

June 8, 1937.

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2,083,408

POTENTIOMETER

Filed May 8, 1936

2 Sheets-Sheet 1

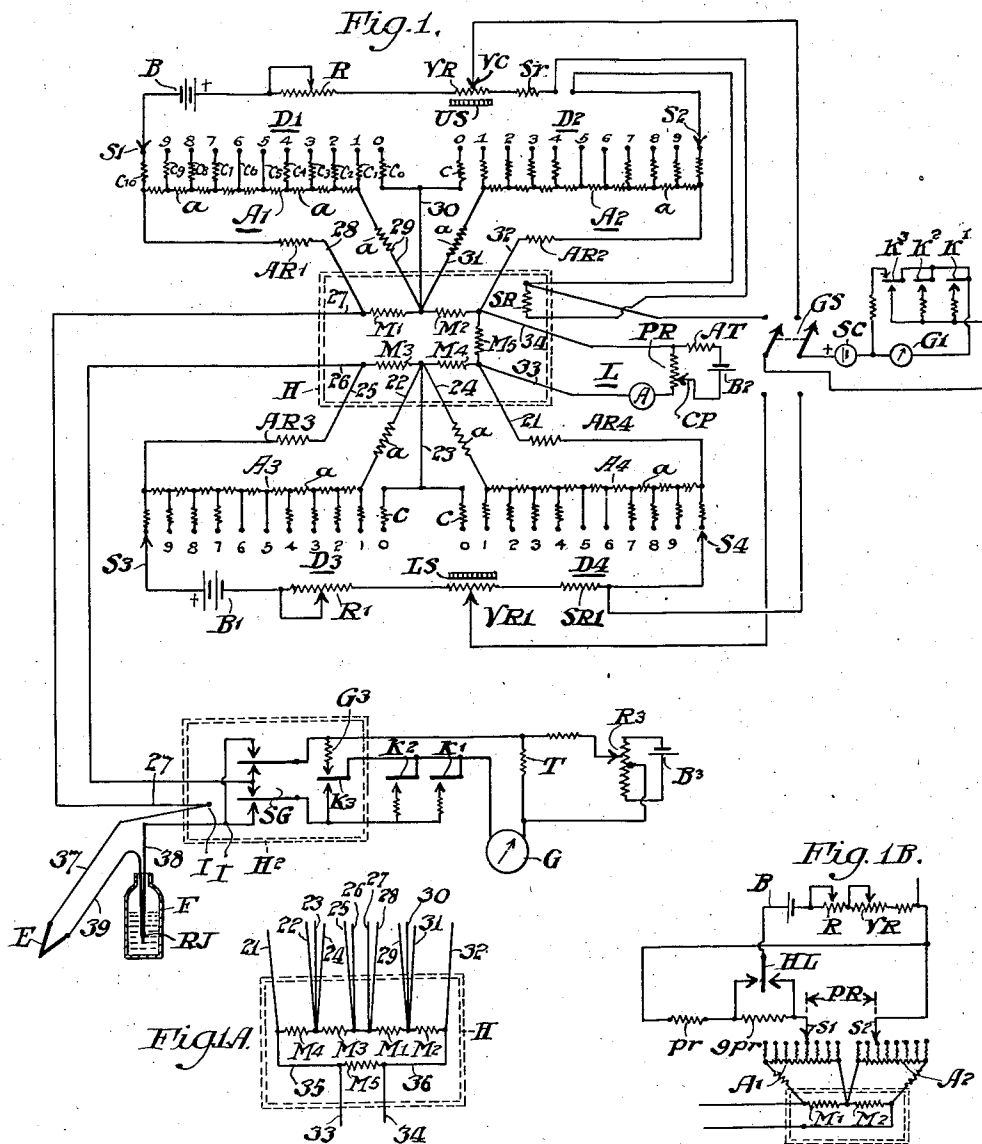


*Fig. 2.*

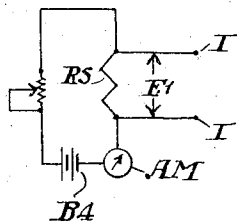
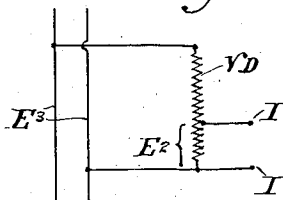


*Fig. 3.*



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Fig. 4.

