Aug. 3, 1943. D. I. FINCH 2,325,759

FERROUS ALLOY THERMOCOUPLE ELEMENT

Filed Dec. 28, 1939 3 Sheets-Sheet 1

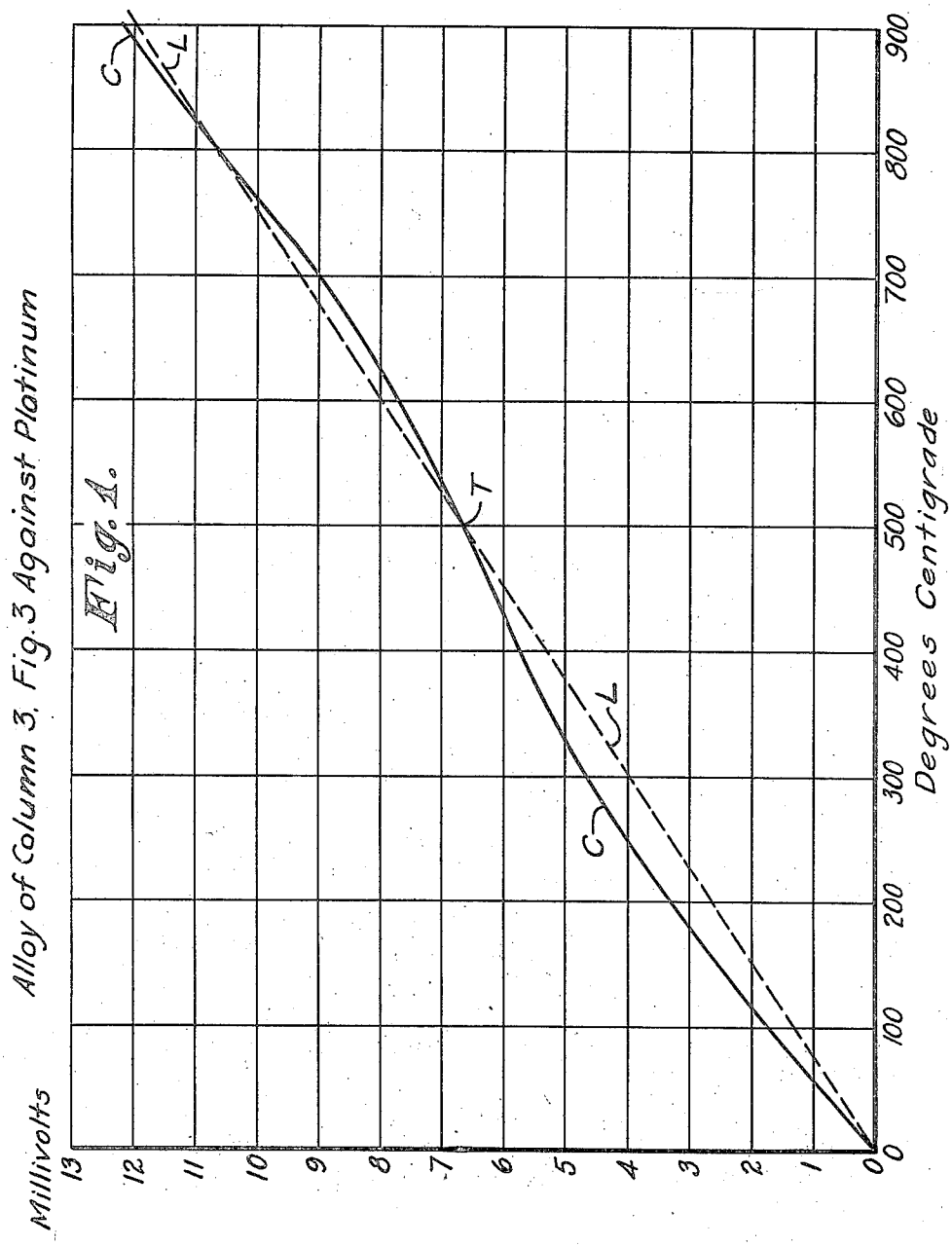


Fig. 1.

