Feb. 26, 1946. L. GOLDSTEIN ET AL 2,395,623

CONDENSER-RESISTOR

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Fig. 1

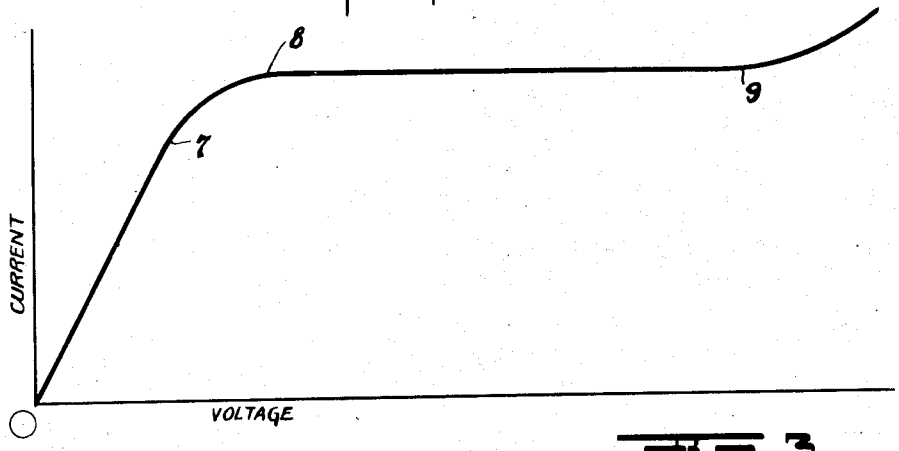


Fig. 2

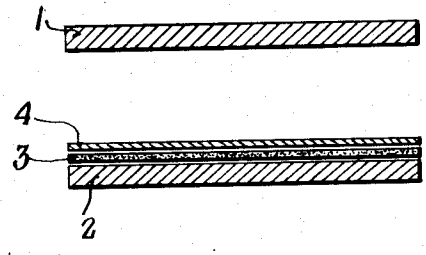


Fig. 3

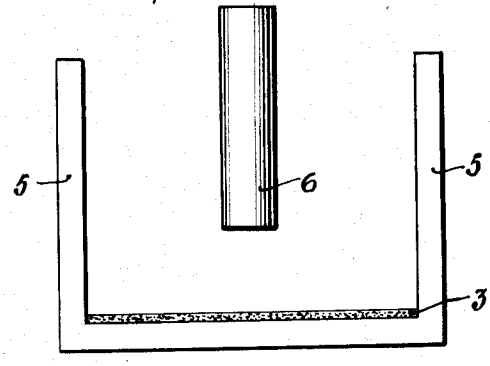


Fig. 4

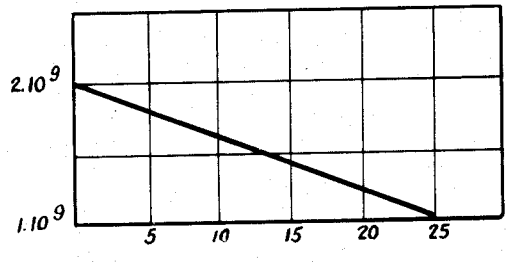
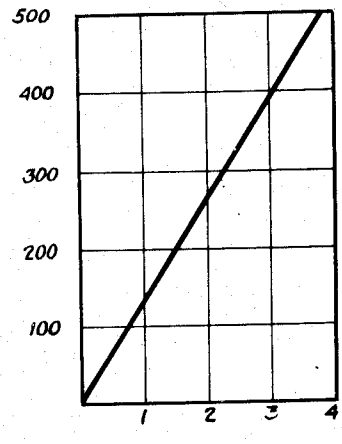