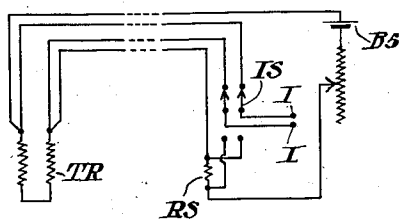


Fig. 5.

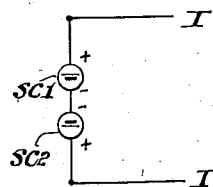


Fig. 6.

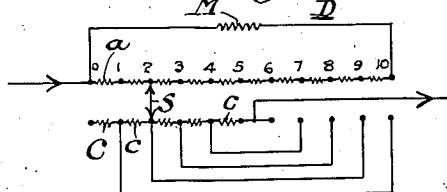


Fig. 7.

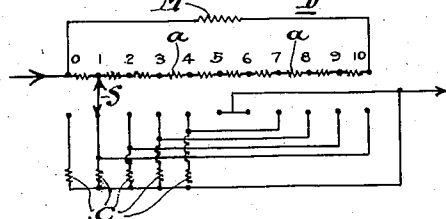


Fig. 8.

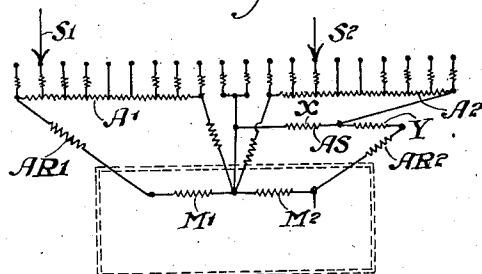
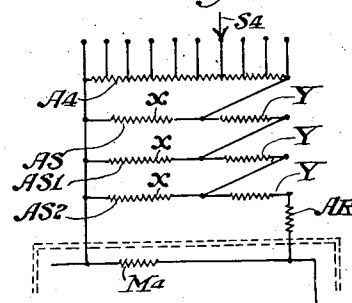


Fig. 8A



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## UNITED STATES PATENT OFFICE

2,083,408

## POTENTIOMETER

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Application May 8, 1936, Serial No. 78,620

14 Claims. (Cl. 175-183)

My invention relates to potentiometers and particularly to potentiometers suited for high precision measurements involving use of thermocouples, precision resistance thermometers, and the like, or for standard cell comparisons.

In accordance with my invention, a small number of fixed main resistances, preferably of low and different magnitudes, are included directly in circuit with a suitable electro-responsive instrument, as a galvanometer, and the voltage to be measured; auxiliary resistances provide paths of fixed resistance in shunt to the main resistances, and a source of standardized current is adapted to be connected to selected points of the shunt paths to vary the comparison voltage introduced into the galvanometer circuit by variation of the current from said source through the main resistances.

More particularly, and preferably, each of the auxiliary resistances is either tapped or comprised of a group of serially-connected resistances, and the taps or junctions are connected to switch or dial points selectively engageable by a relatively movable switch contact connected to a source of standardized current; preferably compensating resistances are interposed in connections from the switch points to said junctions or taps to maintain constant, for the different settings of the switch contacts, the resistance of the path traversed by the standard current.

Further in accordance with my invention, the auxiliary resistances of different groups are of the same magnitude and to obtain the desired ratios between the incremental changes of balancing voltage effected by adjustment of the different switch contacts, there is included in the shunt path for one or more of the main resistances an additional resistance of proper magnitude to effect equality of the sums of the main resistances and their associated resistances connected thereto; each of these additional resistances also serves to attenuate the effect upon its associated main resistance of any thermal electro-motive force developed in the shunt path.

Further in accordance with my invention the main resistances are enclosed in a common housing to insure uniformity of their temperatures, and the remaining resistances are disposed externally of the thermal shield.

My invention further resides in the features of construction, combination and arrangement hereinafter described and claimed.

For an understanding of the invention reference is made to the drawings in which:

Fig. 1 diagrammatically illustrates a preferred

potentiometer system embodying the invention;

Fig. 1A is a detail view of the preferred disposition of the main coils within the thermal shield;

Fig. 1B illustrates a simplified potentiometer system having a range-changing arrangement;

Figs. 2, 3, 4 and 5 illustrate various uses of the potentiometer system;

Figs. 6 and 7 illustrate alternative switching or dial arrangements;

Figs. 8 and 8A illustrate uses of current-attenuating networks in a potentiometer system similar to Fig. 1.