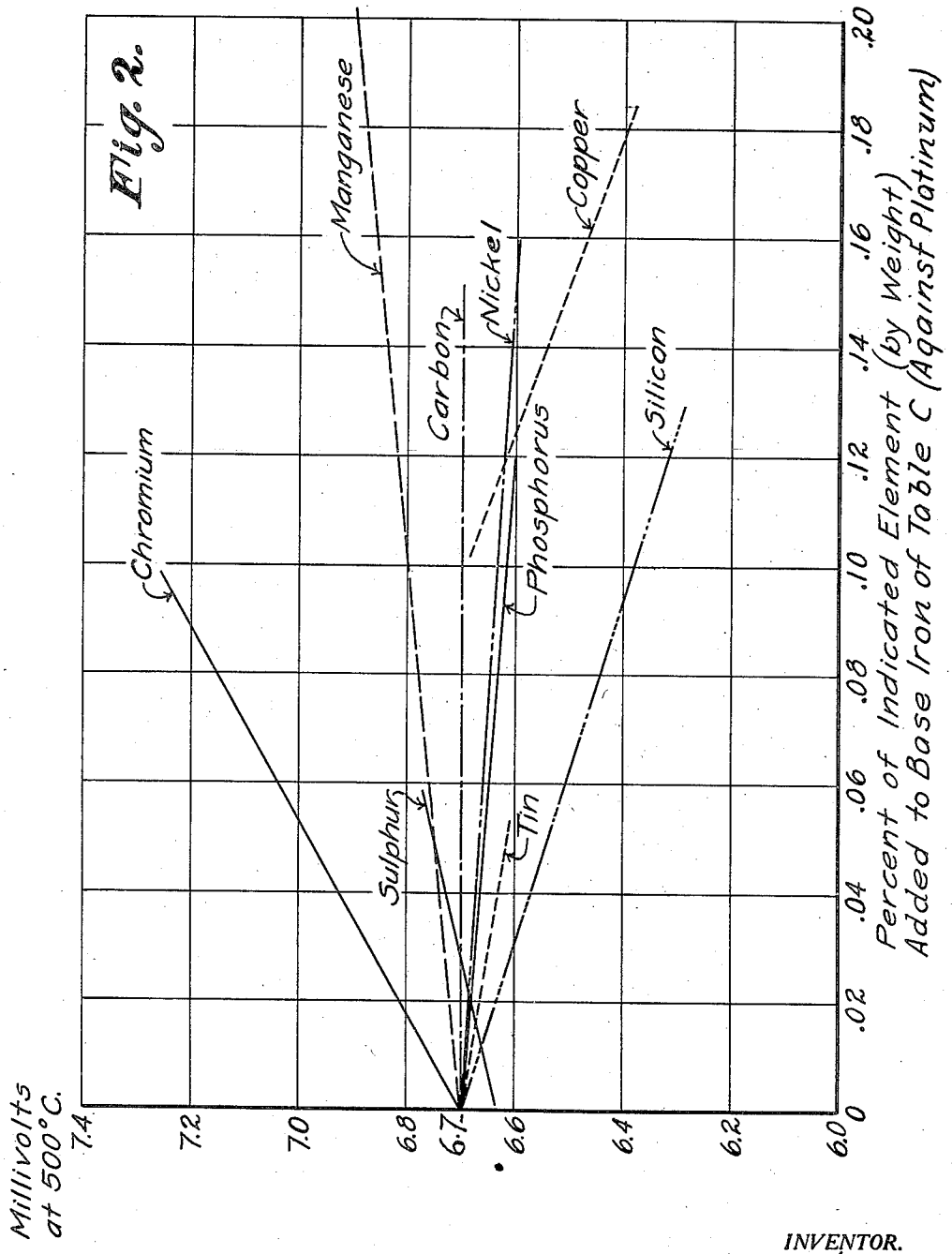
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FERROUS ALLOY THERMOCOUPLE ELEMENT

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Fig. 2.



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FERROUS ALLOY THERMOCOUPLE ELEMENT

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FIG. 3

COMPOSITION-PER CENT BY WEIGHT

ELEMENTS	1	2	3	4	5	6	7	8	9
C	UNKNOWN COMPOSITION	.04 TO .06	.06	.059	"AVERAGE IRON" (OF UNKNOWN COMPOSITION)	.013	.009	.026	.141
Mn		.22 TO .24	.23	.25		.088	.001 IRON	.015	.015
P		<.02	.017	.015		.007	.001	.0042	.004
S		.02 TO .045	.043	.035		.027	.009 ELECTROLYTIC	.018	.018
Si		<.005	<.003	-		<.01	.006	.0039	.004
Ni		.04 TO .05	.047	.050		.021	-	.0122	.012
Cr		<.01	<.01	.007		<.003	-	.025	-
Cu		.115 TO .125	.123	.129		.069	.006	.044	.044
Sn		NIL	<.01	-		-		-	-
Fe		99.53 TO 99.44	99.46	99.46		99.76		99.85	99.76

