

1,199,724.

Patented Sept. 26, 1916.

2 SHEETS—SHEET 1.

FIG. 1.

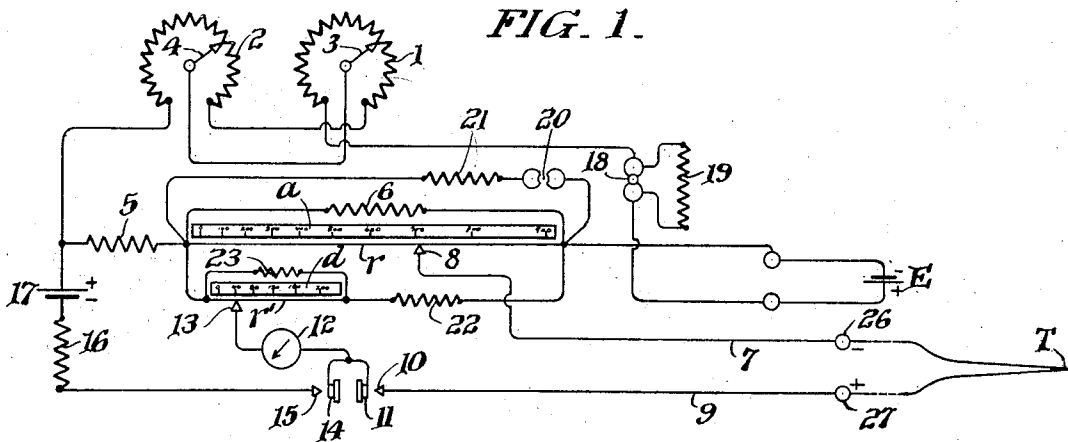


FIG. 2.

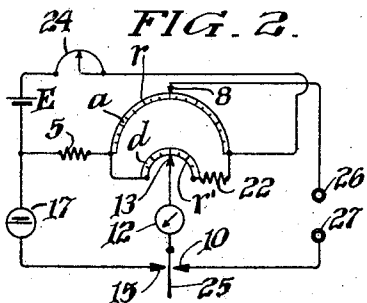


FIG. 3.

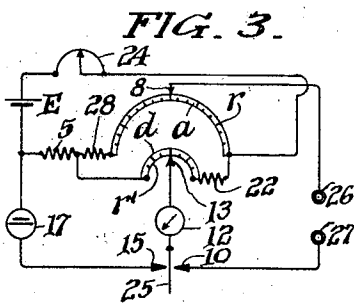


FIG. 4.

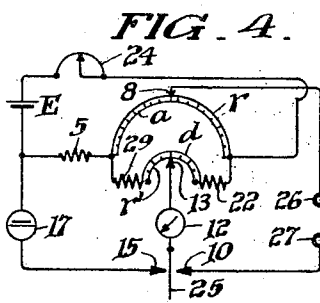


FIG. 5.

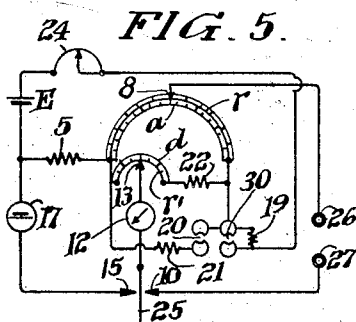


FIG. 6.

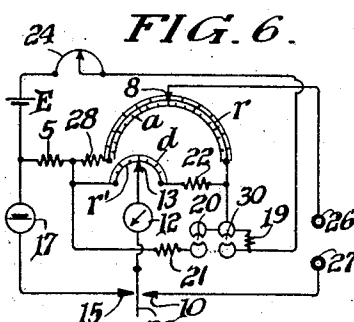


FIG. 7.

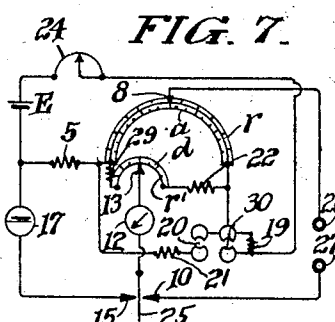


FIG. 8.

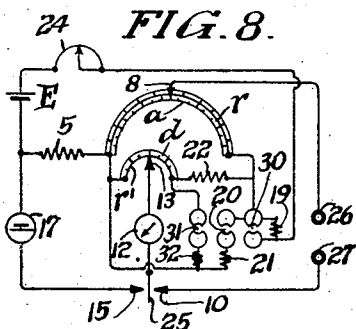


FIG. 9.

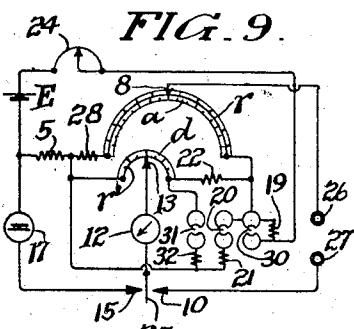
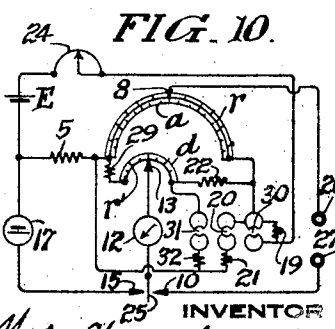


FIG. 10.



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ELECTRICAL MEASURING APPARATUS.

