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REFERENCE TABLES FOR IRON-CONSTANTAN AND COPPER-CONSTANTAN THERMOCOUPLES [1]

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ABSTRACT

Tables have been prepared giving corresponding values of temperature and thermal electromotive force at various temperatures from −200 to 1,000° C (−300 to 1,800° F) for iron-constantan thermocouples. Similar tables from −200 to 400° C (−300 to 750° F) for copper-constantan thermocouples, although not new, have been included for completeness. The temperature-emf relations embodied in these tables are such that (1) each can be reproduced with materials generally and readily available; (2) each is the same (within ±¾ percent) as the temperature-emf relation of a large percentage of such thermocouples of that type now in use; (3) each is near the mean of the extreme limits of the temperature-emf relations for thermocouples of that type; (4) the table for iron-constantan is near the existing table most widely used, while the one for copper-constantan is the one most widely used; and (5) the constantan used with one element to reproduce one table can be used with the other element to reproduce the other table.

This paper also gives (1) average values of the thermal emf of copper, iron which is generally available, and constantan against platinum, as a guide in selecting materials to yield any specified relation between thermal emf and temperature for thermocouples of these types and (2) the variations in thermal emf that might be expected between samples of these materials from the same lot and from different lots.

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I. INTRODUCTION

The foundations of pyrometry as an industrial art were laid more than 30 years ago with the development [2] of a relatively rugged indicator which was suitable for use in industrial plants. The relatively low sensitivity of the indicator necessitated the use of a thermocouple which developed a relatively high thermal emf. It had been known for some time [3] that thermocouples of iron or copper in combination with an alloy of approximately equal parts of copper and nickel, de-

[1] The tables given in this paper are intended primarily for use above 0° C. Values at lower temperatures have been included for the convenience of those who might find use for a table that extends both above and below 0° C.

[2] Wm. H. Bristol. Trans. Am. Soc. Mech. Engrs. 27, 552 (1906).

[3] Stephan Lindeck. Rep. Brit. Assn. Adv. Sci. p. 139 (1892).

veloped a high thermal emf, and it had been demonstrated [4] that such thermocouples were suitable for fairly accurate temperature measurements. These thermocouples fulfilled other requirements (stability, reproducibility, low cost, etc.) of commercial thermocouples as well as any other combination of materials available at that time. There was already on the market a copper-nickel alloy known as "Constantan," so named because its electrical resistivity remained practically constant as its temperature was changed. This alloy was being produced with fairly well controlled electrical properties and its thermoelectric power against either iron or copper was substantially the maximum obtainable with any copper-nickel alloy; hence it was readily adopted as one of the elements of industrial thermocouples.

Accounts of the development and some early investigations of copper-nickel alloys are given by K. Feussner,[5] [6] S. Lindeck,[7] E. Weston,[8] and Fuessner and Lindeck.[9] The name "Constantan" apparently originated at the firm of Basse and Selve. According to Feussner,[5] "Konstanten" was the name given by Basse and Selve to the copper-nickel alloy with zero temperature coefficient of resistance and again, according to Feussner,[6] "Konstantan" was the name given the 60 copper–40 nickel alloy. According to Feussner and Lindeck,[9] "Constantan" was the name given to the 60 copper–40 nickel alloy by Basse and Selve and, according to Lindeck (see footnote 3), "Constantan" was the name of the 50 copper–50 nickel alloy. In any event, the name constantan has become a general name which covers a group of alloys containing[10] 60 to 45 percent of copper and 40 to 55 percent of nickel (with or without small percentages of manganese, iron, and carbon) because all the alloys in this range of composition have a more or less negligible temperature coefficient of resistance. Constantan thus includes the alloys made in this country under such trade names as Advance (Ideal), Copel, Copnic, Cupron, etc., most of which contain approximately 55 percent of copper and 45 percent of nickel.

With the introduction of pyrometers into general industrial use, one of the first requirements was that the scales of the instruments should be graduated to read temperature directly. It is not practicable to calibrate the scale of an instrument in accordance with the temperature-emf relation of a particular thermocouple and to change the scale each time the thermocouple is replaced. Consequently, the scales of such instruments are calibrated in accordance with a particular temperature-emf relation which was considered representative of the materials of this class at the time the relation was determined. New thermocouple materials are purchased or selected to approxinate the particular temperature-emf relation which had been previously adopted.

Before the amount of constantan used in thermocouples became an important item, the composition of constantan was controlled to insure a negligible temperature coefficient of electrical resistivity, but this control did not prevent rather large differences in thermoelectric

[4] A. de Forest Palmer, Jr. Phys. Rev. **21**, 65 (1905).
[5] K. Feussner. Verhandl. physik. Ges. Berlin **10**, 109 (1892).
[6] K. Feussner. Elektrotech. Z. **13**, 99 (1892).
[7] S. Lindeck. Proc. Int. Elec. Cong. Chicago, p. 165 (1893) [Pub. by Am. Inst. Elec. Eng.]
[8] E. Weston. In the discussion of Lindeck's paper, p. 176 of reference 7.
[9] Feussner and Lindeck. Wiss. Abhandl. Physik.-Tech. Reichsanstalt **2**, 514 (1895).
[10] Woldman and Dornblatt. Engineering Alloys (Am. Soc. Metals, 1936).

properties. At the present time, the amount of constantan used in thermocouples is large enough to interest the manufacturers in controlling the composition of certain grades of the alloy to give predetermined thermoelectric properties. Although the differences in thermoelectric power between various samples of constantan made today may be as much as 1.8 μv/°F. (about 6 percent of the thermoelectric power of an iron-constantan thermocouple), these differences are not due to poor control of composition, but to the fact that the manufacturers are purposely reproducing materials made years ago and still in demand. In general, the thermal emf between any two samples of constantan is approximately proportional to the difference between the temperatures of the junctions. (See fig. 2.)

On the other hand, the amount of iron wire used in thermocouples is an extremely small percentage of the total amount of iron wire produced. Consequently, the large producers of iron wire have not been particularly interested in controlling the composition of commercial iron to give predetermined thermoelectric properties. The differences between various samples of commercially pure iron are about one-fifth as large as those in the case of constantan and are due, no doubt, to differences in chemical composition. However, in the case of iron, the thermal emf between any two samples (when plotted against the temperature) may depart considerably from a straight line. (See samples 10 and 21 in fig. 3.) Two samples of iron may give exactly the same thermal emf at 1,400° F, and yet differ by as much as 0.3 mv at 400° F (equivalent to about 10° F on an iron-constantan thermocouple). Twenty or more years ago, the differences between various samples of commercially pure iron used for thermocouples were greater and more irregular than at the present time, because iron wire, in general, was less pure and the composition was not as well controlled.

