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1,455,735

F. A. ROJAS

RHEOSTAT

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4 Sheets-Sheet 1

Fig. 1,

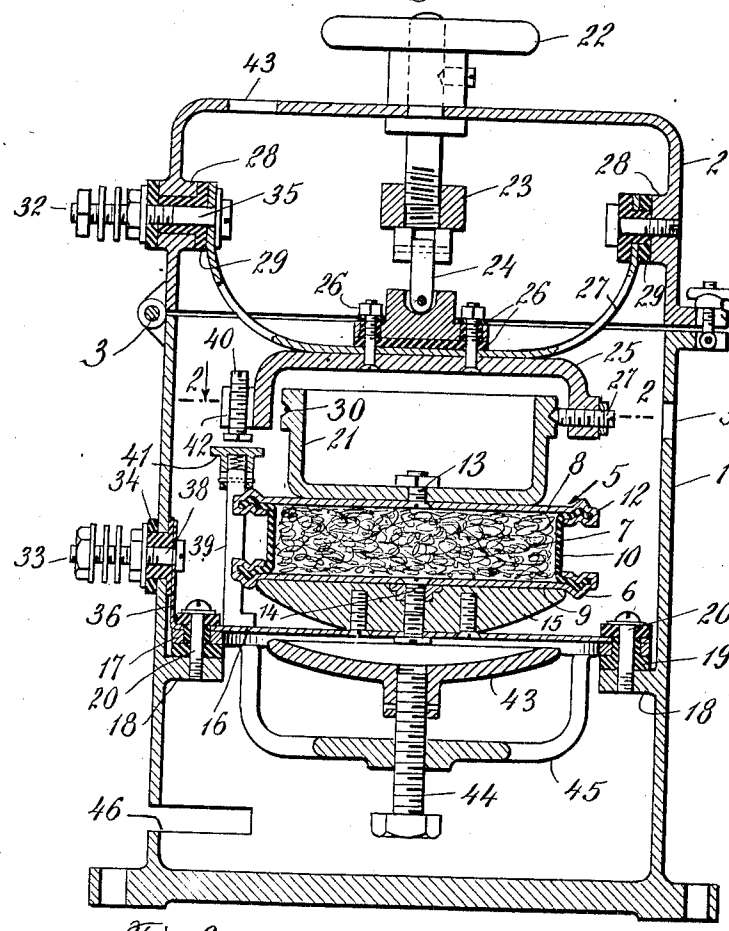


Fig. 3,

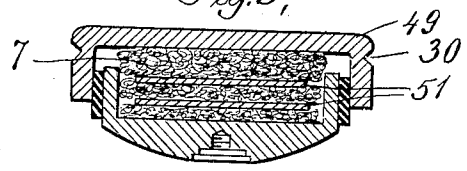


Fig. 4,

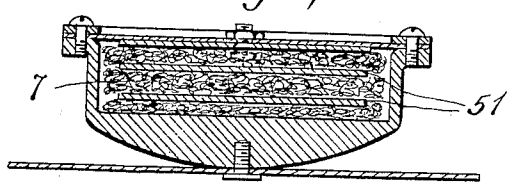
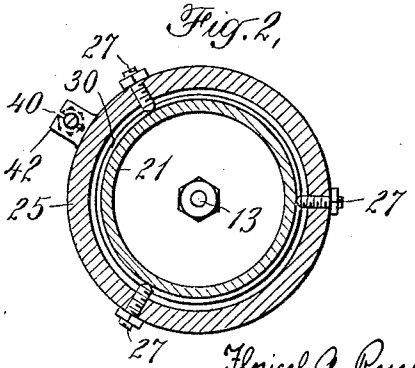


Fig. 2,



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Fig. 5,

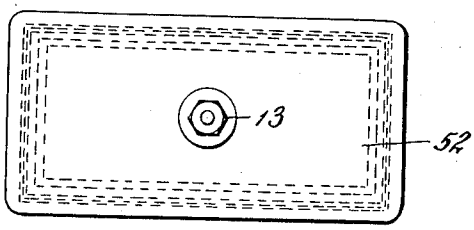


Fig. 6,

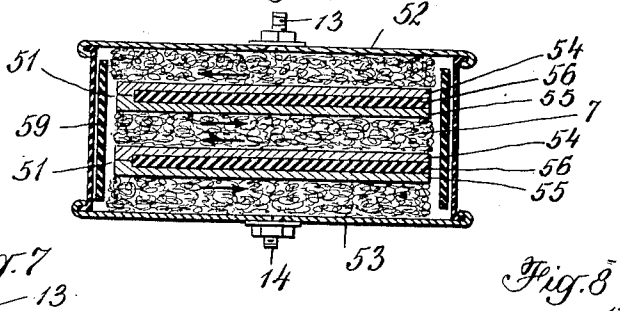


Fig. 7

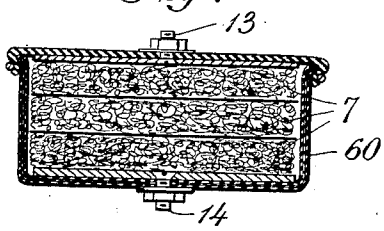


Fig. 8

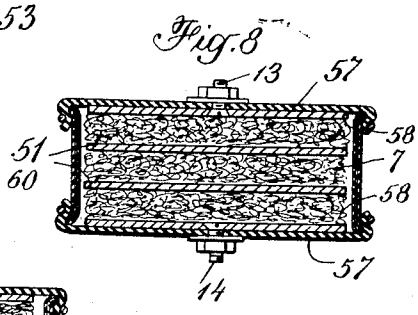


Fig. 17,

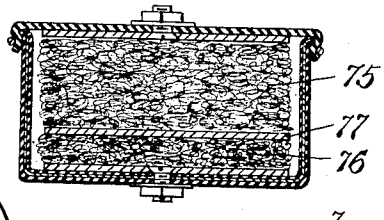


Fig. 9,

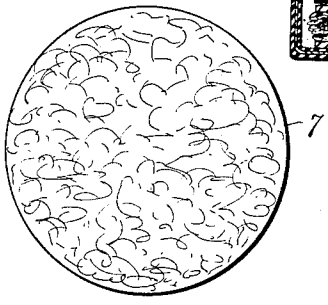
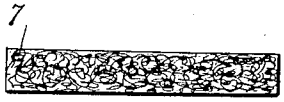