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1,199,724.

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2 SHEETS—SHEET 2.

FIG. 11.

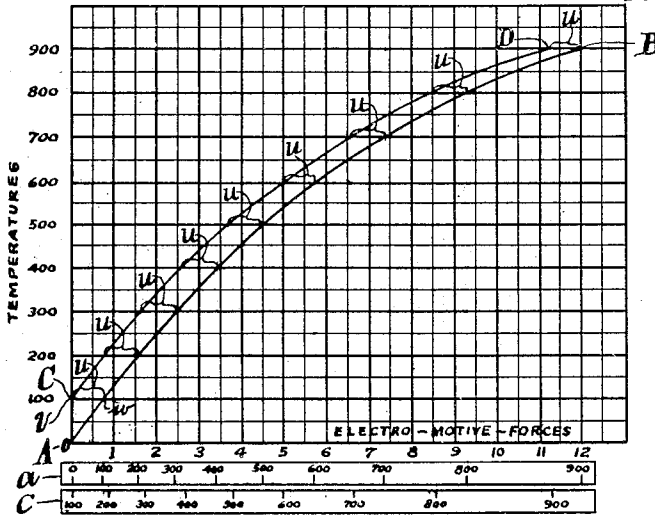


FIG. 12.

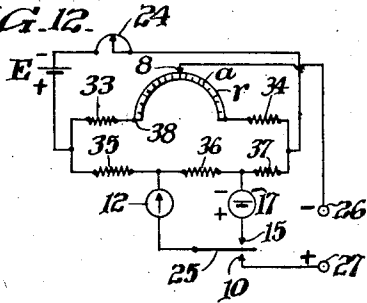


FIG. 13.

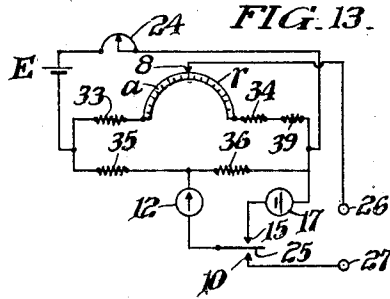


FIG. 14.

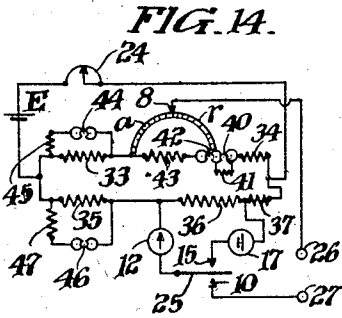


FIG. 15.

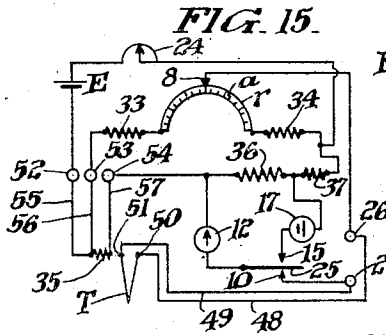


FIG. 16.

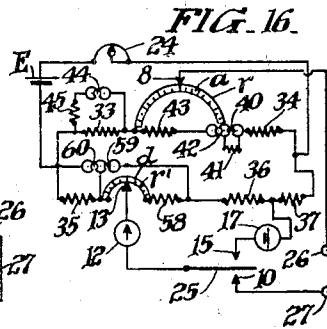


FIG. 17.

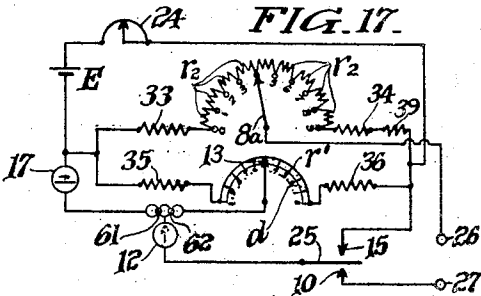
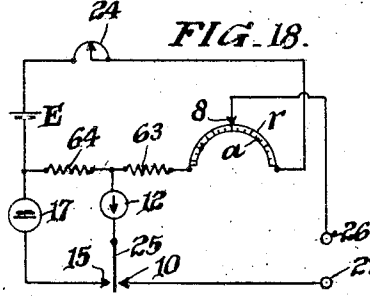


FIG. 18.



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ELECTRICAL MEASURING APPARATUS.

1,199,724.

Specification of Letters Patent.

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Application filed March 4, 1915, Serial No. 11,945. Renewed April 26, 1916. Serial No. 93,765.

To all whom it may concern:

Be it known that I, FELIX WUNSCH, a citizen of the United States, residing in the city of Philadelphia, county of Philadelphia, and State of Pennsylvania, have invented a new and useful Electrical Measuring Apparatus, of which the following is a specification.

My invention relates to electrical measuring apparatus, and particularly electrical measuring apparatus involving potentiometers.

In one of its aspects my invention resides in means for temperature measurements or pyrometry involving the use of a potentiometer, particularly a split circuit potentiometer, and a thermo-electric couple, manually operated or automatic means being provided for correcting or compensating for variations in temperature of one of the junctions of a thermo-couple, generally the cold junction, from a given or predetermined temperature at which that junction was maintained during calibration of the thermo-couple or the apparatus in conjunction with which it is used.

My invention resides in electrical measuring apparatus of the character hereinafter described and defined in the claims.