In comparison with other commercial materials, copper is and has been remarkably uniform in its thermoelectric properties, primarily because electrolytic copper of comparatively high purity has been generally available for years. A difference in thermoelectric power greater than 0.05 μv/° F (about 0.2 percent of the thermoelectric power of a copper-constantan thermocouple) between two samples of annealed copper is seldom encountered.

Owing to the differences in composition and thermoelectric properties between various lots of constantan and of iron, a number of different tables and curves have been published which give corresponding values of temperature and thermal emf for copper- and iron-constantan thermocouples. The origin of all the different curves is not known to the writers but the differences (as large as 7 percent) can easily be explained, as the various curves were determined at different times and by different investigators, using materials of the same general name but differing in thermoelectric properties.

In order to obtain thermocouples which will give the temperature-emf relation of any table or curve for thermocouples of either type, it is necessary to use materials which have the same characteristics as those used in determining that curve. This may be seen from a study of figures 2 and 3. If iron such as sample 21 and iron such as sample 10 are combined with the same constantan to form two thermocouples, the thermal electromotive forces developed by these two thermocouples will be practically identical in the range 700 to 800° C (1,292 to 1,472° F), but they will differ appreciably at other temperatures. In other words, the curves showing the emf as a function of temperature for these two thermocouples do not have the same shape. Therefore, if a reference curve be derived for thermocouples consisting of iron like No. 21 and any sample of constantan, no sample of constantan can be found which can be combined with a sample of iron like No. 10 to yield temperature-emf values which are in agreement with those of the derived curve except over short ranges of temperature.

Most of the tables and curves now being used for iron-constantan thermocouples were prepared 15 or more years ago. Owing primarily to changes in the process of manufacturing commercially pure iron, iron wire now generally available is not the same as that in use at the time the curves were developed. Consequently, it is now necessary to obtain a more or less special iron in order to reproduce these temperature-emf relations over wide temperature ranges. However, as the variations in constantan are much greater than those in iron, it has always been possible to select materials which will match any of these curves in a limited temperature range.

II. PURPOSE AND SCOPE OF THE PRESENT WORK

The National Bureau of Standards has been frequently requested by other Government agencies and some industrial organizations to provide the data necessary for the preparation of specifications for copper-constantan and iron-constantan thermocouples. The important feature of such a specification for each type of thermocouple is a table of corresponding values of temperature and thermal emf that can be reproduced over a large temperature range by the proper selection of materials generally available at the present time. A number of such tables might be prepared, inasmuch as constantan and commercially pure iron, each with different compositions and thermoelectric properties, are still generally available. However, the choice becomes very limited if it is restricted to tables which meet the requirements given below.

It is essential that the temperature-emf relation for each type of thermocouple fulfill the following two conditions or requirements:

1. It should be such that it can be reproduced over a large temperature range with materials readily available at this time (and presumably in the future).
2. It should be the same (within reasonable limits) as the temperature-emf relation of a large percentage of such thermocouples now in use.

It would be desirable if each table could also be made to fulfill the following three conditions, but these may be inconsistent with the two essential ones above.

3. It should be near the mean of the extreme limits of the temperature-emf relation for thermocouples of that type.
4. It should agree with the existing table most widely used.
5. The constantan selected for use with copper to reproduce the relation for copper-constantan should be such that it can be used with a particular iron to reproduce the relation for iron-constantan as well.

After a study of the temperature-emf relations of a large number of thermocouples from different sources it was found (a) that Adams' table [11] for copper-constantan thermocouples meets the first four conditions given above, and (b) that none of the tables being used for iron-constantan thermocouples prior to this investigation would meet the first requirement within the limits specified by some Government agencies and some industrial organizations. Furthermore, it happens that any two tables which will meet requirements 1 and 2 for these two types of thermocouples will meet condition 3 and come so close to meeting condition 5 that this last condition can also be met with no sacrifice of any of the other advantages. Obviously, any table prepared to meet requirement 2 for iron-constantan thermocouples will also come close to meeting condition 4.

The situation then may be summarized as follows: (a) Adams' table meets the requirements for copper-constantan thermocouples; (b) constantan selected for use with copper to reproduce Adams' table has thermoelectric properties near the mean of available constantan; (c) if this mean constantan is combined with iron near the mean of generally available commercial iron, a table is obtained for iron-constantan thermocouples which comes as near meeting all the conditions as appears possible at this time.

The fact that Adams' table covers a large temperature range (−200 to +385° C) makes it more suitable for the present purpose than other published tables [12] [13] [14] which cover ranges only below room temperature.

The particular steps in the procedure followed are then: (1) The thermal emf of copper with respect to platinum was determined; (2) these values were combined with Adams' relation for copper-constantan to obtain the thermal emf of constantan against platinum; (3) the thermal emf of generally available iron against platinum was determined; and (4) these iron-platinum and constantan-platinum values were combined to obtain values for iron-constantan. This was done for the temperature range covered by Adams' table (−200 to 385° C), but it was necessary to make additional observations on constantan to extend the iron-constantan values to higher temperatures.

The thermal emf of each sample studied was determined against the Platinum Thermoelectric Standard Pt 27 of this Bureau. In this way the thermoelectric properties of each thermocouple material could be studied independently of the others and the thermal emf of any two samples against each other could be obtained by combining the values of thermal emf of each against platinum. Thus, in obtaining the data necessary for determining the temperature-emf relation of copper or iron against constantan, representative temperature-emf relations for each material against platinum were determined and some information was obtained on the differences in thermal emf to be expected between samples of wire from the same lot and from different lots.

The results of similar investigations on platinum to platinum-rhodium [15] and on Chromel-Alumel [16] thermocouples have been published recently in this journal.

