded a skeleton table, given in Table 1, which agrees with Adams's table at the gold point and from which nearly all the thermocouples deviated linearly. The few deviation curves which were not straight lines contained no points of inflection. Typical deviation curves from Adams's table and this skeleton table are shown in Figure 1.

FIGURE 1.—Deviation curves of a typical 10 per cent rhodium thermocouple

Several equations were used for interpolating between the values in the skeleton table, since no simple equation was found which would fit the values over the entire temperature range. In order to make the curve and its first derivative continuous, the slopes of each pair of successive interpolation equations were made equal at the point in common. These equations are also given in Table 1.

TABLE 1.—Calibration points and derived emf's

	Temperature	Emf
	$^{\circ}C.$	μv
Melting point of ice.....	0.0	0
Boiling point of water.....	100.0	643
Freezing point of tin.....	231.9	1,709
Freezing point of lead.....	327.4	2,567
Freezing point of zinc.....	419.45	3,436
Freezing point of antimony.....	630.5	5,535
Freezing point of silver.....	960.5	9,117
Freezing point of gold.....	1,063.0	10,301
	1,250	12,522
	1,400	14,312
	1,773	18,690
Melting point of platinum.....		

Equations used for interpolating between calibration points

0° to 231.9° C.,	$E=5.45018t$	$+0.0109517t^2$	$-0.000011535t^3$	
231.9° to 327.4° C.,	$E=-35.01$	$+6.10222t$	$+0.00728131t^2$	$-0.0000050249t^3$
327.4° to 419.45° C.,	$E=-5375$	$+6.29745t$	$+0.00661301t^2$	$-0.0000042712t^3$
419.45° to 630.5° C.,	$E=-309.17$	$+8.29558t$	$+0.00144103t^2$	$+0.0000001634t^3$
630.5° to 660° C.,	$E=-263.93$	$+8.04427t$	$+0.00189675t^2$	$-0.00000010773t^3$
660° to 1,063° C.,	$E=-333.29$	$+8.29175t$	$+0.00161080t^2$	
1,063° to 1,250° C.,	$E=1,858.96$	$+1.76577t$	$+0.00807342t^2$	$-0.00000212935t^3$
1,250° to 1,773° C.,	$E=-2,074.00$	$+10.86774t$	$+0.00106153t^2$	$-0.00000033143t^3$

A table of approximate values for platinum to platinum-13 per cent rhodium thermocouples is given in Bureau of Standards Technologic Paper No. 170. This table was determined before the adoption of the International Temperature Scale, and is subject to the same disadvantages as Adams' table for the 10 per cent rhodium thermocouples. A typical deviation curve from this table is shown in Figure 2.

FIGURE 2.—Deviation curves of a typical 13 per cent rhodium thermocouple

A new reference table for 13 per cent rhodium thermocouples was obtained by comparing four such couples with 10 per cent rhodium couples and by applying the difference between the two types to the tabular values for 10 per cent rhodium couples.

IV. RESULTS

Corresponding values of emf and temperature, as derived in this work for the 10 and 13 per cent rhodium thermocouples, are given in Tables 2 to 5. Below 1,200° C. the maximum difference between Table 2 and Adams' table is 0.7° C.

Previous to this the best working tables available for the temperature emf relations of platinum to platinum rhodium thermocouples were those on pages 306 and 308 (Adams' table) of Bureau of Standards Technologic Paper No. 170, and the bureau has, in the past, recommended their use. Recent progress in optical pyrometry and the adoption of the International Temperature Scale have indicated the desirability of reference tables which represent more accurately the characteristics of these couples. The publication of these tables, however, should not be construed as indicating in any way a change in the characteristics of the couples.

The values in these reference tables above the gold point are practically identical up to the palladium point ($1,555^{\circ}\text{C.}$) with those which would have been obtained by simply converting the temperatures in the old tables to the international scale by means of the differences between the scales inferred from recent determinations of fixed points. This indicates that the thermocouples used by Day and Sosman had essentially the same characteristics as those now being used. As an illustration the emf of the 10 per cent rhodium couple was found to be 16.136 mv at $1,553.6^{\circ}\text{C.}$, the freezing point of palladium, from optical measurements, whereas Adams' table gives 16.14 mv for a temperature of $1,549.2^{\circ}$, the palladium point on the scale of Day and Sosman.

A comparison of the deviation curves obtained from the new reference tables and from the tables previously available are shown in Figures 1 and 2. The former may be extrapolated with confidence practically up to the platinum point.