Fig. 10,



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Fig. 11

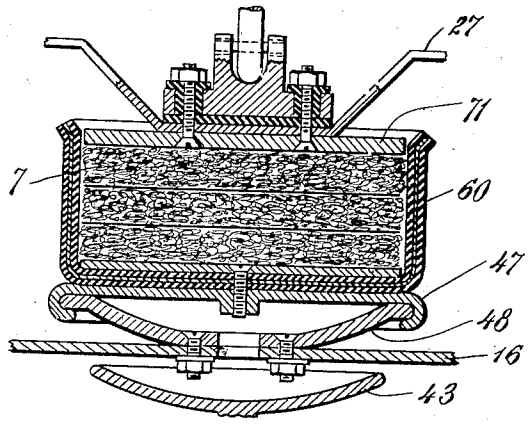


Fig. 12,

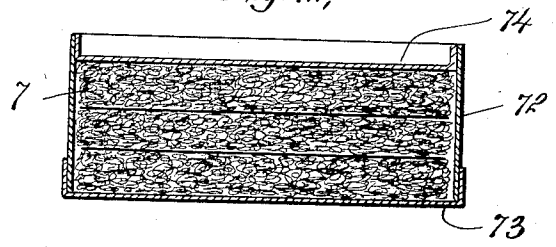
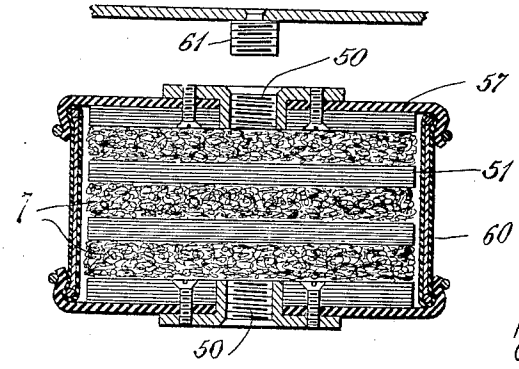


Fig. 13,



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Fig. 14,

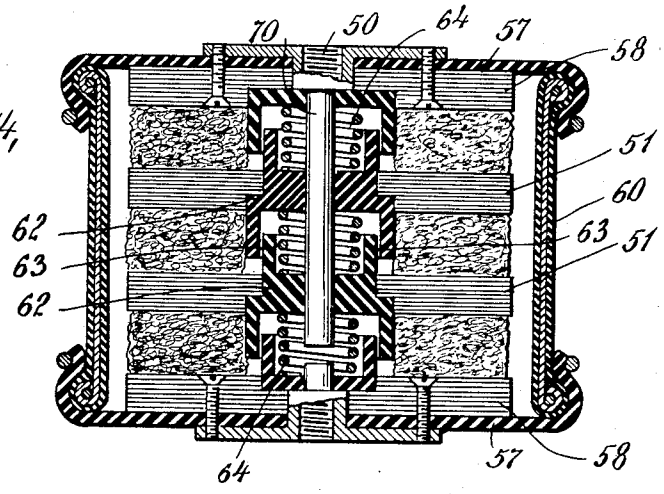


Fig. 15,

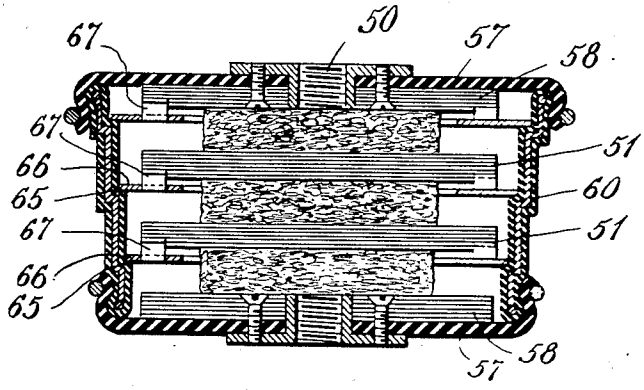
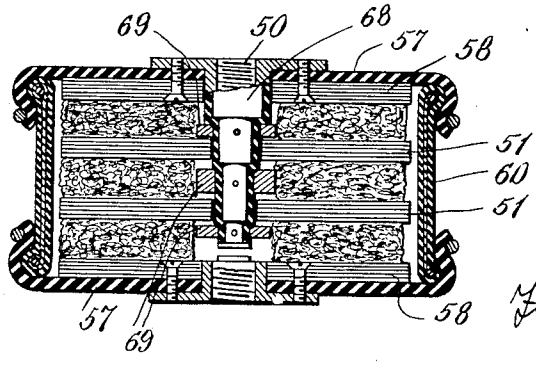


Fig. 16,



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Inventor

By his Attorneys
Pennie, Davis, Marvin & Edmonds

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UNITED STATES PATENT OFFICE.

FLORICEL A. ROJAS, OF NEW YORK, N. Y.

RHEOSTAT.

Application filed March 23, 1922. Serial No. 546,149.

To all whom it may concern:

Be it known that I, FLORICEL A. ROJAS, a citizen of the Dominican Republic, residing at New York city, in the county of Bronx, State of New York, have invented certain new and useful Improvements in Rheostats; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

This invention relates to rheostats of the compressible resistance type. The resistance element of such rheostats consists essentially of a mass of particles of conducting material making imperfect contact with one another and usually held within a mass of non-conducting material. The conductivity of such a mass as a whole is a function of the surface contact of the particles, and as this is increased and decreased, the current flow varies accordingly. The number of particles is so great and the contact so numerous that practically infinitesimal current variations can be effected with pressure changes. Ordinarily such a resistance consists of a fibrous non-conducting material such as asbestos combined with a powdered conducting material such as graphite and held between two relatively movable members, (one of which is usually fixed), the movement of which, by compressing and expanding the material, increases and decreases its conductivity accordingly. Sometimes the asbestos is dispensed with and the conductive elements used in granular form without the addition of a non-conducting element, or this latter can itself be granular. In order to get the best results the resistance material should be secured to both of the relatively movable members, so that a positive expansion, as well as compression, may be effected, and this is true whether the non-conducting element of the resistor be a resilient, fibrous material, such as asbestos, or whether the resistor be granular.

The resistance element and its embracing members or container are mounted in some sort of frame or support and means provided for moving the members to vary the resistance of the compressible and expansible material. Thus the rheostat may be said to consist of two essential parts, the support, and the resistor itself, including its terminal plates and resistance material. The present invention has for its object improvements in both of these parts of the rheostat.