Fig. 5



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FIG. 6

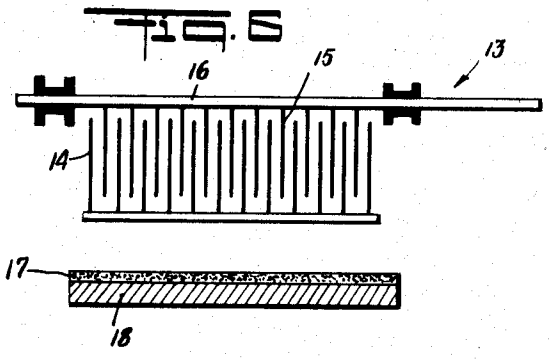


FIG. 7

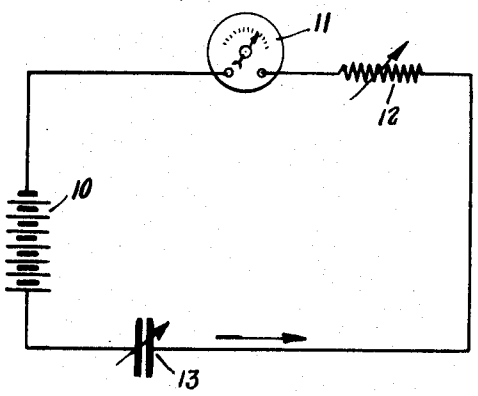


FIG. 8

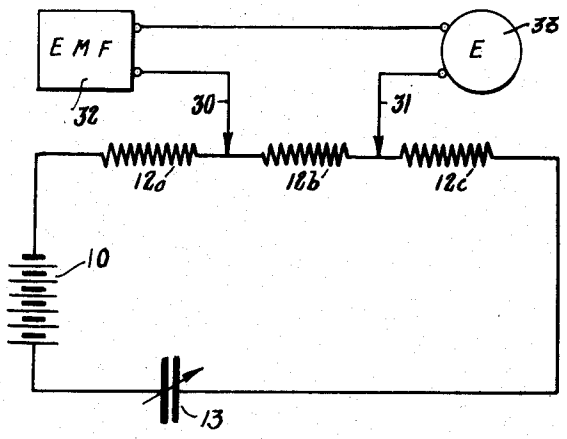
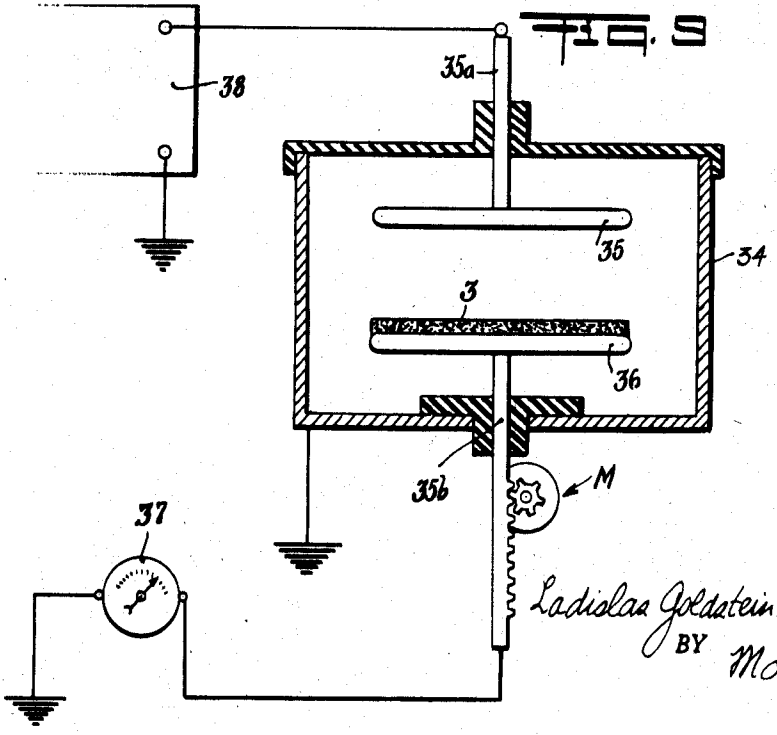


FIG. 9



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CONDENSER-RESISTOR

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Application January 27, 1944, Serial No. 519,934

6 Claims. (Cl. 201—48)

Our invention relates to a new and improved condenser-resistor.