In conclusion it may be well to emphasize the arbitrary nature of these tables. They represent accurately only the shape of the emf temperature curve for the particular type of couple and do not necessarily represent the actual emf even for a thermocouple having exactly the composition given. Using these tables with deviation curves determined by calibration at two points (about 600° and $1,200^{\circ}\text{C.}$), a calibration is obtained which is not in error by more than 3°C. from 0° to $1,500^{\circ}\text{C.}$

V. SUMMARY

Reference tables for two classes of platinum-rhodium thermocouples, the 10 per cent and 13 per cent rhodium alloys versus platinum have been determined. They accurately represent the shape of the emf temperature curves for these couples when the International Temperature Scale is used. The deviation from these tables of the couples now being used show no points of inflection and with few exceptions, are linear.

TABLE 2.—Reference table for Pt to Pt-10 per cent Rh thermocouple
[Emfs are expressed in microvolts and temperatures in °C. Cold junctions at 0° C.]

E Micro-volts	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	E Micro-volts
0	0	146.9	265.0	373.7	477.7	578.1	675.3	769.5	861.0	0
100	17.7	159.4 ^{12.5}	276.2 ^{11.2}	384.2 ^{10.5}	487.9 ^{10.2}	588.0 ^{9.9}	684.8 ^{9.5}	778.8 ^{9.3}	870.0 ^{9.0}	100
200	34.4	171.7 ^{12.3}	287.3 ^{11.1}	394.7 ^{10.5}	498.1 ^{10.2}	597.8 ^{9.8}	694.3 ^{9.5}	788.0 ^{9.2}	879.0 ^{9.0}	200
300	50.2	183.8 ^{12.1}	298.3 ^{11.0}	405.2 ^{10.5}	508.2 ^{10.1}	607.6 ^{9.8}	703.8 ^{9.5}	797.2 ^{9.2}	888.0 ^{9.0}	300
400	65.4	195.8 ^{12.0}	309.3 ^{11.0}	415.7 ^{10.5}	518.3 ^{10.1}	617.4 ^{9.8}	713.3 ^{9.5}	806.4 ^{9.2}	897.0 ^{9.0}	400
500	80.0	207.6 ^{11.8}	320.2 ^{10.9}	426.1 ^{10.4}	528.4 ^{10.1}	627.1 ^{9.7}	722.7 ^{9.4}	815.6 ^{9.1}	905.9 ^{8.9}	500
600	94.1	219.3 ^{11.7}	331.0 ^{10.8}	436.5 ^{10.4}	538.4 ^{10.0}	636.8 ^{9.7}	732.1 ^{9.4}	824.7 ^{9.1}	914.8 ^{8.9}	600
700	107.8	230.9 ^{11.6}	341.7 ^{10.7}	446.8 ^{10.3}	548.4 ^{10.0}	646.5 ^{9.6}	741.5 ^{9.4}	833.8 ^{9.1}	923.7 ^{8.9}	700
800	121.1	242.4 ^{11.5}	352.4 ^{10.7}	457.1 ^{10.3}	558.3 ^{9.9}	656.1 ^{9.6}	750.9 ^{9.4}	842.9 ^{9.1}	932.6 ^{8.8}	800
900	134.1	253.7 ^{11.3}	363.1 ^{10.7}	467.4 ^{10.3}	568.2 ^{9.9}	665.7 ^{9.6}	760.2 ^{9.3}	852.0 ^{9.1}	941.4 ^{8.8}	900
1,000	146.9	265.0 ^{11.3}	373.7 ^{10.6}	477.7 ^{10.3}	578.1 ^{9.9}	675.3 ^{9.6}	769.5 ^{9.3}	861.0 ^{9.0}	950.2 ^{8.8}	1,000