For an illustration of some of many forms my invention may take reference is to be had to the accompanying drawings, in which:

Figure 1 is a diagrammatic view of a thermo-couple pyrometer involving a split circuit potentiometer. Fig. 2 is a simplified diagram similar to that of Fig. 1, for a single range instrument in which the cold junction correction scale starts at the same temperature as the low end of the main scale. Fig. 3 is an elemental diagram of a single range instrument in which the cold junction correction scale begins at a temperature lower than the low end of the main scale. Fig. 4 is an elemental diagram of a single range instrument in which the cold junction correction scale begins at a temperature higher than the low end of the main scale. Fig. 5 is an elemental diagram of a double range instrument in which the cold junction correction scale starts at the same temperature as the low end of the main scales and is correct for one range only. Fig. 6 is an elemental diagram of a double range instru-

ment in which the cold junction correction scale is correct for one range only, such scale starting at a temperature lower than the low end of the main scales. Fig. 7 is an elemental diagram of a double range instrument in which the cold junction correction scale is correct for one range only and starts at a temperature higher than the low end of the main scales. Fig. 8 is an elemental diagram of a double range instrument in which the cold junction correction scale is correct for both ranges and starts at the same temperature as the low end of the main scales. Fig. 9 is an elemental diagram of a double range instrument in which the cold junction correction scale is correct for both ranges and starts at a temperature lower than the low end of the main scales. Fig. 10 is an elemental diagram of a double range instrument in which the cold junction correction scale is correct for both ranges and starts at a temperature higher than the low end of the main scales. Fig. 11 is a graphic representation of relations existing between temperatures and electro-motive-forces of a thermo-couple, together with derivatives from such relations. Fig. 12 is an elemental diagram of a single range instrument involving a split potentiometer circuit employing means for automatically correcting for variations in cold junction temperature. Fig. 13 is an instrument similar to that indicated in Fig. 12, but employing further correction or compensation means. Fig. 14 is an elemental diagram of a double range instrument involving means for automatically correcting for temperature variations of the cold junctions for both ranges. Fig. 15 is an elemental diagram of an instrument for automatically correcting for variations in temperature of the cold junctions of a thermo-couple when the cold junction is located at a distance from the instrument. Fig. 16 is an elemental diagram of a double range instrument in which for one range automatic means are provided and for the other range manually operated means are provided for correcting for variations in temperatures of the cold junctions. Fig. 17 is an elemental diagram of an instrument having means for automatically compensating for variations in temperature of the cold junction and in which the standard cell is

differently employed and approximate balance procured by stepped resistance in one branch and final balance by a slide wire in another branch. Fig. 18 is an elemental diagram of an instrument involving a simple potentiometer with means for automatically compensating or correcting for variations in temperature of the cold junction.

In thermo-couple pyrometry the temperature readings are based upon the fact that there is generated by the thermo-couple an electro-motive-force which is a function of the difference between the temperatures of the hot and cold junctions of the thermo-couple. In most cases it is the temperature existing at one of the junctions and not the difference between the temperatures of the junctions of the couple which is the unknown quantity to be measured. It is accordingly necessary either to maintain one of the junctions at a constant known temperature, or, if this is not done, to apply a correction for the variation in temperature of such junction of the couple from a given temperature. And it is to means for making such correction that my invention relates, more particularly when the measuring instrument is a split circuit potentiometer, to the end that the scale readings of the indicating or measuring apparatus will directly give, notwithstanding variations in the temperature of one of the thermo-couple junctions, the unknown temperature of the other junction, without recourse to computation, tables, calibrations curves or the like.

The electro-motive-force generated by a thermo-couple is a function not only of the difference between the temperatures of its two junctions but varies also with the absolute temperatures of its junctions. Thus the electro-motive-force generated by a thermo-couple for a temperature difference of 100 degrees between its two junctions, one of which is at 0 degrees and the other at 100 degrees, is, generally speaking, quite different in value from the electro-motive-force generated by the same couple when there is a temperature difference of 100 degrees between its two junctions when one junction is at 900 degrees and the other is at 1000 degrees. From this fact it is impossible, with most thermo-couples, to make a true or accurate correction simply by changing the reading of the instrument by an amount corresponding with the temperature variation of one junction from the temperature at which that junction was maintained during calibration of the thermo-couple.

The characteristics of a thermo-couple which are important here may be stated as follows: Assuming any three temperatures, x , y and z , y being higher than x , and z being higher than y , and subjecting one junction of a thermo-couple to a temperature x , and the other to a temperature z , and then

increasing the temperature of the first junction from temperature x to temperature y , the electro-motive-force generated by the thermo-couple in the latter case will be decreased from the value of the electro-motive-force produced by it when one junction is at temperature x and the other at temperature z by a value of electro-motive-force which the same thermo-couple would generate if its one junction were at temperature x and the other at temperature y .

The thermo-couple is usually calibrated by maintaining one of its junctions at a known low temperature and by measuring directly or indirectly the electro-motive-forces generated by the couple when its other junction is at various known higher temperatures.

In Fig. 11 the curve A, B represents a calibration curve whose abscissæ are electro-motive-forces and whose ordinates are temperatures, the cold junction being maintained at 0 degrees temperature and the hot junction being carried up to a temperature of 900 degrees. Below the curve is a scale a , reading in temperatures for a reading instrument of a character whose indications are proportional to the electro-motive-forces, when used in connection with the thermo-couple whose calibration curve is A, B. The markings 100, 200—900 of this scale are found by projecting downwardly from the points of intersection between the curve A, B and the horizontal lines opposite the temperatures 100, 200—900 of the curve sheet.