In Fig. 1 is shown a four-dial potentiometer embodying the invention, though it is to be understood the invention may be applied to potentiometers having a fewer or greater number of dials. The main resistances M1, M2, M3 and M4, corresponding in number to the number of places to which voltages are to be measured, are connected in series with each other, with a suitable indicating instrument, as galvanometer G, and the source E of voltage to be measured, for example, a thermocouple. Preferably the values of the main resistances M1 to M4 are in the ratio 1000; 100; 10; 1. For example, resistances M1 to M4 may be of 11 ohms, 1.1 ohms, 0.11 ohm and 0.011 ohm, respectively. These resistances are accurately calibrated and are made of conductor, as manganin, "Therlo", or gold chromium having a low temperature coefficient of resistance and low thermal electro-motive force against copper.

Preferably, these resistances are enclosed in a housing or thermal shield H suitably constructed to maintain uniformity of temperature within the enclosure. The housing H is preferably of metal, as copper or aluminum having high thermal conductivity so that no temperature gradient of appreciable magnitude can exist between one part of the housing and any other part; preferably the housing comprises two or more complete shells, one within the other, of high thermal conductivity with thermal insulation in the space between the shells. With this arrangement, heat impinging on the outer shell will be distributed by the outer shell, attenuated by the insulation in passing therethrough to the inner shell, and if not perfectly distributed, will be further distributed by the inner shell due to its high thermal conductivity. All of the main resistances and connections within the housing are, therefore, at the same temperature.

Each of the main resistances M1 to M4 is shunted by an associated auxiliary resistance; specifically, the resistances A1, A2, A3, A4 are

connected in shunt, respectively, to main resistances M1, M2, M3, M4. Each auxiliary resistance is connected at intervals to switch points corresponding to the settings "0" to "10" inclusive of the associated dial and with each dial is associated a movable switch contact for engaging a selected switch point of the dial group; or preferably, as shown, each auxiliary resistance may comprise a plurality of serially-connected resistances.

Between the contacts S1 and S2 of the upper dials D1 and D2 is connected a suitable source of current B, such as a storage battery, "Air-Cell", or other battery capable of supplying constant current for suitably long periods of time. The resistance R in series with battery B is for adjusting the battery current to a desired standard value. To standardize the current flowing from battery B, the contact VC is adjusted along the resistance VR to a predetermined position, as read from scale US, corresponding to the voltage of the particular standard cell SC. Switch GS is then closed in its upper position temporarily to connect the standard cell SC and galvanometer G1 across the selected portion of the resistance VR and the resistances SR and Sr. The resistance R is then adjusted to vary the current from battery B until the voltage drop produced by the battery current across resistances SR, Sr and the portion of resistance VR between resistance Sr and contact VC is equal to the voltage drop produced by the standard cell, as indicated by a null deflection of galvanometer G1.

Between the movable switch contacts S3 and S4 of the two lower dials D3, D4 is connected another suitable source of potentiometer current B1. The current from battery B1 is similarly standardized by adjusting the resistance R1 until the voltage drop across the predetermined portion of resistance VR1 and resistance SR1 is equal to the voltage of the standard cell SC. After the battery currents have been standardized, the switch GS may be opened.

For the values of resistance herein given, the battery circuit resistance of the upper and lower dial potentiometer circuits is approximately 500 ohms; for a nominal measuring range of 100,000 microvolts the resistances R, R1 are adjusted so that the standardized current is 0.01 amperes. The voltage of each of batteries B and B1 is between five and six volts. The correct poling of the batteries is indicated.

This circuit arrangement, which makes it unnecessary to shield more than a few coils of a system equivalent to a six-dial potentiometer, introduces a secondary problem arising because even the best obtainable grade of manganin wire has an appreciable temperature coefficient of resistance, for example, about 0.001 per cent per degree centigrade. To hold the error of measurement from this source to not more than about 0.001 per cent, the standard cell coil resistance Sr, SR is divided and that part of it designated by SR is disposed within the housing H; the remainder of it, designated Sr, disposed outside of the housing H, is of such value that the sum of its resistance and one-half of resistance VR is approximately equal to 0.5 per cent of the value of the total standard cell resistance (Sr + SR).