One of the objects of our invention is to provide a condenser-resistor, which consists of a condenser whose dielectric is ionized by suitable radiation, such as alpha or beta or gamma rays, so that an ionization current will flow through said dielectric, when a voltage difference is impressed upon the electrodes of the condenser.

Another object of our invention is to provide a condenser-resistor, in which the proportion between the applied voltage and the ionization current which flows between the electrodes of the condenser, remains constant within a substantial range or stage of applied voltage. In this range, which is designated as the straight-line range or constant-resistance range, the resistance of the improved condenser-resistor is like an ordinary ohmic resistance, but the improved device has many advantages over the ordinary ohmic resistor. Our improved condenser-resistor can have a constant resistance in the constant-resistance range, between 10 megohms or 10^7 ohms, to one million megohms or 10^{12} ohms.

At such high resistance, the ordinary ohmic resistor becomes polarized, so that it develops a counter-electromotive force, which is not developed in our improved condenser-resistor.

Our invention is not limited to any particular resistance value of the improved condenser-resistor in the constant-resistance range. The resistance of the improved condenser-resistor may be fixed or it may be adjustable, or it may vary as a known function of time.

Another object of our invention is to provide a resistor in the form of a condenser, either fixed or variable, whose dielectric, either gaseous or fluid, is subjected to the ionizing rays of radioactive material. In most cases the radioactive material will be a group of radio elements in radioactive equilibrium, the initial element having a very long life, for instance: Radium in equilibrium with radon, Ra A, Ra B, Ra CC¹C''; or Ra D in equilibrium with Ra E and polonium; or radium in equilibrium with all these elements. We may also use ionium or a mixture of ionium and thorium. We can use the radioactive material in the form of its salts or compounds, such as radium bromide, etc.

Another object of our invention is to provide a resistor whose predetermined or desired value is substantially unaffected by variations in temperature, including the heating action of the current which is passed through said resistor. The predetermined value of the resistance of the resistor can thus be maintained with great precision, so that the improved resistor can be used for high precision measurements.

Another object of our invention is to provide a condenser-resistor in which the current remains constant when the voltage is varied through a wide range, in which the voltage exceeds the maximum voltage of the constant-resistance range. We thus secure a constant current, which can be used as a standard for many purposes.

Numerous additional objects of our invention will be stated in the annexed description and drawings, which illustrate preferred embodiments thereof. The drawings are diagrammatic, and not to scale. The invention is not limited to the illustrative examples stated herein.

Fig. 1 is a graph which illustrates the respective relations between current and applied voltage in our improved device, in a plurality of successive voltage ranges.

Fig. 2 is a section of a plate condenser-resistor, whose operation is illustrated by the graph of Fig. 1.

Fig. 3 is a sectional view of a condenser-resistor made according to our invention, in which one electrode or member of the condenser-resistor is a cylinder which is open at one end thereof, and the other electrode or member of the condenser-resistor is a rod which can be axially adjusted.

Figs. 4 and 5 are graphs which illustrate the properties of the embodiment of Fig. 3.

Fig. 6 shows our invention embodied in a multiple condenser-resistor, which has a plurality of stator plates and a plurality of rotor plates.

Figs. 7 and 8 show our invention applied, in order to measure voltage.

Fig. 9 shows our invention applied to the measurement of high voltages.

The dielectric of our improved condenser-resistor may be any gas, or a mixture of gases. Such dielectric may be an insulating liquid, which is exemplified by hexane, C_6H_{14}, and carbon tetrachloride, CCl_4. We prefer to use gaseous dielectrics. The gas may be of the electronegative type, in which a free electron is quickly captured by a molecule or ion of the gas of the dielectric. Oxygen is an example of such electronegative gas. We can use dielectric gases which are non-electronegative, such as helium, argon, neon, xenon, krypton, hydrogen, and nitrogen.