Taking into consideration now the above described characteristic of thermo-couples a derived curved C, D, may be plotted for the same thermo-couple with its cold junction at any other than 0 degrees temperature, in this case 100 degrees. This curve is derived as follows: On the horizontal line opposite the temperature 100 degrees there is measured to the left, from the point where the curve A, B intersects that line, a distance equal to the electro-motive-force generated by the couple when its hot junction is at 100 degrees shown by curve A, B. Accordingly the first point on the curve C, D is at 0 electro-motive-force and on the horizontal line corresponding to 100 degrees. At each of the other temperatures exactly the same distance is measured off to the left from the curve A, B and through these points the curve C, D is drawn. In other words, the distance from point v to point w corresponds with the electro-motive-force generated by the couple when its one junction is at 0 degrees and its other junction is at 100 degrees. This distance u is measured off to the left of curve A, B on the horizontal lines of the curve sheet and the curve C, D then drawn through these derived points. Below the curve sheet is

the corresponding scale c , reading in temperatures derived from the curve C, D in the manner in which the scale a was derived from curve A, B for the same proportionately reading or indicating instrument; that is, by projecting downwardly from the points of intersection of the curve C, D and the horizontal lines opposite the temperatures 100, 200—900 of the curve sheet.

Throughout the following description and claims there will be used for brevity and simplicity terms as follows: The temperature to be measured and the junction of the thermo-couple subjected to that temperature will be known as the "unknown temperature" and "hot junction," respectively, whether that junction be at higher, same or lower temperature than the temperature of the other junction; the constant known temperature and the other junction subjected to that temperature during calibration of the thermo-couple will be known as the "calibration temperature" and "cold junction," respectively, whether that junction be at lower, same or higher temperature than the hot junction; and the known temperature to which said cold junction may be varied when a measurement is made will be known as the "reference temperature."

From the foregoing it will be understood that where the "reference temperature" differs from the "calibration temperature" the electro-motive-force reading is corrected by adding or subtracting the electro-motive-force which would be produced by the thermo-couple when one junction is at the "calibration temperature" and the other junction at the "reference temperature." And it will be further noted that there is no direct arithmetical relation between the temperature variations of the cold junction and the corrections to be applied to the temperature readings.

In Fig. 1 the reading or indicating instrument is a split circuit potentiometer. Here the main slide wire or resistance r is associated with the main scale which may read in milli-volts or temperatures, or both, and when reading in temperatures, as illustrated, may be derived from the calibration curve of the thermo-couple by the method described in connection with Fig. 11. The resistance r is connected in series with the battery E or other source of electro-motive-force, preferably more or less constant, and the resistances 1 and 2 more or less of which may be brought into circuit by moving the adjustable contacts 3 and 4, and a resistance 5. In shunt to the resistance r may be connected the resistance 6 to assure a predetermined resistance in the circuit between the terminals of the resistance r . One terminal of the hot thermo-junction T connects by conductor 7 with the conductor 8 movable in contact with and along the slide

wire r . The other terminal of the junction T connects by conductor 9 with the contact 10 into engagement with which may be pressed the key contact 11 connected with one terminal of any suitable instrument such as a galvanometer 12 whose other terminal is connected to the contact 13 movable along and in contact with the second slide wire or resistance r' whose one terminal connects with one terminal of the slide wire r and whose other terminal connects through the resistance 22 with the other terminal of the slide wire r . Associated with the slide wire r' is the second or correction scale d calibrated in the same way as the left end of the main scale a would be if calibrated in temperatures for the probable range of reference temperatures. In shunt to the slide wire r' may be connected the resistance 23 to insure between the terminals of the resistance r' a perfectly definite resistance. One terminal of the galvanometer 12 is also connected with the key contact 14 adapted to be pressed into engagement with the contact 15 which connects through the resistance 16 with one terminal of the standard cell 17 whose other terminal connects with the circuit including the slide wires r and r' . To change the range of the instrument the plug 18 may be withdrawn from between the blocks forming the terminals of the resistance 19 and inserted into the hole 20 between blocks whereby the resistance 21 is thrown into shunt with the slide wire r and with the slide wire r' and resistance 22. For such double range purposes the scales a and d will each have two series of markings.

The operation is as follows: The contact 13 is moved to the extreme left end of slide wire r' . The key 14 is pressed into engagement with contact 15 and then the large resistance 2 and thereafter the small resistance 1 are adjusted until the galvanometer 12 points to 0, that is, until there is no current through the galvanometer 12, this being the usual method of securing the proper current strength in the potentiometer circuit, because of possible variations from time to time of the electro-motive-force of the source E. The key 14 is released and the key 11 is depressed into engagement with contact 10 and the contact 8 is moved along the slide wire r until the galvanometer again indicates 0 current, in which case the reading may be taken from the scale a corresponding to the temperature of the hot junction T if the cold junction is at calibration temperature. If, however, the cold junction is at a temperature other than the calibration temperature the reference temperature is read on a thermometer located at the cold junction and the contact 13 is moved along the slide wire r' to a point opposite that marking on the scale d corresponding

with the thermometer reading or reference temperature. Then the key 11 is depressed into engagement with contact 10 and the contact 8 moved along the wire r until the galvanometer 12 indicates 0 current, in which case the temperature of the hot junction T will be read from the scale a opposite the contact 8. This reading opposite the contact 8 is the unknown temperature to which the junction T is subjected.