[11] L. H. Adams, Pyrometry, p. 165 (Symposium published by Am. Inst. Mining Met. Engrs. 1920). Int. Crit. Tables **1**, 58 (1926).
[12] Giauque, Buffington, and Schulze, J. Am. Chem. Soc. **49**, 2343 (1927).
[13] Southard and Andrews. J. Franklin Inst. **207**, 323 (1929).
[14] Aston, Willihnganz, and Messerly. J. Am. Chem. Soc. **57**, 1642 (1935).
[15] BS J. Research **10**, 275 (1933) RP530.
[16] J. Research NBS **14**, 239 (1935) RP767.

III. EXPERIMENTAL PROCEDURE

Samples of iron, copper, and constantan were obtained from a number of sources. Most of the samples were supplied by or purchased from pyrometer or wire manufacturers. The other samples were prepared at this Bureau. In addition to the data obtained on the samples included in this particular investigation, data on a number of samples of wires from various sources were already available in the records of this Bureau.

The thermal emf of each sample against platinum was determined in air with no protection from oxidation, in the same way and with the same apparatus as used at this Bureau in the calibration of high temperature thermocouples.[17] From one to five samples of wire are welded together with a platinum working standard. These wires are insulated and placed in a tube furnace with the junction of a calibrated platinum to platinum-rhodium thermocouple inserted in a hole drilled into the composite junction formed by welding the wires being tested to the platinum wire. The standard thermocouple and platinum wire are sealed into porcelain tubes with a Pyrex glass, leaving a very short length of wire exposed at the measuring junction. When possible the reference junctions are maintained at 0° C. In other cases, the temperature of this junction is measured with a mercury-in-glass thermometer. Simultaneous readings of the temperature and the thermal emf of the samples against platinum are made at various temperatures. It is estimated that the accuracy of the measurements and the intervals between observation points were such that the uncertainty in the determination of the corresponding values of temperature and emf of each material against platinum did not exceed $\pm 5\,\mu$v up to 5 mv. and ± 0.1 percent up to the emf corresponding to 900° C (1,652° F). This estimate of the uncertainty includes the effect of changes in the wire during the determination. No claim is made for the accuracy of the temperature-emf relations above 900° C because the thermal emf of some of the samples of iron and constantan changed with time as the temperature was maintained constant.

The thermal emf of only a few selected samples was determined at temperatures below 0° C. These observations[18] were made using a stirred liquid bath[19] cooled by liquid air. A platinum resistance thermometer was used as a standard for determining the temperature.

All the temperature measurements were in terms of the International Temperature Scale[20] of 1927.

IV. COPPER-PLATINUM

Although it is generally accepted that commercial copper is exceptionally uniform as far as its thermoelectric properties are concerned, the thermal emf between a number of samples of copper was measured to determine the differences that might be expected between samples of copper of different sizes and from different sources, before determining the thermal emf of representative copper against platinum. The thermal emf of copper, as with most metals, depends

[17] J. Research NBS **14**, 247 (1935) RP768.
[18] Acknowledgment is made to D. O. Burger and R. B. Scott for the observations at low temperatures.
[19] BS J. Research **6**, 401 (1931) RP284.
[20] BS J. Research **1**, 635 (1928) RP22.

to some extent upon its physical condition, cold-worked copper being thermoelectrically positive to the same material annealed. The magnitude of the thermal emf between the cold-worked and annealed material depends upon the amount of cold working. Differences as large as 24 μv between cold-rolled and annealed samples (junctions at 0° and 300° C) have been brought to our attention.

The thermal emf between a number of samples of copper is given in table 1. In all these measurements a sample of No. 12 gage copper was used as a reference material and the junctions were maintained at 350 and 0° C. Excluding one sample of No. 34 gage wire of unknown origin and the two samples of tubing, the maximum thermal emf between the samples is 29 μv. The authors do not have a satisfactory explanation for the fact that, in general, the smaller wires are thermoelectrically positive to the larger ones. The differences in thermal emf may be caused by differences in the crystal structure or in the amount of dissolved oxygen or oxide.

For determining the thermal emf of copper against platinum, nine samples were selected from those listed in table 1, and the thermal emf of each measured against platinum from 0 to 1,000° C at intervals of 50° C. These nine samples included six samples of No. 8 gage wire and one sample each of Nos. 12, 18, and 22 gage wire. A test made on three sizes of wire (Nos. 12, 18, and 22) showed no detectable drift in thermal emf during 30 hours of heating at 500° C. The values at the higher temperatures are of very little importance. Only one sample, the No. 28 gage wire, was used in determining the thermal emf of copper against platinum at temperatures below 0° C.

TABLE 1.—*Thermal electromotive force between samples of copper wire* [1]

[Temperature of junctions 350 and 0° C]

Samples as received from manufacturer				Wire drawn from the same 0.5-in. rod		
Size (gage)	Electromotive force	Size (gage)	Electromotive force	Size (gage)	Cold-worked	Annealed at 450° C in air
	μv		μv		μv	μv
8	−18	28	0	8	−2	−11
8	−12	28	0			
8	−2	30	−2	12	−2	−11
8	−10	30	−5			
8	−3	32	+11	18	+9	+1
8	−10	32	+11	22	----------	+7
10	−3	32	−7			
12	+2	32	−6			
14	−1	34	−3			
16	−7	34	−110			
18	0	36	+7			
20	0	36	+6			
22	−1	38	+3			
22	−4	40	+6			
22	−1	----------	----------			
24	0	5/64-in. tubing	−93			
26	+6	5/32-in. tubing	−61			

[1] The electrical conductivity of the No. 8 gage wire drawn from ½-inch copper rod and annealed was 102.64 percent of that of the International Copper Standard (1.7241 microhm-cm at 20° C). The samples of No. 8 gage wire listed in the first column were from 4 different manufacturers and ranged in electrical conductivity from 100.65 to 101.20 percent.

The samples of wire, No. 10 gage and smaller, were taken from the storeroom and laboratories of this Bureau and are from various manufacturers.

Corresponding values of emf and temperature of copper against platinum as derived from these observations are given in tables 5 and 6.