With the particular values assumed for resistances M1 and AR1, resistance Sr should, for perfect compensation, be of such value as to place approximately 1.0 per cent of the total standard cell resistance outside of housing H. How-

ever, if this is done, some error will result in dial D2 unless part of resistance AR2 is disposed within the shield. In practice it has been found the compensation afforded by the simpler arrangement shown permits obtainment of highly precise measurements.

In determining the magnitude of voltage developed by the source E, the several dials are adjusted to produce a minimum or null deflection of galvanometer G; when the switch contact S1, for example, is on the point "0" of dial D1, none of the standard current flows through the resistance M1, as the switch contact S1 is moved successively into engagement with the switch points 1 to 10, a greater proportion of the standard current flows through the resistance M1; similarly, the adjustment of each of the other dial contacts S2, S3, S4 effects change in the proportion of the total standard current which flows through the main resistances M2, M3, and M4, respectively, and so varies the voltage drop across the corresponding main resistance produced by the selected fraction of the standard current. The variation in the voltage drop across the main resistance is obtained without inclusion in the galvanometer circuit of contacts relatively adjustable for that purpose, thus avoiding errors due to variations in contact resistance and to the thermal electromotive forces at such contacts.

To avoid change in the magnitude of the battery current for different dial settings, compensating resistances are connected between the switch points and the tapping points of the auxiliary resistances, and these compensating resistances are of such value that for all settings of the switch contacts, the resistance of the circuit fed by the battery remains constant. Assuming, for example, that resistance M1 is 11 ohms and that the auxiliary resistance A1 is comprised of ten equal sections  $\alpha$  of 110 ohms each, the values of the compensating resistances C0 to C10, respectively, should be 300 ohms, 200 ohms, 120 ohms, 60 ohms, 20 ohms, 0 ohms, 0 ohms, 20 ohms, 60 ohms, 120 ohms and 200 ohms; only five different sizes of resistances are used.

The auxiliary resistances and the compensating resistances are of conductor, as manganin, or "Therio", having low temperature coefficient of resistance and a low thermal electromotive force against copper; all of the resistance coils, except where otherwise specified, are of such material.

It is desirable from a manufacturing standpoint that all of the auxiliary resistances A1, A2, A3, A4 be equal and that the compensating resistances be the same for all dials. To that end, the additional resistances AR1, AR2, AR3 and AR4 are utilized; the magnitudes of these resistances are such that the sum of each of them and its associated main resistance is equal to a common predetermined value. In the specific example herein described, resistance AR1 is 99 ohms, resistance AR2 is 108.9 ohms, resistance AR3 is 109.89 ohms, and resistance AR4 is 109.989 ohms; or otherwise stated, the magnitude of each of these additional resistances is 110 ohms minus the resistance of its associated main resistor. These additional resistances also serve to attenuate the effect of any thermal electromotive forces that may be generated in the shunt circuit of each main coil, because they increase the ratio of the resistance of each shunt circuit to the resistance of the associated main coil.

The neutral potentiometer system described has several important features; first, there are no switch contacts included in the main circuit and susceptible of introducing thermo-electric effects into the galvanometer circuit; second, the resistance of the galvanometer circuit is low and therefore conducive to high sensitivity of the galvanometer; third, the resistance of the galvanometer circuit is constant and, therefore, insures good damping of the galvanometer; fourth, the number of thermally-shielded resistances is small, avoiding the difficulties arising when it is necessary to shield forty or fifty coils and to bring out the many leads therefor to proper terminals, fifth, the main resistances are of relatively low magnitude and, therefore, easier to calibrate and better suited to hold their calibration, and, sixth, the system is well adapted to potentiometers readable to five or more significant figures or places.

With the system as thus far described, the potentiometer is direct reading to four places. If desired, the galvanometer G may be used as a deflection instrument in determining two additional places; or preferably, the galvanometer is used as a null instrument and the last two places may be determined by network L including ammeter A.

The resistance M5 of the network L is also preferably enclosed within the housing H and inserted into the galvanometer circuit. In the example given its magnitude should be .01 ohm; the meter A may have a maximum range of .001 ampere, corresponding to a maximum of 10 microvolts. The current through resistance M5 from battery B2 is adjustable by movement of contact CP along the resistance PR. When contact CP is at the lower end of resistance PR, the current supplied by battery B2 to the circuit including the meter A and resistance M5 is a maximum, determined by the magnitude of resistance AT. As contact CP is moved to the upper end of resistance PR, the fraction of the total battery current flowing through M5 is reduced; the minimum value, when contact CP reaches the upper end of resistance PR, is zero.