The correction scale d is preferably always calibrated in temperatures, while the main scale a may be calibrated in temperatures of milli-volts, or both, for each range. In Figs. 2 to 10 inclusive similar parts are indicated by similar reference characters which correspond also with similar parts of Fig. 1.

Fig. 2 is an elemental diagram of a single range instrument corresponding with the single range instrument of Fig. 1, the cold junction correction scale d starting at the same temperature as the low end of the main scale a . Here the adjustable resistance 24 has the function of the adjustable resistance 1 and 2 of Fig. 1, and one terminal of the galvanometer 12 is connected to the key 25 which may be swung into engagement with either of the contacts 10 or 15, the key 25 being functionally the same as the keys 11 and 14 of Fig. 1. 26 and 27 represent the binding posts to which the hot junction T is connected.

The operation is the same as that described in connection with Fig. 1.

In Fig. 3 is shown a single range instrument in which the correction scale d starts at a temperature lower than the low end of the main scale. For this purpose an additional resistance 28 is included with slide wire r at the low end of the scale a in the path in shunt with the slide wire r' and resistance 22.

In Fig. 4 is shown a single range instrument in which the correction scale d starts at a temperature higher than the low end of the main scale a . For this purpose a resistance 29 at the left or low end of scale d is included with the slide wire r' and resistance 22 in a path in shunt with the main slide wire r .

In Fig. 5 is shown diagrammatically a double range instrument for use with thermocouples of different types and in which the cold junction correction scale d starts at the same temperature as the low end of the main scales a , the scale d being correct for one of the ranges only. One range may be for the use of a noble metal thermo-junction, as, for example, platinum with platinum-rhodium; while the other range may be employed for a base metal thermo-junction as, for example, iron with constantan. For one range a plug is inserted in the plug

hole 30, in which case the resistance 19 is short circuited, and the resistance 21 is out of circuit. To change the range of the instrument the plug is removed from the hole 30 and inserted in plug hole 20, in which case the resistance 19 is brought into the potentiometer circuit and the resistance 21 shunts both slide wire circuits. This is similar to the arrangement shown in Fig. 1, and the correction scale d is correct only for the first range, that is, when the plug is in hole 30, in which case Fig. 5 corresponds with Fig. 2.

In Fig. 6 an arrangement similar to that of Fig. 5 is shown except that the correction scale starts at a temperature lower than the low end of the main scales a , for which purpose the resistance 28 is connected in the circuit of the slide wire r at the low temperature end of the resistance r . Otherwise the parts are the same as in Fig. 5 and the two ranges are procured in the same manner.

In Fig. 7 the arrangement is similar to that of Fig. 5, for two ranges, except that the correction scale starts at a temperature higher than the low end of the main scales 2, the resistance 29 being inserted for this purpose as in Fig. 4. Otherwise the apparatus operates for two ranges as described in connection with Fig. 5.

In the arrangement of Figs. 5, 6 and 7 the correction scale d and cooperating parts are made correct for one range or type of thermo-couple and are incorrect for the other range or type of thermo-couple except in the unusual case where the ratio of electro-motive-force corresponding with the correction scale range to the electro-motive-force corresponding with the main scale range for one type of thermo-couple is equal to the ratio of the same electro-motive-forces for the other type of thermo-couple.

In Fig. 8 is shown a diagram for a double range instrument in which the cold junction correction scale d is correct for both ranges and starts at the same temperature as the low end of the main scales a . For one range a plug is inserted in plug hole 30, thereby short circuiting the resistance 19 in which case the arrangement will be that of Fig. 2. For the second range the plug is removed from hole 30 and a plug placed in each of holes 20 and 31, thereby bringing the resistance 21 into shunt with the slide wire circuits, and the resistance 32 into shunt with the slide wire r' only.

In Fig. 9 the arrangement is the same, except that a resistance 28 is included with the slide wire r as in Fig. 3, thereby causing the cold junction scale d to start at a temperature lower than the low end of the main scales a . And in Fig. 10 a resistance 29 is connected in the path with the slide wire r' ,

thereby causing the cold junction correction scale d to start at a temperature higher than the low end of the main scales a .

In the arrangements of Figs. 8, 9 and 10 the correction scale and coöperating parts are correct for both ranges because the shunts to the main and correction slide wires r and r' have such values as to cause for both ranges equality of the ratios of electro-motive-forces corresponding with the correction and main scale ranges.

In Figs. 12 to 18 inclusive are disclosed various arrangements in which the correction or compensation for variations in temperature of the cold junction is accomplished automatically by employing in certain relations resistances of suitable values and suitable temperature co-efficients.