V. COPPER-CONSTANTAN

Primarily because of differences in the thermoelectric properties of constantan, the temperature-emf relations of available copper-constantan thermocouples differ as much as 8 percent. However, a study of the temperature-emf relations of a large number of copper-constantan thermocouples determined at this Bureau shows that the relation given by Adams is very near the mean of the extreme limits of these relations and that it can be easily reproduced by materials now available. Any temperature-emf relation which we might develop as representative of copper-constantan thermocouples at the present time would not differ significantly from the relation given

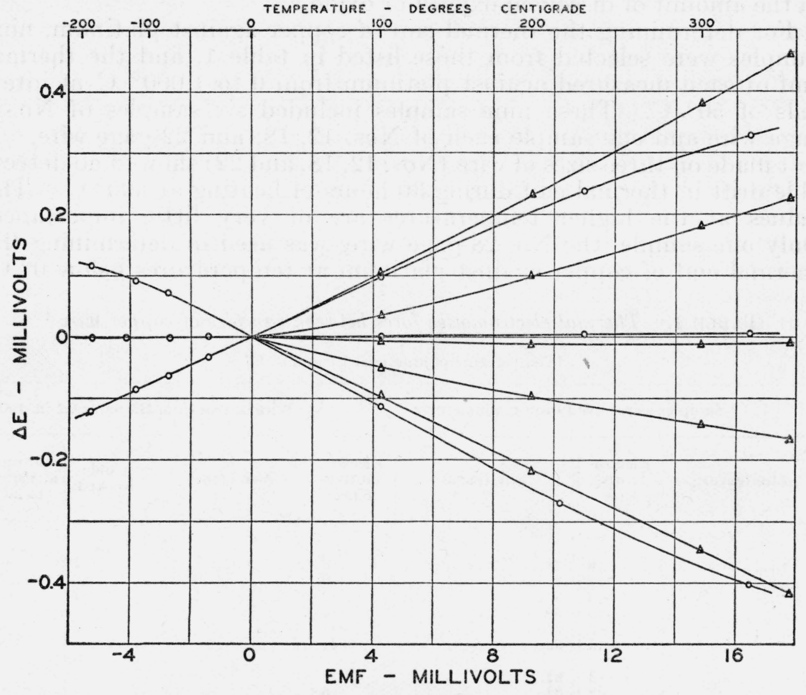

FIGURE 1.—*Differences between the calibrations of some copper-constantan thermocouples and the values in tables 7 and 8.*

by Adams. Corresponding values of temperature and emf as derived from Adams' table are given in tables 7 and 8.

Figure 1 shows the deviations of the temperature-emf relations of several different thermocouples from Adams' table. In general, these difference curves approximate straight lines.

Although copper-constantan thermocouples are not recommended for the accurate measurement of temperatures above 350° C (662° F), they may be used at higher temperatures for less accurate measurements. However, the life of such a thermocouple is very short in an oxidizing atmosphere at high temperatures. There is a slight drift in the thermal emf of this type of thermocouple as oxidation proceeds, but it is not large (the order of 0.2 percent up to the time the copper wire is practically oxidized through). Tables 7 and 8 may be extended to higher temperatures by combining the copper-platinum and constantan-platinum values in tables 5 and 6.

VI. CONSTANTAN-PLATINUM

The thermal emf, relative to platinum, of samples of constantan from 27 different lots was determined at intervals of 50° C from 0 to 800° C. Observations on 17 of these samples were made up to 1,000° C. All of the samples were from lots of No. 8 gage wire which had been selected by pyrometer instrument manufacturers as suitable for use with iron in iron-constantan thermocouples. As most of the iron and constantan used for thermocouples is selected to give a particular temperature-emf relation and as the thermal emf between samples of commercially available iron seldom exceeds 0.3 mv, the temperature-thermal emf curves of most of the samples of constantan against platinum fell within a very narrow band.

Corresponding values of temperature and emf, relative to platinum, of the constantan used by Adams in obtaining the copper-constantan values in tables 7 and 8, were obtained by combining the copper-platinum values in tables 5 and 6 with Adams' values for copper-constantan. However, these values extended only over the range of Adams' table, −200 to 385° C. The thermoelectric characteristics of the constantan which, when combined with iron, approximates the curve most widely used for iron-constantan thermocouples are very similar to those of the constantan which, when combined with copper, yields the values in Adams' table. The values of thermal emf of 18 of the constantan samples against platinum agreed with the derived values for Adams' constantan to ± 100 μv at 350° C (662° F) (slightly less than the equivalent of 2° C on either an iron- or copper-constantan thermocouple). The two extreme samples differed from Adams' constantan by $+515$ and -490 μv at 350° C. Only a small amount of constantan differing appreciably from the mean values (or from Adams' constantan) is being used for thermocouples.

If the temperature-emf values of the 18 samples which fell within a narrow band are averaged, a curve is obtained which gives the thermoelectric characteristics, within narrow limits of most of the constantan now being used for iron-constantan thermocouples. Such an average curve agreed with the derived curve for Adams' constantan against platinum in the range 0 to 350° C, well within the limits of the experimental error. Consequently, there appears to be no objection to modifying this average curve to agree exactly with that of Adams' constantan in the range 0 to 350° C and modifying it correspondingly at higher temperatures. This might be done in a number of ways, all of which give substantially the same result because so many of the samples of constantan were practically the same thermoelectrically as Adams' constantan. It was apparent from the curves that the thermal emf between any two samples of constantan was approximately proportional to the temperature but more nearly proportional to the emf of the samples against platinum. The emf of Adams' constantan against platinum is 13.93 mv at 350° C (662° F). Consequently, if the emf, E_t, of each sample of constantan against platinum at any temperature is multiplied by $13.93/E_{350}$, the modified curves will all coincide at 350° C (662° F) and will agree within very small limits at other temperatures. Excluding 4 of the 27 samples, the maximum difference between the modified curves was about 100 μv at 700° C (1,292° F). The modified curves for 17 of the samples agreed with the mean to ± 30 μv up to 700° C (the equivalent of about 0.5° C on an iron-constantan thermocouple).