FIG. 3A

MILLIVOLTS

TEMP. °C.	AGAINST CONSTANTAN OF UNKNOWN COMPOSITION 1	AGAINST CONSTANTAN 2	AGAINST CONSTANTAN OF TABLE B 3	AGAINST CONSTANTAN ADAMS 4	AGAINST PLATINUM 5	AGAINST PLATINUM 6	AGAINST PLATINUM 7	AGAINST PLATINUM 8	AGAINST TABLE B CONSTANTAN 9
100	5.260		5.260	5.250	1.890	1.877	1.880	1.883	5.326
200	10.780		10.780	10.710	3.540	3.503	3.555	3.538	10.865
300	16.300		16.320	16.280	4.850	4.785	4.910	4.840	16.379
400	21.820		21.830	21.790	5.880	5.795	5.970	5.877	21.853
500	27.390		27.360	27.310	6.730	6.712	6.900	6.804	27.355
600	33.160		33.090	33.040	7.800	7.718	7.895	7.827	-
700	39.190		39.130	39.090	9.120	9.035	9.150	9.139	-
800	45.480		45.520	45.500	10.860	10.783	10.821	10.872	-
900	51.820		51.780	51.780	12.840	12.769	12.724	12.740	-
1000	-		-	-	-	-	14.080	14.078	-

OLD CURVE =

< MEANS "LESS THAN"

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Patented Aug. 3, 1943 2,325,759

UNITED STATES PATENT OFFICE

2,325,759

FERROUS ALLOY THERMOCOUPLE ELEMENT

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Application December 28, 1939, Serial No. 311,258

6 Claims. (Cl. 136—4)

My invention relates to ferrous alloys as elements of thermocouples or thermojunctions for general uses, including more particularly measurement, (which term in addition comprehends indication, recording and controlling) of temperatures within the range from 0° to 900° C., more or less.

For many years, it has been the practice, particularly for measurement of temperatures significant in industrial processes, to utilize base metal thermocouples one of whose elements consisted of a copper-nickel alloy such as "constantan," approximately 55% copper and 45% nickel, and the other or associated element consisted of an iron or ferrous alloy, more particularly mild or low-carbon steel, commonly characterized by a carbon content of less than .15% by weight. Because such thermocouples generally are subjected to rough usage and also to contamination by ambient gases, they eventually fail, either mechanically because of such usage, or electrically because of contamination which affects their voltage-temperature characteristics; in consequence of either type of failure the thermocouples must be replaced after a period of useful life short as compared with the life of their associated measuring instruments. Being so subject to relatively frequent replacements, it is desirable the thermocouples be relatively inexpensive and that their elements consist of materials readily available and of definite reproducible compositions to ensure always a predetermined definite voltage - temperature characteristic. It is and has been usual practice to calibrate the associated measuring instruments in terms of temperature, which imposes the requirement the voltage-temperature characteristics of the thermocouples made from successive batches or lots of element materials shall be substantially identical, to avoid need for inherently expensive or economically inadvisable recalibration of the measuring instruments with which were associated the couples to be replaced, and, in the case of recorders, to avoid need for printing new chart papers or record sheets therefor.

The present voltage-temperature curve or characteristic of one of the iron-constantan thermocouples largely utilized in practice was adopted nearly thirty years ago, at which time the available so-called "iron" was a low-carbon steel whose components, in addition to the element iron, comprised many of such common alloying elements as copper, nickel, carbon, manganese, phosphorus, sulphur, silicon, and chromium, the amounts or percentages by weight of those present then and ever since being unknown; and, more particularly, there were then and now are unknown the amounts of that one or more of the aforementioned alloying materials which, as hereinafter shown, is or are of material influence on the voltage-temperature characteristic and/or deviations thereof from a straight or other line of reference of slope comparable with the average slope of the voltage-temperature characteristic. At the time of early adoption of aforesaid characteristic, the effects of the respective aforesaid alloying elements upon the voltage-temperature characteristic and its deviations were not appreciated, and the "iron" utilized for the one element of a thermocouple was an indefinite alloy of such iron, low-carbon steel, as then currently and regularly produced by steel manufacturers as a commodity to be fabricated for purposes respecting which the compositions or variations thereof as between different batches or melts were of no importance, though of great importance respecting thermocouple uses. In brief, the variations in compositions of the so available irons or low-carbon steels did not affect their utility for mechanical purposes, but were of serious effects from the viewpoint of thermocouple uses. Throughout the period of years subsequent to aforesaid adoption of a particular voltage-temperature characteristic, it has been common with manufacturers of low-carbon steel to utilize a relatively large proportion of scrap steel in making new steel; and within said period the use of such steels for mechanical purposes has become more and more common with the result that the number and amounts of one or more of the alloying elements above pointed to, and coming in via the scrap steel or otherwise, has increased even in the case of low-carbon steels or so-called "irons" here of import. And, in any event, whether or not their compositions were now known, the irons or low carbon steels, upon which were predicated aforesaid thermoelectric characteristic adopted many years ago, are not now generally or at all manufactured or available; in short, it is now necessary to look to irons or steels of new compositions which, at least in most cases, are unsuitable for thermocouples unless materially modified.