E Micro- volts	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	E Micro- volts
0	950.2	1,037.2	1,122.3	1,206.4	1,290.0	1,373.8	1,458.0	1,542.6	1,627.8	0
100	959.0	1,045.8	1,130.8	1,214.7	1,298.3	1,382.2	1,466.4	1,551.1	1,636.4	100
200	967.8	1,054.4	1,139.2	1,223.1	1,306.7	1,390.6	1,474.8	1,559.6	1,644.9	200
300	976.5	1,062.9	1,147.6	1,231.4	1,315.1	1,399.0	1,483.3	1,568.1	1,653.5	300
400	985.3	1,071.5	1,156.0	1,239.8	1,323.5	1,407.4	1,491.8	1,576.6	1,662.1	400
500	994.0	1,080.0	1,164.4	1,248.2	1,331.8	1,415.8	1,500.2	1,585.1	1,670.7	500
600	1,002.7	1,088.5	1,172.8	1,256.5	1,340.2	1,424.2	1,508.7	1,593.7	1,679.3	600
700	1,011.3	1,097.0	1,181.2	1,264.9	1,348.6	1,432.7	1,517.2	1,602.2	1,687.9	700
800	1,020.0	1,105.4	1,189.6	1,273.2	1,357.0	1,441.1	1,525.6	1,610.7	1,696.5	800
900	1,028.6	1,113.9	1,198.0	1,281.6	1,365.4	1,449.5	1,534.1	1,619.3	1,705.1	900
1,000	1,037.2	1,122.3	1,206.4	1,290.0	1,373.8	1,458.0	1,542.6	1,627.8	1,713.7	1,000

TABLE 3.—Reference table for Pt to Pt-13 per cent Rh thermocouple

[Emfs are expressed in microvolts and temperatures in °C. Cold junctions at 0° C.]

E Micro-volts	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	E Micro-volts
0	0	145.3	258.8	361.0	457.4	549.8	638.3	723.5	806.0	886.1	0
100	17.9	157.5	269.4	370.9	466.9	558.8	647.0	731.9	814.1	894.0	100
200	34.6	169.5	279.9	380.7	476.3	567.8	655.6	740.3	822.2	901.8	200
300	50.4	181.2	290.3	390.5	485.7	576.8	664.2	748.6	830.3	909.7	300
400	65.5	192.7	300.6	400.2	495.0	585.7	672.8	756.9	838.3	917.5	400
500	80.0	204.1	310.8	409.9	504.3	594.6	681.3	765.1	846.3	925.3	500
600	93.9	215.3	321.0	419.5	513.5	603.4	689.8	773.3	854.3	933.1	600
700	107.3	226.4	331.1	429.0	522.6	612.2	698.3	781.5	862.3	940.9	700
800	120.3	237.3	341.1	438.5	531.7	620.9	706.7	789.7	870.3	948.7	800
900	132.9	248.1	351.1	448.0	540.8	629.6	715.1	797.8	878.2	956.4	900
1,000	145.3	258.8	361.0	457.4	549.8	638.3	723.5	806.0	886.1	964.1	1,000

E Micro- volts	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	E Micro- volts
0	964.1	1,040.0	1,113.9	1,186.9	1,259.3	1,331.8	1,404.3	1,476.9	1,550.0	1,623.6	0
100	971.7	1,047.4	1,121.2	1,194.1	1,266.6	1,339.0	1,411.6	1,484.2	1,557.4	1,631.0	100
200	979.4	1,054.9	1,128.6	1,201.4	1,273.8	1,346.2	1,418.9	1,491.5	1,564.8	1,638.4	200
300	987.0	1,062.3	1,135.9	1,208.7	1,281.1	1,353.5	1,426.1	1,498.8	1,572.1	1,645.8	300
400	994.7	1,069.7	1,143.2	1,215.9	1,288.3	1,360.8	1,433.3	1,506.1	1,579.5	1,653.2	400
500	1,002.3	1,077.1	1,150.5	1,223.2	1,295.5	1,368.0	1,440.5	1,513.4	1,586.8	1,660.6	500
600	1,009.9	1,084.4	1,157.8	1,230.4	1,302.7	1,375.3	1,447.8	1,520.7	1,594.2	1,668.0	600
700	1,017.5	1,091.8	1,165.1	1,237.6	1,309.9	1,382.6	1,455.0	1,528.0	1,601.5	1,675.4	700
800	1,025.0	1,099.2	1,172.3	1,244.8	1,317.2	1,389.8	1,462.3	1,535.3	1,608.9	1,682.8	800
900	1,032.5	1,106.5	1,179.6	1,252.1	1,324.5	1,397.1	1,469.6	1,542.7	1,616.2	1,690.2	900
1,000	1,040.0	1,113.9	1,186.9	1,259.3	1,331.8	1,404.3	1,476.9	1,550.0	1,623.6	1,697.6	1,000

TABLE 4.—Reference table for Pt to Pt-10 per cent Rh thermocouple

[Emfs are expressed in microvolts and temperatures in °F. Cold junctions at 32 °F.]