Any thermal electromotive forces in the circuit including CP have no effect upon the accuracy of the readings and are ineffective to produce any deflection of meter A when contact PR is in minimum position. Any currents flowing as a result of thermal electromotive forces in the loop including meter A and resistance M5 are greatly reduced by the resistance of PR which is large compared to the resistance of the rest of the loop.

Of the six resistances shown in Fig. 1 within the thermal shield H, only five are connected in the galvanometer circuit and the exact preferred arrangement of these five resistances is shown in Fig. 1A. The circuit 35, M5, 36 is preferably a single piece of manganin wire of the same characteristic used in coils M1, M2, M3, M4, a central portion being tapped off to form resistance M5. The exact resistance of portions 35, 36 is not of importance. With this arrangement, the only junctions of different metals, copper-manganin, directly in the circuit of the sensitive galvanometer G, are the connection of lead 26 with coil M3, and the connection of lead 27 with coil M1; these junctions are located near each other and near the central part of the housing H where the temperature is most uniform. The thermal electromotive forces developed at these junctions are therefore substantially equal and

since the voltages of these couples are in opposition, the residual thermo electromotive force is practically zero. Furthermore, with the exact arrangement of leads shown, there can be no fall of potential in the sensitive galvanometer circuit, due to current from batteries B and B1, when the four dials are all set at zero.

If desired, the system may be equipped with a range changing device of known type to change the standardized current and, at the same time, to change the point at which the current in the network L enters the galvanometer circuit. However, in the system shown having four dials and a 100 division meter in the network L, a range changing device is not necessary, though it would be desirable for a potentiometer of the type disclosed having fewer dials. By way of illustration, Fig. 1B illustrates a two dial potentiometer utilizing the invention and provided with a range changing arrangement permitting the range to be changed by a factor of ten without need to re-standardize the battery current.

When switch member HL is thrown to the right, the potentiometer resistance is shunted by resistances  $pr$  and  $9pr$  in series; resistance  $pr$  is equal in magnitude to the potentiometer resistance PR which, as above stated, is constant for all settings of contacts S1, S2; resistance  $9pr$  has nine times the resistance of  $pr$  or PR. When switch member HL is thrown to the left, the resistance  $pr$  is shunted by resistances  $9pr$  and PR in series. The current from the battery is the same for both positions of the switch, but, as apparent from the foregoing description, the current through PR is changed by a factor of ten; specifically when switch HL is thrown to the right the current through PR is ten times greater than when switch HL is thrown to the left.

For making temperature measurements with a thermocouple, such as E (Fig. 1), a reference junction RJ is provided. For precision measurements, one may use copper-constantan couples; one lead 37 from the couple E is copper and the constantan lead 39 is joined to a copper wire 38 within flask F to form the reference junction. The junctions at I, I while of like metal, copper, should preferably be at the same temperature to avoid thermal electromotive forces; all leads, binding posts, etc. in the galvanometer circuit are copper to avoid thermal electromotive forces. To that same end, the switches SG and K3 which are in circuit when making the final balance of the potentiometer, are constructed of copper conducting parts to be substantially free of thermal electromotive forces, and in addition, are housed in a thermal shield H2 to insure substantial uniformity of the temperatures of all their parts. The junctions I, I may for like reasons also be included within housing H2. The switches K2, K1, disposed exteriorly of housing H2, are used to connect different values of resistance in circuit with the galvanometer to obtain different sensitivities during preliminary balances; they are not in circuit when final balance is made and hence no error can arise because of any thermal electromotive forces these switches may develop. Within shield H2 is disposed the coil G3, of copper, which affords critical damping for galvanometer G when switch or key K3 is in the "up" position.

Coil T is a copper coil of very low resistance, by which a minute electromotive force from battery B3, which may be a single dry cell, may be introduced into the galvanometer circuit. With switch or key K3 in its "up" position, the "zero"

of galvanometer G is checked and if it does not coincide with the mechanical zero, it is made to do so by adjustment of resistance R3. With the arrangement shown, however, the user is not dependent upon the stability of this adjustment, as will appear from the following explanation of the use of the reversing switch SG.