Certain of the alloying elements aforesaid I have found greatly affect the voltage-temperature characteristics; for example, I have found that copper if present in amounts represented by percentages greater than 0.10, has great

effect upon the voltage-temperature characteristic, and cannot be removed or eliminated in the metallurgical processes of manufacture of low-carbon steels for general uses.

In consequence of the variations of compositions of the "iron" or low-carbon steels available from steel manufacturers, unmodified in respect to any particular non-ferrous component or components and so being practically intolerable for thermocouple uses, there has been a gradual and persistent change in the voltage-temperature characteristics of thermocouples employing the unmodified low-carbon steels procurable on the market; this has made it increasingly difficult to obtain low-carbon steels for matching, with satisfactory or necessary accuracy, those upon which were predicated the aforementioned voltage-temperature characteristic long ago adopted and still widely used.

It is an object of my invention to provide ferrous alloys, incuding "iron" and low-carbon steel alloys, which, when comprised in a thermocouple with another element of known composition or thermoelectric behavior, will, as a couple, have a predetermined voltage-temperature characteristic which may be one newly selected or desired, or which, and importantly, will match with all needful accuracy any voltage-temperature characteristic or thermoelectric behavior, heretofore or hereafter known or used, of any thermocouple having one element either of a ferrous alloy or of any other material having generally like thermoelectric behavior.

More particularly, it is an object of my invention to provide, for the purposes aforesaid and herein described, an inexpensive commercially available "iron" or low-carbon steel alloy of such new or different composition, predicated upon modification of composition of a commercially available so-called "pure iron" or a low-carbon steel, which as so modified and when associated with an element of either pure platinum, or of constantan or the like of known composition or of known thermo-electric characteristics, will have any predetermined voltage-temperature characteristic, new or old.

A further object of my invention is to so modify the compositions of ferrous alloys, including those of substantially or so-called pure irons including commercial irons in general and low-carbon steels, as to procure desired new or old thermocouple voltage-temperature characteristics; and, more particularly, to effect the modifications of the compositions by adding one or more elements or materials having the effect of changing to desired extents the voltage-temperature relations of said characteristics, and/or deviations of said characteristics from any chosen reference standard.

My invention resides in ferrous or "iron" alloys, utilizable as elements of a thermocouple, in the method of producing them, and in other aspects, as hereinafter described and claimed.

In assistance to an understanding of my invention, reference is had to the accompanying drawings, in which:

Fig. 1 is a graph including the voltage-temperature characteristic of a ferrous alloy comprehended in my invention; and

Fig. 2 is a graph illustrative of the influence upon the voltage, at a chosen temperature, of additions of various percentages of various metals and non-metals to a ferrous alloy of known composition.

Figs. 3 and 3A are tables referred to in explanation of the invention.

In Fig. 1, C is a characteristic curve whose ordinates are millivolts and whose abscissae are temperatures in degrees centigrade, of a thermocouple whose elements consist of pure platinum, as a usual reference element, and an iron, low-carbon steel (having the composition shown in column 3 of Fig. 3 significantly different as hereinafter explained from the compositions of Table A) which low-carbon steel alloy is typical of the low-carbon steel alloys comprehended in my invention, particularly when to be used with or "against" some other base metal, such as a constantan of known thermoelectric behavior, such as of composition as shown by Table B.

(The slope of the straight line drawn through 0° and 500° C., referred to in column 1 of Fig. 3A, of the "Desired or ancient" characteristic, is 0.05478 millivolt per degree C.)

TABLE A.—*Steel*

	Column 1 average voltage too high	Column 2 average voltage too low
	Per cent [1]	*Per cent* [1]
Carbon	.04	.054
Manganese	.27	.35
Phosphorus	.015	.013
Sulphur	.017	.040
Silicon	Less than .005	Less than .005
Nickel	.046	.116
Chromium	.006	.004
Copper	.092	.213
Tin	Nil	Nil

[1] Percentages by weight.

TABLE B.—*Constantan*

	Per cent[1]
Copper	56.1
Nickel	42.3
Manganese	1.4
Iron	.2
Silicon—less than	.01
Magnesium—less than	.02
Carbon—less than	.02

[1] Percentages by weight.

The alloying metals and non-metals of Table A and their percentages, by weight, there indicated, represent the composition of ferrous alloys obtainable from a steel manufacturer in lots of as much as 40 tons each, and consisting of the steel company's typical composition in regular production for other uses, but to be modified in accordance with my invention as herein explained.