Among the chief difficulties encountered in the use of rheostats of this type, are those which result from the internal heat generated in accordance with Joule's law. This heat is not only likely to burn out the resistance, but is even more likely to interfere with the steadiness of adjustment of the instrument. The evolution of this heat is inevitable, but the rheostat can be so constructed as to render its effects largely innocuous, and this is one of the objects of the present invention. In view of this varying heat loss it is obvious that where steadiness of adjustment is desired, it is first of all essential that the rheostat as a whole have a substantially zero temperature coefficient of resistance. Two factors determine the temperature coefficient of the rheostat; first, the temperature coefficient of the conductive element of the resistance, and second, the resultant coefficient of thermal expansion of the rheostat as a whole, including the resistance material itself. The temperature coefficient of the conductive elements can be made to approach zero by the judicious mixing of substances having positive and negative coefficients, such, for example, as carbon and metals. To secure a mixture the resistance of which is absolutely unaffected by temperature changes, is, of course, impracticable. As this ideal is unattainable error must be made on the side of safety and the mixture have a slightly positive coefficient; that is, if metals are used as the positive constituent, they must be present in more than the theoretical quantity. But, the rate at which the conductivity of metals changes with temperature is much less than the rate of change for carbon, and for this reason, even in a mixture of carbon and metals having a zero coefficient, the metal constituent must largely predominate. This is objectionable, first, because large amounts of metals tend to short-circuit the rheostat, and second, because no easily oxidizable metals should be used, and the cost of those relatively non-oxidizable metals, such as copper, silver, gold, platinum, etc., is deterring if not prohibitive. As stated in my pending application, Serial No. 516,134, filed Novem-

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ber 18, 1921, conductive silicon being inexpensive, non-ozidizable at ordinary temperatures, and possessing a high positive temperature coefficient, is admirably adapted for this use. Accordingly this invention contemplates a resistance material the conductive elements of which consist of a mixture of graphite, or other carbon forms, and conductive silicon.

It is not always necessary that the conductive elements be used in the form of a homogeneous composition or intermixture of particles in order to obtain a zero temperature coefficient of resistance. The different conductive elements may sometimes be made up into separate resistance units of proper relative sizes and used in series. Under certain circumstances, when using silicon and graphite I have found this particularly advantageous for reasons which will be pointed out in detail later.

But a zero temperature coefficient in the conductive elements themselves is not enough to give a zero coefficient to the rheostat as a whole. The generated heat causes the resistance material, both conducting and non-conducting constituents, to expand, which increases the points or surfaces of contact among the conducting particles and thus increases the conductivity of the material. At the same time the metallic parts of the rheostat are expanded tending to counteract the effect of the internal expansion of the resistance material. In order to control these expansion factors I have provided a delicate thermostat in the form of a metallic disc supported at its edges, and upon which the container for the resistance material rests. As this disc is heated it expands and relieves the pressure upon the resistor, thus compensating for the internal expansion of the particles. I have also provided means whereby the effective expansion of this disc can be nicely regulated so that for any given rheostat and resistor the resultant temperature coefficient can be brought to substantially zero. When, however, it is not necessary that absolute steadiness of adjustment be attained, I can dispense with the thermostat and secure an approximate accuracy by means of the composition alone. Thus, if a given rheostat has, as a whole a negative temperature coefficient, that is, if the increase in conductivity due to the expansion of and increased contact among the conductive particles of the material itself more than counterbalances the decrease in conductivity due to the expansion of the metallic parts of the rheostat as a whole, the resistance can be given a positive coefficient to compensate for this under average working conditions. This may be done by increasing the proportion of silicon. A thermostat can, of course, be used in combination with such a resistor.

In compounding a resistance material having any predetermined temperature coefficient, when the conductive elements are embedded in a non-conductive element, the thermal expansion of the latter must be reckoned with to some extent. Thus a granular mixture of silicon and graphite, without asbestos designed for a zero temperature coefficient would be of somewhat different proportions from a similar mixture intended to impregnate asbestos. The differences are, however, not great and the proper proportions can be readily determined by any one skilled in the art and having this specification before him.

Although asbestos wool is the material most commonly employed as the non-conductive element of the resistor, it sometimes becomes necessary to subject the rheostat to temperatures above those at which asbestos can be successfully employed. Under those circumstances powdered granular or flaked substances, such as silica, beryl or flake mica can be used. These materials possess the requisite refractoriness, high electrical resistance and thermal conductivity. Their coefficients of thermal expansion are practically so close to that of asbestos that they can be substituted substantially weight for weight for asbestos when compounding resistance materials have a predetermined temperature coefficient of resistance.

A substantially zero temperature coefficient in a compressible resistance rheostat as a whole is not only essential for accurate work, but it is also essential that the resistance material itself have a zero or slightly positive coefficient to prevent local overheating and possible burning out of the material. It is impossible to distribute the conducting material evenly throughout the mass and it is impossible to apply pressure evenly over the entire body of the resistor. With material having a high negative coefficient, such as carbon, its conductivity increasing with its temperature, it is clear that a concentration of the material or an unevenly distributed pressure resulting in an increase in local current flow would give rise to an inevitable increase in temperature with increased current flow, the vicious cycle thus set up possibly resulting in burning out the resistor. Still further to guard against this local overheating I place within the material a pair or pairs of metallic plates of properly chosen metals or make the movable compression plates themselves of proper metals, which pairs of plates act as thermocouples, and, when the current is flowing in the proper direction, tend to equalize the temperature by absorbing heat at their hot ends and generating it at their cold, in accordance with Peltier's law.

These interposed plates also perform other functions. They serve to conduct heat from

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the interior of the resistor to its periphery, and thus minimize the danger of overheating especially when asbestos is used, asbestos fibres themselves being poor conductors. These plates, being secured to the adjacent resistance material, serve also to strengthen it and prevent the formation of air gaps or pockets during expansion. This same effect can be produced by forming the resistance material in unit slabs which are superposed to produce the desired thickness, the units being secured to one another, preferably by a suitable adhesive. Such an adhesive, as well as the one employed to secure the material to the various plates should be conducting. In accordance with the present invention I produce this result by mixing a metallic salt with the adhesive, the metal of the plate replacing the metal in the salt by electrolytically precipitating the latter.

Another of the fundamental problems which must be solved by the inventor of a successful rheostat of this type, is the problem of expanding the material. This problem is intimately connected with that of controlling and conducting away the generated heat, for if the expansion is uneven, localized overheating will take place, often with disastrous consequences, but it is a problem which presents aspects of its own and may well be separately considered. The first essential of a successful compressible rheostat, as disclosed in my Patent No. 1,315,579, September 9, 1919, is a structureless mass of resistance material, made to adhere to a movable electrode, so that it can be positively expanded as well as compressed. When the material is of relatively great lateral dimensions and of relatively slight thickness, positive expansion can be satisfactorily effected in this way. Where, however, it is necessary to design the resistor of less width, and greater thickness, either because of practical space considerations, or because the difference of potential between the terminals of the rheostat may be of such a magnitude that a thin layer of resistance material would not possess sufficient dielectric strength to prevent volt punctures and short circuiting of the instrument, it has been discovered that the material adjacent the movable plate is subjected to a much greater expansion than that adjacent the stationary plate, due to the frictional resistance of the container walls, the internal frictional resistance of the material itself, and, especially where interposed plates are used, to gravity, (when the expanding force moves counter to gravitational pull). In other words, where the thickness of the resistance material is considerable, it does not act as a true homogenously elastic body, and most of the expansion and compression is effected in that part adjacent the point where the force is applied, that is, the moving electrode. This, of course, results in an unevenly distributed potential drop, practically the entire drop taking place in the expanded zone, which means the development of a high temperature at this point, and consequent danger of burning out. It is a further object of this invention to provide means for overcoming this difficulty. This can, in general be done in two ways: First, the material adjacent the movable plate can be made richer in conducting material, as set forth in my copending application No. 516,134, November 18, 1921, or, second, resilient means can be made to act upon the material at a number of points along its thickness, so that it will be made to expand and compress throughout in approximate conformity to elastic laws. Still another method of securing a substantially uniform expansion and compression contemplated by this invention, is to provide means which shall positively act upon different zones of the material in succession. (All of these will be explained in greater detail in connection with the accompanying drawings.)