The corresponding values of temperature and thermal emf for constantan-platinum above 350° C (662° F) in tables 5 and 6, were obtained by taking the mean of the modified curves. These mean values agreed with the values for Adams' constantan in the range 0 to 350° C to within 7 μv. Figure 2 shows the differences between

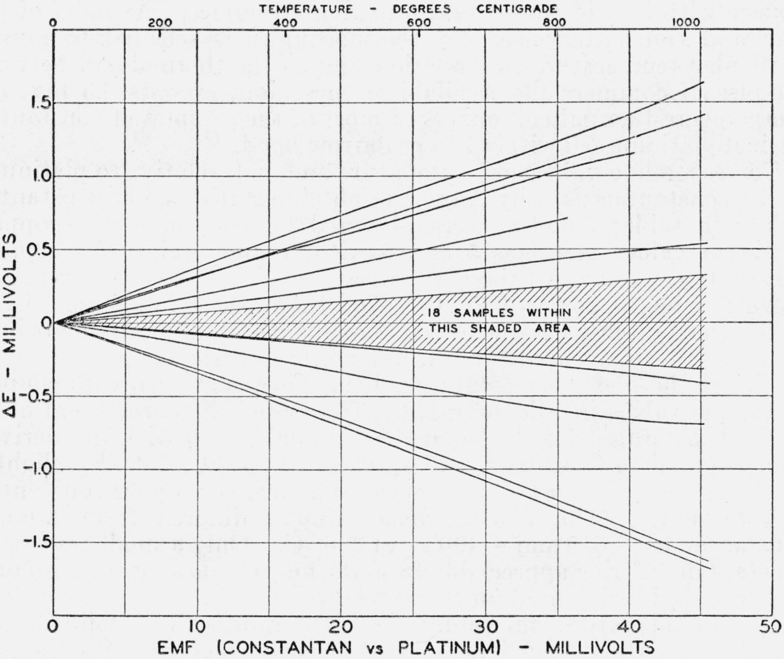

FIGURE 2.—*Thermal emf between samples of constantan and the mean represented by the values in tables 5 and 6.*

the temperature-emf relations of the various samples of constantan against platinum and the mean values in tables 5 and 6. The curves within the shaded area were also practically linear.

A few measurements were made to obtain some idea of the magnitude of the differences that might be expected between samples of wire from the same coil as produced by the manufacturer and between samples from different coils of the same heat.[21]

The thermal emf between two samples of No. 8 gage wire from the same coil was a maximum, 21 μv, at 400° C in one case and a maximum, 36 μv, at 800° C, in another. Table 2 gives the thermal emf of platinum against each of three different sizes of contantan wire drawn from the same 100-lb coil.

[21] A coil, 50 to 100 lb contains 1,000 to 2,000 ft of No. 8 gage wire.
A heat is a melt of metal containing several thousand pounds.

TABLE 2.—*Thermal electromotive force of different sizes of constantan wire drawn from the same coil*

[Reference material NBS Pt 27]

Temperature	Electromotive force (reference junctions at 0° C)		
	No. 8	No. 14	No. 20
°C	mv	mv	mv
0	0	0	0
100	3.51	3.51	3.50
200	7.43	7.44	7.43
300	11.69	11.70	11.68
400	16.17	16.19	16.16
500	20.77	20.80	20.77
600	25.46	23.49	25.46
700	30.18	30.22	30.19
800	34.89	34.92	34.89

The maximum thermal emf between two samples of No. 8 gage wire from different coils was 9 μv at 800° C in the case of one heat, 2 in another, and 72 in the third.

VII. IRON-PLATINUM

The results of measurements on samples of iron wire are shown in figure 3. These curves give the differences between the thermal emf

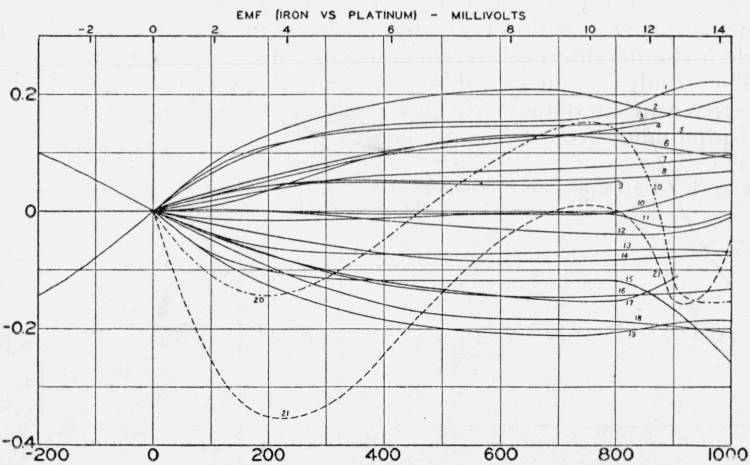

FIGURE 3.—*Thermal emf between samples of iron and the mean of samples 1 to 19.*

of the various samples against platinum and the mean thermal emf of samples 1 to 19. The results on a number of the samples were checked by running duplicates. All the samples but four were obtained from pyrometer manufacturers in this country. Samples 1, 2, and 3 are irons of higher purity than commercial irons and were drawn at this Bureau from materials obtained from metallurgical research laboratories.

The curves for samples 20 and 21 are of particular interest because their shape (markedly different from that of sample 1 to 19) is of the type required to give the temperature-emf relations embodied in the existing tables in the temperature range 0 to 870° C (1,600 ° F). The most significant difference found between the analyses of samples 20 and 21 and the other samples was the manganese content. Sample 20 contained 0.33 percent of manganese and sample 21 contained 0.36 percent of manganese, whereas the maximum in any of the other samples was 0.11 percent. Sample 21 also contained 0.099 percent of phosphorus compared with a maximum of 0.013 percent in any of the other samples.

It appears that commercially pure iron generally available at the present time has the thermoelectric characteristics shown by the curves for samples 1 to 19, as all the samples reported to have come directly or indirectly from a number of large producers of iron wire are included in this group. The corresponding values of emf and temperature given in tables 5 and 6 for iron against platinum represent the mean of samples 1 to 19.

Table 3 gives the results of a few measurements made to determine the differences in thermal emf that might be expected between samples of iron from the same heat. Each of the first three heats investigated included one sample which differed markedly from all the others of that heat as shown by the last column.

Samples of wire were taken from 40 coils of iron wire (from 7 heats) to determine the differences within a coil. The maximum difference observed between the two ends of any coil was 141 μv at 800° C. However, if we exclude the same three samples that were excluded in table 3 the maximum difference becomes 18 μv at 800° C.

The results given in table 4 indicate that there is no significant difference in thermoelectric properties between No. 8 gage iron wire and pipe made from the same heat.