Operation of switch SG effects reversal of the connections of galvanometer G without effect upon the relative polarities of the thermocouple and potentiometer electromotive forces; if these electromotive forces are equal and opposite, the reversal by switch SG does not change the galvanometer indication. If there is an unbalance, moving switch SG from its normal or "up" position to its "down" position will reverse this unbalanced electromotive force as applied to galvanometer G, and change the indication of galvanometer G by an amount which is twice as great as that produced by the unbalance itself. The reversing switch is not used until balance is rather closely approximated using keys K1, K2, K3, after which switch, or key K3 is locked or held down and final balance is obtained by adjustment of the potentiometer for the different positions of switch SG. If, on operating switch SG, there is a residual deflection but this deflection is symmetrical with respect to the zero of the galvanometer, the adjustment of resistance R3 is known to be correct and no residual thermal electromotive forces are present in the galvanometer circuit; hence the deflection should be reduced to zero by further adjustment of the potentiometer dials or resistance PR. On the other hand, if upon reversal of switch SG, equal and opposite deflections are not obtained, resistance R3 should be adjusted to obtain that end.

Since galvanometer G1, used for standardizing the battery currents, is always operating in a circuit involving a voltage of the order of one volt, avoidance of residual thermal electromotive forces in its circuit is not important. It is therefore not necessary to provide a thermal shield for any of the galvanometer keys k3, k2, k1. Galvanometer G1 may be relatively insensitive; it is more convenient to use a second relatively insensitive galvanometer with a short period than to switch the sensitive galvanometer G into the standardizing circuit, which would have the further disadvantage of requiring in the sensitive galvanometer circuit, additional switch contacts which would become possible sources of undesirable thermal electromotive forces.

The potentiometer may be used accurately to calibrate current-response instruments, for example, an ammeter, by measuring the voltage drop produced by flow of the meter current through a standard resistance RS. Referring to Fig. 2, the resistance RS is connected to a suitable source of current, as battery B4 and the potential terminals of the resistance are connected to the terminals I, I of the potentiometer. The voltage drop EI across the resistance is measured by the potentiometer. Then, since the voltage EI and the resistance RS are known, the current through the ammeter AM may be easily calculated by Ohm's law.

Voltages of magnitude in excess of the range of the potentiometer can be measured when it is not objectionable to draw a small current from the source by a voltage-dividing arrangement such as shown in Fig. 3. The source E3 of the voltage to be determined is connected across resistance VD, and a predetermined fraction c of the total resistance VD is connected to the termi-

nals I, I of the potentiometer. After the voltage E2 across that fraction of resistance VD has been determined by manipulation of the potentiometer, as above described, the result is multiplied by the factor which expresses the ratio of the total resistance VD to the fractional resistance.

For making precision temperature measurements by the resistance variation method, the terminals I, I of the potentiometer are connected (Fig. 4) to a reversing switch IS which, for its lower position, permits accurate determination by the potentiometer of the voltage drop across the standard resistance RS, in series with battery B5 and the coils TR of the resistance thermometer, and which for its upper position permits determination by the potentiometer of the voltage drop across the resistance thermometer. The resistance of the thermometer coil is then determinable from the equation

$$\frac{TR}{RS} = \frac{ET}{ES}$$

in which

ES=voltage drop across RS

RS=standard resistance

ET=voltage drop across TR

TR=resistance of thermometer coil.

The potentiometer may be used for making standard cell comparisons by connecting across its terminals I, I (Fig. 5) two standard cells SC1, SC2 so poled that their voltages are in opposition. The potentiometer is then balanced as above described to measure difference between the voltages of the two standard cells. Assuming the voltage of one cell to be known, the voltage of the second is equal to the algebraic sum of the voltage of the first and the measured difference.

Figs. 6 and 7 disclose arrangements of the main dial switches which reduce the number of required compensating coils as compared to Fig. 1. However, they require a more expensive switch and introduce another sliding contact for each dial which is a disadvantage when attempting to limit the error due to variation in contact resistance to less than 0.001 per cent. The arrangements of Figs. 6 and 7 are similar except that in Fig. 6 the compensating coils C are in series whereas in Fig. 7 they are in a "radial" arrangement. Of these two arrangements, that of Fig. 6 is preferable when the compensating coil resistance is high or must dissipate a substantial amount of energy.