Now the heat loss is greatest when the internal resistance of the rheostat is equal to the external resistance in the line, and therefore, it is at this point that the potential drop should be uniform throughout the material. Thus, where uniformity is attained by increasing the conductivity of the material adjacent the movable electrode, the impregnation should be so proportioned that when the material is expanded to a resistance equal to that in the line, (which is when it is about one-half expanded), the resistance will be uniform throughout the thickness of the resistor, and the potential drop likewise uniform. As the resistance varies beyond this point in either direction, the potential drop will not be uniform, but as the heat loss is also falling off, this is not so important.

One of the chief structural defects found in rheostats today resides in the difficulty of removing and replacing the resistance elements. This is notoriously true in the case of wire coil rheostats, but it is also true of those of the compressible type. Should the resistance deteriorate or accidentally burn out, or should it be necessary to employ a resistance of a different range, the entire rheostat must be returned to the manufacturer or sent to a shop to be dismantled and a new resistance element substituted for the old. This is, of course, objectionable, and in accordance with the present invention the rheostat is designed so that the resistor can be readily removed as a simple self-contained unit and replaced by another.

To do this it has been necessary to re-

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design both support and resistor. The resistance material is put up in closed containers or cartridges provided with means for attachment to the support—readily positioned and just as easily removed. Or the removable cartridges can be done away with and the resistance material itself furnished in such form that it may be readily slipped into place in a permanent container and properly secured in place.

Various other improvements are contemplated by this invention, such as the method of preparing the resistance material for use, the method of packaging this material and inserting it in the rheostat, means for lining the container to prevent adherence of the graphite—these and others are shown in the accompanying drawings and will be described more in detail in connection therewith.

In these drawings Fig. 1 is a vertical sectional view of a rheostat constructed in accordance with the present invention, the longitudinal dimensions being somewhat exaggerated for the purpose of more clearly showing the structure. Fig. 2 is a section taken along line 2—2 of Fig. 1, showing the means whereby the resistor is removed from the support. Figs. 3 and 4 are modified forms of the resistor itself held within its container or cartridge. These views also show the interposed plates which serve the various functions noted above. Fig. 5 is a plan view and Fig. 6 a vertical section through a still further modified type of resistor in which the interposed plates are particularly designed as thermo-couples. Fig. 7 is a vertical section through another type of resistor in which the resistance element is in the form of three superposed slabs secured to one another by a suitable adhesive but without intervening plates; Fig. 8 is a vertical section through a still further modified form of resistor. Figs. 9 and 10 are plan and side views respectively of a resistance unit. Fig. 11 is a vertical section through a still further modified form of resistor in which the cartridge or container is permanently fixed to the frame of the rheostat and into which the resistance material is designed to be introduced by the user. This figure also discloses a modified form of thermostat. Fig. 12 is a vertical section through a carton containing a resistor comprising three superposed units, these units being designed for insertion within a container such as shown in Fig. 11 by the user of the instrument; Fig. 13 is a vertical section through another type of resistor showing a different form of interposed plate and different means for securing the resistor container to the frame of the rheostat. Figs. 14 and 15 are vertical sections through another type of resistor in which springs are employed to cause the material to expand and compress in approximate accordance with elastic laws, so that the potential drop will be substantially uniform throughout the thickness of the material; Fig. 16 is a vertical section through a resistor provided with means for positively expanding and compressing the material in stages, as will be explained in greater detail later; and Fig. 17 is a vertical section through a resistor in which units of different conductive elements are placed in series.

In describing the present invention in connection with the drawings I shall first describe Fig. 1, which shows in detail a support for a resistor and means for expanding and compressing it and thermostatic means for compensating for thermal expansions. This support or frame of the rheostat will be described in connection with one type of resistor and the method of mounting the resistor within the support and removing it will be clearly set forth. This having been done the description will then proceed to a consideration of the various types of resistor which form the greater part of the present invention and which may be employed in the support shown in Fig. 1 or conceivably in other supports.

The rheostat shown in Fig. 1 comprises a housing mounted upon a suitable base and designed to hold within it the various parts of the rheostat. This housing comprises a lower portion 1 and an upper portion 2 hinged together at 3 and provided with locking means 4. When it becomes necessary to change the resistor these two parts of the housing are swung apart and the exchange made as will be described later. As shown, the resistor is mounted within the lower part of the casing 1 and the upper part 2 carries the mechanism by means of which the expansion and compression of the resistor is effected.

I shall now describe one type of resistor and its mounting within the casing. The resistor 5 as shown in Fig. 1 comprises a container or cartridge 6 for the compressible resistance material 7, this cartridge comprising upper and lower metallic plates 8 and 9 respectively and side walls 10 of flexible material, preferably asbestos cloth. Plates 8 and 9 are firmly secured to the side walls 10, one type of joint being shown in the drawing at 12. Thus the resistance material is hermetically sealed within the container and cannot spill out. The resistance material is positively secured to plates 8 and 9 by means of a suitable adhesive, or otherwise, as disclosed in my Patents Nos. 1,315,579 and 1,366,945, so that relative movement of the plates effects a positive expansion as well as compression of the material 7.

Plates 8 and 9 are provided with outwardly projecting screws 13 and 14 respectively

by means of which the cartridge is secured to the supporting parts of the rheostat. The resistor shown in Fig. 1 is supported upon a metallic casting 15, preferably in the form of a spherical segment which in turn is mounted upon a metallic, preferably brass, disc 16. (This disc serves as a thermostat, the action of which will be described later.) This disc 16 is peripherally supported by means of a ring 17 supported upon a series of lugs 18 projecting from the inner walls of the housing 1. Both disc 16 and ring 17 are insulated from the lugs 18 by suitable insulation 19 and held in place by screws 20.

I shall now describe the mechanism whereby the upper plate 8 is moved relatively to lower plate 9 to compress and expand the resistance material. Extending through the upper face of part 2 of the casing and journaled therein is the shaft of a hand wheel 22, the lower end of which makes threaded engagement with a nut 23 to which is connected, through the intermediary of a universal joint 24, a flanged casting 25 suitably insulated from the shaft of the hand wheel and the casing by means of insulation 26. Vertical movement of this casting 25 is effected through turning of the hand wheel 22 but stability is attained through the use of a leaf spring 27 which is likewise secured to the casting 25 and extends upwardly on either side and is held fast upon bosses 28 extending inwardly from the walls of the housing. This leaf spring is suitably insulated from the housing by means of insulation 29. A cup-shaped casting 21 is secured through screw 13 to the plate 8 and makes electrical contact therewith. This casting extends upwardly within the flanges of the casting 25, as clearly shown shown in Fig. 1. Casting 25 is provided with a number of set screws 27 which extend inwardly through its depending flange and enter an annular groove 30 within the upper outer face of casting 21, as shown best in Fig. 2. Access to the set screws is had through apertures 31 in the housing 1.