The current through said dielectric, and hence the current through the condenser-resistor, is an ionization current. The radiation, such as alpha or beta or gamma radiation, if constant, produces a constant number of ions per second. The num-

ber of positive ions which are thus produced by said radiation, is equal to the number of negative ions. These oppositely charged ions may recombine, or these oppositely charged ions may be separated and carried to the respectively oppositely charged electrodes, by the electric field between said electrodes. The proportion of ions which are thus extracted at the respective electrodes, and hence the current which passes through the condenser-resistor, has a constant proportion to the potential difference of the electrodes, up to a certain maximum value of said potential difference. This maximum value depends on the shapes of the electrodes, the nature of the dielectric, and the intensity of ionization. This voltage range is designated as the constant-resistance range.

When the maximum voltage of the constant resistance range or stage is exceeded, there is a second range or stage in which the increase of current is smaller in response to the increase in voltage.

When the maximum voltage of this second range or stage is exceeded, there is a third range or stage, designated as a constant-current stage, in which the current remains constant, under a large increase in voltage. The current in this third range is designated as the saturation current. In this third range, the electrodes extract all the ions which are produced in the gaseous dielectric by the radiation.

When the maximum voltage of the constant-current range is exceeded, the gaseous molecules are ionized by collision with electrons, thus producing an increase in current in response to increase in applied voltage.

In Fig. 1, the abscissa denotes applied voltage, and the ordinate denotes the value of the current which flows through the condenser-resistor.

The first or constant-resistance stage is designated by the part 0–7 of the graph. This part of the graph is a straight line of constant slope. This slope may be varied by varying the intensity of the ionizing radiation, or by varying the shape of the electrodes and the capacity of the condenser, or by varying the gaseous dielectric or by varying the pressure of gaseous dielectric. When the ionizing radiations are secured from a radium compound, best results are secured when the value of the respective constant resistance in the constant-resistance range is between 10^7 ohms and 10^{12} ohms.

In this constant-resistance range, the resistance varies only slightly with variations in temperature. The temperature coefficient is less than 0.1 per cent, per degree centigrade. This is a marked improvement over known high resistances of the ohmic type, in which there is a variation in resistance of 1% to 2.5%, per degree centigrade.

The part 7–8 of the graph illustrates the second range, in which the current increases in varying proportion in response to an increase in voltage.

The part 8–9 of the graph illustrates the third or constant-current range.

Above the voltage which is indicated by the point 9, the current increases in response to voltage increase.

Fig. 2 shows a condenser, which has two parallel and circular and flat metal electrode discs 1 and 2. The circular planar faces of said discs 1 and 2 are parallel to each other, and the axial line which joins the respective centers of said discs is perpendicular to said planar faces. In the illustrative example stated herein, the diameter of each disc is four centimeters, and the distance between said discs, along said axial line, is two centimeters. Said discs can be enclosed in any suitable casing, whose wall is preferably made of insulating material. Such a casing 34 is shown in Fig. 9. The dielectric gas in said casing can be maintained under constant pressure, which may be equal to normal atmospheric pressure, or above or below said normal atmospheric pressure. The inner face of disc 2 has a coating 3 of radioactive material, which may be radium bromide. Said coating 3 is covered by a layer 4, which may be made of gold foil, whose thickness is two microns. The use of the gold foil layer 4 is optional. The radium bromide may be dissolved in water or other suitable solvent, and said solution is applied to the respective face of disc 2, and the solvent is then evaporated, so that the radium bromide adheres to the respective face of disc 2. The gold foil 4 is held in position by any suitable adhesive. The radium bromide may or may not be distributed uniformly over the inner face of disc 2. A substantially uniform distribution is preferred. In this example, the weight of the radium in the radium bromide is ten micrograms. Said radium bromide emits alpha particles, which pass through the gold foil, approximately 75% of their range being in the gaseous dielectric at normal atmospheric pressure of 760 mm. of mercury. Such a condenser-resistor has an ohmic resistance in the constant-resistance range 0–7 of 1000 megohms (10^9 ohms), if the potential difference which is applied to electrodes 1 and 2 does not exceed a unidirectional voltage potential of about 10 volts. That is, between an applied voltage of zero volts and 10 volts, the condenser has a constant resistance of 1000 megohms, and it behaves like a pure ohmic resistance, so that there is a constant proportion between the applied voltage, and the current flow through the condenser-resistor. In this example, if the applied voltage exceeds ten volts, the value of the resistance changes, because the value of the applied voltage is above the point 7 in said graph of Fig. 1.