E Microvolts	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	E Microvolts
0	32. 0	296. 4	509. 0	704. 7	891. 9	1,072. 6	1,247. 5	1,417. 1	1,581. 8	0
100	63. 9	318. 9	529. 1	723. 7	910. 3	1,090. 3	1,264. 6	1,433. 8	1,598. 0	100
200	93. 9	341. 0	549. 1	742. 6	928. 6	1,108. 0	1,281. 7	1,450. 4	1,614. 2	200
300	122. 4	362. 8	569. 0	761. 4	946. 8	1,125. 7	1,298. 8	1,467. 0	1,630. 4	300
400	149. 7	384. 4	588. 8	780. 2	964. 9	1,143. 3	1,315. 9	1,483. 5	1,646. 5	400
500	176. 0	405. 7	608. 4	799. 0	983. 0	1,160. 8	1,332. 9	1,500. 0	1,662. 6	500
600	201. 4	426. 7	627. 8	817. 7	1,001. 1	1,178. 3	1,349. 8	1,516. 5	1,678. 6	600
700	226. 0	447. 6	647. 1	836. 3	1,019. 1	1,195. 7	1,366. 7	1,532. 9	1,694. 6	700
800	250. 0	468. 3	666. 4	854. 8	1,037. 0	1,213. 0	1,383. 6	1,549. 2	1,710. 6	800
900	273. 4	488. 7	685. 6	873. 4	1,054. 8	1,230. 3	1,400. 4	1,565. 5	1,726. 5	900
1,000	296. 4	509. 0	704. 7	891. 9	1,072. 6	1,247. 5	1,417. 1	1,581. 8	1,742. 4	1,000

E Microvolts	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	E Micro- volts
0	1,742.4 15.8	1,899.0 15.5	2,052.1 15.2	2,203.5 15.0	2,354.0 15.0	2,504.8 15.2	2,656.4 15.1	2,808.7 15.3	2,962.0 15.4	0
100	1,758.2 15.8	1,914.5 15.4	2,067.3 15.2	2,218.5 15.0	2,369.0 15.1	2,520.0 15.1	2,671.5 15.2	2,824.0 15.3	2,977.4 15.4	100
200	1,774.0 15.7	1,929.9 15.4	2,082.5 15.2	2,233.5 15.0	2,384.1 15.1	2,535.1 15.1	2,686.7 15.2	2,839.3 15.3	2,992.8 15.5	200
300	1,789.7 15.8	1,945.3 15.4	2,097.7 15.1	2,248.5 15.1	2,399.2 15.1	2,550.2 15.1	2,701.9 15.3	2,854.6 15.3	3,008.3 15.5	300
400	1,805.5 15.7	1,960.7 15.3	2,112.8 15.1	2,263.6 15.1	2,414.3 15.0	2,565.3 15.1	2,717.2 15.2	2,869.9 15.3	3,023.8 15.5	400
500	1,821.2 15.6	1,976.0 15.3	2,127.9 15.1	2,278.7 15.0	2,429.3 15.1	2,580.4 15.2	2,732.4 15.3	2,885.2 15.4	3,039.3 15.4	500
600	1,836.8 15.6	1,991.3 15.2	2,143.0 15.2	2,293.7 15.1	2,444.4 15.1	2,595.6 15.2	2,747.7 15.3	2,900.6 15.4	3,054.7 15.5	600
700	1,852.4 15.6	2,006.5 15.2	2,158.2 15.1	2,308.8 15.0	2,459.5 15.1	2,610.8 15.2	2,763.0 15.2	2,916.0 15.3	3,070.2 15.5	700
800	1,868.0 15.5	2,021.7 15.2	2,173.3 15.1	2,323.8 15.1	2,474.6 15.1	2,626.0 15.2	2,778.2 15.2	2,931.3 15.4	3,085.7 15.5	800
900	1,883.5 15.5	2,036.9 15.2	2,188.4 15.1	2,338.9 15.1	2,489.7 15.1	2,641.2 15.2	2,793.4 15.3	2,946.7 15.3	3,101.2 15.5	900
1,000	1,899.0	2,052.1	2,203.5	2,354.0	2,504.8	2,656.4	2,808.7	2,962.0	3,116.7	1,000

TABLE 5.—Reference table for Pt to Pt-13 per cent Rh thermocouple
[Emfs are expressed in microvolts and temperatures in °F. Cold junctions at 32° F.]