From the foregoing description it will be clear that movement of plate 8 toward and away from plate 9 is accomplished through the turning of hand wheel 22, compression of the material 7 being permitted because of the flexibility of the absestos cloth side walls 10 of the cartridge 5. Upward movement of plate 8 effects a positive expansion of material 7 due to the adherence of that material to the plates 8 and 9, and this upward movement may be limited by means of suitable stops, not shown. The method of conducting the current through the resistor, the operation of the shunt which is thrown in parallel with the resistor when the conductivity of the latter has reached full current capacity, and the operation and control of the thermostat for compensating for thermal expansion and thus attaining a zero temperature coefficient yet remain to be described.

The housing is provided with two terminals or binding posts 32 and 33, both of which are properly insulated from the casing, the first at 29 and the second at 34. The path of the current is as follows: From terminal 32 through a bolt 35, leaf spring 27, casing 25, set screws 27, casting 21, plate 8, resistance material 7, plate 9, base casting 15, metallic disc 16, a metallic strip 36, a bolt 38 and terminal 33.

As is common in rheostats of this type, a shunt is provided, in parallel with the resistor, which is thrown in when the conductivity of the latter approaches full current capacity, thus relieving the resistor when no good could be accomplished by passing the current through it. The shunt constructed in accordance with the present invention comprises a rod 39 extending upwardly from the periphery of disc 16 and making electrical contact therewith, and a set screw 40 mounted within a lug 42 on the flange of casting 25. As the casting 25 is lowered with the turning of hand wheel 22 the lower end of set screw 40 eventually makes contact with rod 39 and shunts the current around the resistor. The time at which this shunt is thrown in can be regulated by means of the set screw, access to which is had through an aperture 43 in the upper face of the housing. In order that there be no sudden shock when the set screw 40 impacts upon rod 39, the latter is provided with a spring cushioned cap 41, which yields when contact is made.

As stated above, the disc 16 acts not only to support the resistor, but serves as a thermostat as well. The heat generated in accordance with Joule's law causes a thermal expansion of this disc, which in turn relieves the pressure upon the resistor and tends to reduce the surface contact among the conducting particles, and hence increase the resistance, thus compensating for the decreased resistance due to the expansion of these particles. As it is a physical impossibility to design a thermostat which will automatically and without adjustment compensate for the resistance changes in any given resistor, under any conditions of use, it is imperative that adjusting means be provided. In the present invention these means consist of a spherical disc 43 supported upon a threaded bolt 44 mounted within a bracket 45 secured to a bracket 45 depending from the ring 17. Access to the head of bolt 44 is had through an aperture 46 near the base of the housing, and the disc 43 caused to approach or recede from the disc 16. Thus by moving member 43 up-

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wardly the effective expansion of disc 16 is reduced, whereas if member 43 is downwardly out of all contact with disc 16 a condition permitting maximum expansion is realized.

The operation of this device as a rheostat will be clear from the foregoing, but it may be well to review briefly the manner of removing an old or burned out resistor and inserting a new one. A screw driver is inserted through apertures 31 and set screws 27 withdrawn from contact with casting 21. Lock 4 is then unfastened and the upper part of the housing 2 swung backwardly about its hinge. Casting 21 is then unscrewed from the resistor, the resistor itself removed from its base 15 and a new resistor substituted. The reassembly of the part is simply and rapidly made and after readjustment of the thermostat and the shunt the device is in readiness for use.

Before proceeding to a description of the various forms of resistors and a discussion of the resistance material itself I shall call attention to Fig. 11, which discloses a modified form of thermostat. This thermostat consists not only of the metallic disc 16, but has superposed thereon between that disc and the container for the resistance a second and compound thermostat comprising two metals having different coefficients of expansion. In the form shown it comprises an upper disc 47, which is secured directly to the base of the container, and a lower and dished disc 48, the peripheral edges of the disc 47 being overturned to embrace those of the disc 48. The disc 47 is made of a metal having a lower coefficient of thermal expansion than disc 48, the discs being made, for example, of iron and brass respectively. Under the influence of heat the disc 48 will expand more than disc 47 and cause a collapse of the compound member, thus releasing the pressure exerted upon the resistance. This composite thermostat is useful in cases where great thermostatic action is desired in order to correct the effect of resistors having a high positive temperature coefficient.

Coming now to the construction of the resistors themselves, let us first consider the form shown in Figs. 3, 4, 5, 6, 7, 8, 11 and 13. All of these, with the exception of the one shown in Fig. 11, are sealed, that is, the resistance material is held within a container which is entirely enclosed, and which is intended to be put up in final form by the manufacturer and sold to the user in its completely enclosed condition. Each of these resistors is also provided with means whereby it can readily be mounted within the rheostat support shown in Fig. 1, usually in conjunction with a casting similar to 21, but in the case of the resistor shown in Fig. 3, this casting is done away with, an analogous one, 49, forming a part of the container itself. This casting is provided with the necessary depressions to receive the ends of set screws 27. The resistor shown in Fig. 13 differs from the other resistors in that instead of being provided with the projecting screws 13 and 14 for securing it in place within the rheostat support, it is provided with threaded holes 50 designed to cooperate with outstanding screws 61 on the rheostat support. A resistor of this type possesses a light advantage over the other forms in that it is easier to pack and ship.

It will also be noted that the resistances shown in all of these resistors are, in contradistinction to that shown in the resistor mounted in Fig. 1, made up in a plurality of layers. These layers, as shown in Figs. 6, 7, 8, 11 and 13, are entirely separate and distinct from each other, whereas in Figs. 3 and 4 there is no such sharp definition and they are merely separated by plates 51 which are embedded within and secured to the material. These plates, as well as similar plates shown in Figs. 6, 8 and 13, perform a plurality of functions. The first, and perhaps the most important of these, is the supporting and strengthening of the material which they effect and also the division of the material into definite sections. The fibres of the asbestos wool are not long enough to reach completely across the thickness of the ordinary resistor, from movable electrode to stationary electrode, and the result is that the resistance is likely to develop weak spots within the material so that upon the expansion the fibres pull away from each other and form air gas. This is highly undesirable and results in localized overheating and probable burning out of the material. Where, however, these interposed plates 51 are used some of the fibres actually span the gaps between them, and between them and the end plates, so that the probability of pulling the material apart to form air gaps is greatly reduced. In order thus to strengthen the resistance almost any material can be employed to form these plates, providing, of course, it is an electrical conductor. Thus metals can be used, as shown most simply in Figs. 3, 4 and 8, or carbon, as shown in Fig. 13. Or, as a matter of fact, the plates can be eliminated entirely and the several layers or units or resistance material caused to adhere directly to each by means of intermediate layer of conducting adhesive, as shown in Fig. 7.