The composition shown by column 3, Fig. 3, is that of a low-carbon steel actually obtained from a steel manufacturer upon my specifications shown in column 2, Fig. 3, whose percentages, of the various elements indicated, I was able to specify, in the light of Fig. 2, and in the light of the compositions, of low-carbon steel alloys previously obtained from said manufacturer, shown in columns 1 and 2, Table A; the composition, column 1, Table A, which, unmodified in accordance with my invention, was found to yield throughout the desired temperature range an average voltage or thermo-electric power, too high for matching, with the constantan of Table B, the voltage-temperature characteristic exemplified by column 1 of Fig. 3A; the composition of column 2, Table A, on the other hand, for the same temperature range, produced an average voltage too low for aforesaid purposes of matching. However, having in mind either the composition of column 1 or the composition of col-

umn 2, or both, Table A, I was able, in accordance with my invention, more particularly in accord with Fig. 2 and the within stated facts regarding effects of alloying elements on deviations, to arrive at the final specification, column 2, Fig. 3, which, upon execution by the steel manufacturer, yielded the composition of column 3, Fig. 3, upon which is predicated the "Actual" characteristic defined by column 3, Fig. 3A.

In column 2, Fig. 3, the significant changes were in the percentages of manganese, nickel and copper. Though manganese has the effect of increasing the average voltage of the voltage-temperature characteristic, nevertheless the amount of manganese specified was less than the percentages of the same elements indicated in columns 2 and 3, Table A, because of need suitably to affect the deviations of the characteristic from one of known slope, for example one of constant slope, such as line L, Fig. 1, it being understood that manganese is most potent in causing or effecting corrections for or changes in deviations. In this instance, though manganese has also the property of increasing the average voltage of the thermocouple, its effect within the range of percentages indicated in column 2, Fig. 3 essential for modifying deviations, is insufficient to procure the average voltage necessary for the desired characteristic, and there are then resorted to, in lieu of manganese, significant changes in the percentages of nickel and copper, by way of decreasing their respective percentages relatively to the percentages of nickel and copper in column 2, Table A, thereby raising to desired magnitude the average voltage, because of so decreasing the voltage-depressing effects of both nickel and copper, Fig. 2, while still obtaining via manganese the necessary modification of deviations.

The voltage-temperature characteristic of the couple, whose iron and constantan elements have the compositions of column 3, Fig. 3 and Table B respectively, is the one defined by column 3 of Fig. 3A, and corresponds with satisfactory accuracy to that "Ancient" or "Old" one, column 1, Fig. 3A, for aforesaid thermocouples in use some 27 years ago. Only the voltage-temperature characteristic, column 1, Fig. 3A, of those thermocouples in early use has remained known from the similarly long known and used charts or record sheets of temperature recorders in combination with which they were used. Those charts or record sheets then and now used are comprised of lines or markings spaced unequally transversely of the chart or sheet, in dependence upon and in accord with the non-uniform relationship of the temperatures and millivolts appearing in aforesaid column 1 of Fig. 3A.

The thermocouples whose characteristic was that defined by column 1, Fig. 3A comprised low-carbon steel, as one element, not only the composition of which was unknown, column 1, Fig. 3, but also its thermoelectric behavior against any reference material, pure platinum or otherwise, was unknown; and the other element was a constantan of unknown composition and of unknown thermoelectric behavior with respect to any reference material, such as pure platinum or otherwise.

The range of temperatures of Fig. 1 is from 0 to about 900° C., which, or suitable or chosen portions of that range, is the range for which my ferrous, including low-carbon steel, alloys are suited.

Through point T, Fig. 1, corresponding with any arbitrarily chosen temperature, in this case 500° C., with which, but only incidentally however, corresponds a point of inflection in the characteristic C, is drawn the straight line L. Line L being straight, its constant slope implies constancy throughout the temperature range of magnitude of the millivolts at each temperature divided by the number of degrees of temperature; on the other hand the slope of curve C and of other voltage-temperature characteristics herein referred to varies because the ratio of millivolts to temperature is different at different temperatures. Hence line L, or any other of constant slope, is utilizable as a reference line from which to measure parallel with the axes of ordinates and abscissae, respectively, deviations of the characteristic curve C or others herein referred to in millivolts and temperatures. It will be seen in this example, which is not limitative of my invention, that the deviations of the characteristic C from the straight reference line L are to the left and above, or positive, up to the point T, that between 500° C. and nearly 800° C., the deviations are to the right and below line L, or negative; and that again beyond the last-named temperature, the deviations are again to the left and above line L, or positive.

The ferrous alloys comprehended in my invention and herein described, are for procurement or modification of any particular voltage-temperature characteristic predictable and determinable from or in accord with what I have found to be the effects upon the voltages of the thermocouples produced by the various percentages, by weight, Fig. 2, of the non-ferrous materials chromium, manganese, sulphur, carbon, nickel, copper, tin, silicon and phosphorus, added singly or in groups in suitable amounts to any ferrous alloy of known composition, including so-called pure and electrolytic irons and low-carbon steels herein generically contemplated and specifically described.

In view of the characteristic effects of materials in the percentages shown in Fig. 2, there were added certain of them in suitable percentages predictable from Fig. 2 to substantially pure iron, utilized as a reference base, whose non-ferrous components were of those and of the percentages thereof shown in following table C.