In Fig. 12 the slide wire r and resistances 33 and 34 constitute one branch of a potentiometer and are connected in circuit with the rheostat 24 and the source of current E. The contact 8 movable in contact with and along the slide wire r connects as before with binding post 26 to which one terminal of the thermo-junction is connected. In shunt to the resistances 33, r and 34 of the first branch are the serially connected resistances 35, 36 and 37 constituting the second branch. One terminal of the galvanometer 12 is connected between the resistances 35 and 36 and the other terminal to the key 25 which in one position engages contact 10 connected to the binding post 27 with which the other terminal of the thermo-junction is connected, and in its other position engages the contact 15 connected to one terminal of the standard cell 17, whose other terminal is connected between the resistances 36 and 37. The current from the battery E divides between the two branches, one including the resistances 33, r and 34 and the other including the resistances 35, 36 and 37. The current in the branch including resistances 35, 36 and 37 is kept at a constant value by suitably adjusting the rheostat 24 to such position that the fall of potential across the resistance coil 36 due to the current from source E balances or is equal to the electro-motive-force of the standard cell 17, which condition is observed by pressing the key 25 into engagement with contact 15 and so adjusting the rheostat 24 that the galvanometer 12 indicates no current. Since the current in the branch including resistances 35, 36 and 37 is constant in value, the current in the branch including the slide wire r will also be of constant value provided the ratio of the resistances of the two branches is constant.

The resistance 35 consists of a wire or conductor of nickel or other suitable material having a large positive temperature co-efficient and is located near the cold junction

of the thermo-couple so as to partake of the temperature of the cold junction. For this purpose the resistance 35 may in many cases be located within or at the reading instrument because the cold junction is at or within the instrument. This is particularly the case when employing a base metal couple whose connections to the instrument are made through wires of the same materials as the couple materials.

The resistances 33, r , 34, 36 and 37 consist of conductors or wires of manganin or other suitable material preferably having a negligibly small temperature co-efficient. The values of the resistances are so chosen that changes in the electro-motive-force produced by the thermo-couple due to changes in temperature of the cold junction are balanced or compensated for by corresponding changes in the fall of potential across resistance 35. With a change in temperature of the cold junction, and therefore of resistance 35, the resistance value of 35 changes and therefore the drop of potential across it changes, and this change in drop of potential across resistance 35 balances or compensates for the change in electro-motive-force of the thermo-couple due to a change in temperature in its cold junction. In other words, in taking a temperature reading, with the key 25 in engagement with contact 10, the contact 8 is moved along the slide wire r until the galvanometer 12 indicates no current. If the cold junction is at a temperature other than calibration temperature the effect of resistance 35 is to cause the operator to move contact 8 in procuring a balance to such point along the resistance r that there is read opposite the contact 8 upon the scale a a temperature or electro-motive-force which is the true temperature of the hot junction or the electro-motive-force that would be produced by the thermo-couple if the cold junction were at calibration temperature.

The value of the resistance 33 is so chosen that the scale a starts at 0 or at any other desired temperature or electro-motive-force.

Let

R = resistance of compensating resistance 35 at reference temperature.

c = change in the electro-motive-force of the thermo-couple per degree change in temperature of the cold junction with the hot junction at a given temperature.

k = temperature co-efficient of material of coil 35 per ohm per degree.

t = temperature change of cold junction.

i = current strength in the branch including resistance 35.

e = change in electro-motive-force of the thermo-couple due to temperature change t of the cold junction.

e^1 = change in fall of potential across re-

distance 35 due to temperature change t of the cold junction.

e must be made equal to e^1 .

$$e = ct \quad (1)$$

$$e^1 = Rkti \quad (2)$$

from which we have

$$Rkti = ct \quad (3)$$

$$R = \frac{c}{ki} \quad (4)$$

Therefore the resistance 35 is made equal to the constant quantity $\frac{c}{ki}$, and e equals e^1 regardless of changes in temperature of the cold junction.

The combined resistance of 36 and 37 is chosen high as compared to the value of resistance 35, in order that the ratio of the resistances in the two branches remains practically constant irrespective of changes in value of resistance 35, and consequently the current strength in the branch including slide wire r will remain practically constant.

In Fig. 13 is shown an arrangement similar to that of Fig. 12 with additional means for maintaining the relation of current strength in the branch including the slide wire r with respect to the current strength in the other branch absolutely constant regardless of changes in value of resistance 35. In this figure the parts are similar to those of Fig. 12 except that the resistance 37 of Fig. 12 is omitted and in the branch including the slide wire r is included the additional resistance 39 of a wire or conductor having the same temperature co-efficient as the material of resistance 35. The resistances 35 and 39 are both subjected to the temperature of the cold junction of the thermo-couple. The ratio of resistance 39 to the total resistance in its branch must be the same as the ratio of resistance 35 to the total resistance in its branch.

In Fig. 14 is shown a diagram of connections for a double range instrument for use with thermo-couples of different types, for example base metal and noble metal thermo-couples, but, generally speaking, for use with thermo-couples whose calibration curves are different. When using one type of thermo-couple, for example a base metal couple, a plug is inserted in the hole 40, thus short circuiting the resistance 41. The conditions are then similar to those of Fig. 12. When another type of thermo-couple, for example a noble metal couple is used, the plug is removed from hole 40 and inserted in hole 42, thus shunting the slide wire r with the resistance 43 and bringing the resistance 41 into series with the slide wire r . A plug is also inserted in hole 44, thus shunting resistance 33 with resistance 45; and a plug is inserted in hole 46, thus shunting the resistance 35 with a resistance 47 of material having preferably the same temperature co-efficient as the resistance 35 and

subjected therewith to the temperature of the cold junction. The resistance 41 has such value that the total resistance in the branch including the resistance r for the second range is equal to the resistance of the other branch for the second range.