The second function which these plates perform is that of conducting the internally generated heat from the interior of the resistance to its surface, and to do this it is, of course, necessary to use good thermal conductors, chief among which are the metals. To perform the third possible function these plates must also be made of metal and of particular metals too. This third

function is the special redistribution of heat in accordance with Peltier's law. Thus, if two metals are employed which bear the proper thermo-electric relation to each other, they form a thermo-couple within the mass, and should localized overheating occur near one of their junctions they will tend to absorb this heat and liberate it at their other or cold junction. In order to obtain this result it is, of course, necessary that the current pass in a predetermined direction. Thus, in the case of Fig. 3, if the current is passing through the resistor from top to bottom and the upper plate 51 is zinc and the lower one copper, these plates will tend to equalize the heat in accordance with Peltier's law. This effect is not the major purpose of the plates, but is without doubt beneficial and is one of the factors which should be taken into account.

The resistor shown in Fig. 6 is especially designed to utilize this thermo-electric effect. Here the upper electrode 52 is made of zinc and the lower electrode 53 made of copper. Each intermediate plate 51 is in itself a thermo-couple composed of upper plates 54 of copper and lower plates 55 of zinc, separated along the major portion of their length and by means of suitable insulation 56. If due to uneven pressure or other cause, joints at the right hand end be heated above those at the left hand end, a thermo-electric current will be generated in the direction indicated by the arrowheads, and will tend to cool the right hand end of the resistor and heat the left hand, thus tending to equalize the temperature. In this case it is assumed that the current is flowing from the electrode 52 to electrode 53. This same effect can, of course, be obtained without the use of intermediate plates where the movable end plates themselves are made of properly different metals.

The resistor shown in Fig. 1 and described in connection with that figure, is made up of rigid end plates and flexible sides. This construction is also shown in Fig. 6, but Figs. 8 and 13 disclose containers of an entirely different form in which the side walls are rigid and the ends flexible. To the inner face of these flexible asbestos cloth diaphragms 57, conducting discs 58 are secured. In Fig. 7 the lower face is rigid, but otherwise the structure of the container is similar to that shown in Fig. 8.

When graphite is used as the constituent of the conducting element of the resistance, it has been noted that it tends to form a coating over the surface of the container walls, which coating being electrically conductive acts to short circuit the current around the resistance and causes trouble. Now I have discovered that if the container walls are made of glass or coated with vitreous enamel as disclosed in my copending application, Ser. No. 516,134, or provided with a protective sheet of mica, this difficulty is overcome, and the graphite does not form a coating. Thus, the resistor shown in Fig. 6 is provided with a cylindrical sheet of mica 59, and the resistors shown in Figs. 7, 8, 11 and 13, as well also as those shown in Figs. 14, 15 and 16, are provided with vitreously enameled side walls 60.

I shall now take up a description of the resistors shown in Figs. 14, 15 and 16 which are designed to solve the problem of expanding the material so as to obtain a uniform potential drop throughout its thickness. Each of the containers shown in these figures is provided with vitreously enameled side walls 60 and flexible ends 57 to the inner faces of which are secured carbon plates 58. The resistance material is the ordinary asbestos wool combined with conducting powders and provided at intervals with interposed carbon plates 51. The problem is to effect a uniform compression and expansion.

I shall first consider Fig. 14. Each of the plates 51 is provided with a hub of insulating material 62 provided with flanges 63 designed to telescope with corresponding flanges on an adjacent hub and with corresponding flanges projecting inwardly from the end plates 58. Held within these flanges and bearing against the faces of the hubs themselves are three coil springs 64. Let us suppose that the lower end of the resistor is held stationary and pressure applied through upper plate 58. The several sections of spring 64 act as one entire whole and transmit this pressure equally to the material. Thus, the material in the uppermost zone is compressed no more than that in the lowermost. Upon release of the pressure and an upward movement of the plate 58, a uniform expansion is similarly effected. This form of resistor is shown provided with an internal shunt 70.

The resistor shown in Fig. 15 accomplishes this same result by means of a slightly different mechanism. Here the side walls 60 are provided with a series of annular shoulders 65 upon which rest annular rings 66 having at intervals upstanding spring ears 67 which support plates 51.

The pressure being substantially uniformly applied throughout the mass of resistance material employed in the resistors of Figs. 14 and 15, it is necessary only that the composition of this material be uniform throughout in order to insure a uniform potential drop. When using the form of resistor shown in Fig. 16, this is not the case, as will be evident from the following.

Extending downwardly from upper plate 58 (Fig. 16) is a projecting rod 68 which passes through central apertures in the

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plates 51 and is insulated therefrom. This rod is provided with a series of rings 69 spaced from the discs in a manner which will now be described. Let us assume again that the lower plate is stationary and that a pressure is applied to the upper one. As this upper plate 58 starts on its downward movement it compresses the material in the upper zone. The material in the other zones is also compressed to a slight extent, but due to the fact that the material as a whole does not act as a true elastic body, this compression is relatively slight and most of the action occurs in the zone immediately adjacent the moving part. Ordinarily, this would continue, the upper material being compressed to a much greater extent than the lower. However, when the upper zone has been compressed to a predetermined point the upper ring 69 makes contact with the next lower plate 51. This immediately marks the end of the compression of the uppermost zone, because plate 58 and adjoining plate 51 are then moving downwardly at the same rate, and the second zone is being compressed. This compression will continue until the second ring 69 strikes the second disc 51 and so on. Thus the zones will be successively compressed and each to exactly the same degree. Upon the return movement the compression is released in the reverse order, and when the expansion exceeds the mean position shown, the zones are expanded beginning with the lowest and continuing upwardly in succession. Although a resistor built as shown in Fig. 16 equalizes the pressure in the several zones, it is, nevertheless, necessary to vary the composition of the zones. If we asssume that the position shown in Fig. 16 represents the mean position, the material being expanded half way, this will represent a condition of maximum heat loss, as it is in this position that the internal resistance of the rheostat will probably equal the external resistance in the line. Therefore, at this point it is highly desirable that the potential drop throughout the thickness of the resistor be uniform. Yet having started from an initial uncompressed condition of the maximum conductivity (as will be explained in greater detail later), the mean position shown represents an expansion of the material and, as the lower discs have not yet come into play as effecting the expansion of the material, the uppermost zone has been expanded more than the lowermost. Thus, to have a uniform composition and potential drop at this point it is necessary that when in the initial unexpanded condition the uppermost zone have a composition richer in the conducting elements than the lowermost. The composition of the intermediate zone will lie in between these two extremes.