TABLE 3.—*Variations in thermal electromotive force between samples of iron from the same heat*

Heat	Samples tested	Coils sampled	Maximum difference in electromotive force at 800° C	
			All samples	Excluding 1 sample from each heat
	Number	*Number*	μv	μv
1	26	13	34	12
2	17	10	168	25
3	12	6	115	70
4	22	11	18	----------

TABLE 4.—*Thermal electromotive force of iron wire and pipe from the same heat*

[Reference material NBS Pt 27]

Temperature	Electromotive force (reference junctions at 0° C)	
	No. 8 wire (mean of 13 samples)	Pipe (mean of 3 samples)
° C	μv	μv
0	0	0
100	1, 912	1, 919
200	3, 583	3, 590
300	4, 898	4, 904
400	5, 925	5, 928
500	6, 836	6, 834
600	7, 847	7, 845
700	9, 163	9, 161
800	10, 905	10, 905

VIII. IRON-CONSTANTAN

If the mean of iron samples 1 to 19 in figure 3 is accepted as representative of iron generally available at the present time, it is only

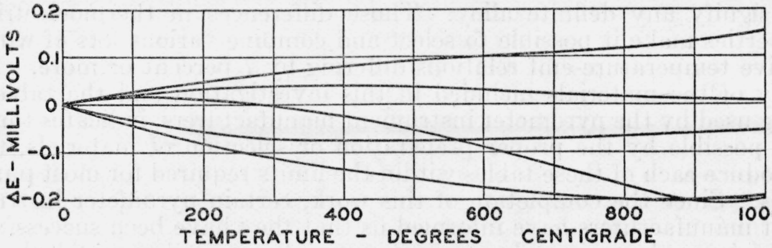

FIGURE 4.—*Differences between the calibrations of some iron-constantan thermocouples and the values in tables 9 and 10.*

necessary to combine the values of constantan-platinum and iron-platinum in tables 5 and 6 to obtain the desired table for iron-constantan thermocouples. Tables 9 and 10 were obtained in this way. Samples received from three different sources gave results very near the mean thus obtained. Although iron samples 1, 2, and 3 are not commercial irons, these samples have been included in the mean because (1) it is our opinion that if there is any change in the composition of commercial irons it will be toward purer iron, and (2) including these samples changes the mean by less than 0.03 mv.

For the past few years some Government agencies have been purchasing thermocouples to give essentially the same temperature-emf relation as that given in tables 9 and 10. As far as we know there has been no difficulty in obtaining wire which will give this relation to ±½ percent. Most of the iron-constantan thermocouples calibrated at this Bureau during the past 5 years give this relation to ±¾ percent up to 1,400° F (760° C). Figure 4 shows the differences between the temperature-emf relations of some iron-constantan thermocouples from different sources and the values in tables 9 and 10.

Although the tables give corresponding values of emf and temperature up to 1,800° F, iron-constantan thermocouples are not recommended for continuous or accurate measurements at temperatures above 1,400° F (760° C) in an oxidizing atmosphere. A few observations indicate that both elements of a No. 8 gage thermocouple of this type will oxidize through in approximately 1,000 hours in an oxidizing atmosphere at 1,400° F. In these tests the emf of the thermocouples changed by the equivalent of about 8° F in 800 hours at 1,400° F and by about 30° F just before oxidizing through at 1,000 hours.

The difference between the temperature-emf relation in tables 9 and 10 for iron-constantan thermocouples and the one most widely used[22] by pyrometer instrument manufacturers at the present time is about 2 percent at 400° F and ⅓ percent at 1,200° F. The fact that this new relation for iron-constantan thermocouples does not agree exactly with any of the tables used by pyrometer instrument manufacturers prior to this investigation obviously does not in any way affect the accuracy with which wire supplied by the manufacturers will conform with the temperature-emf relations which they have been using. Different lots of iron and constantan may have very different thermoelectric properties owing to the fact that commercial iron contains a number of impurities and to the fact that the name constantan does not signify any definite alloy. Those differences in thermoelectric properties make it possible to select and combine various lots of wire to give temperature-emf relations differing by 7 percent or more. A study of the materials included in this investigation and the tables being used by the pyrometer instrument manufacturers, indicates that it is possible by the proper preparation or selection of materials, to reproduce each of these tables within the limits required for most purposes. Since the completion of this work, certain pyrometer instrument manufacturers have informed us that they have been successful in obtaining the more or less special materials required to match their curve over the entire range.

The table for iron-constantan thermocouples given in this paper can be approximated only by selecting materials on the basis of tests at two or more temperatures. It does not differ, however, in this respect from any other such table that is now in use or that can be devised at this time.

The accuracy with which any of these relations can be reproduced depends to a large extent upon the accuracy obtained in the testing and combining of materials into thermocouples. The important advantage of the proposed table over existing ones is that it can be reproduced more accurately, over the entire range, with materials which are readily available.

22 Tech. Pap. BS **14**, 306 (1920–21) T170. Int. Crit. Tables **1**, 59 (1926).

TABLE 5.—*Representative values of the thermal electromotive force of copper, constantan, and iron against Platinum Standard* Pt 27

Temperature	Electromotive force (reference junctions at 0° C)			Temperature	Electromotive force (reference junctions at 0° C)		
	Copper-platinum	Constantan-platinum	Iron-platinum		Copper-platinum	Constantan-platinum	Iron-platinum
°C	mv	mv	mv	°C	mv	mv	mv
−200	−0.19	+5.35	−2.92				
−150	−.35	+4.25	−2.55				
−100	−.37	+2.98	−1.84				
−50	−.24	+1.56	−0.96				
0	.00	0.00	.00				
50	+.34	−1.69	+.97	550	7.35	−23.12	7.27
100	.76	−3.51	1.89	600	8.34	−25.47	7.80
150	1.26	−5.44	2.75	650	9.39	−27.83	8.41
200	1.83	−7.45	3.54	700	10.49	−30.18	9.12
250	2.46	−9.55	4.24	750	11.64	−32.53	9.95
300	3.15	−11.71	4.85	800	12.84	−34.86	10.86
350	3.89	−13.93	5.39	850	14.10	−37.17	11.83
400	4.68	−16.19	5.88	900	15.41	−39.45	12.84
450	5.52	−18.48	6.34	950	16.78	−41.70	13.55
500	6.41	−20.79	6.79	1,000	18.20	−43.92	14.30