The resistance of such a condenser-resistor, in the constant-resistance range, is approximately proportional to the reciprocal of the weight of radium used. For example, if one microgram of radium is used in said condenser-resistor, other conditions being the same, the value of the constant resistance in the range 0–7 of the graph of Fig. 1, up to an applied unidirectional voltage of a maximum of about 10 volts, is increased from 1000 megohms to 10,000 megohms (10^{10} ohms). If the weight of the radium is increased to 100 micrograms, the resistance in said constant-resistance range 0–7, becomes 100 megohms (10^8 ohms) under said conditions.

Fig. 3 shows an ionization chamber or condenser-resistor of the cylindrical type. This shows a metal electrode cylinder 5, and an axial metal electrode rod 6. Said cylinder 5 and rod 6, like the plates 1 and 2, are made of any suitable metal or alloy. The inner face of the bottom of cylinder 5 has a coating 3 of radium bromide or other radioactive substance or salt or compound of such substance. The internal diameter of cylinder 5 is one centimeter, and its height is five centimeters. The height of rod 6 within cylinder 5 is four centimeters. The rod 6 is the inner electrode of the condenser. The diameter of rod 6 is 0.2 centimeter. If the radioactive coating which is placed on the inner face of the

bottom of the cylinder 5 comprises 20 micrograms of radium, and a voltage difference of between zero volts and ten volts is impressed upon the electrodes 5 and 6, the corresponding constant ohmic resistance in the range 0–7, is 1000 megohms (10^9 ohms). In the condenser-resistor of Fig. 3, if the mass of the radium is two micrograms under said conditions, the corresponding ohmic resistance in the range 0—7, is 10,000 megohms (10^{10} ohms). If the mass of the radium is decreased to 0.2 microgram under said conditions, the ohmic resistance is 100,000 megohms (10^{11} ohms), in the range 0–7.

The current through the axial-electrode type of condenser which is shown in Fig. 3, can be varied by varying the length of the axial electrode 6, which is located in cylinder 5, all other conditions being the same.

This is illustrated in Fig. 4, in which the abscissa denotes the length, in millimeters, of the axial electrode 6, which is located in cylinder 5. The ordinate denotes the corresponding ohmic resistance, beginning with a minimum ohmic resistance of 10^9 ohms. The ohmic resistance which is illustrated is between 1,000 megohms (10^9 ohms), and 2,000 megohms (2.10^9 ohms). When five millimeters of the axial electrode 6 are located in cylinder 5, the ohmic resistance is 1800 megohms. When 20 millimeters of electrode 6 are located in cylinder 5, the resistance is 1200 megohms.

Fig. 5 shows the relation between applied voltage and current, in the condenser-resistor which is of the axial-electrode type of Fig. 3, in which the effective length of the axial-electrode 6 within the cylinder 5 is maintained at 40 millimeters. The abscissa indicates applied voltage, and the ordinate indicates the current in arbitrary units. The graph is a straight-line graph, in which the relation of current increment to voltage increment is a constant. The axial-electrode condenser-resistance which was thus tested, had seven micrograms of radium. Of course, when the radium is used in the form of a compound, like radium bromide, said weight of seven micrograms refers to the weight of the radium per se, in the compound.