In Fig. 15 is shown diagrammatically an arrangement for use when the material of the leads or wires connecting the thermo-junction with the potentiometer instrument is unlike one or both materials of the thermo-junction. In this case the hot junction T , for example of noble metals such as platinum and platinum-rhodium, is at a distance from the reading instrument and is connected to the binding posts 26 and 27 of the instrument by conductors or leads 48 and 49, for example of copper, extending to the terminals 50 and 51 of the junction T . The cold junction in this case is at the terminals 50, 51 of the junction T . The compensating resistance 35 in such case must be placed near and subjected to the temperature of the cold junction. For this purpose the instrument is provided with the additional binding posts 52, 53 and 54 connected respectively with the source E , the potentiometer branch including the slide wire r , and the second potentiometer branch. The binding posts 52 and 53 are connected with one terminal of the resistance 35 by the conductors 55 and 56 while the post 54 is connected with the remaining terminal of the resistance 35 by the conductor 57. These conductors 55, 56 and 57 are all preferably of the same material, for example copper, and 56 and 57 are of the same resistance. The lead or conductor 56 is thus in series with the first branch and the lead or conductor 57 is in series with the second branch of the potentiometer. By making the current strength in these two branches equal, the current strengths in the leads 56 and 57 are equal and consequently the fall of potential in the lead 56 compensates for the drop of potential in the lead 57.

In Fig. 16 there is shown an arrangement for a double range instrument for use with thermo-couples of different types or characteristics, in which for one range an automatic compensator for changes in cold junction temperature is provided and for the other range a second slide wire or manual compensator is provided. For the first range the automatic compensating resistance 35 is in circuit, the slide wire r and resistance 38 are short circuited by placing a plug in hole 59, and resistance 41 is short circuited by placing a plug in hole 40. The operation is then that described in connection with Fig. 12 or one range of Fig. 14. For the other range the plug is removed from hole 59 and inserted in hole 60, thus short circuiting resistance 35 and bringing into the second branch the slide wire r and

resistance 58; and in the first branch the plug is removed from hole 40 and inserted in hole 42, introducing resistance 41 into that branch and shunting the slide wire r with resistance 43, and a plug is inserted in hole 44 thus shunting the resistance 33 with the resistance 45. In using the apparatus for the second range contact 13 is moved on slide wire r' to a point on the correction scale d corresponding with the temperature of the cold junction. Then the contact 8 is moved along the slide wire r until a balance is obtained with key 25 in engagement with contact 10, as described in connection with Figs. 1 and 2.

Fig. 17 shows an arrangement similar to that of Fig. 12 except that the standard cell 17 is adapted to be connected across the points where the current divides in the two potentiometer branches instead of being connected, as in Fig. 12, across the resistance 36. When the key 25 is pressed into engagement with contact 15, a plug is inserted in hole 61, thus connecting the standard cell terminals to the extreme ends of the branches, whereupon the rheostat 24 is adjusted as before until the galvanometer 12 shows no current.

For making a temperature reading the key 25 is pressed into engagement with contact 10, and the plug is removed from the hole 61 and inserted in hole 62. Then the switch arm 8^a is moved over the contact studs between which are connected the resistance sections r^2 until an approximate balance is indicated by the galvanometer 12; then the contact 13 is moved over the slide wire r' in the other branch until a true balance is obtained. Then an electro-motive-force value is read opposite the stud on which the switch arm 8^a is in contact and to such value is added the value of electro-motive-force read upon the scale d opposite the pointer movable with the contact 13. This gives the total electro-motive-force generated by the thermo-couple connected to the posts 26 and 27, the nickel or like resistances 35 and 39 automatically compensating for changes in temperature in cold junction of the thermo-couple. From a curve, similar to that in Fig. 11, may be read off the corresponding temperature of the hot junction of the thermo-couple.

In Fig. 18 is shown a simple potentiometer arrangement in which the current strength through the slide wire r , resistance 63, and resistance 64 is adjusted to proper value by pressing the key 25 into engagement with contact 15 and adjusting the rheostat 24 until the galvanometer 12 indicates no current. The resistance 63 has a negative temperature co-efficient, that is, is of such material that as its temperature rises its resistance falls, being in this respect opposite to the hereinbefore described resistances 35 which have positive temperature co-efficients. The re-

sistance 63 is subjected to the temperature of the cold junction, and as such temperature varies the resistance 63 varies in value and automatically compensates for changes in temperature of the cold junction. A suitable material for resistance 63 is carbon, though any other suitable material of negative temperature co-efficient may be employed. The resistances 64 and r as in the previous cases, are preferably of manganin or other suitable material having negligible temperature co-efficient.

While I have herein used the term "slide wire" for the adjustable resistances r and r' it will be understood that such term includes any type of adjustable resistance whether constructed as a slide wire or otherwise.

Pursuant to a requirement of division, I do not herein claim certain subject matter disclosed in Figs. 12 to 18 inclusive, the same being claimed in my co-pending application Serial Number 44,852, filed August 11, 1915.