As stated in the early part of this specification, the composition of the conducting element of the resistance should in most cases have a substantially zero, or slightly positive temperature coefficient. For practical reasons the resistance material as a whole is compounded to have this coefficient. Thus, the conductive elements are combined with the asbestos or other nonconductive element and the temperature coefficient of the whole fixed for given working conditions, thus taking into account the thermal expansion of the asbestos. As examples of compositions having substantially zero temperature coefficients of resistance I instance the following:

	Parts by weight.
Silicon	8
Graphite	2
Asbestos	4
Silicon	9
Graphite	2
Asbestos	2
Silicon	9
Lamp black	1
Asbestos	2

Were the asbestos removed the ratio of silicon to carbon would be slightly varied.

It is to be noted that the ratio of silicon to carbon in these mixtures is high. Now the resistance of silicon when heated is high, so that the specific resistance of these compounds is high. I have discovered that in intimate mixtures of silicon and graphite, the silicon becomes heated by conduction and radiation from the carbon. This so raises its resistance that it fails to carry its proportionate share of the current and for this reason it becomes necessary greatly to increase its proportions relative to the carbon. And so the result is a resistor of high specific resistance. In order to overcome this difficulty I may build the resistance material as shown in Fig. 17, the graphite and asbestos indicated at 75 being separated from the silicon and asbestos at 76, the two being preferably though not necessarily separated by a metal plate 77. In this way the two constituents being in series the current must pass through each and the silicon add its effect to that of the graphite. When arranged in this manner the ratio of silicon to graphite instead of being about four to one, as in the examples given, is about one to four, as shown in Fig. 17.

In making up the layers or units of resistance material employed in these resistors, I take asbestos wool fibres, coat them with the conductive powders, as for example, in a tumbling drum, and then when they are coated, felt them and cut from the felt, units of the proper dimensions. Where lamp black is employed as the carbon constituent, I make a suspension of this lamp black in

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alcohol and saturate the asbestos wool with it. Experiment has shown that the asbestos is impregnated by the lamp black in this manner. The same method can be employed with graphite but with less success. In both instances tumbling in a drum may be combined with the saturation step.

The resistors shown in Figs. 1, 3, 4, 6, 7, 8, 13, 14, 15, 16 and 17 are designed to be made up by the manufacturer and shipped to the user in the form shown, but I have also provided means whereby a permanent container or cartridge may be employed and the resistance material itself inserted by the user of the rheostat. Such a container is shown in Fig. 11. The movable plate 71 is secured directly to the resistance material on the one side and to the leaf spring 27 and the shaft of hand wheel 22 on the other. Should the resistance burn out or should it become necessary to change or renew it, the upper member 2 of the housing is swung open, thus tearing loose the contact between the resistance and the plate 71. The old resistance can then be removed and any adhering fibres scraped from the container and the plate 71. The new resistance is then placed within the container. The manner of doing this will now be described.

The resistance material, either in a single piece or in properly designed units, is put up within a carton 72 shown in Fig. 12, this carton being provided with a removable bottom 73 and a top 74 designed to be pushed within the carton. In order to insert the new resistance within the container shown in Fig. 11, it is only necessary to remove the bottom 73, place the carton over the container, bottom down, and press upon the top 74. This will eject the resistance and position it within the container. Before this is done, of course, the bottom of the container and the plate 71 should be coated with a suitable adhesive. This being done the upper part 2 of the housing is swung into close position, the plate 71 forced down upon the resistance and held in that position until the adhesive has time to set.

The adhesive used can be any suitable adhesive which is conducting, such as glue impregnated with powdered carbon, but where the resistance material is to be glued to a metallic plate, I have found it advantageous to mix with the glue a salt of a metal so related to the metal of the plate in the electro-motive force series that the metal of the salt will be replaced and deposited upon the plate, thus making an admirable contact. For example, where the plate is of iron, I mix copper sulfate with the glue.

As discussed in connection with Fig. 16, the composition of the resistance material is determined by first determining the composition which it must have for minimum resistance. This being determined, the range of fixed resistance is then determined by its expansion. When in a mean position its resistance should be equal to that of the external resistance in the line, (the heat loss in the resistor being greatest here), so at this point the potential drop should be uniform, and therefore the distribution of the conducting material should be uniform. Where the expansion itself is not equal throughout the thickness of the resistor, then those parts which are expanded most must be richer in conductive material, and this in direct proportion to their relative expansions.

Where the temperatures to which the rheostat is to be submitted are above the working temperatures of asbestos, other non-conducting material should be used. Granular silicon, beryl and the like lend themselves quite satisfactorily for this purpose, but I have found that flaked mica is superior to these, for the reason that it possesses a larger resiliency of its own. When compounds of this nature are used, it is necessary to increase the number of units in a multiple resistor to such a quantity as will insure safe distribution of the potential drop throughout its thickness. This procedure will be essential inasmuch as, due to the absence of the fibres of asbestos, a powder or granular compound will not have the high coefficient of elongation, which is characteristic of asbestos wool compounds, and it will be necessary to rely upon the much smaller resiliency of such a compound assisted, however, by the positive drawing apart of its mass by adherence of the outer particles to the plates. As stated above, these materials can be substituted for the asbestos substantially weight for weight.

The principles underlying the construction and operation of a practical and successful rheostat of the compressible resistance type have been set forth at some length in the foregoing specification, and the application of these principles has been made clear by references to preferred mechanisms and methods. It is clear, however, that the principles themselves are broader than these specific illustrations, and it is believed that many a man skilled in the art, after studying this disclosure could construct other pieces of apparatus, compound other mixtures and devise other methods which, although differing from the ones specifically given here, would yet embody the principles herein disclosed for the first time.

This application is a continuation in part of my copending application Ser. No. 516,134, filed November 18, 1921.

I claim:

1. A compressible resistance material having a substantially zero temperature coefficient, comprising carbon and conductive silicon.

2. A compressible resistance material hav-

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ing a substantially zero temperature coefficient, comprising a mixture of graphite and conductive silicon, the ratio of graphite to silicon being about one to four.

3. A compressible resistor having a substantially zero temperature coefficient comprising a unit in which carbon is the conductive element in series with a unit in which conductive silicon is the conductive element.

4. A compressible resistance material having a substantially zero temperature coefficient comprising asbestos impregnated with a mixture of conductive silicon and graphite.

5. A compressible resistance material having a substantially zero temperature coefficient comprising asbestos impregnated with a mixture of conductive silicon and graphite, the proportions by weight being substantially asbestos two parts, conductive silicon four parts and graphite one part.

6. A compressible resistance comprising two or more separate layers of compressible resistance material joined by means of a conducting adhesive.

7. In a compressible resistance rheostat, the combination of a compressible resistance comprising two or more separate layers of compressible resistance material separated by and secured to interposed plates of conducting material, and means for positively expanding and compressing the resistance.

8. In a compressible resistance rheostat, the combination of a compressible resistance comprising two or more separate layers of compressible resistance material separated by and secured to interposed metallic plates, and means for positively expanding and compressing the resistance.