TABLE C

	Per cent[1]
Carbon	.026
Manganese	.015
Phosphorus	.0042
Sulphur	.018
Nickel	.0122
Copper	.044
Silicon	.0039

[1] Percentages by weight.

As shown in aforesaid Fig. 2, the individual effects observed at 500° C. on voltage of the thermocouple whose other element was pure platinum by addition to different or individual masses of substantially pure iron, of Table C, one only of each of aforesaid materials, chromium to silicon inclusive, for each mass of iron, are that manganese, sulphur and chromium have increasingly greater effects in increasing the voltage of the couple, that addition of carbon has little or negligible effect on the voltage, and that nickel, phosphorus, tin and silicon, in the order named, have increasingly greater effects in decreasing

the voltage of the couple; and that copper has even greater effect in decreasing the voltage when present in percentages upwardly of 0.10.

It will be noted from Fig. 2 that, generally speaking, the effects of copper, above 0.10% thereof, are comparable with the effects of silicon.

Molybdenum, it is believed, will act generally similarly to chromium in effecting increase of voltage; and that aluminum will act, generally as in the case of nickel, phosphorus, copper, tin or silicon, to decrease the voltage of the couple.

While in Fig. 2 the voltage-percentage characteristics for the several alloying materials there in view are shown as straight lines, it will be understood that at least some of them are not in fact perfectly straight lines; the differences in the characteristics from straight lines are for the purposes of my invention inconsequential or negligible for determining what shall be in any case the added alloying material or materials and its or their amounts to produce any of my herein contemplated ferrous alloy thermocouple elements.

In my alloys of irons and low-carbon steels, it is desirable to limit the amounts of tin, sulphur and phosphorus to magnitudes below 0.01, 0.04 and 0.02 percent, respectively, because tin and sulphur individually render the alloy brittle when at the higher temperatures within the range herein contemplated; and phosphorus renders the alloy brittle at the lower temperatures of the range. Such brittleness has the undesirable mechanical effect to render the alloy subject to fracture in use. However, any one or more of tin, sulphur and phosphorus may be utilized as materials for modifying voltage-temperature characteristics, where brittleness is of no import or to be ignored.

Some of the materials contemplated by Fig. 2 have the property of affecting the temperature deviations or departures of the characteristic curve, such as generically exemplified by Fig. 1, from a reference straight line such as L; for example, while decreasing as aforesaid the average voltage (voltage change per degree centigrade) of the couple, tin at the same time increases the departures or deviations in millivolts or temperatures of the characteristic curve of a thermocouple from the average straight line such as generically represented by the line L, Fig. 1.

Sulphur, in amounts as high as 0.05%, has substantially no effect on the voltage-temperature characteristic of a couple so far as regards deviations or departures thereof in millivolts or temperatures from a straight line such as exemplified by L, Fig. 1.

Phosphorus has substantially no effect on the average voltage-temperature relationship of the couple, but has a minor or negligible effect on the deviations in temperatures or millivolts from the average straight line such as aforesaid line L.

The materials or elements I prefer to employ for modifying or controlling voltage-temperature characteristics or relationships are manganese, copper, and carbon of which, as aforesaid, manganese in increasing amounts increases the average voltage-temperature ratio or relationship; furthermore, it increases the negative deviations in millivolts or temperatures from an average straight line, such as L, at the lower temperatures of the range, increases positive deviations at intermediate temperatures, and again increases negative deviations at the higher temperatures. Copper, on the other hand, in increasing amounts decreases the average voltage-temperature ratio or characteristic, and, in increasing amounts, increases the negative deviations from a straight line of reference at lower temperatures and increases positive deviations at the higher temperatures. Carbon, having as aforesaid, substantially no effect on the average voltage-temperature relationship, has no effect on deviations of a voltage-temperature characteristic from a straight line at temperatures below 700° C.; at temperatures above 700° C., it has an increasingly greater effect in causing negative deviations which increase with temperature and with the amount of carbon present.

In general, in accordance with my invention, respecting modifications of deviations, manganese is most effective, and less effective, in the order named, are tin, copper and phosphorus. And in any case, where the deviation is of intolerable magnitude, it may be corrected by recourse to one or more of manganese, tin, copper or phosphorus, and if such modification have an adverse effect on the average voltage of the characteristic, then, in that event, the average voltage may be brought to desired magnitude by modification by way of chromium or nickel, or both, in accordance with Fig. 2, chromium having the effect of increasing said average voltage and the latter having the effect of decreasing said average voltage, and neither of them having significant effect upon deviations.