Fig. 6 shows a variable condenser-resistor, with stator plates 14, and rotor plates 15. The maximum capacity of said variable condenser 13, in this example, is 100 centimeters, in the electrostatic centimeter-gram-second system. This is about 90 micro-microfarads. The longitudinal distance between respective adjacent rotor plates 15 and stator plates 14, in a direction parallel to the axis of shaft 16, is 0.1 inch.

The layer 17 of radium bromide has a mass of 0.5 milligram. Said layer 17 is deposited on a carrier strip 18, which is a planar gold strip, the plane of said strip 18 being perpendicular to the parallel planes of stator plates 14 and rotor plates 15. Said layer 17 may be covered by a strip of gold foil (not shown) whose thickness is 3 microns. Said carrier 18 is located at a distance of one centimeter from the adjacent edges of the stator plates 14. The rotor plates 15 can be rotated so as to produce said maximum capacity, or a minimum capacity of 7 cm., without striking carrier 18.

The embodiment of Fig. 6 provides, in effect, a variable rheostat of very high resistance, which is varied by varying the capacity of condenser 13. By calibration, said rheostat device can give very precise values.

The saturation stage of the ionization current, which is represented between the points 8 and 9 of Fig. 1, is produced by selecting a range of the applied voltage, and by selecting the intensity of the ionizing means. The value of said ionization current in said saturation stage, is practically independent of the applied voltage in the respective voltage range. Hence such saturation ionization current remains constant, substantially independent of temperature variation, and aging of the battery which is used as the source of current, if the intensity of the ionizing means remains constant. This condition is fulfilled, for instance, when radium which is in radioactive equilibrium with its disintegration products, is used as the ionizing means or agent. This fixed saturation current is useful for purposes of comparison and standardization.

Since the ionization current is very small, even when it is a saturation current, we can use even "dead" batteries or cells as the source of potential. Such "dead" batteries or cells can deliver their original rated electrostatic voltage, for a period of 2–3 years, even after they fail to deliver an appreciable current.

The best type of condenser to be used in the construction of a current standard is the multiplate type, either fixed or a variable, such as the variable condenser shown in Fig. 6. In this multiplate type of condenser, the saturation stage 8–9 of the ionization current is reached for a fairly low potential difference between the two sets of plates. This is due to the small distance between adjacent plates, so that we can secure considerable electrostatic field intensity by applying a low voltage.

By using a non-electronegative gas, as a dielectric, such as argon, or any mixture of noble gases, we can obtain the saturation stage by using a much smaller applied voltage, or by using weaker electric fields.

For instance, in the case of the variable condenser-resistor shown in Fig. 6, if the dielectric is air, at normal atmospheric pressure, the saturation current in the stage 8–9 has a value of 10^{-8} amperes when said condenser has its maximum capacity of 100 centimeters. This saturation value in the range 8–9 is secured when the minimum applied voltage is 25 volts. For voltages above 25 volts, the intensity of the ionization saturation current in the range 8–9 does not increase until the beginning of ionization by collision. Said beginning of ionization by collision corresponds to a voltage of the order of 2,500 volts. It is well-known that the breakdown voltage of a dielectric is less than the voltage which is required to produce ionization by collision. Hence we select and use an applied voltage, up to point 9 of Fig. 1, which is less than the breakdown voltage of the dielectric, and which is also less than the voltage which is required to produce ionization by collision in the dielectric.

Hence we can produce a constant current when the applied voltage is varied between 25 volts and 2500 volts, in the range 8–9.

In producing such constant current as a standard, we can use a condenser whose plates are maintained in fixed relation, such condenser having either a single pair of plates, or being of the multiple type which has a plurality of pairs of plates.