9. A resistor comprising two relatively movable metallic plates, a compressible resistance material between the plates, the plates being of different metals so related to each other that when the current flows through the resistor in a predetermined direction, the plates act thermo-electrically, in accordance with Peltier's law, and redistribute the heat in the resistor.

10. A compressible resistance provided interiorly with a thermo-couple, which, when the current is flowing through the resistance in a predetermined direction, will absorb heat at its hotter end and generate it at its colder end, in conformity with Peltier's law.

11. A compressible resistance unit, comprising a layer of felted, resistance material made up of a non-conducting material, impregnated with conducting material.

12. A compressible resistance unit, comprising a layer of asbestos fibres, which fibres are coated with a conducting powder.

13. The method of making compressible resistance units, which comprises coating non-conducting fibrous material with conducting powder, felting the fibres thus coated and blanking out the units to the desired size and shape.

14. The method of making compressible resistance material which comprises saturating asbestos fibres with a suspension of conductive particles.

15. A rheostat comprising an expansible and compressible resistance material, and means for expanding and compressing said material, the resistance of the material being substantially uniform throughout its thickness when approximately in its mean position.

16. The combination of a compressible resistance rheostat comprising two relatively movable electrodes, including between them a compressible resistance material, and an external resistance in series with it, the composition of the resistance material being such that the potential drop between the electrodes will be substantially uniform through the thickness of the material when the internal resistance of the rheostat equals the external resistance.

17. The combination of a compressible resistance rheostat comprising two relatively movable electrodes, including between them a compressible resistance material, and an external resistance in series with it, the composition of the resistance material being such that the potential drop between the electrodes will be substantially uniform through the thickness of the material when the heat generated within the resistance is a maximum.

18. A compressible resistor, comprising a sealed container, a compressible resistance within the container, and means for removably mounting the resistor within the frame of a rheostat.

19. A compressible resistor, comprising a sealed container having a flexible wall, a conducting plate secured to the inner face of said wall, and a compressible resistance within the container and adhering to said conducting plate.

20. A compressible resistor comprising a compressible resistance, means for positively expanding and compressing the resistance, and resilient means which distribute the pressure throughout the thickness of the resistance.

21. A compressible resistor, comprising a compressible resistance, an interposed plate within the resistance, two relatively movable compressing and expanding end plates, springs interposed between the end plates and the interposed plate, so that the effect of the relative movement of the end plates is transmitted through the thickness of the resistance.

22. A compressible resistor, comprising a compressible resistance, an interposed plate within the material, two relatively movable

compressing and expanding end plates, means moving with the movement of the end plates to move the interposed plate after the end plates have moved a predetermined distance.

23. A compressible resistor, comprising a stationary end plate, a movable plate, compressible resistance material included between said plates, an intermediate plate within the material and substantially parallel with the other plates, a projection extending inwardly from the movable plate, means on said projection for engaging the intermediate plate and imparting a delayed movement to it.

24. The method of operating a compressible resistance rheostat, which comprises acting upon separate layers of the resistance material in succession to expand or compress them.

25. A compressible resistance material, comprising carbon, a comminuted refractory, thermally conductive, electrically resistant material, and conductive silicon.

26. A compressible resistance material comprising graphite, flaked mica and conductive silicon.

27. A compressible resistance material comprising the following ingredients in substantially the following proportions: graphite one part, flaked mica two parts and conductive silicon four parts.

28. A compressible resistor, comprising relatively movable end plates, a plurality of interposed plates, and comminuted resistance material distributed among the plates.

29. A rheostat comprising a support, a resistor, and means for removably mounting the resistor within the support.

30. A rheostat comprising a support, a compressible resistor, and means for removably mounting the resistor within the support.

31. A rheostat comprising a support, having upper and lower members, means within the lower member for supporting a compressible resistor, and means carried by the upper member for effecting an expansion and compression of the resistor.

32. A rheostat comprising a housing having upper and lower members, a thermostatic disc mounted within the lower member, a compressible resistor mounted upon said disc, and means carried by the upper member for effecting an expansion and compression of the resistor.

33. A rheostat comprising a housing having upper and lower relatively movable members, a compressible resistor mounted within the lower member, vertically movable means depending from the upper member, and means for connecting said movable means to and disconnecting it from the resistor.

34. A rheostat comprising a housing having upper and lower members, a compressible resistor mounted within the lower member, a threaded shaft extending through the upper member, a movable part operatively connected to said shaft, and means for securing said movable part to the resistor.

35. A rheostat comprising a housing having upper and lower members, a compressible resistor mounted within the lower member, a threaded shaft extending through the upper member, a movable part operatively connected to said shaft, a leaf spring supported by the housing and secured to the movable part to steady it, and means for securing said movable part to the resistor.

36. A rheostat comprising a housing having upper and lower members, a compressible resistor mounted within the lower member, a threaded shaft extending through the upper member, a movable part operatively connected to said shaft through a universal joint, and means for securing said movable part to the resistor.

37. A rheostat comprising a housing having upper and lower members, a compressible resistor mounted within the lower member, a threaded shaft extending through the upper member, a flanged casting operatively connected to said shaft and set screws passing through the casting to secure it temporarily to the resistor.

38. A rheostat comprising a housing having upper and lower members, a compressible resistor mounted within the lower member, a movable part supported by the upper member and designed to be secured to the resistor to effect an expansion and compression thereof, and a shunt, one contact carried by the resistor support and the other by said movable part, the parts being designed to contact and shunt the current around the resistor when its resistance has been reduced to a predetermined point.

39. A rheostat comprising a housing having upper and lower members, a compressible resistor mounted within the lower member, a movable part supported by the upper member and designed to be secured to the resistor to effect an expansion and compression thereof, and a shunt, one contact carried by the resistor support and the other by said movable part, one contact of the shunt being adjustable, the parts being designed to contact and shunt the current around the resistor when its resistance has been reduced to a predetermined point.

40. A rheostat comprising a housing having upper and lower members hinged together, a compressible resistor removably supported within the lower member, a movable part carried by the upper member, and means for operatively securing the movable part to the resistor to expand and compress it in relation of the parts permitting the

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readily removal and replacement of the resistor.

41. In a compressible resistance rheostat, a resistor, a support therefor comprising a flexible metallic disc, which by expanding acts thermostatically to relieve the pressure upon the resistor as its temperature rises, and regulatable means for governing the effective expansion of the disc.

42. In a compressible resistance rheostat, a resistor, a support therefor comprising a pair of discs of different metals secured together at their edges, which by differential expansion act thermostatically to relieve the pressure upon the resistor as its temperature rises.

43. In a rheostat, a pile of resistance units, each unit having variable specific resistance and means positively acting upon the pile to increase or decrease the density of the pile as a whole to change its conductibility.

In testimony whereof I affix my signature.

FLORICEL A. ROJAS.