Inasmuch as copper, in steel as currently manufactured as a commodity for mechanical purposes and other than thermocouple uses, can be controlled only by proper selection of the components to be melted in the open-hearth or other furnace, and since, if once present, copper coming in via the furnace-charging materials cannot be removed, it is expected that, in the immediate and more distant future, the amount of copper in low-carbon steel will increase, due to the present large and heretofore increasing amount of copper commonly in scrap utilized as a component of the furnace charge. Then, and in any event when the amount of copper is excessive, as when present in the resultant low-carbon steel in percentage greater than 0.10, correction for the copper, particularly with respect to its voltage-decreasing effect, is accomplished, in accordance with my invention, preferably by addition of chromium, which principally, as distinguished from similarly acting sulphur and manganese, Fig. 2, affects in sense opposite to copper the average voltage-temperature relationship, and has little effect upon deviations of the voltage-temperature characteristic from a reference line, such as L.

If it appears necessary, in order to modify a given voltage-temperature characteristic of a couple, whose one element is a ferrous alloy, to decrease the voltage-temperature relation there preferably may be added to that alloy nickel, which in this respect has an effect similar to that of copper or aluminum, and has no significant effect regarding deviation of the characteristic from a reference standard.

Silicon, while effective in the same sense as copper, both as to voltage-temperature relations and deviations, has a much greater effect than would a like amount or percentage of copper, and, further, is effective in a percentage range where copper it not. However, because of difficulty in controlling the amounts of silicon appearing in the final product or alloy, I prefer to use, in lieu

of silicon, one or more of the materials, copper, nickel and aluminum.

By controlling or modifying the amounts of one or more of carbon, mangenese and copper, a ferrous alloy, such particularly as a low carbon steel, and without modifying the percentages of all other non-ferrous components, to be utilized as one element of a thermocouple, it is possible, in accordance with my invention, within satisfactory limits, to procure practically any desired voltage-temperature characteristic. For example, and as above indicated, to match the voltage-temperature characteristic, of iron-constantan couples, adopted as a standard some 27 years ago, there is employed, in accordance with my invention, in combination with the readily available constantan of the known composition of Table B above, a low-carbon steel alloy of the modified composition of columns 2 and 3, Fig. 3; and the resultant voltage-temperature relationship is that defined by column 3, Fig. 3A.

Low-carbon steels of substantially the compositions exemplified by columns 1 and 2 of aforesaid Table A and any generally equivalent compositions within the spirit of my invention, are now obtainable from manufacturers who are enabled, from and in accord with my specifications predicated upon column 2, Fig. 3, or the like, embodying modification pursuant to Fig. 2, to modify their regularly produced and more or less closely approaching but per se unsatisfactory low-carbon steels, to suit the needs of my invention without affecting the steels from the viewpoint of satisfaction for their usual and primarily intended uses. And the composition of columns 2 and 3, Fig. 3 and generally like compositions within the spirit of my invention are obtainable by modification in the light hereof of substantially or so-called pure irons and other ferrous alloys if their pre-modification compositions be known.

The National Bureau of Standards, in Research Paper RP 1080, page 351, recently has proposed for general acceptance the voltage-temperature characteristic for iron-platinum defined by column 5, Fig. 3A, based on averages of tests of 3 high purity irons and 16 mild or low-carbon steels individually against pure platinum as the other element of each of the nineteen thermocouples. So far as I am aware, specifications of composition of such an average "iron" have not been published (column 5, Fig. 3). In any event, in accordance with my invention, it is possible to obtain upon specifications, of the type of column 2 of Fig. 3, mild or low-carbon steels of the composition indicated in column 6, Fig. 3, which will yield when used against pure platinum a voltage-temperature characteristic defined by column 6, Fig. 3A, which differs in actual temperatures from those of the characteristic defined by column 5, Fig. 3A, by at most ½%; for practical purposes these two characteristics are identical.

The National Bureau of Standards has further published (Bulletin of the Bureau of Standards, vol. 14, page 20) the results of its tests respecting thermo-electric power of a thermocouple, one element of which is pure platinum and the other of which is electrolytic iron, prohibitively expensive, having as components, other than iron, the materials and percentages thereof, by weight, appearing in column 7, Fig. 3.

The voltage-temperature characteristic of a thermocouple having as elements aforesaid electrolytic iron and pure platinum is defined by column 7, of Fig. 3A, which voltage-temperature characteristic does not match that of column 1, Fig. 3A, but corresponds with all necessary accuracy with the characteristic defined by column 6, Fig. 3A.

However, in accordance with my invention the voltage-temperature characteristic of column 7, Fig. 3A is matched by modifying the composition of a ferrous alloy distinct from aforesaid electrolytic iron. For example, by adding 0.025 percent, by weight, of chromium to the far less expensive commercially obtainable "pure iron" of Table C above, there is procured a ferrous alloy, column 8, Fig. 3 which, against pure platinum, has the voltage-temperature characteristic, defined by column 8, Fig. 3A, which will be found to correspond substantially and closely enough for all practical purposes with the characteristic defined by column 7, Fig. 3A; however, neither of the voltage-temperature characteristics of columns 7 and 8, Fig. 3A matches the "Ancient" voltage-temperature characteristic of column 1, Fig. 3A, above.