E Micro- volts	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	E Micro- volts
0	32.0	293.5	497.8	681.8	855.3	1,021.6	1,180.9	1,334.3	1,482.8	1,627.0	0
100	64.2	315.5	516.9	699.6	872.3	1,037.8	1,196.5	1,349.4	1,497.4	1,641.2	100
200	94.3	337.1	535.8	717.3	889.3	1,054.0	1,212.1	1,364.5	1,512.0	1,655.3	200
300	122.7	358.2	554.5	734.9	906.2	1,070.2	1,227.6	1,379.5	1,526.5	1,669.4	300
400	149.9	378.9	573.1	752.4	923.0	1,086.3	1,243.0	1,394.4	1,540.9	1,683.5	400
500	176.0	399.3	591.5	769.8	939.7	1,102.3	1,258.3	1,409.2	1,555.3	1,697.5	500
600	201.0	419.5	609.8	787.1	956.3	1,118.2	1,273.6	1,424.0	1,569.7	1,711.6	600
700	225.1	439.5	628.0	804.3	972.7	1,134.0	1,288.9	1,438.8	1,584.1	1,725.6	700
800	248.5	459.2	646.0	821.4	989.1	1,149.7	1,304.1	1,453.5	1,598.5	1,739.6	800
900	271.2	478.6	664.0	838.4	1,005.4	1,165.3	1,319.2	1,468.1	1,612.8	1,753.5	900
1,000	293.5	497.8	681.8	855.3	1,021.6	1,180.9	1,334.3	1,482.8	1,627.0	1,767.4	1,000

E Micro- volts	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	E Micro- volts
0	1,767.4 13.8	1,904.0 13.4	2,037.0 13.2	2,168.4 13.0	2,298.7 13.1	2,429.2 13.0	2,559.7 13.1	2,690.4 13.2	2,822.0 13.3	2,954.5 13.3	0
100	1,781.2 13.7	1,917.4 13.4	2,050.2 13.2	2,181.4 13.1	2,311.8 13.0	2,442.2 13.0	2,572.8 13.1	2,703.6 13.1	2,835.3 13.2	2,967.8 13.3	100
200	1,794.9 13.7	1,930.8 13.3	2,063.4 13.2	2,194.5 13.1	2,324.8 13.1	2,455.2 13.1	2,585.9 13.0	2,716.7 13.1	2,848.6 13.2	2,981.1 13.3	200
300	1,808.6 13.8	1,944.1 13.3	2,076.6 13.2	2,207.6 13.0	2,337.9 13.0	2,468.3 13.1	2,598.9 13.0	2,729.8 13.2	2,861.8 13.3	2,994.4 13.4	300
400	1,822.4 13.7	1,957.4 13.3	2,089.8 13.1	2,220.6 13.1	2,350.9 13.0	2,481.4 13.0	2,611.9 13.0	2,743.0 13.1	2,875.1 13.2	3,007.8 13.3	400
500	1,836.1 13.7	1,970.7 13.3	2,102.9 13.1	2,233.7 13.0	2,363.9 13.0	2,494.4 13.1	2,624.9 13.1	2,756.1 13.2	2,888.3 13.3	3,021.1 13.3	500
600	1,849.8 13.6	1,984.0 13.3	2,116.0 13.1	2,246.7 13.0	2,376.9 13.0	2,507.5 13.1	2,638.0 13.0	2,769.3 13.1	2,901.6 13.2	3,034.4 13.3	600
700	1,863.4 13.6	1,997.3 13.3	2,129.1 13.1	2,259.7 13.0	2,389.9 13.1	2,520.6 13.0	2,651.0 13.1	2,782.4 13.2	2,914.8 13.2	3,047.7 13.3	700
800	1,877.0 13.5	2,010.6 13.2	2,142.2 13.1	2,272.7 13.0	2,403.0 13.1	2,533.6 13.1	2,664.1 13.1	2,795.6 13.2	2,928.0 13.2	3,061.0 13.4	800
900	1,890.5 13.5	2,023.8 13.2	2,155.3 13.1	2,285.7 13.0	2,416.1 13.1	2,546.7 13.0	2,677.2 13.2	2,808.8 13.2	2,941.2 13.3	3,074.4 13.3	900
1,000	1,904.0 13.5	2,037.0 13.2	2,168.4 13.1	2,298.7 13.0	2,429.2 13.1	2,559.7 13.0	2,690.4 13.4	2,822.0 13.2	2,954.5 13.3	3,087.7 13.3	1,000

WASHINGTON, December 22, 1932.