TABLE 6.—*Representative values of the thermal electromotive force of copper, constantan, and iron against Platinum Standard* Pt 27

Temperature	Electromotive force (reference junctions at 32° F)			Temperature	Electromotive force (reference junctions at 32° F)		
	Copper-platinum	Constantan-platinum	Iron-platinum		Copper-platinum	Constantan-platinum	Iron-platinum
° F	mv	mv	mv	° F	mv	mv	mv
−300	−0.26	+5.02	−2.85				
−200	−.38	+3.73	−2.28				
−100	−.32	+2.24	−1.39				
0	−.10	+0.57	−0.35	1,000	7.12	−22.55	7.15
100	+.25	−1.27	+.73	1,100	8.21	−25.15	7.73
200	.70	−3.26	1.77	1,200	9.37	−27.77	8.40
300	1.25	−5.39	2.73	1,300	10.59	−30.39	9.19
400	1.88	−7.64	3.60	1,400	11.88	−32.99	10.13
500	2.59	−9.98	4.37	1,500	13.23	−35.58	11.16
600	3.37	−12.40	5.03	1,600	14.65	−38.14	12.25
700	4.21	−14.88	5.60	1,700	16.14	−40.66	13.21
800	5.12	−17.41	6.12	1,800	17.69	−43.13	14.03
900	6.09	−19.97	6.62				

TABLE 7.—*Corresponding values of temperature and electromotive force of copper-constantan thermocouples as derived from Adams' table*

[Reference junctions at 0° C.]

Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force
° C	mv	° C	mv	° C	mv
−200	−5. 539	0	0. 000	200	9. 285
−190	−5. 378	10	. 389	210	9. 820
−180	−5. 204	20	. 787	220	10. 360
−170	−5. 016	30	1. 194	230	10. 905
−160	−4. 815	40	1. 610	240	11. 455
−150	−4. 602	50	2. 034	250	12. 010
−140	−4. 376	60	2. 467	260	12. 571
−130	−4. 137	70	2. 908	270	13. 136
−120	−3. 886	80	3. 356	280	13. 706
−110	−3. 623	90	3. 812	290	14. 280
−100	−3. 349	100	4. 276	300	14. 859
−90	−3. 063	110	4. 747	310	15. 443
−80	−2. 765	120	5. 225	320	16. 030
−70	−2. 456	130	5. 710	330	16. 621
−60	−2. 137	140	6. 202	340	17. 216
−50	−1. 807	150	6. 700	350	17. 815
−40	−1. 466	160	7. 205	360	18. 418
−30	−1. 114	170	7. 716	370	19. 025
−20	−0. 752	180	8. 233	380	19. 635
−10	−0. 381	190	8. 756	390	20. 248
0	. 000	200	9. 285	400	20. 865

TABLE 8.—*Corresponding values of temperature and electromotive force for copper-constantan thermocouples, as derived from Adams' table*

[Reference junctions at 32° F]

Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force
° F	mv	° F	mv	° F	mv	° F	mv
−300	−5. 283	0	−0. 671	300	6. 644	600	15. 769
−290	−5. 184	10	−. 464	310	6. 924	610	16. 096
−280	−5. 081	20	−. 255	320	7. 206	620	16. 424
−270	−4. 973	30	−. 043	330	7. 489	630	16. 753
−260	−4. 861	40	+. 172	340	7. 774	640	17. 084
−250	−4. 745	50	. 390	350	8. 061	650	17. 416
−240	−4. 626	60	. 610	360	8. 350	660	17. 749
−230	−4. 503	70	. 832	370	8. 640	670	18. 083
−220	−4. 376	80	1. 057	380	8. 932	680	18. 418
−210	−4. 245	90	1. 285	390	9. 226	690	18. 754
−200	−4. 110	100	1. 516	400	9. 521	700	19. 091
−190	−3. 971	110	1. 750	410	9. 819	710	19. 430
−180	−3. 829	120	1. 987	420	10. 119	720	19. 770
−170	−3. 683	130	2. 226	430	10. 420	730	20. 111
−160	−3. 533	140	2. 467	440	10. 722	740	20. 453
−150	−3. 380	150	2. 711	450	11. 026	750	20. 796
−140	−3. 223	160	2. 957	460	11. 332		
−130	−3. 062	170	3. 206	470	11. 639		
−120	−2. 898	180	3. 457	480	11. 948		
−110	−2. 731	190	3. 710	490	12. 259		
−100	−2. 560	200	3. 966	500	12. 571		
−90	−2. 386	210	4. 224	510	12. 885		
−80	−2. 209	220	4. 484	520	13. 200		
−70	−2. 028	230	4. 747	530	13. 516		
−60	−1. 844	240	5. 012	540	13. 833		
−50	−1. 656	250	5. 279	550	14. 152		
−40	−1. 465	260	5. 548	560	14–472		
−30	−1. 271	270	5. 819	570	14. 794		
−20	−1. 074	280	6. 092	580	15. 118		
−10	−0. 874	290	6. 367	590	15. 443		
0	−. 671	300	6. 644	600	15. 769		

TABLE 9.—*Corresponding values of temperature and electromotive force for iron-constantan thermocouples*

[Reference junctions at 0° C]

Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force
° C	mv	° C	mv	° C	mv	° C	mv
		0	0. 00	400	22. 07	800	45. 72
		10	. 52	410	22. 62	810	46. 37
		20	1. 05	420	23. 17	820	47. 03
		30	1. 58	430	23. 72	830	47. 69
		40	2. 12	440	24. 27	840	48. 34
		50	2. 66	450	24. 82	850	49. 00
		60	3. 20	460	25. 37	860	49. 66
		70	3. 75	470	25. 92	870	50. 32
		80	4. 30	480	26. 47	880	50. 97
		90	4. 85	490	27. 03	890	51. 63
		100	5. 40	500	27. 58	900	52. 29
		110	5. 95	510	28. 14	910	52. 88
		120	6. 51	520	28. 70	920	53. 47
		130	7. 07	530	29. 26	930	54. 06
		140	7. 63	540	29. 82	940	54. 65
		150	8. 19	550	30. 39	950	55. 25
		160	8. 75	560	30. 96	960	55. 84
		170	9. 31	570	31. 53	970	56. 43
		180	9. 87	580	32. 11	980	57. 03
		190	10. 43	590	32. 69	990	57. 63
−200	−8. 27	200	10. 99	600	33. 27	1,000	58. 22
−190	−8. 02	210	11. 56	610	33. 86		
−180	−7. 75	220	12. 12	620	34. 45		
−170	−7. 46	230	12. 68	630	35. 04		
−160	−7. 14	240	13. 23	640	35. 64		
−150	−6. 80	250	13. 79	650	36. 24		
−140	−6. 44	260	14. 35	660	36. 84		
−130	−6. 06	270	14. 90	670	37. 45		
−120	−5. 66	280	15. 46	680	38. 06		
−110	−5. 25	290	16. 01	690	38. 68		
−100	−4. 82	300	16. 56	700	39. 30		
−90	−4. 38	310	17. 12	710	39. 93		
−80	−3. 93	320	17. 67	720	40. 56		
−70	−3. 47	330	18. 22	730	41. 19		
−60	−3. 00	340	18. 77	740	41. 83		
−50	−2. 52	350	19. 32	750	42. 48		
−40	−2. 03	360	19. 87	760	43. 12		
−30	−1. 53	370	20. 42	770	43. 77		
−20	−1. 03	380	20. 97	780	44. 42		
−10	−0. 52	390	21. 52	790	45. 07		
0	0. 00	400	22. 07	800	45. 72		

TABLE 10.—*Corresponding values of temperature and electromotive force for iron-constantan thermocouples*

[Reference junctions at 32° F.]

Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force	Temperature	Electromotive force
°F	mv	°F	mv	°F	mv	°F	mv	°F	mv
		0	−0. 92	500	14. 35	1, 000	29. 70	1, 500	46. 74
		10	−. 63	510	14. 65	1, 010	30. 01	1, 510	47. 10
		20	−. 35	520	14. 96	1, 020	30. 33	1, 520	47. 47
		30	−. 06	530	15. 27	1, 030	30. 64	1, 530	47. 83
		40	+. 23	540	15. 58	1, 040	30. 96	1, 540	48. 20
		50	. 52	550	15. 89	1, 050	31. 28	1, 550	48. 56
		60	. 82	560	16. 20	1, 060	31. 60	1, 560	48. 93
		70	1. 11	570	16. 50	1, 070	31. 92	1, 570	49. 29
		80	1. 41	580	16. 81	1, 080	32. 24	1, 580	49. 66
		90	1. 70	590	17. 12	1, 090	32. 56	1, 590	50. 02
		100	2. 00	600	17. 43	1, 100	32. 88	1, 600	50. 39
		110	2. 30	610	17. 73	1, 110	33. 20	1, 610	50. 75
		120	2. 60	620	18. 04	1, 120	33. 53	1, 620	51. 12
		130	2. 90	630	18. 34	1, 130	33. 86	1, 630	51. 49
		140	3. 20	640	18. 65	1, 140	34. 18	1, 640	51. 85
		150	3. 50	650	18. 95	1, 150	34. 51	1, 650	52. 22
		160	3. 81	660	19. 26	1, 160	34. 84	1, 660	52. 55
		170	4. 11	670	19. 56	1, 170	35. 17	1, 670	52. 88
		180	4. 42	680	19. 87	1, 180	35. 50	1, 680	53. 21
		190	4. 72	690	20. 18	1, 190	35. 84	1, 690	53. 54
−300	−7. 87	200	5. 03	700	20. 48	1, 200	36. 17	1, 700	53. 87
−290	−7. 72	210	5. 34	710	20. 79	1, 210	36. 50	1, 710	54. 20
−280	−7. 55	220	5. 64	720	21. 09	1, 220	36. 84	1, 720	54. 52
−270	−7. 38	230	5. 95	730	21. 40	1, 230	37. 18	1, 730	54. 85
−260	−7. 20	240	6. 26	740	21. 70	1, 240	37. 52	1, 740	55. 18
−250	−7. 02	250	6. 57	750	22. 01	1, 250	37. 86	1, 750	55. 51
−240	−6. 83	260	6. 88	760	22. 31	1, 260	38. 20	1, 760	55. 84
−230	−6. 63	270	7. 19	770	22. 62	1, 270	38. 54	1, 770	56. 17
−220	−6. 43	280	7. 50	780	22. 92	1, 280	38. 88	1, 780	56. 50
−210	−6. 22	290	7. 81	790	23. 23	1, 290	39. 23	1, 790	56. 83
−200	−6. 01	300	8. 12	800	23. 53	1, 300	39. 58	1, 800	57. 16
−190	−5. 79	310	8. 43	810	23. 84	1, 310	39. 93		
−180	−5. 57	320	8. 75	820	24. 14	1, 320	40. 28		
−170	−5. 34	330	9. 06	830	24. 45	1, 330	40. 63		
−160	−5. 11	340	9. 37	840	24. 75	1, 340	40. 98		
−150	−4. 87	350	9. 68	850	25. 06	1, 350	41. 34		
−140	−4. 63	360	10. 00	860	25. 37	1, 360	41. 69		
−130	−4. 38	370	10. 31	870	25. 67	1, 370	42. 05		
−120	−4. 13	380	10. 62	880	25. 98	1, 380	42. 40		
−110	−3. 88	390	10. 93	890	26. 29	1, 390	42. 76		
−100	−3. 63	400	11. 24	900	26. 59	1, 400	43. 12		
−90	−3. 37	410	11. 56	910	26. 90	1, 410	43. 48		
−80	−3. 11	420	11. 87	920	27. 21	1, 420	43. 84		
−70	−2. 85	430	12. 18	930	27. 52	1, 430	44. 20		
−60	−2. 58	440	12. 49	940	27. 83	1, 440	44. 56		
−50	−2. 31	450	12. 80	950	28. 14	1, 450	44. 92		
−40	−2. 04	460	13. 11	960	28. 45	1, 460	45. 28		
−30	−1. 76	470	13. 42	970	28. 76	1, 470	45. 65		
−20	−1. 48	480	13. 73	980	29. 07	1, 480	46. 01		
−10	−1. 20	490	14. 04	990	29. 39	1, 490	46. 37		
0	−0. 92	500	14. 35	1, 000	29. 70	1, 500	46. 74		

WASHINGTON, July 15, 1937.