So far as I am aware, there has not heretofore existed or been known an iron-constantan thermocouple having, throughout a substantial or practically important temperature range, a voltage-temperature characteristic which is very closely or substantially a straight line. In accordance with my invention, however, such characteristic is procurable by employment with constantan of the composition of foregoing Table B an associate element of a ferrous alloy, comprehended in my invention, of the composition respecting its components shown in column 9, Fig. 3, which composition is a modification of that of a commercially obtainable so-called "pure iron" exemplified by Table C above; the composition of column 9, Fig. 3 differs from that of Table C practically solely in its far greater percentage of carbon. The voltage-temperature characteristic of this thermocouple is substantially a straight line, within the range from 100 to at least 500° C., defined as one drawn through end points of 100 to 500° C., for which temperatures, respectively, the corresponding millivolts are 5.326 and 27.355. This substantially straight characteristic departs, in temperatures, on the average, from a perfectly straight characteristic column 9, Fig. 3A to an extent not exceeding ¼ of one percent. For at least the temperature range aforesaid, there may be employed with the thermocouple having such substantially straight line characteristic measuring instruments, more particularly recording and controlling instruments, whose scale or chart calibrations are uniform or of equally spaced markings, so obviating the need for preparing or using uniquely or specially calibrated scales of deflecting instruments or charts or record sheets of recorders or controllers in correction for the curvature or deviations of normally encountered voltage-temperature characteristic curves.

The long heretofore used characteristic, that defined by column 1, Fig. 3A, is matched, with an error in actual temperatures not exceeding ¾ of one percent, by a thermocouple utilizing as one element "Adams" constantan (Table 5, page 351 of aforesaid paper RP 1080) against a ferrous alloy of composition, respecting its non-ferrous components, defined in column 4, Fig. 3. This composition falls within that of column 2, Fig. 3, except as to manganese and copper

which are present in greater percentages to afford with Adams constantan the voltage-temperature characteristic defined by column 4, Fig. 3A, which for all practical purposes matches the aforesaid "Ancient" characteristic, column 1, Fig. 3A.

It will be understood that if there be known the thermoelectric behavior or voltage-temperature characteristic of any of the ferrous alloys comprehended by my invention, when used with any other material or metal, such for example as pure platinum or the like, as a reference element, there becomes known the thermoelectric behavior or voltage-temperature characteristic of a thermocouple comprising the same ferrous alloy and any metal or material, other than pure platinum or the like, such as constantan or the like, if there be known its thermoelectric behavior or voltage-temperature characteristic with respect to the same pure platinum or the like reference material.

What I claim is:

1. A thermocouple element consisting of a ferrous alloy having a composition comprising, among its non-ferrous components, of manganese, nickel and copper in substantially the percentages by weight of .22 to .24, .04 to .05 and .115 to .125, respectively.

2. A thermocouple element consisting of a ferrous alloy having not less than about 99 percent by weight of iron, a copper component in excess of 0.10 percent by weight, and, off-setting at least a substantial portion of the effect of said copper component not exceeding about one percent, of one or more of the group of elements chromium, sulphur and manganese.

3. A thermocouple element consisting of a ferrous alloy having substantially the composition by weight, respecting its non-ferrous components, of

	Percent
Carbon	.04 to .06
Manganese	.22 to .24
Phosphorus	less than .02
Sulphur	.02 to .045
Silicon	less than .005
Nickel	.04 to .05
Chromium	less than .01
Copper	.115 to .125
Tin	less than .01

4. A thermocouple comprising an element consisting of a ferrous alloy having the composition, respecting its non-ferrous components, of

	Percent
Carbon	.04 to .06
Manganese	.22 to .24
Phosphorus	less than .02
Sulphur	.02 to .045
Silicon	less than .005
Nickel	.04 to .05
Chromium	less than .01
Copper	.115 to .125
Tin	less than .01

and an associated element of constantan comprising copper, nickel and manganese in substantially the percentages by weight of 56.1%, 42.3% and 1.4%, respectively.

5. A thermocouple one of whose elements comprises "Adams" constantan and the other of those elements consists of a ferrous alloy the percentage composition by weight of whose non-ferrous components is substantially

Carbon	.059
Manganese	.25
Phosphorus	.015
Sulphur	.035
Nickel	.050
Chromium	.007
Copper	.129

6. A thermocouple element consisting of a ferrous alloy having substantially the composition respecting its non-ferrous components of

Carbon	.013
Manganese	.088
Phosphorus	.007
Sulphur	.027
Silicon	less than .003
Nickel	.021
Chromium	less than .01
Copper	.069

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