In the modification of Fig. 1, as specifically described, the main coils M1, M2, M3, M4 are of different values. They may, however, be of the same value without need to use different auxiliary resistances or to use different arrangements of compensating resistances for the different dials.

Referring to Fig. 8, the main coils M1, M2 are of equal resistance, for example, 11 ohms; the auxiliary resistances A1, A2 are of equal resistance, for example, each comprises ten sections each of 110 ohms resistance; the attenuating resistances AR1, AR2 are of equal value, for example, 99 ohms; and the corresponding compensating resistances of the two dials are also equal as described in connection with Fig. 1. To obtain the desired magnitudes of current through the main resistance M2 for the different settings of contact S2, there is provided the attenuating section AS comprising resistances X and Y; resistance X is connected in shunt to auxiliary resistance A2 and resistance Y is interposed, as shown, between

resistance AR2 and a terminal of resistance A2. The values of resistances X and Y are so chosen that the current divides through the path X, and the path including Y, AR2 and M2 in the ratio of 9 to 1, and are also of such values that the resistance of the network X, Y, AR2, M2 as viewed from the terminals of the auxiliary resistance A2 is the same as the network AR1, M1 as viewed from the terminals of auxiliary resistance A1; for the values above given for M2, A2, etc., resistance X should be 122.2+ ohms and resistance Y should be 990 ohms. The AR2 and Y coils may of course be replaced by a single resistance equal to their combined resistance. Briefly stated, the network AS attenuates the current through main resistance M2 to one-tenth of the current through main resistance M1.

To obtain the desired current through main resistance M4, assuming all main resistances are of the same value, three such current attenuating networks, AS, AS1 and AS2 are employed in cascade, as shown in Fig. 8A; for dial D3, two such attenuating networks may be employed in cascade.

Under the conditions stated, the resistances X of the added attenuating sections are all equal to each other and the resistances Y of the sections are equal to each other.

Though preferred forms have been illustrated and described, the invention is not limited thereto but is coextensive in scope with the appended claims.

What I claim is:

1. A potentiometer comprising an indicating instrument, a source of voltage to be measured, two fixed resistances connected in series with each other, said instrument and said source of voltage, two shunt paths each individual to one of said fixed resistances and each including an auxiliary resistance, a source of standard current, and means for connecting said source of standard current between selected points of said shunt paths.

2. A potentiometer comprising an indicating instrument, a source of voltage to be measured, two fixed resistances connected in series with each other, said instrument and said source of voltage, two shunt paths each individual to one of said fixed resistances and each including an auxiliary fixed resistance, groups of switch points, each group being connected to taps along one of said second-named resistances, a source of standard current, and switch contacts, each movable with respect to one of said groups of switch points, connected to opposite terminals of said source of standard current.

3. A potentiometer comprising an indicating instrument, a source of voltage to be measured, two fixed resistances connected in series with each other, said instrument and said source of voltage, a fixed resistance in shunt to each of said first-named resistances, groups of switch points, each group being connected to taps along one of said second-named resistances, a source of standard current, switch contacts, each movable with respect to one of said groups of switch points, connected to opposite terminals of said source of standard current, and compensating resistances included in the connections to said switch points of such magnitudes as to maintain constant, for the different settings of said switch contacts, the resistance of the path traversed by the standard current.

4. A potentiometer comprising an indicating instrument, a source of voltage to be measured, two fixed resistances of different magnitude connected

in series with each other, said instrument and said source of voltage, auxiliary resistances of equal magnitude each providing a path in shunt to one of said first-named resistances and forming a closed loop therewith, groups of switch points, each group being connected to taps along one of said auxiliary resistances, a source of standard current connected to switch contacts, each movable with respect to one of said groups of switch points, and an additional resistance connected between at least one of said first-named resistances and the associated auxiliary resistance and having proper magnitude to effect substantial equality of the total resistances of said closed loops.

5. A potentiometer comprising an indicating instrument, a source of voltage to be measured, two fixed resistances of different magnitude connected in series with each other, said instrument, and said source of voltage, auxiliary resistances of equal magnitude each providing a path in shunt to one of said first-named resistances and forming a closed loop therewith, groups of switch points, each group being connected to taps along one of said auxiliary resistances, a source of standard current connected to switch contacts, each movable with respect to one of said groups of switch points, compensating resistances included in the connections to the switch points of each group of proper magnitude to maintain constant for the different settings of said switch contacts, the resistance of the path traversed by the standard current, the corresponding compensating resistances for the different groups being of similar magnitude, and an additional resistance connected between at least one of said first-named resistances and its associated auxiliary resistance to effect substantial equality of the total resistances of said closed loops.