Said constant current can be regulated so as to have a plurality of respective constant values by using a variable condenser. In such variable condenser, the respective value of the respective constant current is secured by mechanical adjust-

ment, as in the condenser of Fig. 6. Such a variable condenser can be calibrated, in order to designate the respective constant values of the saturation current in the range 8–9, which is produced by moving the rotor plates. We prefer to enclose the condenser in a casing, to prevent variations in gas pressure.

One important use of a constant current in the range 8–9, as a current standard, is exemplified in Fig. 7 and Fig. 8. The constant current flows through a potentiometer circuit, which includes a resistor, or resistors, or resistor-combinations of known and predetermined resistance values. This produces a known IR drop of potential through the potentiometer, and such known voltage drop can be used for many purposes, since such voltage drop remains constant.

The voltage drop which is used as a standard, can be regulated by regulating the respective value of the constant current, or the resistance of the potentiometer.

Such potentiometers can be used, for instance, for measurements of small electrometric forces from 0 volts to about 100 millivolts. For example, such potentiometers can be used in pH determinations, in measuring the voltage of thermocouples, etc.

In general, the above described potentiometer circuits can be used advantageously for measurements in high resistance circuits, due to the fact that said potentiometers are of the high resistance type.

The improved condenser-resistor can also be used as a voltmeter, by determining the current in any part of the constant resistance stage 0–7, in a condenser-resistor which has plates which are fixed relative to each other, or which has relatively movable plates, and which has been suitably calibrated. By plotting the part 0–7 of the graph, the voltage which corresponds to a respective current in said constant-resistance range can be accurately determined. Such voltmeters have very high resistance. The range of measurement of such a voltmeter may vary from a few millivolts to many thousand volts. Such a voltmeter cannot be injured by the application of even high over-voltage, if a discharge is prevented in he gap of the condenser or in the other part of the circuit of the condenser. This results from the wide range in the portion 8–9 of the graph.

Fig. 7 shows a battery or other current source 10 which delivers a constant and unidirectional voltage. The circuit of battery 10 includes a current meter 11, a variable resistor 12, and a resistor-condenser 13 of the improved type, whose capacity may be variable. The ionization current through the resistor-condenser 13, is in the saturation range 8–9 of Fig. 1, so that said current is constant, but its value can be selected by varying the capacity of the condenser-resistor 13, thus regulating the voltage drop across the resistor 12. We can thus secure a constant and selected voltage drop across resistor 12, which can be used to determine the unknown potential of any source of current or potential. The resistor 12 thus operates as a potentiometer. The current which flows through resistor 12 may be about 10^{-8} amperes, or 0.01 microampere.

Fig. 8 shows three potentiometer resistors 12*a*, 12*b*, and 12*c*, of different respective resistances. The contact points of wires 30 and 31 can be adjusted in any combination along said resistors 12*a*, 12*b*, and 12*c*, in order to provide a selected resistance between said contact points. The source of unknown potential is indicated by the reference letter 32. A zero-indicating voltmeter or electrometer 33 is connected as shown. When the voltage of source 32 is equal and opposite to the tapped voltage between wires 30 and 31, the meter 33 will indicate zero voltage.

Fig. 9 shows our invention when used to measure high voltages, as a kilovoltmeter. Fig. 9 shows a casing 34, in which the plates 35 and 36 are located. Said plates and their respective metal rods 35*a* and 35*b* are insulated from casing 34. Said casing can be made of glass or other insulating material. The top surface of plate 36 has a layer 3 of the radioactive material. Rod 35*b* can be vertically adjusted by conventional mechanism M, to vary the length of the gap between the condenser plates 35 and 36. The dielectric is gaseous. Rod 35*b* is grounded through a microammeter 37. Rod 35*a* is connected to one terminal of the source of high voltage 38, whose voltage is to be determined. The other terminal of source 38 is grounded.