What I claim is:

1. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, said potentiometer comprising slide wire resistances, a scale associated with one of said slide wire resistances derived from a calibration of said thermo-couple with its cold junction maintained at a constant calibration temperature, a scale associated with another of said slide wire resistances and derived similarly to said first named scale, a contact connected with said thermo-couple movable along said second slide wire resistance to a point in said second scale corresponding with the reference temperature to which said cold junction has varied, and a second contact connected with said thermo-couple movable along said first named slide wire resistance to a point balancing said potentiometer, the unknown temperature of the hot junction of said thermo-couple being determined from said first named scale opposite said second movable contact.

2. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, said potentiometer comprising slide wire resistances in parallel with each other, a scale associated with each of said slide wire resistances, one of said scales having markings from which the unknown temperature of the hot junction of said thermo-couple or its electro-motive-force is read, a contact connected with said thermo-couple movable with respect to said scale on one of said slide wires, another of said scales having markings corresponding with reference temperatures of the cold junction of said thermo-couple, and a contact connected with said thermo-couple movable along another of said slide wire resistances over said scale.

3. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, main and correction scales associated with the circuit branches of said potentiometer, and contacts connected with said thermo-couple movable with respect to said scales in engagement with said circuit branches.
4. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, main and correction scales associated with the circuit branches of said potentiometer, each of said branches including a slide wire resistance, and contacts connected with said thermo-couple movable with respect to said scales in engagement with said slide wire resistances.
5. A plural range reading instrument comprising a split circuit potentiometer, main and correction scales associated with the circuit branches of said potentiometer, a thermo-couple contacts connected therewith movable with respect to said scales in engagement with said circuit branches, and means for changing the range of said instrument comprising a resistance in series with said branches and a resistance in shunt with said branches.
6. A plural range reading instrument comprising a split circuit potentiometer, main and correction scales associated with the circuit branches of said potentiometer, a thermo-couple contacts connected therewith movable with respect to said scales in engagement with said circuit branches, and means for changing the range of said instrument comprising a resistance in series with said branches, a resistance in shunt with said branches and a resistance in shunt with a part of the branch with which the correction scale is associated.
7. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, a scale associated with one of the potentiometer branches, a connection from said thermo-couple to said branch, and a second connection from said thermo-couple to another branch of said potentiometer.
8. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, a scale associated with one of the potentiometer branches, a connection from said thermo-couple to said branch, a second connection from said thermo-couple to another branch of said potentiometer, and a correction scale associated with said second connection.
9. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches,

main and correction scales associated with said resistances in the different branches, and connections from said thermo-couple to said resistances in the different branches.

10. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, and a second connection from said thermo-couple to a resistance in another branch.

11. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, a second connection from said thermo-couple to a resistance in another branch, and an additional resistance in one of said branches.

12. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, a second connection from said thermo-couple to a resistance in another branch, and an additional resistance in said other of said branches.

13. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, and an additional resistance in the branch with which said correction scale is associated.

14. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, and an additional resistance in one of said branches.

15. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, a second connection from said thermo-couple to a resistance in another branch, and an additional resistance on each side of the resistance in said other of said branches.

16. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in different branches, and an additional resistance on each side of the resistance of said branch with which said correction scale is associated.

17. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, a second connection from said thermo-couple to a resistance in another branch, a resistance, and means for cutting said last named resistance into and out of circuit in series with said branches.

18. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, a resistance, and means for cutting said last named resistance into and out of circuit in series with said branches.

19. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, a second connection from said thermo-couple to a resistance in another branch, a resistance, and means for cutting said last named resistance into and out of circuit in shunt with said branches.

20. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, a resistance, and means for cutting said last named resistance into and out of circuit in shunt with said branches.

21. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, a second connection from said thermo-couple

to a resistance in another branch, a resistance, and means for cutting said last named resistance into and out of circuit in shunt with the resistance of said other branch.

22. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, a resistance, and means for cutting said last named resistance into and out of circuit in shunt with the resistance associated with said correction scale.

23. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, a scale associated with one of said resistances, a connection from said thermo-couple to said one of said resistances, a second connection from said thermo-couple to a resistance in another branch, an additional resistance in said other of said branches, a resistance, and means for cutting said last named resistance into and out of circuit in shunt with said first named resistance of said other of said branches.

24. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, an additional resistance in the branch with which said correction scale is associated, a resistance, and means for cutting said last named resistance into and out of circuit in shunt with the resistance associated with said correction scale.

25. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, a resistance in shunt with said branches, and a resistance in series with said branches.

26. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, a resistance in shunt with said branches, a resistance in series with said branches, and

means for cutting out said resistance in series with said branches and cutting in said resistance in shunt with said branches.

27. The combination with a thermo-
5 couple, of a reading instrument associated therewith comprising a split circuit potentiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches,
10 connections from said thermo-couple to said resistances in the different branches, a resistance in series with said branches, a resistance in shunt with said branches, and a resistance in shunt with the resistance associated with said correction scale.
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28. The combination with a thermo-couple, of a reading instrument associated therewith comprising a split circuit poten-

tiometer, resistances in the potentiometer branches, main and correction scales associated with resistances in different branches, connections from said thermo-couple to said resistances in the different branches, a resistance in series with said branches, a resistance in shunt with said branches, a resistance in shunt with the resistance associated with said correction scale, and means for cutting in and cutting out said resistances.

In testimony whereof I have hereunto
affixed my signature in the presence of the
two subscribing witnesses.

FELIX WUNSCH.

Witnesses:

NELLIE FIELD,
ALICE S. MARSH.