6. A potentiometer comprising an indicating instrument, a source of voltage to be measured, a small number of fixed resistances connected in series with each other, said instrument and said source of voltage, a housing for said resistances ensuring substantial uniformity of their temperatures, means for producing standard current, and means external to said housing for individually varying the voltage drop across each of said resistances due to flow of standard current therethrough.

7. A potentiometer comprising an indicating instrument, a source of voltage to be measured, a small number of fixed resistances connected in series with each other, said instrument and said source of voltage, a housing for said resistances ensuring substantial uniformity of their temperatures, auxiliary resistances each connected in shunt to one of said first-named resistances and disposed exteriorly of said housing, and means for connecting a standard source of current between selected points of adjacent auxiliary resistances.

8. A potentiometer comprising an indicating instrument, a source of voltage to be measured, fixed resistances connected in series with each other, said instrument and said source of voltage, a housing for said resistances ensuring substantial equality of their temperatures, auxiliary resistances, disposed externally of said housing, each connected in shunt to one of said first-named resistances and forming therewith a closed loop, means for supply of standard current connected to adjustable contact means associated with said auxiliary resistances, and additional

resistances in said closed loops to attenuate the effect upon said first-named resistance of any thermal electromotive forces developed in said closed loops.

5 9. A potentiometer comprising an indicating instrument, a source of voltage to be measured, fixed resistances connected in series with each other, said instrument and said source of voltage, a housing for said resistances ensuring substantial equality of their temperatures, auxiliary resistances, disposed externally of said housing, each connected in shunt to one of said first-named resistances and forming therewith a closed loop, means for supply of standard current connected to adjustable contact means associated with said auxiliary resistances, and additional resistances, disposed externally of said housing, each included in one of said loops to attenuate the effect of any thermal electromotive force developed therein.

10 10. A potentiometer comprising an indicating instrument, a source of voltage to be measured, fixed resistances connected in series with each other, said source and said instrument, a housing for said resistances ensuring substantial uniformity of their temperatures, means for supplying current to said resistances, and means for standardizing said current including a resistance disposed in part within said housing.

30 11. A potentiometer comprising an indicating instrument, a source of voltage to be measured, a small number of fixed resistances connected in series with each other, said instrument and said source of voltage, a housing for said resistances ensuring substantial equality of their temperatures, auxiliary resistances each connected in shunt to one of said first-named resistances and disposed exteriorly of said housing, groups of switch points, each group being connected to taps along one of said auxiliary resistances, compensating resistances disposed exteriorly of said housing and included in the connections to said switch points, a source of standard current, and switch contacts for connecting said source of current between selected switch points of different groups thereof.

12. A potentiometer for determining the magnitude of a voltage to at least four significant figures comprising an indicating instrument, four fixed resistances the ratios of whose magnitudes are powers of ten, means for connecting said resistances in series with each other, said indicating instrument, and the source of voltage under measurement, auxiliary resistances providing paths in shunt to each of said first-named resistances, two sources of standard current, and means for connecting each of said sources between selected points of a pair of said auxiliary resistances.

13. A potentiometer for determining the magnitude of a voltage to at least four significant figures comprising an indicating instrument, four fixed main resistances the ratios of whose magnitudes are powers of ten, means for connecting said resistances in series with each other, said indicating instrument, and the source of voltage under measurement, auxiliary resistances of equal magnitude each providing a path in shunt to one of said first-named resistances and forming a closed loop therewith, and additional resistances in circuit with said first-named resistances and said auxiliary resistances of magnitude to effect equality of the total resistances of said closed loops.

14. A potentiometer for directly measuring the magnitude of voltages of less than about 100,000 microvolts to at least four significant figures comprising an indicating instrument, four fixed resistances, the ratios of whose magnitudes are powers of ten, means for connecting said resistances in series with each other, said indicating instrument, and the source of voltage under measurement, auxiliary resistances of equal magnitude providing paths in shunt to each of said first-named resistances, groups of switch points each group being connected to divide one of said auxiliary resistances into two equal sections, switch contacts for selectively engaging the switch points of each group, and sources of standardized current, each connected between a pair of said switch contacts.

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