As an example, if the plates 35 and 36 are circular discs, each having a diameter of 20 centimeters, and if their vertical spacing is 20 centimeters, and if the radio-active material has 5 milligrams of radium or equivalent emission of alpha-rays, a voltage up to 30,000 volts can be measured in the constant-resistance range 6–7. When the applied voltage is 30,000 volts, the ionization current is 1.8 microamperes.

Such an instrument is not critical so that it cannot be injured by an overvoltage, unless such over-voltage is very high. In said example, if the instrument is overcharged to as high as even 100,000 volts, there will be no breakdown and no sparking, if insulation external to casing 34 is properly maintained.

We have described preferred embodiments of our invention, but it is clear that numerous changes and omissions and additions can be made, without departing from its scope.

The dielectric in the gap or gaps of the condenser-resistor, is preferably free from water or water-vapor. For this reason, we prefer to use an enclosure or casing, so that if the dielectric is gaseous, such dielectric can be maintained free from water or water-vapor.

We claim:

1. A condenser-resistor which comprises electrodes which are separated by an ionizable dielectric, ionizing means located to ionize said dielectric, said ionizing means being of substantially constant ionizing intensity to produce a substantially constant number of ions per second in said dielectric, said ionizing means being of sufficient ionizing intensity to produce an ionization current through said dielectric when a voltage is applied to said electrodes which is less than the breakdown voltage of said dielectric and which is also less than the voltage which is required to produce ionization by collision in said dielectric, said intensity being selected to produce a resistance between said electrodes which is substantially between ten megohms and one million megohms under said applied voltage, said intensity being selected to produce an ionization current which has a substantially constant ratio to such applied voltage, in a voltage range which begins with the starting of said ionization current.

2. A condenser-resistor according to claim 1, in which the capacity of said condenser-resistor is variable.

3. A condenser-resistor according to claim 1, in which said condenser-resistor has stator elec-

trodes and rotor electrodes which are turnable relative to said stator electrodes to adjust the capacity of said condenser-resistor.

4. A condenser-resistor according to claim 1 in which said ionizing means comprise a mass of radio-active material which is located on a face of an electrode which is proximate to a face of another electrode.

5. A condenser-resistor which comprises electrodes which are separated by an ionizable dielectric, ionizing means located to ionize said dielectric, said ionizing means being of substantially constant ionizing intensity to produce a substantially constant number of ions per second in said dielectric, said ionizing means being of sufficient ionizing intensity to produce an ionization current through said dielectric when a voltage is applied to said electrodes which is less than the breakdown voltage of said dielectric and which is also less than the voltage which is required to produce ionization by collision in said dielectric, said ionizing intensity being selected to produce a resistance between said electrodes which is substantially between ten megohms and one million megohms, said ionizing intensity under said applied voltage being selected to produce an ionization current characterized as follows: (A) Said ionization current has a substantially constant ratio to said applied voltage in a first voltage range which begins with the starting of said ionization current, the voltage in said first voltage range being insufficient to extract all said ions; (B) Said ionization current has a variable and decreasing increment in a second voltage range in which said voltage is greater than in said first voltage range, in proportion to the increase of said voltage in said second voltage range, the voltage in said second voltage range being insufficient to extract all said ions; (C) Said ionization current remains substantially constant in a third voltage range in which said voltage is greater than in said second voltage range, the voltage in said third voltage range being sufficiently great to extract substantially all said ions.

6. A condenser-resistor which comprises electrodes which are separated by an ionizable dielectric, ionizing means located to ionize said dielectric, said ionizing means being of substantially constant ionizing intensity to produce a substantially constant number of ions per second in said dielectric, said ionizing means being of sufficient ionizing intensity to produce an ionization current through said dielectric when a voltage is applied to said electrodes which is less than the breakdown voltage of said dielectric and which is also less than the voltage which is required to produce ionization by collision in said dielectric, said ionizing intensity being selected to produce an ionization current under said applied voltage which has a substantially constant ratio to said applied voltage in a voltage range which begins with the starting of said applied voltage.

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